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REPORT

ON

SURVEY ON THE WESTERN FRONT 1914—1918

LONDON:
PRINTED BY HIS MAJESTY'S STATIONERY OFFICE.

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INTRODUCTION.

THIS account begins with a short historical note which deals in chronological order with the development of the various branches of the Survey organisation in France during the war. The main portion of the history is divided into two parts, with some appendices. Part I. deals with the Provision of Maps, or what is, strictly speaking, the Engineer side of survey; Part II. with Artillery Survey, or the Artillery side.

In Part I., the first chapter describes map production up to the point of the finished drawing. Section I. describes the development of the Survey units, from the original Ranging Section to the Field Survey Battalions. Section II. deals with survey operations in the field, and describes the work done and the technical methods employed. Section III. is concerned with the indoor work, and in this Section the subject of Air Photography in relation to survey is discussed. In Section IV. lessons are drawn from the experience of the war.

Chapter 2 deals with the map after the finished drawing was handed over for reproduction. Section I. treats of the development of the organisation for reproduction, including apparatus as well as personnel. Section II. deals with the technical side of reproduction, and describes the machines, methods and processes used. Section III. deals with the whole subject of Map Supply, both from England to France, and in France from G.H.Q. to Armies, and from Armies to troops. In Section IV. lessons are drawn for future guidance.

Part II. is divided into four chapters, each dealing with a certain branch of Artillery Survey. Chapter 1 describes the origin and growth of the work of surveying, and giving line to our own batteries, being subdivided into two Sections dealing respectively with Battery Survey and Artillery Boards. Chapter 2 treats of Cross Observation (or Flash Spotting, as it is popularly termed), Section I. relating the growth of the Observation units; Section II. describing the technical methods employed; and Section III. giving deductions from experience. Chapter 3 deals with Sound Ranging, and on a similar plan gives in three Sections the history of the Sound Ranging units, an account of technical methods, and deductions. Finally, in Chapter 4 an account is given of the compilation and co-ordination of the results obtained by Observation Groups and Sound Ranging Sections, and of the co-operation of these and other observing agencies for the common purpose of fixing targets.

Throughout the work the principle has been observed of keeping the history of what may be termed the military side (that is, the formation and growth of units, with their organisation and establishments) apart from that of the technical development. It has not always been possible to do this, for the history of technical units is often inseparable from the history of their technical work. Hence a certain amount of overlapping and repetition has been unavoidable. It is, however, believed that this principle is sound, and will enable the history of the development of the whole organisation to be more clearly followed.

The Appendices deal with various subjects which are more conveniently treated there than in the body of the historical account. Technical survey questions are the subject of I. (The Geodetic Problem), II. (Levels), and III. (Map References). Appendix IV. gives the syllabus of the various courses of instruction given at G.H.Q., as a record for future reference. Appendix VI. gives the history of Screen Calibration, an interesting development of the war, but only connected with survey by the fact that it was the Survey organisation which developed it. Appendix VII. gives an account of the use of panoramas (photographic and hand drawn) in the war; and Appendix VIII. contains a short description of the survey organisation in the American, Belgian, French and German Armies, which is of considerable interest for the purpose of comparison with our own.

GENERAL DEDUCTIONS FROM THE EXPERIENCE OF THE WAR.

At the end of each chapter will be found deductions and lessons for the future, in the particular subject dealt with, drawn from the experience of the war. The more important of these may conveniently be summarised here.

Engineer Survey.

Survey.—Survey is a necessary part of modern warfare, and every body of troops which takes the field should include a proper proportion of survey units.

Accurate survey is the basis of all map production and of the fixing of positions both on our own and on the enemy's side of the line. Consequently there should be one recognised authority on technical survey questions, and that should be the staff responsible for the fundamental survey; that is to say, the R.E. Survey Staff.

Geodesy.—Geodetic study and research is of prime importance, and should be provided for both in peace and war.

Air Photography.—Air photography is of fundamental importance to survey in war. A clear policy should be laid down for co-operation between airmen and surveyors, and research should be carried on in the development of methods and apparatus, for use both in the air and on the ground.

Reproduction.—Apparatus for reproduction must be designed for war, standardised and uniform. Reproduction units must be complete and self-contained as regards apparatus and power, and must be mobile. Provision must be made for cameras adequate for the largest size of plate to be used.

Map Supply.—Troops should carry few maps on the person; mobile reserves should be carried close at hand. Transport for supply must be ample.

For European warfare, while a map on 1/100,000 scale is sufficient for marching, a map on the scale of at least 1/50,000 is required for fighting.

Artillery Survey.

Training.—All Artillery officers must be trained in survey, and a proportion must reach the professional standard.

Observation.—Observation units (Observation Groups and Sound Ranging Sections) must be self-contained, mobile, adequate in personnel and transport, and commanded from the Corps or similar formation.

Research in methods and apparatus must be carried on in peace and improvements continually sought.

There should be a single general control, vested in a technically qualified Artillery staff, of all means of target fixing.

General.

Survey units (whether Artillery or Engineer) form a very small percentage of any force, but their effect on operations is great and out of all proportion to the numbers involved.

Hence it is false economy to starve this service. By so doing the technical service is crippled, while the numbers added to the fighting line are negligible and often of unsuitable material.

Geographical Section,
General Staff,
War Office.

October, 1920.

REPORT ON SURVEY ON THE WESTERN FRONT, 1914-1918.

GENERAL HISTORICAL NOTE.

THE provision in the original Expeditionary Force for map supply was as follows. At G.H.Q. was the Topographical Sub-section of the General Staff, known officially as I. (c), but more commonly as "Maps, G.H.Q.," and consisting of one officer (G.S.O. 3) and a clerk; on the L. of C. there was one officer and a clerk; and divided between L. of C. and the Army was the Printing Company, R.E. The Printing Company was organised as a H.Q. Section for work on the L. of C. and small mobile sections for work with Corps (which at that date consisted of two Divisions).

The Topographical Sub-section, or Maps, G.H.Q., as it will hereafter be called, was augmented in the first month of the war by one clerk and a box-car. The L. of C. Map Section was increased before the end of 1914 to five clerks and storekeepers, and a map depot established, first at Abbeville and later at Rouen. The Printing Company was, with the exception of a small letterpress printing section, which was left on the L. of C., concentrated wholly at G.H.Q. in September, 1914, the Corps Sections having been withdrawn.

Towards the end of 1914 the need of better provision for large-scale maps having become apparent, advantage was taken of the presence in France of the 1st Ranging Section, consisting of one officer and four other ranks, all expert surveyors, to start survey work in the field. The Section was augmented by topographers obtained from the Ordnance Survey, and others from Field Companies and other R.E. units in France, and was finally, in April, 1915, attached to Maps, G.H.Q., as the 1st Ranging and Survey Section, which became responsible for survey in the field for the whole Expeditionary Force.

In March, 1915, a "Maps and Printing Section," consisting of an officer, a small staff, and a detachment of the Printing Company, was formed for each of the two Armies then in being.

In the autumn of 1915 the personnel of the Ranging and Survey Section was divided into three, forming "Topographical Sections" for the First, Second and the newly-formed Third Army. These Sections included the "Maps and Printing Sections" above mentioned.

In the meantime the problem of fixing the positions of enemy batteries by cross observation had been taken up in various ways, and the system developed was finally incorporated in the Survey organisation on the formation of the Field Survey Companies in 1916.

Concurrently, the system of fixing the position of enemy guns by recording the sound of their discharge (known as Sound Ranging) was being developed. The first British Section was formed in November, 1915.

By the beginning of 1916 survey work had increased to such an extent that a considerable increase in establishment was found necessary, and in February the Topographical Sections were converted to Field Survey Companies. These Companies included a staff for survey, map compilation and drawing, and printing, as well as the Observation Groups and Sound-Ranging Sections.

By the summer of 1916 there were five Field Survey Companies formed on this model for the five British Armies.

With the continued increase of the British Forces, and of the front and area to be dealt with, the need began to be felt of a small organisation with each Corps to provide for local mapping needs. Consequently Corps Topographical Sections were authorised in February, 1917. These Sections formed a part of the Field Survey Company of the Army to which the Corps belonged.

As the work of the Survey units expanded it became necessary to make provision for instruction and training. The Experimental Sound-Ranging Section was formed in August, 1916, and transferred from the front to G.H.Q. in March, 1917. At the same time the nucleus of a workshop for the maintenance of Sound-Ranging apparatus was collected. In April, 1917, the School of Instruction for Flash Observation, formed in the 3rd Field Survey Company, was taken over by G.H.Q. To co-ordinate these units and to superintend generally the training and supply of personnel for the Field Survey Companies, the Depot Field Survey Company was formed in April, 1917.

No other material change in the organisation of the Field Survey units was made, but the continual growth of the work necessitated further increases in establishment. The first of these was authorised in December, 1916, when the establishment of the Field Survey Companies was considerably enlarged.

In September, 1917, proposals were made for the conversion of the Field Survey Companies into Field Survey Battalions, with Lieutenant-Colonels in command, and these were authorised in the following August. Further proposals for enlarging the establishment were made, but the military situation in the early part of 1918 rendered any increase impossible. This was the situation at the termination of hostilities in November.

In the meantime the establishment of Maps, G.H.Q., had been altered and increased to meet the growing needs of the situation. The officer in charge was advanced to G.S.O., 2nd grade, in March, 1915, and again, in May, 1917, to G.S.O., 1st grade, with (from June, 1918) the temporary rank of Colonel. The Staff was increased in May, 1917, by one G.S.O. 3 for map reproduction and supply, and in June, 1918, by the following attached officers:—1 Lieutenant-Colonel (Technical Assistant), 2 Majors (Advisers in Sound Ranging and Flash Observation), 1 Captain (Personnel), and 1 Lieutenant (Equipment).

On the L. of C. the officer in charge, having completed the organisation of the work, left in November, 1914, and the Base supply was thereafter in charge of a Warrant Officer. A large Base Depot was established at Rouen, with an advanced depot at Abbeville. Subsequently, on the reorganisation of the L. of C. into L. of C., North and South, a depot for the Northern system of supply was formed at Calais, while the depot at Abbeville was enlarged and supplied formations on the Southern system. At the same time the depot at Rouen was abolished.

The Printing Company at G.H.Q. having originally provided Detachments for the Armies, and these Detachments having later been absorbed into the Field Survey Companies, remained as a separate unit responsible for letterpress printing and map reproduction for G.H.Q. Its establishment was increased on three occasions. On the formation of the Depot Field Survey Company in April, 1917, the Printing Company was absorbed into that unit, becoming a "Printing Section"; on the formation of the Depot Field Survey Battalion (1918) the Printing Company was restored to its former status of an independent unit.

PART I.

PROVISION OF MAPS.

CHAPTER 1.

MAP PRODUCTION.

SECTION I.—DEVELOPMENT OF SURVEY UNITS.

1. Provision with the Expeditionary Force.

The organisation for map provision with the original Expeditionary Force consisted of the Topographical Sub-section, General Staff, I. (c), which included one officer (G.S.O. 3) and a clerk; an officer and clerk attached to H.Q., L. of C., to look after reserve supplies; and the Printing Company, R.E., for reproduction. The scheme was based on the needs of a very small force operating in favourable conditions, and on the supply of nothing but small scale maps, produced in England.

The Expeditionary Force took the field with a full supply of such maps, the arrangements for the issue and replacement of which will be found described in Chapter 2, Section III., Map Supply.

The provision made for survey in the field was that, by arrangement between the War Office and the Board of Agriculture, three Survey Sections, which included personnel and stores for map reproduction by manual labour, were held in readiness by the Ordnance Survey. It was, however, decided by the War Office that these Sections would not be required. This decision was doubtless due to the fact that the war was in a civilised and mapped country, and that it was not foreseen at that date what an important role would be played in the war by survey in the field. The consequence, however, was the dispersal among various field units of valuable trained personnel, only a portion of which was with difficulty recovered when later the demand arose for skilled surveyors.

2. First Demands for Large Scale Maps.

The earliest demand for large scale maps was made during the Battle of the Aisne, when for the first time warfare became stationary. The British Army happened at that time to be in the only area in this part of France which had been mapped on the new Topographical Survey of France on the 1/50,000 scale. The sheets of this map were procured, and were reproduced by the Printing Company, and issued in small quantities. This excellent topographical map served the needs of the moment, but its use was limited by the very small area covered and the difficulties of local reproduction.

The Ordnance Survey was then requested to produce large scale maps of probable areas, which was done by enlargement of the French 1/80,000 map. These enlargements proved, however, to be quite unsuitable for accurate artillery work, and it became evident that it would be necessary to survey on the ground.

3. Ranging Section.

There was at that date a unit in France called the "Ranging Section, R.E.," consisting of an officer and four other ranks, which had been formed at the Ordnance Survey, Southampton, for the purpose of fixing the position of an aeroplane at the moment that it dropped a smoke bomb (or other signal) over a hostile target, and thereby fixing the position in plan of the hostile target itself. This unit arrived in November, 1914, and experimented for about two months. The proposed scheme did not come into practical use for various reasons, the chief being that it was superseded by the superior method of signalling from the aeroplane by wireless. The personnel of the Section were, however, expert surveyors, and were thus immediately available for the commencement of survey in the field.

Capt. (now Lieut.-Col.) Winterbotham, R.E., the O.C. Ranging Section, was put in charge of the work. The Section was reinforced by 11 Topographers obtained from the

Ordnance Survey, Southampton, and 3 from R.E. units in France, and survey was begun on 25th January, 1915. The Ranging Section was thus the first Survey unit to work in the field.

4. Maps and Printing Sections.

During 1915 the strength of the Expeditionary Force grew, and it was organised into Armies. In March a "Maps Officer" was appointed to each of the two Armies (First and Second) then existing, to superintend map supply. He had a staff of one clerk and one draughtsman, and a box-car.

Soon after an Army Section of the Printing Company (see Chapter 2, Section I.) was put under his command. This combination was known unofficially as a "Maps and Printing Section." The strength of an Army Section of the Printing Company was 14, including 11 tradesmen, with 1 box-car and 1 3-ton lorry.

The Maps and Printing Section was responsible for map supply to the Army (*i.e.*, for distributing maps printed in England); for reproducing small numbers of maps for Army H.Q.; for small urgent printing jobs; and for taking panorama and other official photographs, and such other photographs as were necessary in connection with map work, such as enlargements or reductions to required scale.

5. Ranging and Survey Section.

In April, 1915, the Ranging Section, which had now practically ceased to have anything to do with ranging, and was entirely occupied with surveying, was transferred from the 8th Division Artillery to G.H.Q. and re-named the Ranging and Survey Section.

It was given the following establishment (No. 49, dated 22/4/15):—

Ranks.		Occupations.	
Major, Capt. or Sub. ...	1	Officer	1
Sergeant	1	Trig. Observers ...	3
Corporal	1	Topographers	4
2nd Corporal	1	Attached	4
L.-Corporals or Sappers	4		
Attached:			
Batmen ...	1		
Drivers, M.T.	3		
	12		12

Transport: 1 touring car, 1 30-cwt. lorry.

This Section carried out survey in the field for the whole Expeditionary Force, the front extending at that time from north of Ypres to Bethune.

During the year the Ranging and Survey Section was reinforced by a number of Ordnance Survey topographers who had been serving in Field or Army Troops Companies, and by others from England. With the extension of the front and the area to be dealt with, and the development of the Army organisation, it became impossible to continue the centralisation of control of survey work at G.H.Q. Another reason which conduced to the expansion of the survey organisation was the growing need for putting the responsibility for all mapping in the hands of trained surveyors. Up to the middle of 1915 the responsibility for the maps of forward areas lay with the General Staff (Intelligence), but it became obvious, for reasons which will be explained in Section III., that mapping should be taken up by the expert.

6. Topographical Sections.

These facts led to the formation (July to September, 1915) of a Topographical Section for each Army (First, Second and Third).

These Sections were formed by the division of the Ranging and Survey Section into three, the addition of new personnel, and the incorporation of the Maps and Printing Sections. The officers who commanded these Topographical Sections were, in First Army, Captain Gaine (later Captain Tapp); in Second Army, Major Reid; in Third Army, Major Winterbotham.

The establishment (No. 129 d/2/10/15) was as follows :—

Ranks.	
Captains or Subalterns	2
C.S.M. or Sergeant	1
Corporals, 2nd Corporals and Sappers	13
Attached :	
Batmen ...	2
Drivers M.T.	3
	21

Occupations.	
Officers	2
Clerks	1
Trig. Computers	1
Draughtsmen	3
Trig. Observers	3
Topographers	6
Attached	5
	21

Transport : 1 touring car, 1 box-car.

To these Sections the Maps Officers and Army Printing Sections were attached, bringing the total strength to 38, with total transport 1 touring car, 2 box-cars, and 1 3-ton lorry.

These Sections were responsible for all survey work in the Army, and for map supply and reproduction on the same lines as the previous Maps and Printing Sections.

7. Observation Groups and Sound Ranging Sections.

During 1915 the question of fixing the position of hostile guns by cross observation was being taken up. This will be dealt with in Part II. ; in the meantime it is enough to mention that in the First and Third Armies, towards the end of 1915, the O.C. Topographical Section was made responsible for the control of "Flash Spotting." In the Second Army, control of Flash Spotting was not vested in the O.C. Survey unit until the formation of the Field Survey Company in 1916.

In the same year (1915) a beginning was made with Sound Ranging; the first Section was formed in November and others during 1916, and these were incorporated in the Field Survey Companies which had then been authorised.

8. Field Survey Companies.

The Survey requirements of the Armies continued to grow with great speed, and within a few months of the formation of the Topographical Sections it was found that they were totally inadequate to deal with the mass of work to be done. Trench mapping had become of vital importance, and required a large staff of the most expert draughtsmen and interpreters of air-photos; the requirements of the Army H.Q. made increasing demands on the limited printing resources of the Sections; and the size of the areas and the number of formations in the Armies made map supply a matter of considerable difficulty, even in the absolutely stationary warfare then going on.

Consequently, proposals for an increased establishment were put forward, and in February, 1916, the formation of Field Survey Companies was approved. The name was adopted (instead of Survey Companies, which would have been enough) to avoid confusion with the existing Survey Companies in England, which were R.E. Companies composed of surveyors, but not equipped for war conditions, and whose personnel had, moreover, been almost entirely transferred to France and other theatres of war.

These Field Survey Companies were a great advance on the Topographical Sections. The O.C. was ultimately given the rank of Major (though not without considerable delay in the case of those who did not already hold that rank) and a point was made of securing for this post R.E. Officers who were expert surveyors. The first to hold the commands were : 1st F.S.C., Major H. Wood, R.E. ; 2nd F.S.C., Major C. S. Reid, R.E. ; 3rd F.S.C., Major H. St. J. Winterbotham, R.E. ; and 4th F.S.C., which was formed at this date (February, 1916), Captain M. N. MacLeod, R.E. In July the 5th F.S.C. was formed, under the command of Captain B. F. E. Keeling, R.E.

The organisation laid down for the original Field Survey Companies was as follows :—

(1) Headquarter Section. Functions.—Supervision and administration, and compilation of results of Observation and Sound Ranging.

(2) Topographical Section. Functions.—Survey and topography.

(3) Map Section. Functions.—Reproduction and map supply.

(4) Observation Section. Function.—General observation and flash spotting. The Section consisted of a number of Obs. Groups.

(5) Sound Ranging Section. Function.—Sound Ranging. The Section consisted of two Detachments.

This organisation was not adhered to throughout in practice, the three first-named sections being combined in the 3rd, 4th, and 5th F.S.C. as one H.Q. Section, as in the organisation which was officially adopted later.

The establishment in this first organisation was as follows (W.E., No. 239, d/11/3/16; later numbered 351/51):—

Headquarter Section.

Ranks.		Occupations.	
Officers	3	Commander	1
Q.M.S.	1	Adj. & Qr.Mr.	1
Clerks	2	Compiling Officer	1
Other ranks (no ranks laid down) ...	6	Clerks	2
Attached :		Q.M.S.	1
Batmen ...	3	Pay duties	1
Desp. Rider	1	Trig. Computer	1
Drivers M.T.	2	Opticians	1
		Draughtsmen	1
		Buzzer Pioneers	2
		Attached	6
	18		18

Topo. Section.

Ranks.		Occupations.	
Officer	1	O.C.	1
C.S.M. or Sergt. ...	1	Trig. Computers	1
Sergeant	1	Draughtsmen	3
Corporals	2	Trig. Observers	3
2nd Corporals	2	Topographers	6
L.-Corporal	1	Attached	3
Sappers	6		
Attached :			
Batmen ...	1		
Drivers M.T.	2		
	17		17

Map Section.

Ranks.		Occupations.	
Officer	1	O.C.	1
Clerk	1	Clerk	1
Attached :		Photographers	2
Batmen ...	1	Lithographers	6
Drivers M.T.	3	L.P. Printers	3
Printing Co.*	11	Batmen and drivers	4
* See para. 4	17		17

The total strength at Headquarters was thus 5 officers and 47 other rank. In addition there was a variable number employed on Observation and Sound Ranging, the establishment for which services is dealt with in Part II.

The transport available among the above three sections was 2 touring cars, 3 box-cars, 1 3-ton lorry, 1 motor-cycle.

9. Enlargement of Field Survey Companies.

Although, as stated, the Field Survey Companies were a great advance on the Topographical Sections, the work grew so rapidly that in six months the new establishment was found to be insufficient.

Among the increases may be mentioned the formation of additional Observation Groups and Sound-Ranging Sections to cover the whole front without a gap. This entailed largely increased supervision and administrative work. At the same time trench maps became more complicated, and the demand for accurate maps and for survey work for the Artillery grew rapidly. This entailed heavy work on the part of surveyors and draughtsmen of the Field Survey Companies.

Consequently in December, 1916, a revised establishment was approved with the following modified organisation :—

(1) Headquarter Section. Functions.—Supervision and administration. Survey and topography. Map reproduction and printing. Map supply. Compilation of results of observation and sound ranging.

(2) Observation Section, consisting of several Obs. Groups.—General observation and flash spotting.

(3) Several S.R. Sections.—Sound Ranging.

The establishment (No. 407, d/7/12/16) was as follows (Headquarter Section) :—

RANKS.	
Major	1
Adj. and Qr.-Mr.	1
Capts. and Lieuts.	4
Clerks	3
C.S.M.	1
C.Q.M.S.	1
Sergeants	5
Corporals	5
2nd Corporals or Bombrs.	5
L.-Coporals or A/Bombrs.	5
Sappers, Gunners or Ptes.	38
Attached :	
Batmen	6
Despatch Rider	1
Drivers, M.T.	7
R.A.M.C.	1
	84

TRANSPORT, ETC.	
Touring cars	2
Box-cars	3
Motor cycles	2
Lorry, 3-ton	1
Bicycles	12

OCCUPATIONS.	
Officers :	
O.C.	1
Adj. and Qr.-Mr.	1
Topography	1
Maps and Printing	1
Compiling	2
Clerks	3
C.S.M. and C.Q.M.S.	2
Pay Duties	1
Topographers	7
Trig. Observers	3
Draughtsmen	14
Trig. Computers	2
Carpenter	1
Photographers	2
Lithographers	7
L.P. Printers	4
Buzzer Pioneers	2
Storemen and Packers	4
Instr. Repairers (Optical)	1
Cooks, Orderlies, etc.	10
Attached	15
	84

In April, 1917, the above establishment was modified (W.E., No. 501/42, d/3.4.17) by the addition of two draughtsmen for the Army Branch Intelligence Section. These two men were detached to the B.I. Section, and had no effect on the work of the F.S Company.

10. Corps Topographical Sections.

The experience of the Somme fighting in 1916 showed the need for some decentralisation of topographical work and map production during operations, and especially for some small map organisation in each Corps which could provide an immediate representation of the situation. The Field Survey Company was necessarily too far from the line for it to produce and distribute maps with the necessary speed. Prior to this, Corps had already produced many temporary maps, but these maps were of the same order of accuracy and showed the same faults as those prepared by the Army Staffs in the early portion of the war. It was necessary, then, to train the officers for this purpose in good mapping methods, and to equip them with a few draughtsmen who had been specially trained in plotting from air photos. The subject was raised by the Third and Fourth Armies, and Corps Topographical Sections were formed in most Armies during the autumn of 1916, training being carried out at the F.S.C. Headquarters. The 3rd F.S.C. may be specially mentioned as having given a particularly thorough training, officers and men being put through a course which lasted between two and three months. The Sections were officially authorised in February, 1917, the establishment being one officer, five draughtsmen, three topographers, with two motor-cycles, one having a side-car. In addition, two draughtsmen were borne on the strength for employment with the Branch Intelligence Section attached to the Corps Squadron (R.A.F.). The Sections were equipped with Ellam duplicators.

The functions laid down for the Corps Topograhpical Sections were :—

(1) To supplement the work of the F.S.C. in battery fixing and provision of Artillery Boards, especially for Field Artillery.

(2) To produce daily during operations maps in time to distribute early next morning, giving the latest information as to the situation.

During active operations mapping was usually confined to the above description, and to trench maps (1/10,000 or 1/20,000) showing new trench detail, and new topographical information. During normal periods of position warfare many other maps were produced, such as counter battery and target maps, barrage maps, maps of our own trenches, traffic, railway, and other communication maps and diagrams of various kinds.

It will be useful here to review briefly the subsequent history of these Sections.

Corps Topographical Sections were raised as integral parts of the Field Survey Companies, but in practice there was often little connection between them and their parent Company. It was difficult for the O.C. Company to exercise any close supervision, and it frequently happened that changes of personnel or of the officer in charge were disapproved of by the Corps, with the inevitable consequence of stopping promotion and interfering with desirable changes.

Apart from this, the Sections were called upon to perform duties for which they were not originally intended. In the first place, the addition of topographers for battery survey was an afterthought, and not included in the first proposals. They were added to meet the real need for greater decentralisation of this work, and had a supply of skilled personnel been available, they would have been invaluable. By the end of 1916, however, all the really skilled topographers were already employed, and the men for the Corps Topographical Sections had to be trained, and there was not time enough to make them expert. They consequently needed supervision, but as the officer in charge was already fully occupied with his heavy office work, it was impossible for him to spare the necessary time in the field. Consequently battery survey by Corps topographers fell off until finally little was done. Occasionally the men were used for mapping back-area trenches and areas under cultivation, and also for contouring, but as few of them were expert enough to contour properly, little reliance could be put on their work.

Another factor that handicapped the Corps Topographical Sections was their employment on manuscript work for the Corps Staff. There is always a mass of this work to be done—for example, colouring maps to show different activities, correcting the front line to date, layering maps, and mounting wall and other maps. The trained men of the Survey units were not intended for this work, which requires comparatively little skill; but as a rule so few draughtsmen were available for it that demands were constantly made on the Survey units, and particularly on the Corps Topographical Sections. In many cases the latter were quite swamped by this work, with the result that when the time came for quick but accurate map making the staff were untrained and inexperienced, and the work was consequently poor and slow.

It may be said, then, that while the Corps Topographical Sections would probably have been sufficient for the purposes for which they were originally intended, they proved quite unequal to the additional tasks put upon them, and that, though undoubtedly useful to the Corps Staffs, they were, except in a very few cases, of little value for useful survey work.

11. Depot Field Survey Company.

In April, 1917, the Depot Field Survey Company was formed in order to co-ordinate and supervise the training of personnel for the F.S. Companies. Hitherto training for Sound Ranging had been carried on by the original Sound-Ranging Section, which was formed in 1915 and had remained in Second Army area. The Experimental Sound-Ranging Section was formed in August, 1916, with a view to carrying on research and instruction, and was transferred in the beginning of 1917 to G.H.Q. to act as an Experimental Section and School of Training. At the same time the excellent School of Flash Observation formed in the 3rd F.S.C. was taken over by G.H.Q. and formed into the School for Observers. These units were included in the one organisation of the Depot Field Survey Company, which was thereafter the training establishment for all the special Field Survey Company trades and the Depot for trained reinforcements. The Depot absorbed the Printing Company, R.E., which became the Printing Section of the Depot F.S. Company.

The establishment (No. 501/43, d/3.4.17) was as follows :—

H.Q. Section.

Ranks.		Occupations.	
Major ...	1	O.C.	1
Adjutant	1	Adjutant ...	1
Subaltern	1	Equipment Officer	1
C.S.M. ...	1	C.S.M.	1
C.Q.M.S.	1	C.Q.M.S. ...	1
Clerks ...	2	Clerks	2
Sergeants	2	Storeman ...	1
Corporals	1	Instr. Repairer	1
Sappers	1	Carpenter ...	1
Attached :		Pay Duties ...	1
Batmen	3	Attached ...	9
Cooks, Storemen and Orderlies ...	6		
	20		20

Printing Section.

Detail given in Chap. 2	61	61

Experimental Sound Ranging Section.

Ranks.		Occupations.	
Captain	1	O.C. and Instructors	4
Subalterns	3	Senior N.C.O. ...	1
Sergeants	2	Photographer	1
Corporals	2	Linemen	9
2nd Corporals	2	Buzzer Pioneers ...	2
L.-Corporals	2	Forward Observers ...	9
Sappers and Pioneers	16	Instr. Repairers ...	2
Attached :		Attached	6
Batmen ...	4		
Drivers, M.T.	2		
	34		34

School for Observers.

Ranks.		Occupations.	
Captain	1	O.C.	1
Clerk	1	Clerk	1
Sergeants	2	Instructors	6
Corporals	4	Attached	3
Attached :			
Batmen ...	1		
Miscellaneous	2		
	11		11

The total strength was thus 126 (9 officers and 117 o.r.).

The transport was one touring car and one 3-ton lorry allotted to the Printing Section and one car and one box-car allotted to the Exp. S.R. Section.

On the conversion of F.S. Companies into Battalions the Depot F.S.C. became the Depot Field Survey Battalion. It retained the same organisation, with an enlarged establishment, except that the Printing Section ceased to form a part of the Depot, and was restored to its former status of an independent unit.

The establishment of the Depot Field Survey Battalion was as follows (No. 1592, no date). :—

H.Q. Section.

RANKS.		OCCUPATIONS.	
Lieut.-Colonel ...	1	O.C.	1
Adjutant	1	Adjutant	1
Subaltern	1	Equipment Officer	1
R.S.M. ...	1	Warrant Officers	2
Q.M.S. ...	1	Pay Duties	1
Sergeants ...	4	Orderly Sergeant	1
Corporals ...	3	Storemen	3
2nd Corporals	3	Carpenter	1
Sappers and Pioneers ...	22	Clerks	4
Attached :		Draughtsmen (Topo.) ...	22*
Drivers, M.T. ...	4	Attached	10
Cooks, Orderlies, etc.	6		
	47		47

* Includes 2 for B.I. Section.

Experimental Sound Ranging Section.

RANKS.		OCCUPATIONS.	
As before, except 4 Batmen ...	30		30

School for Observers.

RANKS.		OCCUPATIONS.	
Major	1	O.C. and Instructors ...	3
Subalterns	2	C.S.M.	1
C.S.M.	1	S.P. Observers (Instructors)	15
Sergeants	8	Clerks	2
Corporals	8	Storemen	1
2nd Corporals	1	Instr. Repairer (Optical) ...	1
Sappers and Pioneers	3	Pioneer	1
Attached :		Attached	2
Miscellaneous	2		
	26		26

Batmen allowed on Scale C.

The strength was thus 103 (10 officers, 93 o.r.).

The transport was :—

For H.Q. Section, one touring car, one box-car, one 3-ton lorry.
For Exp. S.R. Section, one touring car, one box-car.
For School for Observers, one motor-cycle, one bicycle.

The above establishment was superseded by No. 1802/16, which differed only in omitting the two draughtsmen for the B.I. Section.

12. Various Schemes for Reorganisation.

Towards the end of 1917 it became evident that the work of a F.S.C. was too centralised, and that the burden on the O.C. was consequently too great.

Another difficulty that was felt by all was the need for greater elasticity in the organisation. The H.Q. Section remained of precisely the same strength in every Army, in spite of widely varying conditions of length of front, area, nature of operations and state of maps. One Company might have quite twice as much work as another, but had the same personnel and transport available. To meet these needs—for decentralisation and elasticity—various proposals were made. The O.C. 4th F.S.C. (Major MacLeod) suggested an organisation of Corps Survey Companies, each of which would be responsible for all the Survey work, including observation and sound ranging, for its Corps; the whole to be co-ordinated and supervised by a Director of Surveys at Army H.Q., who would also have an Army Survey Company for such work as did not fall within the province of the Corps Companies. This scheme had much to recommend it and was strongly supported by the G.O.C. Fourth Army (General Rawlinson). It certainly provided complete decentralisation and made the strength of the Survey organisation automatically correspond to the strength of troops engaged, which went a long way—probably as far as was practically possible—in the direction of complete elasticity. It was, however, generally agreed that map production could not be satisfactorily decentralised to the extent proposed, the disadvantages involved being greater than the advantages to be gained. Hence, while accepting the principle of a Corps Survey Company organisation as sound for observation, sound ranging, battery fixing, and map distribution, it was decided that it was not sound to apply it to map production, or, with the existing type of plant, to map reproduction in quantity. In other words, it was considered advisable to retain at Army H.Q. the organisation for compiling, drawing, reproducing and printing maps.

Another proposal that was made, with a view to meeting the need for a variable strength for varying work, was to have a number of "reinforcement sections" at the disposal of Maps, G.H.Q., to be allotted to any F.S.C. upon which extra burdens were thrown.

Both these proposals, unfortunately, involved increases of personnel which would be saved by adhering to the old organisation, and as the man-power situation was becoming serious at this date, they had to be abandoned on that account alone.

13. Field Survey Battalions.

The result was that the next step in the development of the Survey units, namely, the formation of Field Survey Battalions (authorised in 1918) became simply an expansion of the Companies, with no change in organisation, except that three Majors were added with the object of decentralising work and relieving the O.C. One Major was to be in charge of the H.Q. Section, and two to be in charge of "Artillery Sections."

An Artillery Section was to consist of about half the Observation Groups and S.R. Sections in the Battalion, and the idea was that the supervision and control of an Artillery Section was to be delegated to a Major, the O.C. being thereby relieved of a good deal of detail work. The Artillery Section was admittedly a compromise. Had the situation allowed of the provision of a small staff and some transport for the use of the officer in charge, the scheme might have worked better; but as this was impossible, it was handicapped from the outset. It must be admitted, however, that the Artillery Section Commanders did valuable work, and the presence of a controlling officer near the front had a markedly good effect.

The F.S. Battalion organisation was otherwise exactly the same as that of the F.S. Company, consisting of a H.Q. Section, Corps Topo. Sections, Observation. Groups and Sound Ranging Sections, the last two units being grouped into "Artillery Sections." The H.Q. Section consisted of a Lieut.-Colonel in command, an Adjutant, 3 Majors, 4 Captains and 4 Subalterns, and 174 other ranks. The officers were classified as 1 O.i/c H.Q. Section, 2 O.i/c Artillery Sections, 2 Printing, 2 Survey, and 2 Compiling Officers, and two other subaltern assistants. The other ranks comprised a largely increased staff of draughtsmen, lithographers, etc. There was no change in the W.E. of the Observation Groups and Sound Ranging Sections.

The detail of this establishment (No. 1591, d/17/8/18) was as follows (Headquarter Section):—

RANKS.

Lieut.-Colonel	1
Majors	3
Adj. & Qr.-Mr.	1
Captains	3
Subalterns	5
Supt. Clerk	1
R.S.M.	1
Q.M.S.	1
C.S.M.	3
Sergeants	12
Corporals	12
2nd Corporals	12
L.-Corporals	20
Sappers and Pioneers	97
Attached :	
Batmen ...	6
Despatch Riders	1
Drivers, M.T.	7*
R.A.M.C. ...	1
	187

* Includes 1 N.C.O.

† The Chief Topographer, Draughtsman and Litho printer had rank of C.S.M.

OCCUPATIONS.

O.C.	1
Adj. & Qr.-Mr.	1
Majors :	
O.i/c H.Q. Section	1
O.i/c Artillery Sections	2
Captains :	
O.i/c Survey	1
O.i/c Printing	1
O.i/c Compilation	1
Assistants, Subalterns	5
Senior Warrant Officers	3
†Topographers	10
Trig. Observers and Assts.	6
Helio and Vandyke workers ...	6
†Draughtsmen	40
Draughtsmen, Clerks	2
Draughtsmen, Litho	10
Computers, Trig.	2
Instr. Repairer Opt.	1
L.P. Printers	8
Transferers and provers	10
†Machine Minders	6
Machine Feeders	6
Engine Men	3
Photographers	4
Carpenters	2
Telephonists	3
Clerks	7
Storemen, etc.	8
Electrician	1
Pay Duties	1
Cooks, orderlies and fatigue men ...	20
Attached	15
	187

The transport was 2 touring cars, 3 box-cars, 1 3-ton lorry, 2 motor cycles, and 15 bicycles.

Two of the draughtsmen were for employment in the B.I. Section. The establishment was subsequently modified (No. 1801/56, no date) by the omission of these two draughtsmen and the addition of two bicycles.

Proposals were also made at this date for the inclusion of certain other units—to wit, Calibration Sections and Wind Detachments—but as these never materialised as parts of the F.S.B. organisation, they will be dealt with in the technical account only, and not here.

The following officers commanded the Field Survey Battalions :—

1st. Lieut.-Colonel B. H. Wilbraham (who had succeeded Major H. Wood in com mand of the 1st F.S.C.).

2nd. Lieut.-Colonel C. S. Reid.

3rd. Lieut.-Colonel B. F. E. Keeling (who had succeeded Lieut.-Colonel Winterbotham in command of the 3rd F.S.C. on the latter joining the G.H.Q. Staff in August, 1917).

4th. Lieut.-Colonel M. N. MacLeod.

5th. Lieut.-Colonel F. B. Legh (who had succeeded Major Keeling in command of the 5th F.S.C. when the latter was wounded).

14. Proposals for Increase.

The establishment of a Field Survey Battalion, which was authorised in August, 1918, though it came into force locally in June, had been proposed in the autumn of the previous year. In the interval the fighting power and activity of the British Army had increased to such an extent that the new establishment, by the time it was approved, was inadequate.

Fresh proposals for increase were therefore made, but by this time the question of man-power had become acute, and the situation in the spring of 1918 made any increase quite impossible. From that time on the total strength of the F.S. Battalions was limited to the numbers then authorised, so that an increase to any section could only be made at the expense of others. In the autumn of 1918 proposals were on foot to bring up the strength of the H.Q. Sections to something approximating to the work they had to do by disbanding certain Observation Groups and Sound-Ranging Sections, but these did not materialise before the Armistice.

15. Corps Company Organisation.

It only remains to say that during 1918 further experience and the lessons of the rapidly increasing mobility of warfare showed the imperative need for the adoption of a Corps organisation as originally advocated by the Fourth Army in 1917. It was agreed by the F.S.B. Commanders that the only way to meet the varying needs of the situation was to abandon the "territorial" principle in the case of Groups and Sections (whereby these units were responsible for definite *areas* and not for definite *units*), and to attach to each Corps its Observation Group and Sound-Ranging Section, with an officer at Corps H.Q. to represent and look after them. Increase of personnel being absolutely vetoed, the only way to provide for such an organisation was to disband some Corps and Sections, and it was agreed to recommend that this should be done even though this involved the risk of leaving the front inadequately covered. The cessation of hostilities prevented this scheme of Corps Companies from coming into being, but it is mentioned here as being the organisation finally agreed to in principle. It may also be mentioned that the Fourth F.S.B., when advancing into Germany, formed Corps Companies with the aid of borrowed personnel, so that the organisation was put by them to practical test in some measure.

The Corps Company, as proposed, would have had an O.C. (Major) and a small staff for administrative and Artillery Survey work, and would have included one Observation Group and one S.R. Section, and the Corps Topo. Section.

16. Maps, G.H.Q.

The original establishment in the Expeditionary Force for dealing with survey matters was as follows :—

At G.H.Q. Topographical Sub-section G.S. (I.c.).—One officer (G.S.O. 3), one clerk.

At H.Q. L. of C. Map Section.—One officer (G.S.O. 3), one clerk.

No transport was allotted, but in the first month of the war a box-car was obtained from the Base, and at the same time an extra clerk was secured. In March, 1915, the officer in charge was advanced to G.S.O., 2nd Grade.

The officer in charge of the L. of C. Map Section, Lieut. O. E. Wynne, R.E., remained until November, 1914, organising the system of map depots and Base supply. He was then transferred to other work and left Q.M.S. J. E. Clemons, R.E., in charge. The organisation and staff of the map depots are given in Chapter 2, Section III.

The work of Maps, G.H.Q., increased greatly as soon as the war settled down to trench fighting. When field work began it was fortunately possible to put it from the outset into the capable hands of Captain Winterbotham, but the office work of general superintendence, map supply, provision of technical stores for the growing Survey units, working out of establishments and so forth had by 1917 increased far beyond what a single officer could satisfactorily handle.

In October, 1916, Captain Field acted as officer in charge of map supply, his appointment being sanctioned in the following May, and in November Lieut. Allingham joined as Equipment Officer, being later (April, 1917) borne on the establishment of the Depot F.S.C. In January, 1916, the establishment of clerks had been increased to three.

The staff at G.H.Q. was thus, from the beginning of 1917, three officers (one G.S.O. 2, one officer i/c Map Supply, later made G.S.O. 3, and one Equipment Officer), three clerks.

In May, 1917, the officer in charge was advanced to 1st Grade.

In August, 1917, Lieut.-Colonel Winterbotham joined Maps, G.H.Q., as Technical Assistant, pending an increase of establishment to allow of that post, but unfortunately he was ordered to Italy in October and did not return until the following January. The final organisation of Maps, G.H.Q., began to be formed about this date, though sanction was not received until June, when the following establishment was approved :—

G.S.O. 1.—Colonel.
G.S.O. 3.—Map Supply.
Attached :
1 Lieut.-Colonel, Technical Assistant.
2 Majors, Advisers in Sound Ranging and Cross Observation.
1 Captain, Personnel.
1 Subaltern, Equipment Officer.
28 Clerks, Draughtsmen, Storemen, etc.
Transport (with 12 drivers) :
3 Touring cars.
3 Box-cars.
2 3-ton lorries.
1 30-cwt. lorry.
1 Motor cycle.

making a total of 7 officers and 40 other ranks on establishment.

In addition to the above, two officers (Assistant to the O.i/c Map Supply and Adviser in Geodesy) and about 10 other rank from the Depot F.S.B. were constantly employed on G.H.Q. work, so that the total of the G.H.Q. Survey Staff at the end of the war may be taken as 9 officers and 50 other rank.

The officers who held the above posts were as follows :—

Officer in Charge, Colonel E. M. Jack.
Technical Assistant, Lieut.-Colonel H. St. J. Winterbotham.
Sound Ranging, Major W. L. Bragg.
Cross Observation, Major H. H. Hemming.
Map Supply, Capt. E. E. Field and Lieut. Whitby.
Personnel, Capt. G. Carlyle.
Equipment, Lieut. G. A. Allingham.
Geodesy, Lieut. G. T. McCaw.

It will be convenient here to summarise briefly the work of Maps, G.H.Q. It comprised the following duties :—

General superintendence of technical work.

Technical advice on survey questions to other branches.

Mapping.—Control and co-ordination, allotment of areas of responsibility, map policy. Co-ordination of trigonometrical work was tackled seriously only towards the close of hostilities.

Map Supply.—All questions connected with publications of editions, reproduction by W.O., O.S., or O.B.O.S., records, and map supply in bulk. (For details see Section III.)

Sound Ranging and Cross Observation.—Development and organisation on technical and military sides. Training, research, allotment of Sections and Groups.

Personnel.—The Personnel Branch acted as technical advisers to the A.G., and were concerned with obtaining and allotting suitable personnel, officers and other ranks to the Field Survey Battalions.

Stores.—Supply of all technical stores. This included in many cases design and arrangements for manufacture. Responsibility for supply was confined to the special stores (*i.e.*, N.I.V. stores) required for survey, sound ranging and cross observation, but in order to be ready for sudden emergencies approval was obtained for holding in the G.H.Q. store a certain reserve of ordinary vocabulary stores.

Technical Literature.—Technical pamphlets on Sound Ranging and Cross Observation were prepared and issued, and handbooks for future use were put in preparation. Technical literature of foreign survey organisations, allied or enemy, was as far as possible studied. A good deal of work was also done in connection with artillery work as affected by survey, as, for example, pamphlets on methods for artillery survey and artillery procedure in connection with sound ranging and cross observation.

Conferences were held from time to time between Maps, G.H.Q., and the officers commanding F.S. Battalions. These were usually with a view to settling questions of technical methods and organisation of the survey units.

Liaison with allied survey organisations was maintained by occasional visits by various members of the staff.

SECTION II.—SURVEY IN THE FIELD.

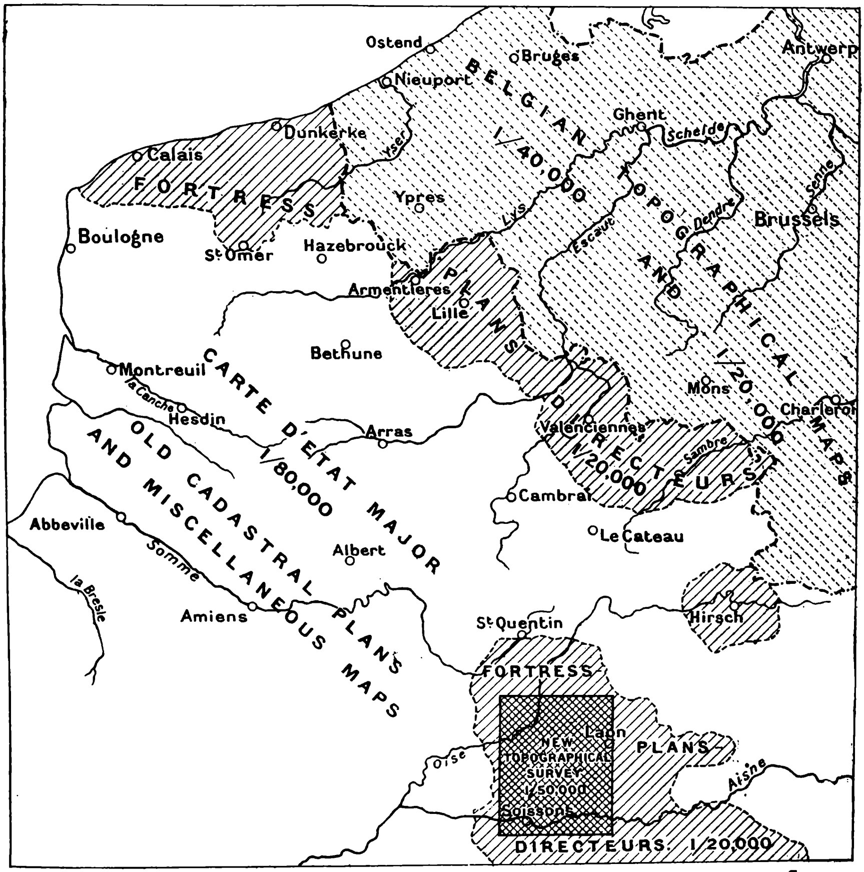
1. Material already available.

In order to understand properly the problem of the production of large scale maps for the British Armies in France, it is necessary to describe shortly the mapping material that was already available in the area occupied; that is to say, in Belgium and the northern part of France.

The trigonometrical problem is not dealt with here. It will be found fully discussed in Appendix I.

In the list that follows, small scale maps are included. These do not affect the question of large scale maps, except for the small extent to which they were used for enlargements, but it is convenient to give them, and so make the list of material complete.

MATERIAL EXISTING BEFORE THE WAR.



BELGIUM.

(a) Small Scale.

A complete series of 1/250,000 and 1/100,000 sheets covering the whole of Belgium, and prepared on the basis of the Belgian 1/100,000, had been prepared at the War Office before the war.

(b) Large Scale.

Belgium is covered by a complete series of 1/40,000 and 1/20,000 sheets, which show topography and ground forms in great detail. This map was at first considered to be quite good enough for all requirements. Subsequent investigation showed that it required considerable revision in parts, but it remains on the whole a good topographical map. The plates of this map were all salved from Antwerp, and were therefore available for printing. The original drawings on 1/10,000 scale were also saved, and from these drawings plates were made when required.

FRANCE.

(c) Small Scale.

The maps available were as follows :—

Produced by the French General Staff—

1/200,000, coloured and contoured.

1/80,000, black with hachures (published also in an enlarged edition, 1/50,000).

Produced by the Ministry of the Interior—

1/100,000, coloured, with ground forms indicated by shading.

Produced by private firms—

Motoring and cyling maps, such as the Taride 1/250,000, the Michelin 1/200,000, etc.

A new topographical map, coloured and contoured, was in course of production by the Service Geographique when the war broke out; but no part of the published portion of this map fell within the area occupied by the British, except when we were on the Aisne. This map should not be confused with the 1/50,000 enlargements of the 1/80,000, which are published in quarter sheets in black only, like the original 1/80,000.

(d) Large Scale.

Plans Directeurs.—The only French large scale maps prepared for war purposes were the Fortress Plans Directeurs; a series of topographical maps, surveyed on 1/10,000 and published on 1/20,000 scale, covering an area along the frontier and the northern coast, and around certain fortresses. These are excellent topographical maps, printed in black, with accurately drawn contours. They suffer, however, from lack of revision, and contain certain errors.

Cadastral Plans.—The whole of France was mapped for revenue purposes, between the dates of (approximately) 1810 and 1850, on the scale of 1/2,500. Each commune was represented by a different survey, and was completed in a number of separate parts (from two to eight, according to the area). Three manuscript copies of the original surveys exist, and these copies are kept as a rule at the Mairie of the Commune and at the Revenue Office of the chief town of the Department. Their survey value varies. Some have been found exceedingly accurate, while others show considerable errors. For purposes of reference a diagram to the scale of 1/10,000 was made of each commune, showing the relative positions of the various portions which were surveyed on the larger scale. These indexes were made from hand reductions of the originals, and are as a rule neither so accurate nor so detailed.

This original cadastral survey has never been published, and only in a few cases has it been revised. After the abandonment of the new cadastral survey of 1899 (mentioned below) a certain number of the old plans were revised, and some of these fell in our area, between Amiens and Albert. But the great bulk of these plans show the state of the country as it was in the early part of the nineteenth century. In spite of this their value as a foundation for a modern map is great. The chief topographical features, such as roads and rivers, have changed very little, while all proper boundaries can be clearly traced between the different areas of cultivation. With the aid of air photos these maps can consequently be brought up to date with little difficulty.

In 1899 it was decided to begin a new cadastral survey of France, but little was done before the scheme was abandoned, and the number of modern cadastral plans is so small that no further mention need be made of them.

Most of the topographical maps of France ultimately rest on the old cadastral plans. Thus the skeleton of the 1/80,00 Carte de l'État Major is compiled from them, though much new survey had to be done in order to complete the map. The other plans and maps mentioned below are most invariably based on the 1/10,000 indexes to the Communal Surveys.

Railway, Canal and Road Plans.—Railway and Canal Plans are available practically everywhere. They are usually, however, only compilations, and the compilation is often not above reproach. They appear also generally to represent the engineer's plans for construction, rather than a survey of the finished work, and cases are frequent in which the actual trace of railway or canal is found to differ materially from that given in the official plans.

As material for accurate large scale mapping, therefore, little is to be got from these plans, and it is best to neglect them altogether if air photos are available of the area in question.

In the majority of cases, however, the plans are accompanied by profiles, which add considerably to the data available for contouring. In one or two cases they had been contoured in the field, as, for example, the excellent plan of the Canal du Nord from Douai to Peronne.

Mining Area Maps.—In the coalfields the various mining companies had produced maps based on the original cadastral surveys, and amplified by additional work on the ground. Some of these plans were of great assistance, but difficulties arose occasionally from the inclusion of projected villages, railways, etc., which had never been constructed.

2. Early Surveys by Field and Tunnelling Companies.

Surveys, usually on a large scale, are a common preliminary to most engineering undertakings. They are as necessary in war as in peace, and to the military as to the civil engineer. For this reason a surveyor is borne on the strength of each Field Company, and every officer of the Royal Engineers is trained in Survey work irrespective of whether he is destined for a purely survey career or not. For the same reason the equipment of the Field Company includes a few purely survey stores (such as the service plane table).

From the beginning of the war Field Companies produced sketches and rough maps, and from the time when, in October, 1914, the line became more or less stationary, they made, revised and issued large scale plans of the trenches held by the division to which they belonged. When F.S.B. maps became general the Field Company surveyors usually started with an enlargement of the Field Survey Battalion map, laid out contemplated work on it, and kept it up to date, issuing copies to the staff and to relieving troops. By the close of 1915 good 1/10,000 trench maps were everywhere complete, and from that time onwards original surveys were rarely done by Field Companies.

In the early days before the field survey units were raised, Field Companies were thrown on their own resources and made maps and sketches on various scales and of various degrees of accuracy. Most important among these plans were those which dealt with the front line trenches. As a general rule these surveys were done with the prismatic compass, but occasionally the plane table was also employed. An example of valuable work done on the plane table was a sketch survey undertaken by the 23rd Field Company after the battle of the Marne, on the Chemin des Dames. The object of this survey (which proved exceedingly valuable) was to direct enfilade machine gun fire on a portion of the German front line. The plane table was oriented on the pole star (with a correction for azimuth).

Another example of Field Company survey was the compass traverse of the trenches from a point west of Laventie to Neuve Chapelle, carried out by Captain (now Lt.-Col.) Pears. Other surveys were made of second and third line systems and of strong points. No doubt these extended generally along our front line. One might mention in particular those of the 7th and 8th Divisions.

Early in 1915 two young R.E. Officers were killed whilst attempting to map the trenches by compass bearings.

There were in various R.E. units many officers of the Corps who had been engaged on the surveys of the British Isles and of India. Where they had been posted to Field Companies, surveys of a higher order were generally made. Both North and South of Bethune such surveys were particularly noteworthy. In the latter case Major (now Bt.-Lieut. Colonel) Russell-Brown mapped a considerable area on the plane table, and afforded valuable information and help to the artillery in that region. North of Bethune Captain (now Bt.-Lt.-Colonel)

C. M. Browne (from the Survey of India) made an excellent map of Givenchy and the Indian Village.

Such surveys, however, depending upon their own bases and azimuths, and differing in scale and character, can never take the place of systematic mapping of the whole area of operations. The first essential—the dependence upon a general ruling triangulation—is absent. Discrepancies on the mutual edges cannot be adjusted without fresh original work. This fact has been proved often in practice.

In February, 1915, the positions of the stations of the French national triangulations had been received. The 1st Ranging and Survey Section had started a systematic survey, and a circular was sent to all Royal Engineer units asking for their co-operation in map-making, and stating that the triangulation and levelling data for our theatre of operations were in our possession and would be sent to anyone who would use them. This circular elicited no response; this being due, no doubt, to the fact that few Field Companies could devote much time to the task, and that the temporary officer who was replacing the regular in the lower ranks did not possess his training or knowledge in survey matters.

The formation of Tunnelling Companies brought a new impetus to the question. Trench survey of a high order of accuracy became essential. As an instance of the necessity for such surveys the mining operations opposite Albert may be quoted. When this area was taken over from the French little knowledge of the positions of the various galleries relative to the German trenches was available. A survey was immediately begun by the 3rd Field Survey Battalion, but with the small number of surveyors available it was found impossible to cope with the demands for mining surveys, and they were taken over by the officers of the Tunnelling Companies, many of whom had much experience in this work. These mining surveys were naturally on a very much larger scale than the ordinary trench map. Small local surveys on scales varying from 1/5,000 to 1/1,000 were common, and were made generally with the miner's dial, or with theodolites provided with a compass attachment.

As mining gradually decreased in importance so did these mining maps diminish in number, until by August, 1917, original trench survey was confined to field survey units.

One may say in conclusion that much good survey work was done both by Field and by Tunnelling Companies, but that the value of these surveys was invariably ephemeral, because they were not made in consultation with Field Survey units, and were not based upon any triangulation.

3. First Field Work by Survey Units.

The first attempt to produce a large scale map for general use took the form of an enlargement, to 1/20,000 scale, of the 1/80,000 French General Staff map. Though this enlargement (which is discussed in detail in Section IV.) proved to be of no use for accurate work, it was thought that it might provide a sufficiently good basis to allow of its being revised on the ground, in the same manner as are the Ordnance Survey maps of Great Britain. Had this been the case much time and labour would have been saved, as it would have been unnecessary to carry out a triangulation and a complete topographical survey. A short trial proved, however, that the enlarged map was useless for the purpose of revision. The magnitude of the errors and the difficulty of selecting any points which might be taken as accurate made such methods impossible. As a final effort, a traverse was run, closing on itself, and covering about ten miles of road, from which attempts were made to revise the whole country in the neighbourhood; but it was found that this practically amounted to a re-survey. Consequently, it was decided to make an entirely new map on the scale of 1 in 20,000.

4. First Survey.

(a) General Scheme.

(a) When the construction of large scale maps of Northern France was first undertaken (by enlargement of the 1/80,000) it had been decided, as a matter of general principle, to make them form an extension westwards of the Belgian 1/40,000 series and to adhere to the size, shape and scheme of that series. Full records of Belgian mapping and triangulation existed, and the adoption of the Belgian projection and sheet lines promised a consecutive series of maps stretching as far as the German frontier. This scheme was consequently adhered to when the survey on the ground was started, and the work was undertaken on the basis of 1/20,000 sheets.

The scheme of nomenclature adopted was as follows: The four 1/20,000 sheets which covered the area of a 1/40,000 sheet were named N.W., N.E., S.W., S.E. Later, when

1/10,000 sheets were introduced the four sheets covering a 1/20,000 sheet were numbered 1, 2, 3, 4. A 1/20,000 was thus called, for example, 28 N.W., and a 1/10,000 sheet, 28 N.W.3. In addition the sheets were usually given names.

(b) Area Undertaken.

(b) The British front at this date (December, 1914) extended from north of Ypres to Bethune. The sheets involved were 27, 36A, and portions of 28, 36, 27A and 36D. The British area thus fell partly on ground covered by Belgian maps, partly on French Fortress Plans Directeurs, and partly on the country of which no maps existed, except the French 1/80,000. These circumstances, combined with the fact that at this date no one anticipated that the war would last for several years, were governing factors in the method of conducting this first survey.

(c) Principles Adopted.

(c) It was decided to accept the Belgian maps and Fortress Plans Directeurs as they stood, and to survey and map the remainder of the area from the front line to about ten miles west of St. Omer, and to carry this survey out as quickly as possible, the idea being to provide a good working map in time for it to be of use without going into refinements of accuracy. Among the provisions made to ensure speed were the omission of detail in the towns and of many minor hedges and ditches, and to do no contouring in the field. As the country to be dealt with was nearly all very flat, this last provision was possible without affecting seriously the value of the map.

(d) Execution.

(d) The first step was to secure the latitude and longitude of the points of the French Triangulation and to calculate the rectangular co-ordinates, on the Belgian Bonne projection, which corresponded to these geographical co-ordinates.

Work in the field started on the 25th of January, 1915. Each plane tabler was given one-third of a 1/20,000 sheet—that is to say, an area of 20.6 square miles or 207 square inches to complete. On the 28th of February the material was complete and all field sheets were forwarded to the Ordnance Survey for reproduction.

(e) Remarks on Result.

(e) This first survey produced the second edition* of the sheets in question, the first edition having been the redrawn enlargement from 1/80,000. The sheets were the 1/20,000 quarters of 27 and 36A, with 27A N.E. and S.E., 36D N.E., and portions of 28 S.W. and 36 N.W. and S.W.

This edition had numerous defects. The hasty methods of survey described above could not result in the highest accuracy, and the drawing was of a corresponding nature, so that the sheets produced were coarse in comparison with the fine maps produced later by Field Survey Battalions. Apart from this, certain errors crept in for which the surveyors were not responsible—for example, there were clerical errors in some of the geographical co-ordinates supplied from Paris. One such case occurred at the southern end of our line and caused detail on the map to be displaced by about 150 yards. In another case the original trig. point had been replaced by a new church tower, built close to, but not on the site of, the old one, which caused an error on the map of 50 yards.

In spite of these defects this survey was a very great advance on the previous maps. Its effect on artillery methods was at once apparent, and its comparative accuracy gave rise to renewed demands for a more accurate map of the territory in German occupation.

It should be noted that at this date the value of the old French cadastral plans was either unknown or not appreciated. No use was made of them in the first survey.

5. Further Surveys.

(a) Extension to South and West.

(a) The principle having been adopted that survey in the field was necessary, the survey had to be continued with each increase in the British area. Whilst the first survey was in progress our line was lengthened towards the south. Additional area was taken up, therefore, and at the same time the series was extended westwards to G.H.Q. in order to include training

* It should be noted that this edition did not in all cases bear the number 2 (see Chap. 2, Section III., 14).

grounds, etc. For these subsequent sheets time was not so important a factor, and the survey was carried out with greater care and with a higher order of accuracy. Contours were surveyed on the ground at the same time as the detail. This survey holds extremely well in comparison with work done still more thoroughly in 1918.

(b) Revision of Calais Plan Directeur.

(b) The 1st Ranging and Survey Section having been largely reinforced with surveyors from England or from units in France, the additional personnel made it possible to start at once on a map of Calais which was required. Calais is included in one of the Fortress Plan Directeur Series, but new camps, railway construction and other works made it imperative to have a good and up-to-date map. The originals of the Fortress Plan Directeur (drawn on a scale of 1/10,000) were secured from Paris, and in April, 1915, the revision of these was begun. Curious errors were found, some of which appeared to be due to a discordance in the trig. points, and to a subsequent equation of intervening detail. The map of Calais was completed in three 1/10,000 sheets, based not upon the Belgian Bonne, but on a Cassini Projection, whose origin was Notre Dame in Calais. The town portion of the work was also published on the 1/5,000 scale, by enlargement from the revised 1/10,000.

(c) Revision of Sheet 19.

(c) It was decided next to revise sheet 19 lying to the North of our area, and to fit it to the Belgian Sheets, which lay upon its Eastern edge. This sheet is covered mainly by the Fortress Plan Directeur of Dunkerque, which was found to be exceedingly accurate on the whole. Areas of inundation, new railway construction, and a good deal of recent detail around Dunkerque were added, not without a considerable amount of opposition on the part of the inhabitants. This work was completed in May, 1915.

(d) Revision of Portions of First Survey.

(d) In March, 1915, the battle of Neuve Chapelle advanced our line to some small extent in Sheet 36 S.W., and owing to this fact and the original error mentioned in paragraph 4 (e), it was decided to revise that portion of the original survey which stretched from Bethune to Laventie. A portion of the personnel was employed on this task, therefore, which was completed in August.

(e) Survey of New Areas.

(e) The situation in the summer of 1915 was that the Second Edition was available in Flanders, that a few General Staff* trench maps existed in the First and Second Army areas, and that in the new Third Army area there were French Plans Directeur which had been prepared by the French Army previously holding that portion of the line.

In July, 1915, the Third Army was formed, and took over an area south of Arras previously held by the French. The difference of grids and sheet lines used by the British and the French and various differences in the interpretation of the topography made it necessary to remap this sector of the line. This work was immediately put in hand by the 3rd Topo. Section, together with the survey of the area in rear of the first line not touched by the French. The same process was repeated when, in March, 1916, the Third Army took over the Arras sector from the 10th French Army, the 3rd F.S. Co. mapping the area for which they were responsible, while the 1st F.S.C. extended their surveys southwards to meet them. Similarly in July, 1916, the 5th F.S. Co. found itself, on its formation, with a new area which required survey. It was at this date (early in 1916) that cadastral plans were used for the first time as a basis for plane-tabling. The plans, which were copied and reduced to 1/20,000, were compiled on a plane-table and sent out for revision. The consequence was a topographical survey not more accurate in the open rolling downs, but considerably more accurate in very close intersected valleys and in the interior of towns and villages.

(f) Revision of French and Belgian maps.

(f) While most of the Field Survey Companies were occupied to a large extent with survey on the ground, the northern Company—the 2nd—whose area lay wholly on Belgian maps or Fortress Plans Directeurs, made a study of these maps and found that they were

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* *i.e.*, not produced by Survey units.

susceptible of much improvement, either by revision of detail that was out of date, or correction of errors of topography and of plotting. This work was therefore undertaken, partly in the field and partly, with the aid of air photos, in the office.

6. Survey of Back Areas.

(a) Commencement in 1918.

(a) During the war the importance of surveying the area in rear of Armies was realised, but lack of personnel and the pressing nature of other work made this impossible. Consequently the German attack in the spring of 1918 found us unprepared in this respect. Our line was driven back in the south to the extreme limit of the area that the Field Survey Battalions had been able to map, and in some cases beyond it. It became imperative to prepare maps of the back area at once, in case of a further retirement, and this work was put in hand in April, 1918, the Depot Field Survey Battalion being charged with its execution. Fortunately at this time a number of topographers had recently been sent from England and were held as reinforcements. The presence of these men, with a number from the 5th F.S.B. (temporarily out of action), enabled the work to be pushed on rapidly. The 3rd F.S.B. undertook six 1/20,000 sheets, and two were later completed by the 5th F.S.B., the rest being done by the Depot.

(b) First Methods.

(b) The Survey was carried out, as in previous cases, on the 1/20,000 scale. The method adopted for this work is interesting and instructive, as it was a combination of ground survey and air survey. It enabled a reliable map to be produced in a remarkably short space of time.

The method followed at first was as follows :—

(i) *Trigonometrical work.*—A rapid test of the triangulation in the sheet, and the addition of a number of subsidiary points and heights.

(ii) *Topographical Skeleton.*—The addition, by topographers using plane-tables, of a number of cross roads and other points of detail easily recognisable on the cadastrals. These constituted a sort of fourth order of triangulation.

(iii) *Cadastral framework.*—The compilation of cadastral plans on the above topographical framework.

(iv) *Supplying detail.*—Detail was filled in on this framework mainly from air photographs. Where these did not exist or were doubtful men were sent on to the ground.

(v) *Contouring* was done by topographers on the ground.

The rapidity of this work depended largely on the supply of good photographs, and the co-operation of the R.A.F. was essential.

The first four sheets produced under this system were done at very high pressure, as it was possible that a further retirement might have to take place at any moment. Each of these sheets took, from the time that work was started to the time the finished drawing was sent for reproduction, on the average 18 days. The result was a map which, though far from perfect, was on the whole reliable, and in the circumstances would have been invaluable to the Artillery.

In theory the above system (*i.e.*, based on plane-table control) was sound, but in practice it did not work perfectly. It was impossible always to be sure of the cadastrals, either in the matter of scale or accuracy. The plane-tablers moreover were not infallible, and occasional mistakes occurred, which caused doubt and waste of time.

The remaining sheets were done under less pressure, as it became evident that the enemy was not in a state to advance farther, and the opportunity was taken to benefit by the experience gained in the early sheets and to modify the system of control.

(c) Later Methods.

(c) In the later sheets the work of triangulation was very largely increased, and the country eventually covered with a network of triangles of about one mile side. The next problem was to identify the positions of these trig. points on the cadastrals, which was not an altogether simple matter when it is remembered that the cadastrals were made before there was any trig. control, and that in many cases the detail was wrongly shown or had changed.

Each trig. point was examined in relation to the adjacent detail. If the detail appeared to be truly represented, the position of the point in relation to this detail was fixed by short linear measurements, and plotted on the cadastral (which was printed on tracing paper). It was usually found possible to fix at least two points on each cadastral.

The cadastrals were then fitted on to the compilation sheet by means of the trig. points only. If an individual cadastral did not fit it was evidently due to one of the following causes : (1) Incorrect scale, (2) Faulty cadastral, (3) Faulty recognition of detail from which the trig. point was fixed, (4) Alteration of detail since the cadastral was made. As a matter of fact little trouble was experienced, and the cadastrals on the whole fitted very well.

This system led to a marked increase in accuracy, and to a great saving in time. The extra time spent by the triangulation party was more than compensated by the time saved to the topographers who formerly fixed the cross roads. Under the later system the topographers took the field with the cadastral compilation as well as the trig. points plotted on their tables.

The initial steps of the survey on this method were thus :

(i) *Trig. work.*—An extended triangulation by which points were fixed at intervals of about one mile over the area.

(ii) *Plotting points on cadastrals.*—Identification of the trig. points in relation to detail, and plotting their positions on the cadastrals. This was done concurrently with (i).

(iii) *Cadastral framework.*—The compilation of the cadastral plans on the above trigonometrical framework.

The later steps were the same as under the old system. It may be mentioned, as bearing on the general question of survey with the aid of air photographs, that it was always necessary to do a considerable amount of work on the ground, apart from contouring. Photographs give on certain questions, such as the possible presence of small streams, information that is uncertain, and no information on others, such as height of banks, road classification and names. These points have consequently to be investigated by the surveyor on the ground. As this work can be done concurrently with contouring, it does not entail a great increase in the time taken.

The experience of this back area survey will be referred to again when dealing with methods of compilation in Section IV.

(d) Organisation, etc.

(d) Subjoined are details of the organisation, numbers employed, etc., which may be of value for future surveys.

(i) *Triangulation.* A party consisted of two officers, one batman, two computers, a driver for one car, and a cook. Each 1/20,000 sheet was completed, as an entity, on the ground, and the trig. values were despatched to Headquarters.

(ii) *Topography.* Each party consisted of four topographers and a cook. They were billetted centrally in a sheet and rode bicycles to and from their work. Learners were often added to a party, and these worked alongside the more skilled surveyors and carried out a duplicate of the work.

(iii) *Fair Drawing.* With one or two exceptions, all fair drawing was done at Headquarters. As each topographical party completed a sheet, it was moved to Headquarters, with a view to discussion between topographers and draughtsmen. In some cases draughtsmen were attached for a period to a field topographical party and topographers were attached to the drawing office, in order that a closer liaison between office and field might be established.

(iv) *Supervision.* There were generally three triangulation and four topographical parties in the field at a time. Each party was visited weekly by the O.C. Depot Battalion.

(v) *Reproduction.* All maps were reproduced by the Overseas Branch of the Ordnance Survey. Considerable trouble was experienced in making plates that would register well, because the fair drawing for each colour plate was generally done in several pieces in order to save time, the consequence being that unequal distortion in the paper occurred. The detail and water were generally drawn together, but as the contours were drawn on a separate sheet, it was often necessary to pull a blue impression from the detail plate which contained the grid, pin this to the photographer's screen, cut up the contour tracing into as many as twenty pieces, and superimpose these with the grid lines fitting.

(vi) *Personnel.*

Trig Officers	6
Drawing Officers	1
Trig. Computers ...	12
Topographical Surveyors	25
Draughtsmen	20
Batmen	4
Cooks	8
Motor Drivers	4
Total personnel	80

(e) Area Surveyed.

(e) The total area surveyed and mapped from the time that " back areas " were taken up in April, 1918, was as follows—in round numbers—

Area completed and published ...	2,180 sq. km. (1)
Partially completed	4,810 sq. km. (2)
	6,990

(1) Of this 640 sq. km. were done by 3rd F.S.B., and 320 by 5th.
(2) Of this 320 sq. km. were done by 3rd F.S.B.

The results of this work have all been handed over to the French, and constitute a valuable addition to the topography of northern France.

For diagram of area surveyed during the war see p.

7. Traverses.

(a) Reasons for Adopting.

(a) Throughout the war efforts were made to confine survey as much as possible to interpolations from already established trigonometrical points, rather than to rely on fixing positions by original measurement of length. The reasons are precisely those which have led to the introduction of interpolation on the plane table in contradistinction to traversing or to too much reliance upon intersection. The advantages of interpolation are briefly that the error of one point is not taken forward to the next, and that the whole is in tune with the trigonometrical control, even if it is not of highest relative accuracy. This explains why traverses were not more numerous, and why new surveyors were warned particularly against them.

Nevertheless, in many cases, traverses were found necessary owing to lack of trig. control or to topographical difficulties.

The traverses done may be divided into three classes :—

(a) For independent surveys for particular ends, as, for example, for Sound Ranging bases or for battery survey.

(b) For amplification of the direct control in difficult country, in order to provide points for "location" bases or for battery survey.

(c) For topographical purposes only, the accuracy required being that sufficient to keep within the limits of plottable error.

(b) Traverses for Special Purposes.

(b) It occasionally happened that the surveys of Sound Ranging microphone positions done by direct interpolation were not of sufficient relative accuracy, and it was necessary in consequence to resort to traversing. Such traverses were carried out with a 4-inch micrometer theodolite and a 300-foot or 100-metre steel tape. It is to be noted that the accuracy required in this case is greater than can be secured by Subtense or Tacheometric methods. Distances were taped twice, and angles measured on one face on each of two separate arcs. In two or more cases, the azimuth was determined from sun observations, and the whole survey was placed in position by such trig. interpolations or triangulation from the back as was necessary. These surveys usually took 6 to 7 days. As Sound Ranging bases were often close to the line, the work was dangerous and often interrupted by shelling. In consequence of this, on one occasion a base accurately surveyed in itself was placed about 100 yards wrong in position relative to the map, and to the hostile batteries as shown thereon. As a general lesson it may be said that traverses near the line should never be resorted to if it can be helped, because they take too long and are apt to get out of sympathy with the map. Traverses for battery survey were fairly frequent; as they were shorter and generally carried out under cover, the same objections did not apply. It should be noted, however, that in all cases some check is essential, even if it be only a bearing check from the last point of the survey.

(c) Traverses to Amplify Trig. Control.

(c) Traverses to amplify the trig. control were carried out in districts where the front line lay in woody and difficult country, and interpolations were impossible. An example is the traverse from Bethune to Fleurbaix. This survey, which was carried out in four working days, was an invaluable aid in subsequent battery and location surveys. The points were carefully marked and described, and were recovered on many subsequent occasions. Other traverses were made for similar purposes, but not always with the same care and value, because of the tendency to mark the points badly and to make a description which included no measured distances. It is to be noted that traverses for the purpose of extending the general control cannot be safely done by subtense methods, as these do not provide the necessary accuracy.

(d) Traverses for Topography.

(d) Traverses for topographical purposes were carried out wherever dense wood or other causes made interpolation impossible. Such traverses were run through the Forêt de Nieppe, through a forest south-east of Cambrai, and in many other places. The accuracy required was that sufficient to introduce no plottable errors. In our service subtense methods were not used, but they might have been with profit and advantage, as they are admirably suited to this class of traverse.

(e) Tapes.

(e) The tapes used were either steel or metallic-woven linen. At first tapes divided in feet were used, of stock pattern; but as metric units came more into use tapes divided in metres and metric subdivisions gradually replaced the others.

It may be noted here that where rapidity of work has to be combined with accuracy, as is usually the case on active service, a very convenient method of providing an automatic check with the least possible loss of time is to have tapes graduated in different units (say metres and feet) on opposite sides. This was not actually done during the war, but on many occasions such tapes would have been of great value. In the case of steel tapes, on which experience showed that it was best to mark the divisions with brass tallies rather than by engraved lines, certain practical difficulties arise, but these might be met by some other method of marking.

The following notes refer to tapes actually used in the war.

The chief points to notice in the pattern of the steel tapes used were the following :—

> The tape should be not less than ⅜ inch wide; ¼ inch was found to be too weak.
>
> Divisions should be marked by brass tallies, not by etching, which becomes illegible in mud.
>
> It is sufficient to subdivide the terminal units only; if the divisions are in feet, into tenths of a foot; if in metres, into decimetres, and the final decimetres into centimetres.
>
> The tape should project about a foot beyond the end divisions, to allow of its being shortened in case of a break.
>
> Handles should be double swivelled. Each tape should have a drum, made to fit, and of about 11 inches diameter.

The steel tapes supplied were mostly 100-metre or 300-ft. A few 30-metre steel tapes of similar pattern were also provided.

The linen tapes were of the usual 100-ft. O.S. pattern, or of 30-metre length, and divided on both sides in metres, d/m. and c/m. throughout. The usual leather box for rolling the tape up was supplied, there being an excess of tapes over boxes.

Repairing sets for steel tapes were supplied and proved useful.

All tapes used were made by Chesterman.

8. Subtense Methods.

Tacheometry and subtense measurement were used for measuring short distances in original surveys and for topographical purposes.

The above terms are used here in the sense laid down in the Textbook of Topographical Survey—namely, tacheometry for measurement with a fixed angle on a graduated bar and subtense for measurement of the variable angle subtended by a bar of fixed length. Both are, strictly speaking, subtense methods.

Subtense methods (using the term in the general sense) give an order of accuracy which is sufficient only for the measurement of short and final distances—that is, those upon which nothing else depends. These are eminently suitable for some purposes, and have been more widely developed in America and British Overseas Dominions than in England. They have not been so closely studied by British military surveyors. The survey in France did not on this account lose as much as might appear at first sight, because the method of tacheometry, for example, could not be practised near the front line, since it is necessary for a man to stand upright both at the instrument and at the pole or staff. There were, however, undoubtedly many occasions when these methods might have been used with advantage.

Tacheometers manufactured by British instrument makers are (owing no doubt to the comparative neglect of the method in this country) as a rule clumsy, heavy, and of antiquated design. Owing to the difficulty of obtaining good instruments and good staves, stadia wires were often inserted in diaphragms of theodolites at the H.Q. of the Field Survey Battalions, and in this connection the value of having an optician in such a unit is evident.

Tacheometer bars were made in practical fashion by dividing them on the ground on measured bases. This method of graduation, it should be noted, eliminates the correction which is otherwise necessary when using an ordinary theodolite for tacheometry, because the bar is measured against the true distance. These home-made tacheometer bars were of great value.

The experience of the war shows that it is advisable for instruments used on a campaign to be provided with stadia wires.

For independent surveys near the line, subtense measurement is more suitable than tacheometry, because the line for the measured base can be laid flat and under cover. A subtense bar was taken out by the 1st Ranging Section of special construction, but following generally on the lines of the Survey of India pattern described in the Textbook of Topo. Survey. This bar was used on numerous occasions to lay out a short base rapidly. For the special purpose of the Ranging Section, which had to be ready in the shortest possible time to take observations from the ends of a measured base to an aeroplane, a regular drill was developed by which the Section was able to measure a 1,000 yd. base and have all ready for observation within half an hour.

For battery survey subtense measurement is very useful. The final leg of a traverse, or a simple bearing and distance from an interpolation, can be measured straight to the pivot of a gun upon which a stadia rod or subtense bar is placed. Taping for this purpose, it may be noted, is usually difficult owing to the gun being under cover.

Mention will be found in the following paragraph of American employment of subtense methods with the plane-table, the results being recorded graphically.

An artillery surveyor should be fully acquainted with these methods, as they are peculiarly applicable to his work.

As a general remark on traverses and subtense methods, it may be stated that our experience of the war showed that military survey in the field should, as far as possible, be based on the triangulation of the Field Survey Units and on interpolations from that triangulation. Subtense methods are suitable for some purposes, but the training of the surveyor in undeveloped countries, whose survey is usually complete in itself, often leads him to rely on traversing and subtense measurement, when interpolation would generally yield far better results. It is also often the impulse of the young surveyor to complete his survey in itself without thinking of the comparative uselessness (in many cases) of work which is out of sympathy with the rest of the survey in the country. It is necessary to guard against this tendency.

The Resection Problem (*General Staff, I* (*c*), *G.H.Q., Nov.,* 1918).—This gives three selected typical methods, including a graphic method of finding a point whose co-ordinates are known. It is more clearly expressed and easier to follow than the first-named work.

The problem of finding on the ground the position of a point whose co-ordinates have previously been fixed is a development of the interpolation problem. It had to be solved constantly for the fixing of microphone positions, which in the British service were as a rule laid out at equal intervals on the arc of a circle. The problem consists briefly of three operations :—

(1) Interpolation of a position as near as possible to the required point.

(2) Computation of the bearing and distance from the interpolated point to that whose position it is required to fix.

(3) Measurement on the ground of this bearing and distance.

A second resection was made on arival at the supposed correct position, as a check, and possibly a second bearing and distance had to be computed.

11. Heights.

Whenever time and circumstances permitted, the contours of our own area were surveyed on the ground. This was done by the usual topographical methods, namely, the drawing of form-lines with the aid of the Indian clinometer, based on trigonometrical heights and the bench marks of the local levelling systems.

To be of use to the Artillery it was not sufficient for these form lines to show the form of the ground only; they had to conform as nearly as possible to true contours, so that they might provide accurate information as to ground heights. The degree to which they approached the true instrumentally surveyed contour depended mainly on the skill and experience of the topographer, and as the area of operations expanded the propoition of really skilled men naturally decreased.

For example, the formation of Corps Topographical Sections including 3 topographers theoretically provided an opportunity for doing some extra topographical work, as the fixing of field batteries for which these men were intended would not in quiet periods occupy all their time. Attempts were made, therefore, to improve the contouring on various portions of the map. Actually, however, these men were as a rule not nearly skilled enough for this, which is almost the most difficult work a topographer has to do. Most of them had to be trained in the country, and it was impossible to produce a really skilled topographer in the time available. Further, the officers of the Sections were so occupied with office work that they could do no supervision in the field. Hence such contouring as was done by the Corps Topo. Sections was as a rule not of great value.

On the other hand some really useful work was done by some of the Observation Group officers. With the development of observation for ranging on the air-burst, it became essential to know the exact height of the survey posts. These were determined instrumentally (with the theodolite) and the height was occasionally found to disagree with the local contours. The Observation Groups included many keen and zealous officers who had a good knowledge of topographical methods, and the result was a number of valuable additions to the map contours in the neighbourhood of survey posts.

The question of the various systems of levelling and their comparative value is dealt with in Appendix II.

12. Personnel.

(a) Officers.

(a) The position of the officer in charge of Trigonometrical work in a Field Survey Battalion was a most important one, and increased in importance as the war went on. It required a sound professional knowledge and considerable experience. Every F.S.B. had at least one assistant Trig. officer, and similar qualities of professional knowledge were required of him.

During the war the rule was made that regular R.E. Officers were not to be employed in F.S.B., except in command. The choice of survey officers was, therefore, limited to those who had had experience in civil life. Some excellent officers were obtained thus, among whom particular mention may be made of those who had had experience in the surveys of S. Africa, Ceylon, and the Federated Malay States.

Officers with suitable qualifications were also collected at the O.S. for this work, and put through a course of instruction, and in 1918 a course was given at G.H.Q., France.

As survey in the field is now recognised as a military necessity we shall in any future war, doubtless, have regular officers available who have had peace training for the work. For any war of the nature of a European war we shall, however, certainly have to supplement the supply from outside sources; and those same sources will have to provide officers for territorial units. It is as well, therefore, here to emphasise the fact, amply proved by experience, that it is essential to have thoroughly competent officers for this work; and that, consequently, those civilian surveyors who are ear-marked for it should have special training and experience on manœuvres for the purpose.

(b) Other Ranks.

(b) It was explained in Section I. that the personnel of the original Survey Companies in England was distributed early in the war among various units. A number of these men were recovered. In many cases when they heard that survey was being undertaken in the field they applied to be allowed to return to their proper employment. Others had, however, already risen to higher rank in Field Companies or other units, and either could not be spared or preferred to remain where chances of advancement appeared greater.

When the supply of Ordnance Survey men ceased, the Survey units were dependent on :—

(1) Men with some knowledge of survey or topography in units at the front.
(2) Men trained at the Ordnance Survey.

These men were really the same material, but those who came from England had already had a course of training at the O.S. This training was, naturally, sound; the men only lacked experience.

Men obtained in France were trained by attachment to experienced hands, or, in some cases, by regular courses of instruction held by F.S.B.

Some very good men were obtained thus. As might be expected, however, the general level of the newer men was lower in topographical knowledge and experience than that of the old Ordnance Survey hands.

13. Survey for Engineering Purposes.

A certain amount of survey is included in many branches of engineering work, and it would be neither convenient nor economical for all such survey to be done by survey units. On the other hand much survey work was done in the war by other units which could have been done by the Survey organisation certainly more expeditiously and more economically, and in some cases with better results.

Instances of such cases are the survey of inundation areas, carried out by a party of Ordnance Survey men sent out specially from England to work under the Engineer-in-Chief; the survey of forest areas carried out by plane-table, when at least half of the work was available in the French cadastral surveys; and survey of railways, roads and mines, laid out without any reference to the trig. points. The explanation of these cases lies, no doubt, largely in the employment of colonial cadastral surveyors, who are accustomed to work without data because they live in countries in which none are available. In France, however, full data of all kinds were available; the Survey organisation was in touch with all sources of survey information, and was in a position to advise on the most efficient and economical way of carrying out any large survey or levelling scheme, and to provide whatever material was available for the purpose.

In the interests of economy of effort, so essential to success in war as in all big undertakings, it is, therefore, most important that all surveys which partake of the nature of mapping, as distinct from the making of a plan of buildings or works, should be referred, in the first instance, to the Survey staff. Such a reference will ensure that efforts are not wasted through want of knowledge of what material already exists, and also that such surveys are not only useful for the immediate purpose for which they are required, but that they will also fit into the general scheme and be available for the revision of existing maps.

SECTION III.—PRODUCTION IN THE OFFICE.

1. Production of Small Scale Maps.

The small scale maps used in France were prepared entirely in England, and do not therefore come within the scope of this history. It will be useful, however, in order to complete the account of the maps used, to note briefly how they were produced.

(a) 1/250,000.

(a) The 1/250,000 (4 miles to 1 inch) which covered Belgium in four sheets and extended from Dunkerque to the Rhine, had been prepared at the War Office before the war, and was completed shortly after its outbreak. It was printed in five colours (outline, water, woods, roads and contours), and was a first-class map of its kind. This map was extended early in the war to cover the northern part of France down to about the 47th degree of latitude, the work being done at the Ordnance Survey. To economise time a simpler style was adopted for the new sheets, following to some extent the French 1/200,000 (*e.g.*, roads were shown by a single red line). This series was based on a meridian to the west of that adopted for the original four sheets, so that sheet lines of the new and old sheets fell at a slight angle with each other. The new sheets were printed in five colours, and formed a useful addition to the cartography of the area, though, being produced at speed, they were less complete than the first four sheets.

(b) 1/100,000.

(b) The 1/100,000 map had been completed to cover Belgium (excepting an area in the N.E.) before the war. It was taken from the Belgian 1/40,000, and was printed in five colours. It was designed to cover the area of Belgium only, and extended only so far as was necessary to include the frontier. It was published in ten sheets, of which one (Mons) was much smaller than the remainder.

As soon as the area of British operations settled down in the north this series of 1/100,000 was extended westward and southward until it covered the whole of Northern France, to the coast and as far south as the 49th degree of latitude, in a uniform series of sheets. The extension westward was constructed from the French 1/80,000, and therefore gave no more information than was to be found on that map; but the 1/100,000 was clearer to read, and obviated the disadvantage of having a break of scale at the Belgian frontier. Sheet 4 (Maeseyck), in the N.E. of Belgium, was also produced from the Belgian and Dutch 1/100,000. The preparation of all these sheets was undertaken by the Geographical Section, War Office.

Outline plates for the western part of Germany had been prepared before the war at Southampton, under the instructions of the Geographical Section, War Office, from the German 1/100,000. Early in the war the Ordnance Survey prepared colour plates for those maps.

(c) 1/80,000.

(c) The 1/80,000 used in the earlier part of the war was a photographic reproduction of the French Carte de l'Etat Major. The original map is not always easy to read owing to the heavy black hachures. The British edition suffered in the process of reproduction, and is still less clear. Contours were added by us, based on the 1/200,000 map, and were printed in red. This map was produced by request of the Geographical Section, War Office, at the Ordnance Survey, the contours being compiled at the War Office.

(d) Smaller Scales.

(d) Various other small scale maps were used, but were office rather than field maps. Among them may be mentioned the 6 miles to 1 inch (1/380,160) of Belgium, the 1/500,000 of Northern France, and the 1/M. of the Western Front.

The 6-mile map was a pre-war preparation; it was prepared and printed with layers by the Geographical Section, and was useful as a general strategical map.

The 1/500,000 was prepared by the Ordnance Survey, and was used chiefly for showing administrative areas and indexes for large scale maps.

The 1/M. was an extension of one of the International 1/M. Series, and covered the whole front from the coast to Switzerland.

2. Reproduction of French 1/50,000.

Mention has been made of the reproduction of the French 1/50,000 (New Topographical Survey) by the Printing Company for the fighting on the Aisne in 1914. It is referred to here only because this was actually the first map on a scale larger than 1/80,000 to be used by the British Army. It was simply a copy of the French map, a few sheets of which happened to have been published of the area in which the British Army found itself. It was printed in colours and distributed in small quantities. It had no squares.

3. Enlargements of the 1/80,000.

When, from the experience of the battle of the Aisne, the need for large scale maps (mainly for the use of Artillery) became apparent, the Ordnance Survey was requested to produce them, and this was done by enlargement from the French 1/80,000. At first these were direct photographic enlargements, with the addition of colours to distinguish roads, water and contours. As soon as possible a new edition was produced in which the photographic enlargement was redrawn, which got rid of the coarse appearance of the first edition. It was, however, evident almost immediately that an enlargement from a small scale map has little practical value. On a small scale, such as the 1/100,000 or 1/80,000, the detail is of necessity generalised, and some features have to be greatly exaggerated (as, for example, the roads in their width). In an enlargement of such a map to the scale of 1/40,000 or 1/20,000 the generalities and exaggerations become gross distortions; details such as houses along roads are thrown entirely out of position, and the enlarged map no longer gives anything approaching to a true representation of the features of the ground. The only possible value of such a map is to provide space to write notes and directions, for which the original small scale map does not give room, but for the purpose of accurate Artillery fire or trench representation it is quite useless.

It may be worth while to mention that, should an enlarged map be required, it is much better to leave it in the rough state of a direct photographic enlargement than to redraw it. The former has a coarse appearance which probably warns the user that the map is not accurate, but the redrawn map, with its finer detail, has a fictitious appearance of accuracy which is dangerous.

4. Air Photography in Relation to Survey.

(a) Errors in Air Photographs.

(a) Air photography entered largely into all mapping questions after the earlier surveys had been completed. It played a particularly important part in the problem of mapping forward areas, which was mainly office work, so that the subject requires special mention in this Section.

Air photographs were used for mapping from an early date in the war. As soon as those concerned in their use went beyond the study of the individual photograph and tried to combine several it was found that they were subject to a variety of errors which impaired their value. A detailed consideration of these errors is a matter for a separate treatise, and would be out of place in this account. It is enough for our purpose to say that they may be classified as :—

(i) Variation in, or uncertainty of, scale, due to variation in the height of the plane, inequalities in the ground, and oblique pointing of the camera (non-vertical exposure).

(ii) Misrepresentation, due to relative motion of the plate and view during exposure or to lens distortion.

(b) Necessity for Control and Rectification.

(b) A careful investigation of these errors, which [particularly in the case of (i)] are often considerable in amount and the more dangerous in that they are not always apparent from inspection of the photographs, is only to be expected from those who have devoted time and study to the subject, and who have moreover the knowledge which makes such study profitable. There is consequently a widely prevalent idea that photographs as taken towards the end of the war, which were admittedly extremely good, were in themselves all that was necessary for the making of a good map. This is not the case. It is true that photographs, even when they include large errors of representation, provide an excellent picture of the ground which is of the greatest value, and for some purposes may be all that is required. Thus a photograph of a portion of a trench system, though it may from various causes show an inaccurate plan, may give all the information that is required for finding out the nature of those trenches, their organisation and the type of obstacles before them, and so be quite adequate from the point of view of the Staff Officer who is planning an attack. But the moment that accuracy of delineation, of relative position, of distance and bearing is required, the photograph that does not give a correct representation of the detail in plan is of no use without control and correction.

It is necessary to emphasize this point for two reasons. Firstly, it is desirable to explain the necessity for the work that was done by the Field Survey Battalions in the course of producing maps with the aid of air photographs. Secondly, it is necessary to guard against the error into which many are apt to fall, on seeing the excellent "mosaics" made up of a large number of air photos fitted together, that such a mosaic provides all that is required in the way of an accurate map.

Accuracy of delineation is by no means the sole desideratum in a map, and it has been shown that it is not always necessary. But if accuracy of delineation can be combined with correct information of military value, the map becomes useful to all arms, and to the Staff as well as to troops, and consequently much more valuable. To produce such a map was therefore the problem, the solution of which fell mainly to the survey organisation, and the first duty of the latter was to provide an accurate representation of detail.

For this purpose the two requirements, in order to make proper use of photographs, are control and rectification.

By control is meant the provision of an accurate framework to which the photographs can be fitted in order to prevent the accumulation of small errors which may cause in the end a large displacement of position. Such an accumulation is particularly liable to take place in the building up of a "mosaic" or compilation of small portions without any control. Even when the positions of certain points are fixed, the intervening detail, if these points are far apart, may be greatly distorted. The problem is not an easy one when dealing with cadastral plans, as will be described later. It is much more difficult when dealing with photos, with unknown errors and distortions.

By rectification is meant the correction of errors, either of scale or of representation, in each individual photograph.

(c) Control.

(c) Control of air photographs is provided as a general rule by establishing on the ground a reliable framework that can be recognised in the photos, but there is also another form of control provided by air photography itself which, though subordinate to survey control, is of great importance and is described below.

(i) *Survey Control.*—When the ground is accessible this affords no difficulty. A trigonometrical framework is surveyed, and provided that the trig. points can be identified on the photos, and that there are enough of them, the problem is solved. If detail between the trig. points is accurately fixed, this, of course, provides an additional safeguard. This is what was done for all survey in rear of the front line in which air photos were utilised. The details of the methods adopted are described in Section II., para. 6.

For the area in the enemy's occupation the problem was less simple, because here fewer points could be fixed, and no detail survey could be done on the ground. Reliance had, therefore, to be placed on a framework provided by the old cadastral plans, controlled by such points as it was possible to fix. The chief difficulty encountered in this method was that it was known that the cadastral plans were not wholly reliable. Thus, when a photograph differed from a cadastral it was not always possible to know which was correct. Every case had to be considered on its merits, and a sound judgment could be arrived at only after considerable practice. In this work previous survey experience was a most valuable asset. On the whole the cadastrals provided a good and trustworthy general control, and when they were not available, as was the case in certain areas, the map made from photographs alone was considerably less accurate and reliable.

(ii) *Air-Photo Control.*—If a photograph can be taken which covers an area of country sufficiently large to include several fixed points, it is evident that it will supply a valuable control, provided that it is not subject to errors which cannot be corrected. To obtain such a photograph it must be taken from a high altitude with a lens of short focal length and wide angle. Such a photograph is, from the purely military point of view (apart from military mapping), valuable only as providing a general indication of military works, areas of activity, new construction, etc., but it does not give the detailed information which is required for tactical purposes. Hence these small scale photographs are not as a rule in great request by the General Staff.

Their value in an unmapped country, or in any country in which mapping (as, for example, of trenches) has to be done over a large area is, from the survey point of view, very great, and when it is considered of what importance an accurate map is in modern warfare there seems little doubt that the taking of such photographs should be regarded as one of the first requirements when dealing with a new area, or with any new works or features. This is a very important point, because up to the end of the war this matter was regarded as one of desirability, but not of prime necessity—that is to say that an aeroplane was detailed for this special duty of high-altitude photography only if it could be spared from other work. There is no doubt that this led to the loss, or delay in provision, of military information of the highest value.

One instance may be given to illustrate this point. In the German retreat on the Somme in 1917 it became of great importance to have good maps of the Hindenburg line of trenches, and it was especially important that these maps should be accurate as to position, on account of the artillery bombardments which would be required as a preliminary to attack. Many hundreds of air photographs were taken at low altitude, but in spite of repeated requests no high altitude photos were taken until later. As a result none of the numerous low altitude photographs could be utilised for mapping, because, owing to lack of detail in the ground, it was impossible to locate them accurately. Had a series of high altitude photos been taken *first* (and the weather conditions did not make this impossible), all other photos could have been fitted into their places with ease.

It must not be forgotten that this air photo control does not in itself supply all that is required for the map. As mentioned above, it is subordinate to survey control, for the high altitude photos may evidently contain the same kind of errors as are found in those taken low down. But a good series of high altitude photos will supply a key to which the larger scale photos can be fitted, and may thus—though not providing a *final* plan—fill a great want, and save much time.

(d) Rectification.

(d) The rectification of a distorted air photograph is necessary in order to bring the detail into conformity with the true plan. It may be done either by transferring the detail from a distorted photograph to its true position on the plan; or by a previous correction of the photograph.

As a preliminary it may be noted that the only errors in a photograph which can be completely rectified by geometrical or mechanical means are those variations of scale which are due to perspective effect caused by non-vertical exposure. By perspective effect is meant the effect caused by the fact that the angles subtended by any object at a given point vary inversely as its distance from that point; so that the far side of a rectangle, for example, when viewed from any point not vertically above, appears smaller than the near side. There is no known method, nor is it easy to imagine the possibility of a method, which will correct, from a single photo, variations of scale or misrepresentation caused by inequalities of the ground or by motion of the camera during exposure; though errors due to the former cause can be corrected from two photos of the same area. Hence the methods described below do not presume to deal with such errors. But though these errors cannot be completely removed, it does not follow that they are always so serious as to affect the map materially. Whether they do or not will of course depend on the circumstance of the case.

It may be mentioned that, with the best apparatus, high altitude photos appear to be free from errors due to movement of the camera during exposure or to lens distortion.

The systems of rectifying a photograph may be broadly divided into two classes :—

A. Making the detail on the photo conform to the known position of that detail. This is the system of rectification by the trig. framework, and implies previous knowledge of the ground, but requires no knowledge of the position of the camera during exposure.

B. Correcting the amount by which the optical axis of the camera deviated from the vertical at the moment of exposure. This is the system of rectification by suitable manipulation of the camera, and implies knowledge of the "tilt," but requires no knowledge of the ground.

Throughout the war system A only was employed, because no means were devised to enable system B to be used.

The following methods of rectification, based on system A, were employed in France during the war.

(i) *Geometrical or Survey Methods.*—It is evident that if a plan be distorted merely by tilting, so that perspective effect is introduced, straight lines remain straight lines, and prolongations, intersections, etc., may be used for the purpose of fixing detail, which can then be plotted in its correct position on the true plan by similar methods. This was the method that came most naturally to our older surveyors, as it was that to which they had been trained for the purpose of correcting and inserting detail when revising Ordnance Survey maps. It was therefore by this method of geometrical intersections, combined with the use of proportional compasses to correct to the required scale, that most of our draughtsmen worked throughout the war. Provided that there are no serious errors of "misrepresentation" in the photograph, this method is satisfactory; but should there be such errors it is possible to plot detail quite wrongly on the map, in complete ignorance of the fact that any mistake is being made.

The French used a similar method, but based rather on pure geometry than on field methods, depending on the well-known geometric principle that the "cross-ratios" of a pencil of four lines remain unaltered in a perspective. It is theoretically sound (which the use of proportionals is not) but is much slower to use. There are occasions when the method is of value, but it is not suitable for building up the detail of a map.

(ii) *Camera Lucida.*—This instrument consists of a small prism mounted on an arm which can be screwed on to the edge of a table, and adjusted so that the prism is held at a convenient distance above the table. If now a map be fixed on the table beneath the prism, and a photograph mounted on a vertical board a short distance away, it is possible by looking downwards at the map past the edge of the prism to see at the same time the map and the reflection of the photo. The photo can be adjusted so that the detail on it falls on the corresponding detail of the map, and if the board or easel has suitable movements it can also be adjusted to correct distortions in the reflected image, and to bring it to the same scale as the map.

The advantage of this apparatus is that when once the adjustment has been made all the detail on the photo can be drawn in far more quickly than if it has to be plotted point by point by "prolongations," proportional compass or any other methods.

Unfortunately the adjustment, unless done by a trained man who thoroughly understands the principles of perspective to which the distortion is due and how to correct it, is rather difficult and may take a long time. The use of the apparatus also severely strains the eye, and for this reason it was not popular in our service.

The French made much use of it, but even their apparatus is susceptible of much improvement.

There is little doubt that we should have employed the method to a much greater extent had it been possible to give time to designing and constructing a better apparatus and working out more fully the geometrical problems involved.

(iii) *Projectograph.*—This was the name given to an instrument which was designed in its first form by Sergt.-Major Wright, of the 1st F.S.B., and was developed by the Depot F.S.B. It was a projecting lantern designed to throw the image of the photograph on to the map or drawing, at the correct scale and with distortion corrected by tilting the negative. The idea is obvious, and the theory simple; and more than one instrument of this kind has been suggested and produced. Certain difficulties in the optical arrangements are, however, encountered, and in the model in question an apparatus was produced that was altogether too bulky and cumbersome, and it was little used.

(iv) *Corrected photos.*—The projectograph aimed at combining in one operation the various processes of correction for distortion and for scale, and of application to the map. It is questionable whether it is sound to attempt so much. In the 4th F.S.B. Lt.-Col. MacLeod and his printing officer, Capt. Cursiter, devoted much attention to the problem of correcting the photograph, leaving the application to the map to be done later. The method evolved depended upon the identification of four fixed points (the minimum necessary to solve the problem). The image of the negative was projected upon a screen on which the fixed points were correctly plotted; an ordinary projecting lantern being used, but provided with a special arrangement for tilting the copying board in any required direction. Provided that the "tilt" be not too great (more than 4°), a new photograph can thus be made, correct to scale and free from all distortion that it is possible to remove. The corrected photo is then handed to the draughtsman, who can trace it at once on to the map.

The correction of air photos by a similar method was tried by Capt. Thomas, R.A.F., in Palestine, but discontinued as being too laborious. It seems probable, however, that the procedure in each case was governed by local conditions rather than by its intrinsic merits. In France there was a fairly good skeleton of trig. points and cadastrals on which to hang photographs; in Palestine there was practically nothing.

(v) *Conclusion.*—A consideration of the above methods leads to the conclusion that the procedure adopted in the 4th F.S.B. was the soundest. On the principle that specialising in various functions leads to economy and efficiency, it is evident that the draughtsman should be relieved of all work except his own proper duty of transferring details to the map. Hence it is sound to confine all photo correction to another branch, and to hand over the corrected photo to the draughtsman. His work is then simple and straightforward and he can use the photo without further thought.

(e) Considerations for Future.

(e) As stated above, during the war all rectification of photos depended upon knowledge of the ground framework, referred to as system A, because no other system was possible.

But it is evident that it may not always be possible to obtain a recognisable trig. framework in the area to be photographed (as was actually the case, to a large extent, in Mesopotamia and Palestine), and that it would be of great value if we could be independent, at any rate to some extent, of such a framework. In other words it is most desirable that we should be able, if possible, to work on system B, the rectification of photographs by correcting the tilt. For this purpose what is required is an automatic means of registering, on the plate, if possible, the *amount* and *direction* of the tilt at the moment of exposure.

Knowledge of the tilt would not only be valuable when no trig. points existed; it would also save a great deal of time in the rectification of photos by fixed points. At present without such knowledge the correct relative position of negative and copying board has to be determined by trial and error; but when the horizontal axis of tilt is known it is only a matter of revolution of the negative about that axis to bring it to its proper position, and the time required to rectify the photo is greatly reduced. This means also that it might be possible to produce *accurate* mosaics quickly when time did not allow of the preparation of a map.

Another point which it is necessary to know, in the absence of a trig. framework, is the scale of the photograph, and this can only be obtained by a knowledge of the height of the camera above the ground at the moment of exposure. At present we are dependent for this knowledge on barometer readings combined with knowledge of the height of the ground itself above sea level, and this can hardly be regarded as a sufficiently accurate method for the purpose. The alternative would seem to be to record height above the ground by observation. A possible means, suggested by Capt. Thomas, would be the taking of stereoscopic photographs from the extremities of the aeroplane wings.

It should be noted that knowledge of tilt will enable a photograph to be rectified, and knowledge of height will enable scale to be fixed; but that these cannot either alone or in combination remove the necessity for ultimate control by fixed points. There will always be certain errors, and in making a map from photographs we cannot do away with a general control by fixed points any more than we can when carrying out a topographical survey on the ground. But if we can rectify the photographs the number of fixed points required for control can be very much reduced.

Knowledge of tilt and height will be a great advance in air photography; it will save much time; and it will enable photographs to be used with sufficient accuracy pending the subsequent provision of a good control.

The case may be shortly stated thus :—

> In a surveyed country knowledge of tilt will enable photos to be used much more quickly, and will solve the problem of determining heights from photos.
>
> In an unsurveyed country knowledge of tilt and height will make it possible to produce quickly a comparatively accurate map, pending the provision of a control of fixed points.

In considering the question of the direction in which future experiment in reference to the *pointing* of the camera should be carried out, the possibility of ensuring verticality naturally suggests itself, as this would do away with the necessity for registration of tilt, and for rectification of the photograph, otherwise than for scale. A gyroscopic camera was actually constructed with this idea in view in February, 1919, but at the time of writing it has not been tested in the air. Failing automatic means, an observer could point the camera with the aid of a suitable level or plumb bob, provided that the plane were moving at the time at a uniform velocity in a straight line.

It is, of course, impossible to ensure by any means absolute verticality at all times, as there must always be some residual error. It might, however, be possible to obtain direction sufficiently near the vertical to serve the purpose, and it is in this sense that the word verticality is used.

There are, however, reasons in favour of investigating in the direction of securing automatic means of registering tilt. These reasons are :—

(1) Flying conditions (either atmospheric or due to the enemy) will often make the steady flying necessary for taking vertical photographs impossible; and even in the best conditions accidents will happen at times. Such cases will make photographs taken out of the vertical failures, or at any rate difficult to rectify, which would not be the case were the tilt automatically measured.

(2) It is actually desirable at times to take photographs with a tilt, provided that the tilt can be measured; for example, to obtain information about vertical relief.

For these reasons experiments in the direction of securing automatic registration of tilt would seem to be more important than attempts to secure verticality.

We may then sum up the conditions necessary to allow of air photographs being used successfully for mapping, with an indication of the direction in which experiment is required.

Some of these conditions are of general application; but the subject is here viewed from the standpoint of military requirements.

1. In order to use an air photo for mapping we must either—

(a) Know the scale, and the direction and amount of tilt.

or (b) Have a framework of fixed points recognisable in the photograph.

The former condition is to be preferred.

2. If tilt and height cannot be measured, the provision of an *elaborate* instead of a simple framework of points is a necessity, because for accurate work four points on each photo are required. Since for the sake of economy the number of fixed points must be kept to a minimum, this means covering as large an area as possible with a single exposure.

3. Experiment should therefore be directed to devising an automatic and reliable means of determining the height above the ground, and the direction and amount of tilt, at the moment of exposure.

Failing a satisfactory solution of this attention should be directed to methods of covering a large area with a single exposure. Scheimpflug's system might with advantage be studied in this connection.

(f) Use of Air Photos.

(f) Air photographs were employed for various purposes in connection with mapping, and in each case required to some extent different handling.

(i) *Topographical detail.* The use for this purpose is too obvious to require description. Experience was needed to detect the presence of hedges, fences and walls, ditches and small streams, etc., and to distinguish correctly between these features.

(ii) *Trenches.* Besides the plan of the trenches much information could be deduced from good photos with regard to their depth and nature, and the position of bomb and ammunition stores, trench mortar and machine gun emplacements. The elucidation of these points lay within the province of the General Staff, but in practice a large amount (in some cases the bulk) of this work was done in the F.S.B., whose personnel were peculiarly fitted for it both by their previous training and by their close examination of air photos for mapping purposes.

It should be noted that air photos afforded the only reliable means of mapping our own trenches, as these could not be surveyed by ordinary methods. It therefore became of importance to take air photos over our own lines as well as the enemy's.

(iii) *Battery positions.* Whenever a battery could be seen from the air the air-photo formed the final evidence of its position. But in most cases the position could not be seen, though air photos would often afford contributory evidence, such as track marks. Usually the position adopted was a weighted mean between the results of Sound Ranging and Flash Spotting, and the evidence of the photos, if the latter gave evidence which differed.

It may be said that in the early days, before much trust was put in the results of Sound Ranging and Flash Spotting, it was considered that a battery was not finally fixed without the evidence of the air photo. At a later date, when Sound Ranging and Flash Spotting had proved their reliability, proportionately less importance was attached to the air-photo.

The work of fixing positions fell to the Compilation Section. Much experience was required to determine the position of well-concealed batteries, such as those in woods and villages.

(iv) *Enemy organisation.* An exhaustive study of air photos revealed much information with regard to frequently used roads or tracks, centres of activity, ammunition and supply dumps, telephone lines, and other details bearing on enemy organisation. The collection of this information was the work of the General Staff, but in practice, in this as in other cases, a great deal of it was done by the Field Survey Battalions in the course of their photo-examination for map making. Enemy organisation maps were thus produced which proved of great assistance to the Artillery.

(v) *Ground forms.* A good deal more information with regard to ground forms can be extracted from air photos than would at first be imagined; but the subject is still in its infancy, and much study and experiment is required. It is referred to again in paragraph 5 (d).

(g) Co-operation between R.A.F. and Survey.

(g) Close co-operation of the R.A.F. with the Survey organisation is a most important matter for mapping. While acknowledging the great assistance received from the R.A.F. on all occasions, it is not clear that any policy has ever been laid down as to the functions and duties of the R.A.F. in this respect. If it be acknowledged that the basis of distributing accurate information about the enemy is in the large majority of cases a good map, it follows that such a policy should be laid down; and that it should be clearly recognised that one of the first duties, if not the first, of the R.A.F. when dealing with a new area is to take such photographs as are required by the surveyors.

In this connection Branch Intelligence Sections may be mentioned. These Sections were established to form a link between the G.S. Intelligence and the R.A.F. They were attached to and worked with a R.A.F. Squadron. Among the duties of the O.C. of such a Section in the future would appear to be liaison with the Field Survey units, and with the Artillery Survey units.

5. Mapping of Forward Areas.

(a) Nature of Problem.

(a) The account of survey given in Section II. deals entirely with the mapping of areas under our own control. The mapping of forward areas, however, though taking a shorter time to describe, occupied by far the greater portion of the time of the Field Survey Battalions. This work presents a very different problem from that of the survey on the ground. Topographers cannot be sent on the ground; few points can be fixed, and those that are fixed are liable to be obliterated; while it has already been seen that there is grave danger in trusting to the positions of points fixed in old triangulations, owing to the reconstruction of signals on different sites, and other reasons. The difficulty of getting a reliable topographical framework of an area which cannot be visited is in fact very great.

(b) Early G.S. Maps.

(b) Mention has already been made (I. 5) of the fact that up to the middle of 1915 the responsibility for maps of forward areas lay with the Intelligence Branch of the General Staff. These maps had been produced without any general scheme of sheet lines, without recourse to the trig. skeleton, and without much technical skill. Indeed, the work of map making is not so intrinsically simple that it can be pursued with success at a moment's notice by one unacquainted with the guiding principles. Numerous cases occurred which deserve mention. For example, in one enlargement contours were drawn based on the bench marks of systems whose data differed considerably. In another case a marsh was inserted on the evidence of a refugee, when all the topographical data available gave evidence to the contrary. Experience generally showed that reports by agents or refugees as to topographical position had to be accepted with great caution. It became evident that compilation, where actual survey was impossible, called for expert handling even more than maps of the area behind our own line.

As a first step, air photographs were handed over to the "Maps and Printing Sections," who transferred information to the maps by proportional compasses and detail. The work becoming too great for their limited staff, Ordnance Survey draughtsmen were obtained by Maps G.H.Q., given a short preliminary training, and two were sent to each of these Sections.

(c) Compilation Maps.

(c) Later the problem was met by the use of the old cadastral plans, described in II. 1 (d). As explained in that section, these form the most valuable framework for a modern map, provided that there is some means of checking them and bringing them up to date. The method adopted therefore was to make a framework, or compilation, of the area required from the cadastral plans, their position being based on such trigonometrical points as it was possible to fix or to identify. This compilation was filled in, corrected and brought up to date by means of air photos, and also by such railway, canal, or mine plans as were found to be reliable. The air photos provided the best evidence of what detail was actually on the ground, and required only to be controlled by a reliable framework to guard against errors of distortion. This framework the cadastral plans provided.

The first map produced by this system was the 1/10,000 Ovillers sheet (57D, S.E.4) published by the 3rd F.S.C. in October, 1915. This was incidentally the first British 1/10,000 map made.

It should be mentioned that the plans used were in many cases not the original cadastrals on the scale of 1/2,500, but the 1/10,000 index diagrams. The former were used when available, but it frequently happened that they were not, in which case there was no course left but to use the 1/10,000 diagrams. Fortunately these were in most cases quite accurate enough for the purpose required.

When the work began the reductions were commonly done with the pantagraph; but later they were reproduced by the helio zinc process, and several copies printed on drawing and tracing paper. The labour of reduction and reproduction was very heavy, a large number of plans being involved. The work was done partly in France (by the Service Géographique, the Field Survey Battalions, or by the Overseas Branch of the Ordnance Survey) and partly in England at the Ordnance Survey, Southampton.

(d) Vertical Relief.

(d) The maps thus constructed with the aid of cadastral plans and air photos were accurate and reliable representations of the ground in plan, with few omissions of importance. There remained the difficulty of representing the vertical relief. The lines of levels of the Nivellement Général provided an accurate control, but were of little use for determining ground forms, as these lines are confined almost entirely to roads, canals, and railways. The only information generally available was the hachured 1/80,000 map. These hachures are based on form lines sketched originally in the field, and redrawn in the office. Reproductions of these office drawings were obtainable for some areas, and these, or in their absence the hachured features of the 1/80,000 map, served as the basis for the contouring of the forward areas. Wherever possible railway or other plans were utilised, and these often provided valuable information. A great deal of information was also obtained from the air photos themselves. The courses of small streams, areas of standing water, the lines of ploughing or cultivation, shadows thrown by the sun when near the horizon, all provided evidence of ground forms which the expert was able to utilise.

The difficulties encountered were, however, great. The shape of the ground as shown by the 1/80,000 hachures is often wrong, and there are errors in the spot levels which occasionally reach nearly 20 metres. The 1/80,000 therefore affords but a poor basis for contouring on the 1/20,000 scale, and in spite of all the labour spent on them the contours of the forward areas remained of necessity the weakest part of an otherwise excellent map.

It was hoped that the capture of enemy maps would supply reliable material for the representation of ground forms, but the German maps were disappointing in this as in other respects. Some of the most recent maps bear evidence of contouring on the ground, but for the greater part of the war, and for the bulk of their area, the Germans seem to have been content to copy French or British maps, or to rely on conventional form lines which could have been of little practical value.

(e) Maps of our own Trenches.

(e) The mapping of our own trenches, though not strictly speaking in the forward area, presented a similar problem, as ordinary survey methods were not usually possible. The subject has been dealt with in Section II. Various attempts were made, without great success, to map our own trenches by work on the ground. The subsequent development of mapping from air-photographs, however, made it possible to produce good maps for this purpose.

(f) Progress.

(f) The compilation of forward areas was pushed on as fast as the supply of skilled personnel would allow, and by midsummer, 1917, had joined up in most places with the frontier Plans Directeurs or the Belgian maps. Difficulties were met with in places. Opposite the First Army, in the La Bassee region, there was an area for which it was found impossible to obtain cadastrals, and the maps here at a late date barely reached finality with the aid of small scale air photos. On the Fifth Army front there was a wide gap, due to the great area to be covered, and the lack of draughtsmen, many of whom had been sent to reinforce the northern Companies during the fighting on the Passchendaele Ridge. Compilation therefore went on very slowly and had barely reached the Plan Directeur of Hirson before the British retreat in 1918.

For diagram of total area surveyed during the war see p.

6. Drawing Office.

The chief duties in the drawing offices were the compilation and fair drawing of the topographical detail, revision and correction of this detail from time to time, and drawing of trenches.

(a) Methods of Compilation.

(a) The methods of compilation have already been described in detail in para. 5 (c) and Sect. II. 6. The work was, as a rule, done on the 1/10,000 scale, but circumstances, and especially time, made it necessary on occasions to compile on the 1/20,000 scale. The processes may be briefly recapitulated as follows :—

1. Drawing correctly to scale sheet lines and grid, and plotting trig. points.
2. Plotting of intervening detail, such as cross-roads, if these had been fixed.
3. Transferring outline of cadastrals to sheet, hung on to trig. or other fixed points where it was possible to identify them.
4. Transferring railway, canal, or other plans that were found to be reliable.
5. Correcting and plotting detail from air photos.
6. Transferring contours from plane tables, railway and other plans, 1/80,000 enlargements, or whatever material was available. Possibly checking or modifying with the aid of air photos.
7. Fair tracing in ink on stout tracing paper.

(b) Drawing for Reproduction.

(b) Separate tracings were, as a rule, made for (1) Outline (including grid), water and names, (2) Contours, (3) Trenches.

On the drawing for outline and water the black detail was drawn in black and the blue detail in cadmium. This method ensured negatives of identical size and so made registration easier, but it had the disadvantage that it entailed a large amount of duffing out on the negative, which was difficult work when the detail was close.

Trenches were sometimes drawn on a tracing, sometimes on a combined blue print of the outline and water-plates. The latter method gave a drawing which was less liable to distortion by changes in humidity, but it could only be used when the outline plate had been prepared previously.

(c) Drawing for Different Scales.

(c) A problem that was encountered at an early date, and for which an easy solution could not be found, was that of drawing for different scales of reproduction. During trench warfare maps on three scales were required—namely, 1/40,000, 1/20,000 and 1/10,000—and maps on 1/5,000 scale were also produced in many places. When operations became more mobile, and it was impossible to continue the larger scales, there was still a demand for both 1/40,000 and 1/20,000, until movement became rapid. The difficulty was how to produce these different scales in a satisfactory manner, because, on the one hand, it was impossible to draw the original separately for each scale, and, on the other, enlargement or reduction by photography was in many ways unsatisfactory. The latter method was tried at first. All maps were drawn on 1/20,000 scale, and were then reproduced on the three scales 1/40,000, 1/20,000 and 1/10,000. The result was, however, that the 1/10,000 was coarse and did not represent the detail truly, so that difficulties were experienced in fitting trenches, while the 1/40,000 tended to become illegible. There is a limit to which enlargement or reduction can be satisfactorily carried out by mechanical means, and this limit is passed when the scale is halved or doubled, unless special provision is made in the drawing.

It was generally agreed that the 1/20,000 map was the most important of all. It made a good trench map, it was suitable for artillery, and it covered enough area to allow of some movement. At the same time the 1/40,000 was a most useful map for administrative work, and in the complicated system that grew up with trench warfare was practically essential. The most satisfactory result was therefore obtained by drawing the 1/20,000 with slight modifications to make it suitable for reduction to 1/40,000. This meant drawing detail just on the large side, and writing names rather larger than strictly necessary for the 1/20,000 scale. The result was a 1/20,000 map which, though rather bolder than required for that scale, was not coarse or repellent, and a 1/40,000 which was legible in a bad light. The 1/10,000, if required, had to be drawn specially on that scale, as was the case with the 1/5,000. This policy seems to be the correct one. It is probable that with an easily legible 1/20,000 the demand for the 1/10,000 scale would be greatly reduced. (See also para. 8 (c)).

(d) Conventional Signs.

(d) The conventional signs used on British maps showed the Ordnance Survey tradition. Most of the signs used were the regulation O.S. signs, which were to hand and the use of which saved much time early in the war, and the stamps used were supplied by the O.S. These signs, though suitable for the O.S. large scale maps, were less suited to the smaller scales used in the war and to the character of the country represented. As an example, the tree sign may be quoted. When this was used to denote the tree-lined roads which are such a common feature in France, or the small orchards which often surround villages, the result was inclined to be heavy. The French conventional signs are, as a rule, lighter than ours, and when, in 1918, the order was issued by Marshal Foch that steps were to be taken to secure uniformity of signs used on Allied maps, the British cartographers welcomed the opportunity of adopting many of the French signs. A uniform system of signs was agreed to at Inter-Allied Conferences which met in Paris, and these would have been put into force on all maps used in France by the end of 1918 had the Armistice not intervened. In justice to the O.S. signs it is, however, only fair to add that the objections to them were largely due to the characteristic features of the country mapped, and would not have arisen had we been operating in typical English country.

Another point that may be mentioned is the drawing of roads. The system that has always been adopted in England for military and O.S. maps is to show the boundaries of a road that has a hedge, fence or ditch by a firm line, and of one that has no such obstacle as a boundary by a broken line. In a country where hedges, etc., are very uncommon nearly all roads were thus shown with pecked or broken lines, and these are hard to follow in a poor light, especially when printed in grey ink. By the French system all roads are shown by firm lines, and it was found that map users much preferred to be able to see clearly where the road was, and also its traffic capacity (which could be denoted by the thickness of the line) than to know if it had hedges or not. Here again the question was largely decided by the character of the topographical detail in the country.

The question of uniformity of conventional signs is one of considerable importance when Allies are working together, and one which should undoubtedly be borne in mind when making provision for the future.

(e) Application of Air Photos to Drawing.

(e) The question of application of air photographs to survey and hence to map drawing has already been considered in some detail in para. 4, and therefore need not be treated at length here. Topographical draughtsmen who have to supply detail from air photos must be trained to their use, and neither quick nor accurate work is to be expected from those who are not so trained. As stated in para. 4, it is best, if possible, to supply the draughtsman with photos that have already been corrected for distortion. In addition, it usually saves time and mistakes to have the photos previously marked by an expert to show special details, or those that are obscure and difficult to recognise. Many draughtsmen become experts, but it should not be regarded as the duty of a draughtsman, as such, to recognise and represent correctly the detail on an air photo. His duty is the transference of that detail in its correct position to the map, but the recognition and interpretation of the detail is properly the duty of an expert, who should in most cases be an officer.

(f) Drawing Trenches.

(f) This was mainly a matter of transference from the photo, and correct representation depended largely on having correct topographical detail on the map to start with.

(g) Drawing for New Editions.

(g) New editions were brought out from time to time, when change in the detail made this necessary. In topographical detail changes in the maps were usually the result of better information obtained from air-photos or otherwise, in trench detail the changes were generally due to new work in the trenches themselves.

The method of preparing a drawing for a new edition to be prepared at the Ordnance Survey, Southampton, depended on the amount of change required. If this was great, an entirely new drawing was prepared; if it was small, a correction drawing was sent consisting of a proof of the old edition with the necessary corrections indicated in red ink, or on tracings of the portions to be changed.

(h) Sheet Histories.

(h) The constant issue of new editions embodying fresh material and information, combined with the frequent changes of Army areas, which involved the handing over of mapping material by one F.S.B. to another, pointed to the desirability of keeping a record of every sheet, which would show the various stages through which it passed, the nature and reliability of the material embodied, or any other explanatory information that might be useful. Instructions were consequently issued that a "Sheet History" should be maintained of every sheet, embodying the above information. As these instructions were given at a late date in the war the work of compiling the history sheets was heavy, and in many cases it proved impossible to prepare them.

The point is, however, an important one to note for future use. Such History Sheets if started at the commencement of any map are easy to keep up and provide the most valuable information for those who have to take charge of that map at a later date, and who have not the advantage of personal knowledge of its earlier history.

7. Types of Map Produced.

The following are the various types of map produced for use on the Western Front:—

(a) Scales.

(a) The small scale maps have already been described and need be only briefly recapitulated.

1/250,000 and smaller scales. These were office, wall, strategical and motoring maps.

1/100,000. The general administrative and tactical map.

The large scale maps (including in that term scales greater than 1/80,000) were as follows:—

The 1/40,000 was the general administrative map in trench warfare. It became a trench and tactical map in the latter phases of the war, but as a rule it was not regarded as a trench map. It was used for Artillery of longest range.

The 1/20,000 was the map commonly used by the Artillery, and as trenches could be shown on it in sufficient detail to be of use to the infantry it was the most useful scale of all, and the one that could least easily be dispensed with.

The 1/10,000 was regarded as essentially the infantry trench map, it being possible to show on this scale all but the minutest detail. This map was also used to a large extent by field artillery.

The 1/5,000 was never issued as a regular trench map, but certain sheets were produced on this scale at various times and generally for special purposes. It was commonly used for the preparation of special village plans. In 1916 the Fifth Army made a special point of this scale, and a series of maps was produced by the 5th F.S.B. covering the Army front.

(b) Forms.

(b) The above-mentioned maps were produced in a variety of forms. They were printed in different ways according to the use to which they were to be put, *e.g.*, full colours for general use, or light grey outline to serve as a background for overprinting information. In addition certain special editions of all scales were brought out for various purposes. The following list includes most of the maps issued.

Administrative Maps.

(i) *Administrative Areas.*—Made to suit the area of the Army or other formation concerned. Usually on 1/100,000 scale, and latterly often made by reducing the 1/40,000 so that square references could be used.

(ii) *Traffic.*—Made for the Q. branch of the Staff. Showed traffic directions and orders.

(iii) *Railway.*—A variety of these were kept at G.H.Q. One important map was a reproduction of the Chemin de Fer du Nord system showing all stations. Another was a diagram of our own system, including narrow gauge and trench tramways. For some time each Army produced its own type, but at the end of 1917 a standard series of five 1/100,000 Railway maps was introduced, the information being supplied by the D.G.T. These maps required constant revision to keep them up to date.

Intelligence Maps.

(iv) *Enemy Order of Battle.*—Produced periodically by G.S. Intelligence at G.H.Q. and Armies to show dispositions of enemy troops.

(v) *Various* other kinds, to illustrate summaries of information, to show locations of hostile aerodromes, details of enemy rear organisation, etc.

Engineer Intelligence Maps.

(vi) *Road and Bridge.*—Showed positions, types and capacity of bridges, quality of roads, and gauge of railways, printed in colours on grey 1/100,000 sheets. Information prepared at first by E. in C., and later by G.S. 1(a).

(vii) *Water Supply.*—A series similar to the Road and Bridge, prepared in the office of the E. in C. Showed details of water supply.

(viii) *Geological.*—Information prepared by E. in C.

Artillery Maps.

(ix) *Hostile Battery Position Maps.*—These embodied the results of the work of Sound-Ranging Sections, Observation Groups, Aeroplane Reconnaissances, etc., as digested and compiled by the F.S.B. Compilation Sections and agreed to by the R.A. They showed battery positions that had been fixed, areas that were suspected, zones and zone numbers. These maps were, with few exceptions, on the 1/20,000 scale.

(x) *Enemy Organisation Maps.*—This was the term finally adopted for maps produced in all Armies under slightly different names, such as Target and Harassing Fire, but all with practically the same object in view—namely, to show where the enemy was busiest, his main lines of communication and supply, and his various nerve centres, for the purpose of enabling the Artillery to harass him with the greatest effect. These were, as a rule, produced on the 1/20,000 scale. They were occasionally combined with the Hostile Battery Positions as one map.

(xi) *Barrage Maps.*—To illustrate details of barrages.

Trench Maps.

(xii) *Trench Maps.*—As a rule confined to scales larger than 1/40,000. These were divided into :—

> *Ordinary edition*, showing enemy trenches, and at successive stages of the war the following information about our own trenches :—(1) nil; (2) front line; (3) front-line system to depth of about 600 yards; (4) all trenches, but making no distinction between old and new, used and unused.
>
> *Secret.*—The issue of a secret trench map was at first confined to the 1/10,000 scale, and until 1918 any representation of Allied trenches was considered as within the definition of secret. In January, 1918, it was ruled that a map need not be considered secret unless it gave information which could not be obtained from an air

photograph, and under this new definition the secret edition was limited to the 1/20,000 scale, unless the Army specially ordered a secret 1/10,000.

Two other types of trench map were produced at different dates which, although they did not last, are of historical interest.

Maps Showing our own Trenches Distorted.—These were produced in response to the great need for maps of our own trenches. The idea was to provide a map which would serve as a guide to the trenches, but which would be useless (as an artillery map) to the enemy if captured. Trenches were consequently shown as conventionalised lines, bearing no resemblance to the true shape in plan, but preserving the correct number of junctions, cross and communication trenches, and giving the trench names. These maps did not prove of great value and were not continued.

Sectional Maps.—These were sections of the ordinary 1/10,000 trench maps, wide enough for an Infantry Brigade front. A blank margin was provided on which various tactical information about the front was printed. British trenches were shown by the conventional system described above. These maps were designed in the First Army; they were not ordered for general use, and found little favour elsewhere. They had serious disadvantages from the point of view of production, as Brigade areas were constantly changing, and every change involved the production of a new map and the cancellation of an old one. They were gradually dropped

Miscellaneous Maps.

(xiii) *Special Flying Maps.*—On 1/250,000 scale, prepared at the request of the R.A.F. and to their design. They were intended to represent the country more or less as it looks from the air, and also for use at night with transmitted light, and to this end the ground-work was printed in a greenish-grey, roads were kept white, and all minor detail was omitted. A good deal of work was spent on their preparation, but it is believed that these maps were not widely used.

(xiv) *Maps for Corps Squadrons (R.A.F.).*—Special editions of the 1/20,000 were produced for the use of the R.A.F. with green woods, green borders to tree-lined roads, prominent blue for water, etc. They were occasionally combined with the Hostile Battery Position maps.

(xv) *Message Maps and Traces.*—A message map was a small portion of a large scale trench map, on the back of which a series of reports and messages were printed after the style of the Field Service postcard. The sender could fill in details of position, numbers, ammunition and reinforcements required and similar information, and strike out irrelevant parts. In a later form tracing paper was used with the grid only printed on it, on which the sender could trace a portion of the map to describe his position. These message maps proved very useful for sending back information during attacks.

(xvi) *Maps for Corps Typo. Sections.*—Very large numbers of outlines were printed, some in England but most in France, for the use of the Corps Topo. Sections. They were on absorbent paper for use in the Ellam Duplicator, and consisted of portions of maps (usually 1/20,000 scale) of brief size. These were issued by the Corps Topo. Sections with information of various kinds overprinted. A large number of these maps were also used without overprint, as they were of a handy size and convenient for writing reports.

(xvii) *Situation Maps.*—To show positions reached by our own troops. Usually overprinted on existing trench maps, and issued during the progress of a battle.

(xviii) *River and Canal Pocket Maps* were prepared specially for the Inland Water Transport Branch to show details of the navigable waterways of Northern France and Belgium, with connections to road and rail. Each map was made in strip form, following the course of the particular river or canal which it illustrated, and folding within a cover to go into the pocket. The scale was 1/20,000. The information was provided by Commandant Van Halteren, and is believed to be of value, but owing to the course of the war they were not put to any general use.

(c) Layered and Shaded Maps.

(c) In addition to the above, certain of both small and large scale maps were published in layered form—*i.e.*, showing differences of altitude by tints. A layered edition of the 1/100,000 and the 1/40,000 was produced in England comparatively early in the war with the idea of a strictly limited issue for commanders of formations and staffs. In order to read the large scale maps more easily it became the practise to colour layers on the 1/20,000 and

1/10,000 by hand, and this led to a demand for a printed layered edition. In response to this various layered 1/20,000 sheets were printed by the Field Survey Battalions, but no layered maps on a scale larger than 1/40,000 were produced as a regular issue. It was realised that, owing to the hasty military education of officers, the standard of map reading was not high, and several attempts were made to produce a map which would assist the user to read the ground forms without involving too much printing. A layered map with several shades of one tint (requiring only one extra printing) was tried, but did not meet with much favour. Hill shading was also tried, but with a similar result. An experiment was made with "shaded contours"—*i.e.*, contours heavily shaded on their southern and eastern sides, giving the map the appearance of a model made of cardboard layers. This, though an eyesore from the cartographic point of view, was said to be of great assistance to inexperienced map users, and was strongly advocated by more than one practical officer. As a whole, however, the feeling about a map of this kind was half-hearted, and no general issue was made.

(d) Models.

(d) A consequence of the settled conditions of trench warfare was the production of relief or model maps of various kinds. To meet the demand the W.O. undertook the production in quantity of plaster models of 1/20,000 sheets. The work was entrusted to an agent, who organised a staff for the purpose. These models were made with the vertical scale to the horizontal as 4 to 1. The map, printed on special extensible paper, was pasted in position on the plaster. Models of this nature were issued to the higher commands, and proved very useful for the study of the ground.

The plaster models were reproduced from an original, the basis of which was a series of cardboard layers of suitable thickness, each cut to the shape of a contour. This basis was covered with wax, moulded to shape, and a plaster matrix was taken from it. An experiment was tried with the cardboard layers only, the map being previously mounted or printed on each layer. The result was a model which represented the ground as a series of ledges or steps, the proportion of the vertical to the horizontal scale being as 4½ to 1 (or for exceptionally flat areas, 9 to 1). Though they were to some degree a false representation, these cardboard models proved to be very popular. They had several advantages. They were light, they did not break if dropped, or, if damaged, were easily repaired, and it was possible to stick pins into them and draw on them. A disadvantage was that each model had to be made independently, so that they were expensive. The Ordnance Survey organised the supply of these cardboard models, and produced one thousand of them. They were issued in sets, to cover the front of the formation, down to Infantry Brigade Commanders.

The value of these models has often been questioned. There is no doubt that they were of real use to some commanders, but it is also certain that many were never used at all, or were mishandled, lost, or taken away as mementoes. On the whole, considering their cost and the fact that they cannot be kept up to date, it is questionable whether they are worth making and whether the money would not be better expended on layered maps.

8. Map Policy.

It will be of advantage to consider shortly the policy followed in certain map questions during the war with a view to guidance in the future.

(a) Tactical Maps.

(a) The question of what was the official tactical map was raised on more than one occasion during the war and has been mentioned since. It is, however, impossible to lay down that any one map shall be the tactical map at all times and in all circumstances. During this war occasions have been frequent when a 1/5,000 map was essential in order to carry out a tactical operation such as a trench raid. For settled trench warfare the 1/10,000 might be taken as the scale for the infantry tactical map. With increased activity and the possibility of movements of the line the 1/20,000 became the tactical map; with mobile warfare the 1/40,000 became necessary.

Thus the scale of the tactical map depends entirely on the nature of the operations, and on the relative degree of movement.

One clear lesson, however, is that for modern *fighting*, in which the co-operation of all arms and the mutual transmission of accurate information is so important, a gridded or squared map of fairly large scale is essential. We used the 1/40,000; probably 1/50,000 is the smallest practicable scale.

The 1/100,000, formerly regarded as a tactical map, is too small for European fighting. It is useful for marching, but as soon as fighting begins the larger scale is necessary.

Throughout the war the fact that we might eventually have to come back to the 1/100,000 was kept in sight, and troops were reminded that they should be familiar with its use, and the event proved that this policy was correct, though not in the sense that had been foreseen. When eventually it came again into general use it was as a marching map, but not a tactical map in the strict sense.

In the final phase of the war so long as there was any fighting the 1/40,000 was supplied to the troops, albeit with some difficulty at times.

It seems clear, then, that for a European war, while the 1/100,000 may be issued beforehand as a marching map, a map on at least 1/50,000 scale will always be required for fighting, and that provision must be made to supply it whenever and wherever wanted.

(b) Large Scale Maps.

(b) As a matter of general policy it may be said that experience has shown that if economy were enforced, and if the number of scales of maps issued were strictly limited, the right large scale maps to maintain for European warfare are those of scales approximating to 1/40,000 and 1/20,000. It has been shown that these can be produced satisfactorily from one drawing, which means economy of labour, and with them troops would be provided with a useful trench and artillery map, with a very good administrative map, and with a tactical map sufficient for modern requirements.

This does not mean that the 1/10,000 map is unnecessary. Should trench warfare develop the 1/10,000 will doubtless be required again as it was in this war, and it is possible that future developments may demand larger scales for general use than those mentioned above. But the lesson of the experience of this war is that the two scales mentioned above are the more important and more economical, and are those on which effort should be concentrated at first.

(c) Identity of Detail on Different Scales.

(c) When large scale maps were first produced in a regular series and in quantity a great point was made of the necessity for absolute identity of detail on corresponding maps of different scales. (The remarks in this paragraph refer only to large scale maps, say, 1/40,000 and upwards. It is obvious that identity of detail in scales differing so widely as 1/100,000 and 1/10,000 is impossible.) Such absolute identity can evidently be ensured only by mechanical enlargement or reduction from one original drawing, and this is the method that was at first adopted. But it has been shown in paragraph 6 of this Section that this method is, from the cartographic point of view, unsatisfactory.

The rule, made early in the war, that detail on different maps of the same area must be identical is based on the perfectly sound reason that there must be no chance of a mistake in carrying out orders owing to the fact that the recipients are in possession of different maps. An order must be unmistakable, no matter what map is used.

Though perfectly sound in theory, the argument is, however, to some extent a counsel of perfection, for where maps are subject to fairly frequent revision, as is apt to be the case in stationary warfare, it is not usually possible to keep more than one drawing up to date, from which, by suitable arrangement, maps on two scales, but not more, can be produced. This was the case in the war. Throughout the period of trench warfare the troops had 1/40,000 maps that, with few exceptions, were considerably behind the 1/20,000 and 1/10,000 in the matter of revision.

It is true that this point is not so serious as it sounds, for what usually happens is that only two scales at any particular period are of real importance. During trench warfare the two that mattered most were the 1/20,000 and 1/10,000; the fact that the 1/40,000 was slightly different was not of serious moment, because it was used mainly for marching and transport. Later, when some movement began, the important scales were the 1/40,000 and 1/20,000, and the 1/10,000 ceased to be required. Still, there were occasions when discrepancies between the 1/40,000 and the larger scales were remarked on and when difficulties arose, even if nothing serious happened, and there is no doubt that it is of the greatest importance to aim at the ideal that all maps should be identical so far as limitations of scale allow.

The question is how this problem can be met when the nature of operations necessitates the use of three scales? The problem did not arise in an acute form in the war—that is to say, the fact that the 1/40,000 differed from the other scales was accepted and few complaints were made. But it is a question that is so likely to arise at the commencement of any future war that it is as well to refer to it here, and to determine what solution is suggested by experience.

In the first place, a point which was not perhaps appreciated in the early days of the war is that absolute identity on three scales such as 1/40,000, 1/20,000 and 1/10,000 is for some reasons absolutely a disadvantage. If one is limited to showing on the 1/10,000 scale only as much detail as can be clearly represented on the 1/40,000, the greater part of the advantage of the larger scale is lost. Mere size is no advantage, and to depend solely on mechanical magnification for the larger scale, as was done in France in the early days, is to produce a map which gives more space, but is not superior in any other way.

The great advantage of a larger scale is to enable the cartographer to show more detail than is possible on the smaller. If precisely the same detail is shown on all scales, then either the smallest scale is crowded and illegible or the largest is empty, and fails of its chief purpose.

The conclusion is that it is *not* desirable that the same detail should be shown on all scales. The main features should of course be identical in position; but on the larger scale detail should be shown which is not possible on the smaller.

It has already been shown in paragraph 6(c) that a satisfactory map on both 1/40,000 and 1/20,000 scales can be produced from one drawing on the larger scale, drawn slightly bold to allow of reduction. It is suggested that the policy should be to make the 1/20,000 the basic map, with the 1/40,000 produced from it by reduction, these two maps thus being identical; and that the 1/10,000 or larger scales should be produced as *independent* maps, based in the main outlines on the 1/20,000, but showing as much detail as is possible on the larger scale.

Ambiguity will be avoided either by the usual precaution of always quoting the map on which orders are given; or perhaps better by ordering that, unless expressly stated to the contrary, the 1/20,000 is always the map referred to. As a practical fact, however, the danger of confusion would appear to be slight, assuming, as one may fairly do, that the cartography on the larger scales is accurate. It should also be remembered that the surveyors who produce the map are themselves soldiers and fully alive to the importance of the question.

(d) Secret Maps.

(d) Until a late date in the war there was a good deal of misconception on the subject of secret maps. A secret edition of the 1/10,000 map was published, which showed the plan of our own trenches, but gave no other information about them. It was issued in very small numbers (*e.g.*, 1 per Infy. Bde.). The result was that the troops, who had urgent need of a map to find their way about the trenches, made their own diagrams and sketches. These were freely distributed, and from the information of all sorts which they bore were far more dangerous than would have been a regular issue properly controlled. The position became absurd when it was found that troops relied on captured enemy maps for an accurate representation of their own trenches. It became evident that there was no reason for secrecy in showing the trace of our own trenches, provided that no really secret details were inserted. Such secret details obviously include battery and trench mortar positions, command posts, ammunition stores, telephone routes, etc.; in fact any detail which cannot be readily located and plotted from air photographs. It was therefore decided in January, 1918, that the ordinary edition of every trench map should show the detail of our own trenches, the secret edition being reserved for such information as could not be obtained from an ordinary air photograph; including under this head the difference between used and unused trenches. These maps showing our own trenches proved of the greatest value to the troops, a value which far outweighed any problematical advantage they might give to the enemy.

There was also until 1918 considerable opposition to the publication of a 1/20,000 map showing our own trenches, on the ground that it would give information about our system of defence; or at least that it would, if captured, save the enemy the trouble of photographing back areas. Here again, however, it is considered that the advantage to our own troops would have more than counter-balanced the possible advantage to the enemy, for the production of such a map, and its issue on a reasonably liberal scale, would have saved a large waste of labour and personnel. Monthly defence schemes, reports on defence lines, etc.. necessitated the production of large numbers of these secret 1/20,000 maps, which, owing to the absence of an official issue, had to be drawn by hand. This was recognised by the order of January, 1918, which permitted the production of a secret 1/20,000.

The history of secret maps shows the gradual realisation of what secrecy really means, and the growth of more liberal ideas with regard to the distribution of secret information.

(e) Layered Maps.

(e) The question of the extent to which layered maps should be printed as a regular issue for troops is one that is ruled largely by practical considerations. A layered map involves extra printing and this extra printing cannot be done with the limited staff which was available during the war, in times of pressure. It is admitted that layers help everyone to read a map, and that such help is of great military value. The matter therefore resolves itself into a question of relative values. If a layered map can be provided by installing, say, four extra printing machines and twenty men to work them, who would otherwise be employed on mending roads, will the Army gain or lose by the transaction?

On the whole, the experience of the war shows that provision should be made for layered maps up to (as a limit) the scale of 1/20,000; and that layered maps should be provided for the whole area of operations and distributed on a fairly liberal scale. This would give troops the necessary assistance in reading and studying ground forms. Should circumstances (such as limited staff) make it improbable that a continuance of the supply could be expected at all times, each layered map might bear an imprint, stating that it is provided for the purpose of assisting in the study of the ground but that it will not be replaced, and that a supply of such maps for all areas is in no way guaranteed.

It is not suggested that such a supply should be made to the troops of an Expeditionary Force before a campaign had begun; but it is considered that the necessary preparations should either be made in peace time, or envisaged as a step to be taken immediately on the outbreak of war.

(f) Map References.

(f) A sound method of identifying points is essential in the use of military maps. The system used by us, of fixing a point by its co-ordinates within a square or rectangle, is thoroughly practical in that it is adaptable to maps bearing squares or rectangles of any kind, and which may be identified in any way. In the particular application of this method which was provided by our adaptation of the French system of abbreviated metric co-ordinates, it leaves little to be desired, being simple, complete, logical, and providing an easy transition from the map reference to the mathematical co-ordinates. (A full description of the various systems mentioned will be found in Appendix VI.).

A point in which, however, our maps failed was that our square system applied only to our large scale maps. The ideal to be aimed at is evidently that the same system of referencing should apply to all maps in use, of whatever scale; so that if a point be described it can be found with ease on *any* map, though naturally the degree of precision with which it could be identified would vary with the scale of the map.

To permit of this it would only be necessary to print on the small scale maps the same system of squaring as is found on the large scale, omitting, of course, the minor squares and unnecessary letters and figures. It is of interest to note that this was done with the latest 1/100,000 maps of Germany by the Army of the Rhine at Cologne. It would be a convenience, but it is by no means essential, for the small scale sheets to bear some definite relation to the large; such, for example, as covering the area of a definite number of the large scale sheets.

(g) Signs and Colours.

(g) In 1918 it was ordered by Marshal Foch that steps should be taken to secure uniformity of maps among the Allies, and as a consequence a uniform scheme of colour and of conventional signs was agreed upon for use on the western front. The advantages of such uniformity are obvious when it is remembered what frequent interchanges of allied troops took place, and how often troops hastily put into another area had to use foreign maps.

9. Total Area Mapped.

The final results of mapping on the Western Front are as follows:—

	Sq.Km.	Sq.M.
Area surveyed* and published for the first time as a reliable map on a large scale	9,550	3,687
Area previously surveyed, but revised and brought up to date and published	4,678	1,806
Total mapping completed and published	14,228	5,493
Area of which survey was complete, but not published	1,618	625
Total mapping completed	15,846	6,118
Area of which survey or revision was partly completed ...	3,605	1,392

* "Survey" includes here survey or revision on the ground, and compilation of cadastrals revised with the aid of air photos.

The foregoing does not include areas previously surveyed, such as French Plans Directeurs or Belgian maps which were redrawn and published in the British series, but without photo revision. Of these there were a large number, especially in Belgium.

Of the total MAPPING COMPLETED, approximately 7,425 sq. km. (2,867 sq. m.) were done by work on the ground, the remaining 8,421 sq. km. (3,251 sq. m.) being compilation, photographic revision, etc., in the office. The area partially completed was all done on the ground.

For illustration, see Plate I. at end of book.

SECTION IV.—DEDUCTIONS.

1. Importance of Survey.

It cannot be too strongly emphasized that accurate survey is the basis of all map production and of the fixing of artillery positions either on our own or on the enemy's side of the line. During the war all this work was under one head, and a single control was possible. In future wars the Artillery will be responsible for their own work. It is most important that it should be remembered that Artillery Survey is a branch of the main work, and that though a single control may not be possible, a single authority on technical survey questions should be recognised. It will be fatal to the success of accurate Artillery work in the future if there is any cleavage between the two sides on the ground that highly scientific methods are not necessary for practical Artillery requirements. The war has shown conclusively that what seemed to be purely scientific and theoretical questions have far-reaching practical effects.

The conclusion is that, despite the division of work in the field, the Artillery should continue to be guided and advised in the future as in the past in technical survey matters by the survey experts.

2. Training.

The work of R.E. surveyors and cartographers in peace gives them a thorough technical training; but training for war purposes is required in addition, and special attention will have to be directed to this in future. Artillery officers should receive a training in survey which will ensure that all officers have a sound knowledge of survey methods, and a good proportion reach the professional standard.

3. Geodesy.

Geodetic study and research is of the highest practical importance. It should be carried on in peace time and continued in war, and the best possible expert knowledge on the subject should be available for military work.

4. Air Photography.

Air photography is of fundamental importance for military surveying in war. Study and research is required on the lines indicated in the text. A policy should be formulated defining clearly the part played by survey in military operations and by air photography in survey, and a definite line of action should be laid down in training manuals and Field Regulations for the guidance of surveyors and air photographers in these matters in order to prevent waste of effort.

5. Standardisation of Methods.

Methods of drawing, conventional signs, forms and titles of maps, and kindred matters should be standardised and rigidly controlled. A certain laxity in these matters during the war led to much waste of effort. Certain standards should be laid down at the outset and whenever new points arise, and no variation should be permitted from these in deference to the opinions of various Staffs. As a rule it does not greatly matter what standards are adopted so long as they are strictly observed. What matters is deviation, as this causes confusion, mistakes and waste of time.

From the outset a detailed history should be kept of every sheet produced.

6. Map References.

Map references should be on one uniform system applicable to the whole area of operations and to every scale of map.

7. Scales of Issue.

The scale of issue of maps should be liberal, allowing, on the one hand, an ample supply for H.Q. Staffs, so that there shall be no temptation to hold up maps intended for troops, and extending, on the other hand, to senior N.C.O.'s. It should be based on the provision of a map for *movement* and a map for *fighting*, the scale of the latter being determined according to circumstances. It should include a supply of layered maps and of secret maps, according to the proper definition of secrecy.

Relief maps, shaded contours, etc., should be unnecessary, given a supply of layered maps.

8. Future Developments.

The tendency of all methods to get more complicated as science advances should be recognised and provided for. It means that greater accuracy and more refinement will be required in the future than in the past, hence more maps and maps of larger scale. Where our 1/20,000 satisfied requirements, future needs will probably demand either, say, a 1/10,000 scale, or refinements of cartography which will enable more detail to be shown on the 1/20,000.

9. Allocation of Responsibility for Map Preparation.

The problem of how to deal with map preparation when areas of responsibility are liable to change at short notice is a difficult one. Map preparation is a complicated process, involving the custody and examination of numerous documents and a large amount of detail work which involves personal attention on the part of draughtsmen and other workers. It is not easy to transfer such work from one authority to another. This had, however, to be done frequently during the war. Army boundaries were changed many times, and with them the responsibility for map preparation and supply.

It would undoubtedly simplify matters greatly if the responsibility for map preparation and kindred matters could be allotted by definite areas which would remain independent of changes in military command. This has been proposed on more than one occasion, and in theory it is what ought to be done. It is, however, difficult to see how such a system could be made to conform to practical conditions. Map preparation is connected with and dependent on so many other branches of work, all of which depend on the military command, that it seems impossible to render it independent. Instances of such work are General Staff requirements and preparations, information obtained through the Intelligence Branch, the arrangements for taking aeroplane photographs and access to documents. It is easy to see that if these requirements and arrangements have to be met by channels which do not conform to those ordinarily in use difficulties and delays will arise, especially during the strain of operations. Such a situation does arise when the responsibility for map preparation extends far beyond the limits of the military command.

Hence, although it must be admitted that a change over of mapping responsibility involves difficulties, and, what is more important, some waste of time and effort, it is considered that these disadvantages are less serious than those that would arise if the areas for map work were independent of the areas of military command.

The boundaries of the two can, as a matter of fact, rarely coincide exactly, as map work must be defined by sheet lines, while military command has no connection with them. But it can always be arranged that an area bounded by sheet lines can be chosen which conforms approximately to the area of the command. Beyond that the difficulties must be met partly, as in the past, by adaptability and hard work on the part of the survey staff, and partly, in the future, by more rigid standardisation of methods and records, and by subdivision of survey units to provide greater elasticity.

In other words, the style of maps in drawing, signs, size, titles, and the records in connection with them must be standardised, rigidly enforced, and not subject to change by Army or other orders, and survey units must be organised on a system of small, self-contained sections, which can be transferred when required bodily from one command to another without detriment to their work or their prospects.

Such arrangements, though they cannot abolish the difficulties that will arise with changes of area, will do much to lessen them. A large amount of assistance will also be given if adequate provision is made in establishments for survey to be carried on by G.H.Q., so that the Army units are relieved of all anxiety as to areas with which they are not immediately occupied.

The above remarks also apply in large measure to the question of map supply. (See next chapter, Section IV.)

CHAPTER 2.

REPRODUCTION AND SUPPLY.

INTRODUCTION.

Previous to the war the necessity for producing large scale maps in quantity was not foreseen, as it was supposed that the existing small scale maps of the various National Surveys and enlargements from these would suffice for most tactical purposes of war in civilised countries.

The equipment taken into the field was designed for producing a small number of copies with great rapidity and to be completely mobile. The real problem before the printer has proved to be very different. The necessity for accuracy (which will always reappear when artillery is used in any quantity) and the great quantity required have called for the rapid but careful reproduction of large numbers of maps as nearly as possible under the eye of the map-maker. Mobility, whilst it retains much importance, has ceased to be so vital. Machines have replaced hand-presses. Similarly letterpress printing has become a large business, and the amount of work required has necessitated linotypes and machines in place of hand composition and manual presses.

The Armies in France had, throughout the whole period of the war, the great advantage of the assistance and co-operation of the Geographical Section at the War Office and the Ordnance Survey at Southampton. All the small scale maps issued to the troops and the vast majority of the large scale maps of the Regular Series were printed in England, about nine-tenths of the work being done by the Ordnance Survey. In the earlier days, when a set of drawings for a new edition was sent to Southampton, the edition of perhaps 10,000 copies was usually received within 14 days, and in specially urgent cases this period was considerably reduced. As time went on, owing to the vast increase in the number of maps issued from Southampton, it became impossible for the Ordnance Survey to maintain this rate.

It therefore became increasingly necessary that local resources should be improved and strengthened, and at the end of the war facilities existed at the H.Q. of each Army for rapid reproduction in colour of sheets up to double-demy size, and for the printing of large editions, while at the Base the Overseas Branch of the Ordnance Survey was established, which placed the great resources of that Department at the immediate disposal of the troops in the field.

The object of this chapter is to trace the development of map reproduction and printing in the field, to point out some of the continued difficulties which had to be overcome in the earlier days, and to indicate the direction in which further improvements can be made.

SECTION I.—DEVELOPMENT OF UNITS AND APPARATUS.

1. Printing Company.

(a) Distribution and Equipment of Original Company.

(a) The peace establishment of the Printing Company consisted of 1 officer and 39 O.R., including the following tradesmen:—14 lithographers, 8 photographers and 9 letterpress printers. The trade of lithographer included drawing on stone, zinc or transfer paper, as well as working the stone or plate. The Company was divided into 4 Sections, of which No. 1 Section was to be attached to G.H.Q., while the H.Q. and remaining 3 Sections were to be normally on L. of C., Nos. 2 and 3 being available for detachment either to the Cavalry Division or to the H.Q. of an Army of two or more Divisions (W.E. dated 1914). No 1 Section was equipped with 1 foolscap (17 x 13½) hand litho. press, 2 Roneo duplicators, 1 C.B.D. copier, 1 typewriter, 1 Boston hand printing press, a field copying camera with developing box, 2 hand cameras, a sun printing frame and stereoscopic equipment. Nos. 2 and 3 Sections were similarly equipped, except that they had no sun printing frame, and carried an extra C.B.D. copier. These three Sections were completely mobile, having a car and lorry each, which carried the whole of their personnel and equipment. No. 4 Section had 1 demy (22½ x 17½) litho. press, 1 treadle printing press, 1 copying camera and developing box, 4 hand cameras and sun printing frame, and no transport.

(b) Concentration at G.H.Q.

(b) On mobilisation No. 1 Section joined G.H.Q. and Nos. 2 and 3 Sections the H.Q. of the 1st and 2nd Armies, or Corps as they were called a little later. During the retreat, or shortly after, the 1st and 2nd Corps sent the personnel of their Sections back to the H.Q. of the Company, stating that they had no use for them. At the same time they retained the Section transport. In October, 1914, the H.Q. and bulk of the Printing Company were concentrated at G.H.Q., leaving only a small section with the treadle printing press at the H.Q., L. of C.

This rejection by the Corps of the Printing Sections originally provided for their use had a marked effect on future policy. The decision was based on the experiences of a short period of rapid movement, when no conception could be formed of future mapping needs. There is no doubt that at a later period of the war Corps would have given much to have had these self-contained mobile sections, and the original decision to discard them certainly carried weight when the question of Corps equipment was being considered, and even had its effect on Army equipment. For example, when the First Army was formed, the Chief Staff Officer begged that they should not be cumbered with printing plant, saying that all he required was a few zinc plates. This entailed delay in the provision of equipment when later it was found necessary.

The Printing Company continued to workas a G.H.Q. unit for the remainder of the war. Its work was always mainly for G.H.Q. and L. of C., but it also supplemented the Army Printing Sections, until the latter outgrew their parent.

(c) Establishment in 1915.

(c) In 1915 the Printing Company was re-organised and increased as follows (W.E. No. 16, d/1915). The H.Q. and G.H.Q. Section consisted of one officer and 19 o.r., including 3 photographers, 6 lithographers and 5 printers. The I.G.C. Section consisted of 5 o.r. (2 lithographers and 3 printers). An Army Section consisted of 14 o.r., including 2 photographers, 6 lithographers and 3 printers. The G.H.Q. and Army Sections were provided with a box-car and a 3-ton lorry each, and the same equipment as the former numbered sections. At about this time all sections were provided with a suitable stand and telephoto lens, which enabled them to use their cameras for taking panoramas.

These Army Sections were detached from the Printing Company to the Map Sections, to the Topographical Sections and to the original Field Survey Companies. Printing personnel was not included in the establishment of a Field Survey Company until the second W.E. of that unit was authorised in December, 1916.

(d) Inclusion in Depot F.S.C.

(d) In April, 1917, the Depot F.S.C. was formed as a G.H.Q. unit, and the G.H.Q and I.G.C. Sections of the Printing Company were absorbed by it, with an increase in numbers; the Army Sections having been previously absorbed (with the addition of two men) by the Field Survey Companys. The Printing Section of the Depot F.S.C. consisted of 1 officer and 60 o.r., including 25 printers, 25 lithographers and 6 photographers.

The principle of including survey and reproduction at G.H.Q. in one organisation was sound, but in the existing circumstances it was not easy to combine them in one unit. The Printing Company had been for long established as a unit working almost entirely for G.H.Q. needs; the Depot F.S.C. was separated from it geographically and had other objects and interests. Hence the connection remained to a great extent a nominal one, and when the Depot F.S.C. was, in October, 1917, converted into a Battalion, its Printing Section again became an independent Printing Company.

Although in the light of the above experience the conclusion may appear paradoxical, it is considered that in the future organisation reproduction for G.H.Q. should be carried out by the unit responsible for all G.H.Q. needs in survey and mapping. The decision to divide responsibility in this war was, it is considered, governed largely by special and antecedent circumstances. It may be noted, moreover, that in a future organisation it is considered that all map reproduction behind Armies should be carried on under one technical control. In this war such an arrangement, which is evidently logical, was never possible, because the Overseas Branch of the Ordnance Survey, which was the principal reproduction establishment at the Base, was a separate organisation, responsible to the Director-General of the Ordnance Survey.

(e) Final W.E.

(e) The establishment of the Printing Company in October, 1917 (W.E. dated August, 1918), was 1 officer and 66 o.r., including 25 lithographers, 10 photographers, and 25 printers, but with no transport. This establishment was modified slightly in 1918, on the decision to transfer the responsibility for all letter-press printing, except the small amount required for mapping work, to the D.A.P.S.S. For this purpose 16 letterpress printers were transferred to the strength of the Army Printing and Stationery Services.

The omission of transport was a mistake, as a unit of this sort, having constant dealings with various branches and with the Base, requires a box-car.

(f) Changes in Equipment.

(f) The equipment of the Printing Company remained unaltered until 1916, except for the addition of certain cameras and an increase in the number of hand presses. In October, 1916, a demy machine was obtained. In 1918 a second similar machine was provided. Other additions were an Ordoverax outfit and a Halden electric copier.

2. Army Printing Sections.

In April and May, 1915, an Army Section of the Printing Company was attached to each of the First and Second Armies, to work under the Maps Officers who had just been appointed. These Sections were immediately employed on the production of trench maps, which were then in their infancy. 1/10,000 maps were made by enlarging from the 1/20,000 and redrawing. On each sheet the outline was printed in grey, grid and contours in brown, German trenches in red, and target numbers in blue. In spite of this formidable undertaking it was found possible to produce from 300 to 500 copies per Division of these trench maps. Later, owing to the great strain on the meagre establishment, the outline, contours and grid were printed at the Ordnance Survey, and the trenches only were overprinted by the Army Sections, and also by the Printing Company at G.H.Q.

During this very strenuous period the excellent training and discipline of the old personnel proved its value, and the standard maintained reflects the greatest credit on all concerned.

3. Printing Sections of Survey Units.

Reproduction continued on similar lines when the Topographical Sections were formed and, later, with the F.S. Companies, but on the formation of the latter units mechanical methods of reproduction and machine printing were gradually introduced.

The establishment of printing and kindred trades remained unchanged until December, 1916, when 1 lithographer and 1 printer were added.

On the formation of the Field Survey Battalions there was a considerable increase, and provision was made for mechanical methods. The following trades were included in the W.E. (No. 1591):—

Litho. Draughtsmen	10	Engine Men	3
Transferers and Provers	10	Helio. and Vandyke Workers ...	6
Machine Minders ...	6	Photographers	4
Machine Feeders ...	6	L.P. Printers	8

When the responsibility for letterpress printing was taken over by the D.A.P.S.S. in 1918, 4 l.p. printers were transferred from each F.S. Battalion.

4. New Maps and Increased Needs.

July, 1916, saw the first overprinting of Battery and Target Maps. At this time the growth of the respective artilleries and of artillery intelligence methods meant frequent revisions and a large increase of printing generally. In addition many maps were reproduced showing our own defences.

Civilian presses were kept fully employed, and the hand-presses at Headquarters proved to be inadequate for the preparation of plates. Demands had been made for extra demy presses by all the Field Survey Companies (as the Topographical Sections had then become), but even so, the number available had to be increased by the hire of large hand-presses from Arras. These hand-presses were of a clumsy and antiquated pattern, but they had the advantage of size, and they saved a large number of maps and made possible the preparation of plates which were as big as could be printed by the civilian firms mentioned above. The 1st, 3rd and 5th Companies profited much.

The personnel was also increased by drawing in trade hands from the ranks. This expansion hardly kept pace, however, with the increase of lithography called for, and the litho. draughtsmen were kept particularly busy.

The Somme Battle brought up a new type of map—the Corps sheet. The succession of small offensives and gains and the changing situation called for frequent editions. The result was that more printing had to be done on the spot, and that outlines had to be made up locally by transferring from other plates. A very great strain on the personnel resulted, and more men were drawn in from the ranks.

It was at this period that the inefficiency of the material and methods hitherto employed began to be so evident. Map issues had already begun to be a question of thousands, not hundreds; the number of plates to be grained, sensitized and prepared, and the waste of time in drawing everything by hand pointed without question to the need for provision of graining and printing machinery and of photo-mechanical processes.

5. Introduction of Machines.

In the Autumn of 1916 a demy machine was secured for the Printing Company at G.H.Q., but some time elapsed before it was finally erected. At the same time the Field Survey Companies began to make demands for machines for their own use.

The provision of printing machines thus urged by the Armies was considered at G.H.Q. The principle was admitted to be sound, but it was decided that in the interests of mobility a demy and not a double demy should be issued. It was not appreciated that a flat-bed machine made to be erected on a prepared bed or floor can hardly be described as mobile whatever its dimensions may be. As a matter of fact, experience showed that there is not very much to choose in the matter of mobility between a large and a small machine. All the parts of either will go individually on a 3-ton lorry. The troubles of mobility are mainly in the taking down and re-erecting, and the additional weight of the double-demy machine is more than compensated by the large amount of time and labour saved in the printing of any particular area. Demy machines were ordered, however, and began to arrive in April and May, 1917.

Meanwhile the 3rd Field Survey Company had been ordered to produce a daily situation map during operations which were to start on the Arras Front early in 1917. The programme could not be carried out with hand presses, and a double-crown machine was bought privately and erected in time to print for the battle. This machine printed about 800 impressions an hour, and was kept running continuously throughout the 24 hours, averaging (with stops to change colour) 10,000 runs per diem.

6. Introduction of Mechanical Processes.

Outfit for the Vandyke process was asked for and obtained early in 1917. The Ordnance Survey offered to train the personnel, and before midsummer all Companies were provided with Vandyke apparatus and were turning out good Vandykes, and so saving the time previously spent on litho. drawing.

In August, 1917, the first large copying camera (of a size to cover a double-demy plate) was bought privately and installed at 3rd Army Headquarters. Before this time the 4th Field Survey Battalion had started making small wet plates and patching up. A good deal of ingenuity had been shown in so doing, and it was due largely to these early experiments that all Field Survey Battalions were finally equipped.

In September, 1917, copying cameras were received for all Field Survey Battalions. In order to reduce weight they were only large enough for half a double-demy sheet. This proved to be a mistake, but it is doubtful if so many full-sized cameras could have been obtained.

About this date the Dorel or Ordoverax process was also introduced and used largely by all the Battalions.

7. Provision of Larger Machines.

Double-demy machines were provided for each Field Survey Battalion in the autumn of 1917, as were two power proving presses. Each Army had therefore two machines, one demy and one double demy, and four to six proving presses. They had also both Helio and Vandyke outfits, and were capable of printing the special Army maps required and of supplying Corps Topo. Sections with most of the outlines used by them for over-printing additional Corps information.

Taking the Battle of Cambrai as an example, an average of over 10,000 runs a day was printed on Army maps for the month of November, and some 5,000 odd runs for Corps Topo. Section outlines.

8. Assistance from D.A.P.S.S.

Early in 1917 the Director of Army Printing and Stationery Services installed double-demy litho. machines in connection with his Advanced Sections in Army Areas. Process copying cameras also formed part of the equipment of these Sections. This was a period of great activity, and at the time we had nothing larger than demy machines and no large cameras. It was therefore of the greatest assistance to be able to hand over plates to this Department for printing, and they undertook a very large number of runs for us. In certain cases, too, such as message maps, diagrams, etc., original material was handed over to them for reproduction by photography.

It was found, however, that there were considerable disadvantages in getting printing done at a distance from the Headquarters of the Field Survey Unit. Not only was time lost in transporting the plates, proofs, paper, etc., but in many cases the machine minders had not been trained to watch the minute register and exact matching of colour which are required to get the best results in map printing. Furthermore, the small final corrections and the touching-up of plates during a run can only be efficiently attended to if the machine is close at hand to the proof examiners and litho. draughtsmen.

In spite of these drawbacks, the assistance received from this department at a time when the equipment of Field Survey Units was still in an early stage of development proved invaluable.

9. Employment of Civilian Establishments.

Prior to the installation of machines a considerable amount of work was given to civilian firms in towns behind the lines. These firms had, as a rule, very little idea of the requirements special to map printing, particularly as regards register and matching of colours, and they were inclined to resent too close a supervision. Their work was very slow, and they were sometimes unable to work because of a holiday, or because their power was cut off, or because they had a job for their Government. They could therefore not be depended on for urgent work, nor could maps of a secret nature for obvious reasons be printed by them.

In a hostile country if any machines were to be found in running order these difficulties would largely disappear, for the plant and workmen could be "commandeered." But experience has shown that the Army should be so equipped that no reliance at all need be placed on local resources for map printing.

In one instance a civilian printing establishment was found in a deserted town, and the stones and hand presses formed a most valuable addition to the equipment of the Field Survey Unit in that area.

10. Overseas Branch of the Ordnance Survey.

The establishment of the Overseas Branch of the Ordnance Survey in France in December, 1917, gave the Survey organisation for the first time a satisfactory reserve of printing power in the country. The O.B.O.S. had a strength of 2 officers, about 120 o.r. and 60 W.A.A.C., and an equipment of 6 (later increased to 10) large litho. machines and plant for all the usual mechanical processes. Work could be done by this establishment with an expedition far beyond what was possible for the main office of the Ordnance Survey, which had many other calls upon it and was divided from the front by the sea.

Valuable work was from the start done by the O.B.O.S., under the direction of Lieut.-Col. W. J. Johnston, R.E., but it was during the retreats in the spring of 1918 that its services became most in evidence. At that time, when most of the Army map-printing plants were out of action it may be said to have saved the situation from the point of view of map supply.

O.B.O.S. was itself, however, compelled to move in April, 1918, and was established in a new site at Wimereux, where it remained until the end of the war. The change was effected without stopping work, a portion of the plant continuing in action at Wardrecques until the remainder was ready to start at Wimereux. Throughout the move printing was continuous.

SECTION II.—TECHNICAL.

1. Hand Apparatus and Methods.

The Printing Company, R.E., took the field at the beginning of the war with an equipment designed for the rapid reproduction, by lithography or duplicator, of field sketches, enlargements of existing maps, panorama sketches, etc., and for the printing of such orders and memoranda as might be required by the Staff at G.H.Q. It consisted of hand litho. presses (demy and foolscap), a "Zygad" multicolour duplicator, a "Boston" letterpress machine, a treadle press, a 5 in. x 4 in. copying camera, which was set for enlarging either twice or four times, and a "Panros" 5 in. x 4 in. camera for taking panorama photographs.

Mobility and rapidity of getting to work on change of Headquarters were considered of prime importance, and the printing of large surfaces and large numbers of copies was not provided for.

The personnel of the Printing Company had been trained at the School of Military Engineering, and had attained a very high degree of proficiency in the strictly limited field covered by their training. The normal rate of working for the demy press, with three men at work, was about 120 copies per hour, laying to register with needles. These men were conspicuous for the loyal manner in which they would work for long hours at the highest pressure, and fully realised the importance of their work to the fighting troops. Many of them kept well ahead in the developments of plant and methods which afterwards took place, and remained in the more responsible positions in the Printing Branch of the Field Survey Units.

The Printing Company produced several enlargements during the mobile operations on the Aisne in 1914, and later in Flanders. These were made by litho. tracings from photographic enlargements of the original.

Only two methods of producing work on stone or zinc were practised by the Printing Company—namely, direct drawing and drawing on transfer paper and subsequently transferring to the stone. Practically all work was done by the latter method. When alteration of scale was required tracings were made from photographic enlargements or reductions.

Both stones and zinc plates were carried, but the former were much preferred, and the personnel were not really skilled in the use of zinc.

2. Process Reproduction.

The various mechanical processes used by the Field Survey Battalions are here dealt with only from the point of view of practical employment in the field. No detailed technical description is attempted unless the process is one that is not commonly known.

(a) Vandyke.

(a) The Vandyke process is particularly suitable and convenient for work in the Field. The process is a rapid one, and under good conditions it is possible to turn out a plate in an hour or two, though such speed is not desirable except in an emergency. The apparatus is not bulky. It is possible to work without the two biggest items—namely, the whirler and artificial light—in which case the only bulky parts are the two developing baths and the printing frame. A whirler is, however, very desirable, and unless artificial light is available the process cannot be depended on to turn out urgent work with certainty in a northern climate, and with the possibility of night work coming in.

There are certain points which must be recorded as against the many advantages of the process :—

(1) For registered work in colour it is necessary that the different drawings should be exactly to size. No small adjustments can be made, as the drawing is in direct contact with the zinc plate. This difficulty is minimised if all the drawings are made in the same room and the plates are made close at hand and under the same conditions as nearly as possible.

(2) Being a contact process, it does not allow for enlarging or reducing from the original.

(3) The best results are only got from finished drawings in firm black lines, which entails good draughtsmanship. The fineness of the line, however, is immaterial provided it is thoroughly clean and opaque. If the drawing is poor it is better to photograph it for the Helio process.

(b) **Helio.**

(b) The Heliozincographic process proved to be indispensable both for direct copying and for the production of enlargements or reductions. Before the necessary equipment was provided for the Survey Units the only means of doing such work was either to send the originals to Southampton for the plates to be made or to photograph with the small copying camera and make a litho. tracing from bromide prints. The former method involved delay and the latter was cumbersome and laborious, and gave indifferent results.

For work in the field the Helio process has the disadvantage that the outfit is very bulky and requires most careful packing for transport. Also, it is largely dependent on a plentiful supply of pure water.

Pending the supply of the outfit, the 4th Field Survey Company made some interesting experiments to produce plates by photography with their existing means. The first efforts attempted to adapt the Vandyke process. Bromide prints were used as originals for Vandyking, but it was found impossible to get the density in these prints necessary to give good results. Attempts were then made by using glass positives made from the negatives, but the attractions offered by the Helio direct from negatives led to a more determined research on these lines. For the Helio process it is necessary that the negative should be reversed, and two methods were tried to gain this end: (1) reversing the plate in the dark slide, glass outwards; (2) photographing from the back the drawing, which for this purpose had to be on tracing paper. The second method was found the more successful. The map was placed on a frame against a window and photographed by transmitted light. Considerable difficulty was experienced in dealing with the yellow tint of the tracing paper, and also its grain or texture. A blue screen outside the window had a beneficial effect. The only camera available for this work was the 5 in. x 4 in. copying camera, and allowing for overlaps, three dozen negatives were required to cover the surface of a demy-size map.

Ordinary "Process" plates were used, and the greatest care was necessary to ensure that all the negatives were of equal density, or, rather, equal clarity in the lines, as the slightest fog gave broken results.

A direct Helio was made on a zinc plate sensitised with egg albumen and bichromate of ammonia for these negatives, and re-transfers were pulled and patched up for the area required and transferred to stone or zinc. A complete set of maps on the 1/20,000 scale was prepared from 1/10,000 originals in this way, each map made up from 36 separate transfers.

Later on an 8½ in. x 6½ in. camera was obtained and greatly helped matters, but as dry plates were still used, the absolutely clear negatives required for photo process work were not obtained until the materials for the wet-plate process were supplied.

24 in. x 20 in. cameras were supplied in 1917, and as this allowed a demy sheet to be completed in a single exposure, thenceforward the methods used did not differ in any way from the ordinary practice of process reproduction. In the meantime the 3rd F.S.B. had provided themselves by private arrangements with a full-sized camera (36 in. x 24 in.), which was later taken over by the public, while the 4th F.S.B. made an extension for their 24 in. x 20 in. camera which, with the use of a larger lens which was obtained for them, would have allowed full-sized plates to be taken; but unfortunately, owing to the lack of a silver bath of the required size, it was never used. The other Battalions continued to use the demy-size cameras.

In future it will always be advisable to provide cameras capable of taking the full size of the standard sheets in use. The extra bulk of such apparatus need not be considered as against its advantages. It increases accuracy and saves the time and labour of re-transferring and patching-up. Provision in advance is necessary, as the large lenses required are not easily obtainable.

(c) Dorel or Ordoverax.

(c) *Dorel or Ordoverax Process.*—From an early date a great amount of use was made by the French of the Dorel process. The process is similar to the Ordoverax or "True-to-Scale" process of Messrs. B. & J. Hall and Son, of London, and depends on the chemical action between ordinary ferro-prussiate blue printing paper and a patent composition. The blue print, in an undeveloped state, is rubbed down by hand on a table coated with the composition, left in contact for a short period, and then pulled off. Wherever the light has been excluded by the work on the original tracing the composition will hold ink when rolled up. The table is rolled up for each impression, which is pulled off by merely rubbing the paper on by hand, and under ordinary conditions 30 to 50 impressions can be got off before the work begins to break up. As many as 90 impressions have been obtained. If more are wanted a fresh sunprint can be made from the original, and the process repeated. Any good rag-litho. paper can be used for printing, but a good stout cartridge paper gives the best results.

It is possible, by rolling up with transfer ink, to pull a transfer for laying down on stone or zinc; but the results are usually rough, and in spite of its name, exactness of size is not one of the great features of the process.

Registered work in colours has been attempted and fair results obtained. It is, however, a slow process, as each pull must be carefully fitted by hand. Another drawback to work in colour was that the inks supplied were not sufficiently brilliant to give a really good effect, and further experiments in this direction might be made. There seems no reason why ordinary litho. inks should not be used.

An advantage of the process is the large surface that can be printed on, which is only limited by the size of the sun-printing frames used. Provided that the light is good, or artificial light is to hand, it is a very rapid method of producing a limited number of copies. Skill in manipulation is of prime importance, but that can be easily acquired by any painstaking man. Efficiency depends largely on temperature and humidity, and in hot weather, such as was experienced in Italy during the summer, little use could be made of the process.

The chief practical difficulty encountered with this process was in the nature of the composition. That supplied by Messrs. B. and J. Hall was found to be too susceptible to heat. The Dorel composition (Maison Dorel, Paris) was better, while the composition made during the war by the Service Géographique was an improvement on either. On the other hand, the special table made by Messrs. Hall is well designed and most useful. It embodies an endless band of linoleum, on which the melted composition is spread. The band can be rotated to provide fresh surfaces.

The process, subject to its limitations, is undoubtedly a useful one, and should form part of the equipment of a Survey Unit. The French used it largely for printing and overprinting maps, though in the British Army, owing to the size of the editions usually required for issue to the troops, it was not much used for map work. But it proved invaluable for reproducing working diagrams for the Engineers, line charts for the Signal Service, etc., and as many as 10,000 prints in a month have been turned out by one unit. It was used also for making working prints from drawings of maps which were about to be sent away to Southampton for reproduction.

(d) Duplicators.

Ellam Duplicators.—Exhaustive experiments were made before the war with duplicators of various kinds, and there is no doubt that the pattern adopted was the most practical and satisfactory for general purposes. In the form supplied to the Printing Company it was known as the "Zygad," but the apparatus provided during the war was made by the Ellam Company. In this duplicator the design is drawn with a hard point on a waxed silk sheet. The point carries away the wax and leaves the silk bare, forming a stencil, through which the design can be transferred to paper, in any colour desired, by means of inked rollers.

The Multicolour Duplicators which formed part of the equipment of the original Printing Company were seldom used by that unit. They were much quicker to use than the hand presses, but gave far inferior results. Ellam Duplicators were, however, extensively used by lower formations for the production of sketches to illustrate Intelligence summaries, Reconnaissance reports, etc., and considerable skill was acquired in their use. The work is limited in size; 16 in. x 13 in. was the largest size supplied, and it is understood that there are practical difficulties in the way of increasing this. In hot weather trouble is experienced with the wax sheets on which the drawings are made. The paper used must be of an absorbent nature, otherwise the impressions never dry properly, owing to the nature and quantity of ink that must be used.

A stencil can be prepared in about two to four hours, depending on the amount of work done, and 300 copies in one colour can be pulled in one hour unless the weather is too hot.

A very large number of outlines on absorbent paper were printed on the litho. machines at Army H.Q. to be over-printed on the Ellam Duplicators at Corps H.Q. As an example of the number of Corps maps used, three Corps Topo. Sections issued in one month before the Battle of Cambrai a total of over 100,000 maps.

Other Forms.—Considerable use was made by lower formations of hektographs and clay copiers. These proved satisfactory within their limitations, and possess the advantage that the complete drawing in all its colours can be laid down, and no trouble with register is encountered. Any size of sheet can be printed if a suitable tray for the composition is made. It is noteworthy that the Germans made extensive use of these copiers for their trench maps of local sectors of the front. The disadvantage of this form of copier is that the number of copies that can be taken is limited to about 50, and the colours lose brilliancy rapidly in the later copies.

Sun-printing frames and accessories were issued to Field Survey Units, being used chiefly in connection with the Ordoverax process. Sun-printing was, however, extensively employed by certain other technical units and departments.

3. Letterpress Printing.

As above stated, the equipment of the original Printing Company included a treadle printing press, intended for use at the Base, a Boston hand letterpress machine, and a limited quantity of type.

The printing of Routine Orders and all other letterpress jobs required by the Staff were undertaken. Boston presses proved thoroughly reliable, and some of those which started work at the beginning of the war were still in good order at its close after very hard usage. They are, however, extravagant in labour, three men being required to get the best speed out of them, but their output of about 1,100 copies an hour is satisfactory.

As work increased it was found necessary to add a treadle press (which could also be driven by power if required) and a further supply of type to the equipment with each Army. The staff of compositors was also strengthened, and the letterpress branch became one of the busiest departments of the Field Survey Units.

Concurrently the Director of Army Printing and Stationery Services had installed a printing establishment at the Base fitted with the most modern machinery. This, to some extent, relieved the demands made on Field Survey Units, but not altogether. The delay caused by sending jobs away and the time lost in returning proofs for correction caused the Staffs to prefer that their work should still be done on the spot by Survey Units. This was therefore done, but the work proved a strain on the Field Survey Battalions, who, with their small treadle presses, were not properly equipped to deal with the printing required by modern conditions. It was recognised therefore that it would be sound for the Director of Army Printing and Stationery Services to take over all printing, and this transfer of responsibility was carried out towards the close of the war. At the same time it was admitted that experience had shown that the special conditions at Army Headquarters could only be satisfied by having a printing outfit close at hand, so that daily jobs could be undertaken and urgent work rushed through when required. The D.A.P.S.S. therefore installed local presses and took over the bulk of the plant and staff previously employed by the F.S.B.

The fact that Field Survey units will always require a letterpress outfit must, however, not be forgotten. There is a constant demand for type transfers for notes, headings, etc., for maps. Furthermore, it is very desirable that all technical printing, such as lists of Trig. points, circulars on survey matters and maps distribution, pamphlets of instruction, etc., should be printed under the direct supervision of the Survey Unit.

The supply of type for this purpose should be liberal, and should include all varieties likely to be required, including Greek type and mathematical signs. One of the greatest difficulties throughout the War was the continual shortage of type.

4. Plant and Machinery.

(a) Stones and Plates.

(a) The original equipment included zinc plates, but the men of the Printing Co. had not been trained in up-to-date methods of using them. It is fair to say that this was an omission in their training. It is true that stones have certain advantages over zinc for quick work and for the special purposes for which the Printing Company was designed; but as zinc plates were carried it would have been wise to have attached more importance to their use.

In the event two factors made the use of zinc plates imperative, namely :—

(1) The stationary warfare, which entailed the keeping of a large number of outlines, indexes, etc., ready for reprinting.

(2) The adoption of double-demy sheets, and the consequent weight of stones and the impossibility of getting enough of them.

Many of the trade hands obtained from the Infantry were experts in zincography, and in addition valuable instruction in the best modern methods was given by Mr. Crawford, Superintendent of Lithographic Printing at the War Office, who visited all the Survey Units.

To obtain good results with zinc, an abundant supply of pure water is essential. This is not always easily obtainable in the field, and in this respect stones have a distinct advantage. The graining is also an important point, and it is necessary, if the plates are to stand long runs, that sand of the right quality be forthcoming. Graining can be done by hand, but it is a slow process, and less reliable than a machine, which should always be provided for a Survey Unit.

(b) Litho Machines.

(b) A list is given below of the various hand presses and machines used. These call for no special remarks, except that on the whole they proved reliable, and stood the constant dismantling and re-erection better than might have been expected. All machines supplied were second-hand, with the consequence that some were shaky and made good registration difficult. One was not provided with fliers, which made it necessary to employ an extra hand.

It was not till towards the end of 1916 that the first machine was working in France. Previously all printing had been done in England. The Field Survey Units were not all equipped with machines till May, 1917. The first machines supplied were demy size, and some very good work was done with them. Later, a double-demy machine was added to the equipment of each Unit, and the larger printing surface saved a very great amount of time and labour in covering any particular area. The difference as regards portability of the two sizes turned out not to be a very important factor, as was at first feared, for no individual part of the double demy, when dismantled, is too large to go on to a 3-ton lorry. Three lorry loads were required to transport one of these machines.

At the close of the war the two southern Field Survey Battalions had one demy and two double-demy machines in action, the two extra double-demy machines being from reserve.

An American direct-printing rotary machine, mounted on a special lorry, was also lent by the American Topographical Section, and proved of the greatest use.

The proving presses used call for no special comment, except that the tympan frames of some were found to be slightly too small to take a double-demy plate. But this merely emphasises the necessity for a rigorous inspection before despatch, as mentioned elsewhere.

SIZE AND SPEED OF PRESSES, MACHINES AND DUPLICATORS USED.

Presses, Machines, etc.	Pattern.	No. per hour in one colour.	Printing surface in inches.
HAND PRESSES.			
Foolscap	Furnival.	—	13½ x 16½
Demy	"	—	22½ x 17½
Royal	Greig, Edinburgh.	—	25 x 20
Double demy	Various.	—	35 x 22½
Quad demy with machine drive	Mann.	—	45 x 35
PRINTING MACHINES (Flatbed).			
Demy	Furnival or Mann.	900	22½ x 17½
Royal	Furnival or Mann.	900	25 x 20
Double Crown	Furnival or Mann.	800	30 x 20
Double demy	Ratcliffe.	750	35 x 22½
" (Rotary direct printing) American		1,800	34 x 22½
ORDOVERAX.	*English.*— Messrs. Hall, revolving band on table.	Average 50 per hour; depends on job and size and number of operators.	Up to 45 ft. x 35 ft., depending on size of printing frame.
DOREL.	*French.*—Zinc Plates		
DUPLICATORS.			
Brief	Ellam.	250	13 x 16
"	Zygad.	250	about 14 x 17

Nearly all flat-bed machines were rebuilt machines by Mann.

(c) Other Machines.

(c) (i) Each Battalion had a guillotine. They were worked by hand power and met requirements. A guillotine is an essential adjunct and should have a blade long enough to cut paper lengthwise.

(ii) All Battalions had graining machines, which were in most cases of local manufacture. They should be part of the regular equipment of a Field Survey Battalion.

(iii) A small stitching machine is useful for binding pamphlets, etc. These were carried by each Battalion.

(d) Power.

(d) Power was provided by oil engines. The shifting of these when Army Headquarters moved was always a difficult problem, as the weights to be moved were great and the provision of concrete foundations took up much time and labour.

Power was transmitted in all cases by shafting and belts. This was one of the most serious causes of delays. The erection of the shafting was always a troublesome business, and it frequently had to be altered and re-arranged to suit the building into which the machines were put. The need was felt early of a more convenient form of transmission, and arrangements were made for all machines to be fitted for electric drive, but hostilities ceased before this could be put into force. Electric drive is undoubtedly the only practical method of dealing with machines that have to be shifted constantly, and all machines for active service should be fitted in this way.

(e) Light.

(e) A certain number of acetylene lamps (of "overhanging" table pattern) were carried as an emergency reserve in case of breakdown; but the usual lighting was electric. Current was provided by a "Lister" petrol-driven ($5\frac{1}{2}$ h.p.) set, giving 3 kilowatts at 110 volts. This pattern had the advantage of being standardised throughout various branches of the Army, and spares were, therefore, the more easily obtainable. The set is convenient for moving about, in that the whole unit, including the water-tank, is self-contained on a single bed-plate. A battery of 30 "Edison" accumulators was provided.

Good lighting of the Headquarters of a Field Survey Unit, including the administrative offices, draughtsmen's offices, and printing rooms, is of prime importance. Current was occasionally obtainable from public mains, but it is essential that a set of at least the capacity described above should be carried as part of the regular equipment, and it would be better that it should be duplicated.

Light for printing and for illuminating the copying-board for photography was provided by Cooper-Hewitt mercury vapour tubes. Their chief disadvantage for work in the field is that they are fragile, and require the most careful packing for transportation. In all consignments received from the makers it was usually found that a proportion were broken, and allowance should be made for this when ordering. They also require skill in use, and it is for consideration whether it would not be better to use arc lamps in the field as being more reliable.

A Halden electric copier, which consists of a glass cylinder around which the tracing and blue-print paper are fixed, and illuminated by an arc lamp inside the cylinder, proved very useful. These copiers were chiefly used for making blue prints for Ordoverax. They also require careful handling for transport.

SECTION III.—MAP SUPPLY.

1. Early History.

(a) Arrangements for the E.F.

(a) Small scale maps had been prepared for the original Expeditionary Force in the event of a possible war on the Continent. These comprised one strategical map on the scale of 6 miles to 1 in. (1/380,160) and 26 sheets of a tactical map. The latter consisted of 10 sheets of the 1/100,000 of Belgium (including the old small Mons sheet) and 16 sheets of the 1/80,000 of France. The area covered was that north of a line drawn from Le Havre to Luxembourg.

In addition to the above maps plates had been prepared for sheets to the south of this area from which a supply could be printed quickly if required.

The tactical maps were divided into five "sets," lettered A to E, each consisting of from four to six sheets, and the maps were packed in boxes containing either a supply of all sets or of one set only. The boxes were kept with the mobilisation stores, and on the outbreak of war were taken to the front by each Division. The plan was that the particular set required would be issued and the remainder kept in the divisional transport, or, if it appeared that they were unlikely to be required, would be sent back to the Base.

The whole of the first issue was thus with the troops in the field. The arrangement for replacement was that another complete issue would be printed and sent to the Overseas Base as soon as mobilisation was ordered.

It was not long before the whole of these maps had found their way to the Base on returning supply trains or had been left in Belgium.

The criticisms that may be made on this scheme are as follows:—

(i) The number of maps carried by the troops was altogether too great. The supply of 26 sheets for a single Infantry Brigade weighed considerably over a ton, or, allowing for one set issued, meant about one ton to be carried in transport.

(ii) The division of maps into sets was a mistake. It meant that in order to obtain, say, two sheets required for operations, two sets, amounting to 10 or 12 sheets, might have to be issued. It is impossible in a campaign to know what set will be required or if operations will fall conveniently upon a set, so that packing by single sheets is the only practical method.

(iii) The break of scale in the middle of the area was a grave mistake. It was due to the decision that as the French would fight on the 1/80,000 we must do so also. There was practically no overlap between the two scales, the result being that troops had actually to fight on two adjoining maps of different scale and style.

(b) Supply during Retreat.

(b) The troops quickly got off the area for which maps had been supplied. A stock of 1/80,000 sheets of the area to the south had been obtained, and a number of these were recovered from Rouen, while others were obtained from the Service Géographique in Paris. A few hundred of each sheet was all that it was possible to obtain in those days, but the smallness of the force made these numbers enough to be of some use. Supply was carried out personally by the Officer i/c Maps, G.H.Q., assisted at times by officers of the Intelligence Corps.

(c) Supply until Armies were Formed.

(c) From that time until the First and Second Armies were formed map supply was carried out direct to Divisions and occasionally Brigades by Maps, G.H.Q., with the aid of one box-car. The supplies consisted mainly of small scale maps, supplemented by a few 1/20,000, produced by photographic enlargement of the 1/80,000.

2. Arrangements in 1915.

(a) Issues of Small Scale Maps.

(a) As the situation became clearer troops subsequently sent to France were supplied before embarking with maps of the area in which they were likely to operate. These were five sheets, 1/80,000 Arras, Lille and St. Omer, and 1/100,000 Ostend and Tournai.

In February, 1915, the opinion of Divisions that had been much on the march was obtained as to the number of maps that could conveniently be carried. The general opinion was that 16 sheets could be taken, of which four would be carried on the person and six in the first-line transport of the unit. These numbers were convenient, as for the officer they represented a useful area and for the transport they meant (for an Infantry Battalion) two map boxes. The sheets issued under this scheme to troops leaving England as well as to those in France were:—

1/80,000.—7 Arras, 8 Lille.
1/100,000.—1 Ostend, 2 Ghent, 3 Antwerp, 5 Tournai, 5a Hazebrouck, 6 Brussels, 7a Mons, 8 Namur.

By the autumn of 1915, when it was evident that trench warfare would continue perhaps indefinitely and the British front had greatly increased, troops in France received only 4 1/100,000 sheets, according to the Army to which they belonged, while troops proceeding from England received only two sheets, 5a Hazebrouck and 11 Lens, these being the sheets in which practically all detraining took place.

Other maps required by newly arrived troops were issued under Army arrangements.

(b) Beginnings of Large Scale Maps.

(b) During 1915 large scale maps gradually came into general use. The 1/20,000 of Belgium was available from an early date, while that of France was being produced as described in Chapter 1. The 1/40,000 of Belgium was also available at once, but that of France did not appear until some time after the larger scale, except for the areas of which Fortress Plans Directeurs existed, as round Lille.

The issue of 1/20,000 was confined strictly to troops in the fighting line, artillery, and Staff. The issue of the 1/40,000 was at first very limited, and no squared maps were issued to Signal and Supply Units, Divisional Cavalry, Cyclist Companies, Field Ambulances, R.E. other than Field Companies, etc. It was ordered in February, 1915, that references to maps other than the 1/80,000 and 1/100,000 must only be made when it was known that those concerned were in possession of them.

Continual demands were received from other units for the issue of squared maps, because orders so constantly referred to them. No objection was raised by G.H.Q. to the issue, but it was considered that the need for them should be established before embarking on much larger scales of issue than had previously been contemplated. Finally, after reference to the Armies, G.R.O. 878 was issued in May, 1915, authorising an issue of 1/40,000 to all units. It is noticeable that this scale did not allow of 1/20,000 for Infantry. It is evident that the large scale map was at first and for some time regarded as a purely artillery need, and that at this date the detailed trench map for infantry was not contemplated, at any rate as a general issue.

(c) Mobile Reserve.

(c) The G.R.O. above quoted laid down that the scale of issue of large scale squared maps therein authorised applied "only to siege operations like the present." The great value of the larger scales was, however, appreciated, and in the autumn of 1915 a "mobile reserve" of 1/40,000 was issued to units of the First and Second Armies (but not to the Third, as no 1/40,000 were then available of their area).

Maps 3265, of 7/10/15, states, "It should be clearly understood that the object of this issue is to provide Staffs and Commanders with a map for reference which will give them more detailed information about the ground than can be obtained on the 1/100,000, but that during moving operations the 1/100,000 will be the official tactical map on which orders will be given."

This reserve consisted of ten 1/40,000 sheets, Nos. 21, 22, 23, 29, 30, 31, 37, 38, 39, 44, and covered the area from the 1/40,000 sheets already issued as far as Brussels. It was issued packed in boxes or packets, marked "Reserve sheets 21-44," to Corps, Divisional and Infantry Brigade Staffs, G.O.C.R.A., C.R.E., Signals, and certain other units. The rate of issue was 10 to Divisional and Brigade Staffs, and 2 to units.

As the organisation for Map Supply developed, and the reserves held by the Survey units increased, this Mobile Reserve became unnecessary, and it was not maintained. It would have proved very useful had a forward movement taken place in the early days of the war. and it was probably used by those units that possessed it in the final advance.

3. Supply to Armies.

With the gradual growth of the use of large scale maps, and the increase in requirements generally, map supply developed into a big organisation. At first this supply was based entirely on England. Later, as means of reproduction became available in France, a large proportion of the work in connection with large scale maps was transferred overseas; but a certain amount of large scale work was done in England to the end of the war, and practically the whole of the small scale production throughout.

(a) England to G.H.Q.

(a) Maps supplied from England were sent to France by two routes.

(i) Non-urgent maps by steamer from the Ordnance Survey, Southampton, to Havre, thence by rail to the depots at Rouen, Abbeville or Calais.

(ii) Urgent maps by steamer from Folkestone to Boulogne, thence by road to G.H.Q.

The consignments of non-urgent maps were sent to Havre weekly. Urgent maps went by train from the Ordnance Survey Southampton to London, where they were checked by M.I.4 and seen on to the Folkestone train. The supplies via Boulogne arrived daily, without exception, from about November, 1914, until hostilities ceased.

(b) G.H.Q. to Armies.

(b) From G.H.Q. maps were supplied in bulk to Armies by road. It was on several occasions suggested that the supply should be carried out by rail, in order to save motor transport, and a trial of this method was made more than once; but rail transport proved entirely unsuitable. Maps were nearly always wanted urgently, and the delays incidental to rail transport put that method out of the question. Map supply is quite different from the supply of ammunition, food, and other stores for which the time taken on the road does not as a rule matter so long as a regular daily supply is forthcoming at rail-head. Maps of the kind required in the war must travel quickly, or they become useless. Moreover, again unlike food supply, certain maps must go to certain destinations, and interchange is not permissible.

At the end of the war an Advanced G.H.Q. Depot was formed at Arras and maps were sent there by rail from Boulogne, but the situation had then changed greatly, and was mainly a question of large quantities of small scale maps.

Rail was also used for the conveyance of small scale maps or any maps not required urgently, from the port to the Base Depots, and thence to G.H.Q. or direct to Armies as required.

(c) Time Taken.

(c) It is of interest to note the time taken to obtain maps and kindred stores during the period when map supply was dependent entirely on England.

The demands sent were as a rule of the following three types.

(i) *For blues.*—A new drawing or correction drawing sent, and blue impressions only required.

(ii) *For copies.*—Either new drawings or correction copies for the preparation and printing of a new edition.

(iii) *For zinc plates.*—Duplicate plates to be made for F.S. Battalions from drawings as above.

The times taken were on an average as follows. In each case 2 extra days are included to allow for uncertainty of communication. It was not uncommon for sailings to be stopped on account of mines, and other delays happened. The shorter time was possible when a complete drawing was sent; the longer is due to the extra time required when correction copies only were supplied.

The time in every case means from dispatch from the Army to receipt by the Army.

(i) For blues, 8 to 9 days.
(ii) For copies, say, 10,000 (this includes folding), 13 to 15 days.
(iii) For zinc plates, 8 to 10 days.

The above may be taken as average times.

Much more rapid work was done on special occasions, but this probably meant the suspension and consequent delay of other work.

For example, at the end of 1917 a case arose in the Third Army in which 10,000 copies of each of two maps in four colours were wanted very urgently. A special messenger was sent from the Army to convoy the plates to Southampton and bring back the finished copies.

The following is the time-table.

Date—

November 8	10.45 p.m.	Left Army H.Q.
November 9	5.00 a.m.	Arrived Boulogne.
	9.20 p.m.	Arrived O.S. Southampton.
November 11	11.00 a.m.	Printing completed and packing started.
November 12	4.50 p.m.	Left Southampton.
November 13	4.00 p.m.	Arrived Boulogne.
November 14	10.00 a.m.	Arrived Army H.Q.

Say, 5½ days.

(d) Supply in France.

(d) When Field Survey Battalions carried out a large part of their own reproduction, and later when O.B.O.S. started work, supplie from England were (as far as large scale maps were concerned) mainly confined to 1/40,000 scale and to flat copies of 1/20,000 for local over-printing.

Maps printed by O.B.O.S. were as a rule sent to Armies through Maps G.H.Q., as orders had often to be distributed among more than one Army. Occasionally they were sent direct.

The time saved on normal orders by the establishment of O.B.O.S. was about two days for travelling, two for uncertainty of communication, and about one for extra quickness in transmission of orders; a total of about five days less on any order.

4. Supply to Troops.

(a) Division of responsibility between G.H.Q. and Armies.

(a) Maps G.H.Q. supplied maps direct to formations directly under G.H.Q., such as Cavalry Corps, Indian Cavalry Corps, G.H.Q. Troops; while Field Survey Battalions supplied to all troops in the Armies. Troops temporarily under G.H.Q. orders were supplied under instructions from Maps G.H.Q., as it was usually more convenient for the nearest F.S.B. to provide for them.

(b) Supply to Units.

(b) Theoretically maps should have been delivered by F.S.B. to the Corps, but as the Corps has no organisation for map distribution, in practise the Survey units almost invariably delivered direct to Divisions throughout the war, and the Divisional Staff was responsible for distribution within the Division.

In one Army deliveries were made to the Corps H.Q., but it was found that troops did not get their maps so quickly nor so certainly by this method, and unless the Corps is provided with proper organisation and transport for map supply it should not be adopted.

At the beginning of the war maps were supplied in bulk to Divisional H.Q., but it was soon found that the Divisions had neither the means nor the knowledge to ensure a correct distribution to the troops. Consequently the system was adopted of supplying maps ready packed in parcels addressed to the various units or lower formations. Parcels were made up, for example, for each Infantry Brigade, for the Artillery, Engineers, R.A.M.C., etc. This made it reasonably sure that each unit would get the maps to which it was entitled.

Occasionally during the rapid movements in 1918 maps were again delivered in bulk, but at that date both divisions and troops were full of experience and were able to deal with them.

(c) Advanced Map Depots.

(c) In order to cope with the difficulties of distance and lack of transport, Advanced Map Depots were established near the front line by most of the F.S.B. These saved a good deal of wear and tear of transport, and were also a great convenience to troops, as replacements could be obtained from them in small quantities without reference to higher authority.

(d) Special Map Cars.

(d) During the 1918 retreat the 3rd F.S.B. sent out box-cars conspicuously marked "MAPS," with a roving commission to deliver maps to any troops found in need of them. These cars were in charge of officers, and did valuable service.

5. Transport.

The efficiency of map supply to troops is very largely a question of transport. As stated above, maps are usually required urgently, and the nearer one gets to the front, the worse and more congested do roads become. To be of use transport must therefore be plentiful, reliable, and able to go on any road on which motor traffic is allowed.

The transport allotted to a Field Survey Battalion was (excluding two touring cars), three box-cars, which should have been 15 cwt., but were erroneously put down in the W.E. as 8 cwt., and one 3-ton lorry. When it is remembered that at least one box-car was required for the very important work of transporting parties of surveyors for fixing our own batteries or other work, and that apart from breakdowns (which were frequent) every vehicle had to go into the shops for inspection and overhaul once a fortnight, it will be seen that what remained for map supply was absurdly inadequate. In an Army an average of 12 Divisions had to be supplied, and this number was frequently largely exceeded. The complete supply of maps for a newly-arrived Division totalled about 10,000 sheets, and weighed something over a ton. The 3-ton lorry was not allowed on many roads, and its usefulness was consequently greatly curtailed.

When operations were contemplated or in progress all difficulties were multiplied many times. The situation could only be met by using the box-cars and lorries of the Sound Ranging Sections, and by borrowing from Army or G.H.Q. pools. The former method was merely robbing Peter to pay Paul, as it rendered the Sections immobile at a time when they might have to move. Few instances occurred when it was possible to get help from Army pools, as these were naturally required as a reserve for breakdowns; so that the G.H.Q. pool was the last resource. It must be acknowledged that help was generally obtained here, to the extent of about three light (6 or 8 cwt.) box-cars for an Army engaged in operations; but it meant personal application and effort on each occasion, and there were times when it was really extremely difficult for G.H.Q. to allot any help at all.

Difficulties of this nature were due to the general situation, and will doubtless occur again in similar circumstances, but they will be at least mitigated if needs are recognised and ample provision made in establishments.

Objection was taken above to the decentralisation of map distribution to the Corps, but this objection would vanish if there were a Survey unit with the Corps, responsible and properly equipped for map supply. Such a unit should have, say, two 15-cwt. box-cars and one 30-cwt. lorry. If the Survey unit with the Army had two similar box-cars (for map supply only) for urgent deliveries, and, say, two 30-cwt. and one 3-ton lorry for deliveries in bulk, the question of map supply to troops would be on a satisfactory basis.

The transport at G.H.Q., for map supply only, was three 15-cwt. box-cars, two 30-cwt. lorries, and three 3-ton lorries. With this all urgent consignments of maps had to be brought from Boulogne to G.H.Q., where they were sorted and sent on to Armies. The division of responsibility was that G.H.Q. delivered to Army H.Q. and F.S.B. delivered beyond that; but the F.S.B. frequently had to send their own lorries back, as breakdowns or the many calls on the G.H.Q. transport made it impossible to guarantee a certain service.

Much assistance was obtained towards the end of the war from O.B.O.S., which had two good box-cars and a 30-cwt. lorry.

6. Supply to Troops moving to other Parts of British Front.

From the middle of 1916 the practice of moving Divisions rapidly from one part of the front to another became common, and arrangements had to be made to provide them with the maps they required both for the movement and on arrival.

For this purpose it was arranged that each F.S.B. should hold a stock of small scale maps of other areas, to issue to troops transferred from their Army to another (to provide for the march and billetting on arrival), and a special stock of large scale maps for issue to troops on arrival. Troops transferred were thus provided with a small supply of small scale maps before leaving, and received their fully supply of small and large scale on arrival. Special arrangements had to be made for this, as the movement of Divisions was frequent and rapid. Stocks were therefore made up, ready packed, and held as a special "Reinforcement Reserve."

7. Supply to Troops Transferred to other Fronts.

(a) Interchange of Material.

(a) In February, 1918, the possibility arose of British Troops operating on the French front and vice versâ.

It was therefore decided to interchange maps and topographical information with the French. This was carried into effect, and we exchanged 12 copies of every existing 1/20,000 map, battery position and enemy organisation maps, map indexes, trig. lists, and conventional sign lists; and this was kept up for every new edition.

In this way both the French and British had immediately available the current information for any region to which troops might be sent.

(b) Liaison Officers.

(b) In order that map supply might proceed satisfactorily arrangements were made to send a liaison officer to Maps, G.H.Q., if French troops intervened in British area, or to the Service Géographique if British troops went to the French area. From these Headquarters liaison officers were to be despatched immediately to the Field Survey Battalion or the Groupe de Canevas de Tir which dealt with the sector in question.

Under the arrangement of interchange the liaison officer was in a position to take to the moving troops a small supply of the maps for the sector to be taken over.

Certain scales of issue for both British and French troops were fixed.

In the case of British troops moving to the French front the following duties were laid down for the liaison officer :—

(i) To make himself thoroughly acquainted with the French maps available.

(ii) To know the scales of issue current in French and British Armies.

(iii) On arrival at the Service Géographique in Paris, to explain in detail the area being occupied by the British Force and the strength of the Force. To find out when maps would be available.

(iv) On arrival at the Groupe de Canevas de Tir of the Army, to find out all the geographical data available.

(v) To get into touch with the British troops as soon as possible and to supply them with all material from the G.C.T.A.

(vi) To report regularly and frequently to Maps, G.H.Q.

The work of this officer was intended to be the preliminary arrangement to ensure that supply was put into proper running order. He was to be the intermediary only and to hand o er everything to the O.C. Corps Topo. Section, who would keep the map stocks and make issues.

British troops did subsequently operate on the French front, and the arrangements for liaison were put into force. The result proved satisfactory in every way, and the Corps concerned received without delay all maps required.

(c) General Instructions.

(c) General instructions for Map Supply to a British Corps operating in an area where the whole or part of the maps were French were issued to each British Corps. This explained the work of the liaison officer, and also gave detailed instructions to be followed by the Corps to obtain maps before the arrival of the liaison officer in the case of a move into French area at short notice. These instructions were accompanied by short notes on French maps and plans and by index diagrams to British small scale maps.

(d) French Troops on British Front.

(d) It was found that in general French troops arrived before the Groupe de Canevas de Tir. The Field Survey Battalions therefore issued maps at once direct to the French Divisions, the numbers required being given by the French liaison officer attached to the British Army concerned. The scales supplied for a French Division were in all cases very much smaller than those for a British Division. Indeed, so small did they appear to be by comparison with our own issue that we increased them by a half. The French forces were completely satisfied with the maps and numbers supplied them.

It was found that specially detailed French liaison officers were not required for this map work. The French units have permanently attached liaison officers. These proved to be a sufficient channel of communication for all needs.

8. Map Supply in 1918.

(a) Retreat.

(a) During the German attack in 1918 unexpected and heavy demands had to be met at short notice, and this for almost the whole of the front. Fortunately O.B.O.S. was in action. Existing stocks were soon used up, but the situation was kept in hand by printing back-area sheets at full pressure at O.B.O.S. The situation was made more difficult by the fact that four of the five Field Survey Battalions had to move their H.Q., two of them so quickly that large numbers of maps were abandoned. Probably the greatest difficulty of this period was to keep in touch with units. Maps were available, but in some cases they did not reach the units requiring them simply because they could not be found. This was not in any way the fault of the map supply organisation, but simply due to the abnormal conditions at the time.

(b) Advance.

(b) The change from defensive to offensive warfare was very sudden. The strain thrown on the map supply organisation was consequently severe. Up to the very moment of the first Allied attack we had been engaged upon the preparation and issue of back-area sheets to provide troops in case of the necessity for further retirement.

In the early stages of our advance special provision was made for each stage of the attack. Later, when the advance became general and more rapid, our energies were concentrated on the supply of the eastern sheets of Belgium. The 1/10,000 scale was soon suspended, as the advance became too rapid for it to be of use, and printing facilities were required for the provision of the smaller scales. Very large numbers of 1/100,000 and 1/40,000 sheets were issued, and in the later stages the 1/20,000 scale was only issued when a temporary delay in a particular area was experienced. The scale of issue of 1/40,000 sheets was increased to correspond with that of the 1/20,000 scale, when the latter was suspended.

The chief difficulties of supply and provision during the rapid advance before the Armistice were :—

(i) The absence of any warning of impending special attacks by us. Special provision could not therefore be made.

(ii) The frequent changes of units from one portion of the front to another, which involved many new issues.

(iii) The uncertainty of the line of advance of the various Divisions. This necessitated in many cases the issue of several sheets to the same Division and increased enormously the total required. Many such issues were never used.

(iv) The continual increase in the distance over which maps had to be transported and distributed.

Some idea of the number of maps distributed at this time may be obtained from the fact that, during the two and a half months from the beginning of August to the middle of October, Maps, G.H.Q. distributed to the Field Survey Battalions over two million sheets. One million one hundred and nine thousand went to the Third Army alone, and of these half a million were on the 1/20,000 scale. These figures are additional to the maps printed by the Field Survey Battalions themselves. Their own printings were very heavy.

9. Reserves of Small Scale Maps.

The reserves held varied from time to time according to the nature of operations.

(a) Up to 1917.

(a) Up to the end of 1916 reserves were based on the following principles :—

(i) That enough should be available in the country to permit of a full issue to all troops of any sheets which might be wanted at comparatively short notice—*i.e.*, of sheets immediately to the east or south of the British Front.

(ii) That enough should be held to allow of a half issue of certain other sheets —*i.e.* those further east or south.

(iii) That the reserve of any maps in use should be a minimum of 25 per cent. of the full issue.

(iv) That a similar 25 per cent. reserve should be held by the War Office.

The above reserve was (in France) called "A," or Normal Reserve, and was kept up automatically by Maps, L. of C., without reference to G.H.Q.

The full issue (see (i) above) was at first held by G.H.Q. and later by the Armies, and when issued was automatically replaced by a 25 per cent. reserve in the L. of C. Depots.

Stocks held on the L. of C. under this system varied from 10,000 to 55,000 of any single 1/100,000 sheet, and went up to 15,000 of certain 1/250,000 sheets.

In addition to the A Reserve, a B Reserve was held as required. This was a reserve collected for special operations, ordered by G.H.Q. and not touched without reference to G.H.Q.

(b) During 1917.

(b) At the end of 1916 the system of A and B Reserves was dropped, being replaced by a reserve on the L. of C. sufficient for a definite number of Divisions which might be put into any part of the line to carry on the results of a definite series of operations. The actual operations were provided for by special orders for maps, based on the number of troops taking part in the operation itself. The maps received in response to these special orders were not treated as reserve, but were sent immediately to the Army.

Under this scheme reserves of sheets east of the line were held for 20 Divisions, which at the rate of 1,350 a Division came to 27,000 of each 1/100,000 sheet except the most southerly, of which half that number was held. Later this reserve was increased to 30,000. Of sheets on which the line fell about 20,000 were held. At the same time from 5,000 to 15,000 of the 1/250,000 sheets were kept.

(c) 1918; Final Phase.

(c) During 1918 the constant movement of troops led to very heavy demands for 1/100,000 maps, so that additional stocks were necessary. 90,000 of some sheets were issued. It was impossible to lay down a definite stock, and the situation had to be considered from day to day in order to provide for requirements and to settle the order of precedence of supply of sheets.

During this period the normal stock in hand was 30,000 of all 1/100,000 sheets to the German frontier, and from 5,000 to 15,000 of the 1/250,00.

10. Reserves of Large Scale Maps.

Reserve stocks of large scale maps varied in the same way according to the period of the war.

(a) Until 1917.

(a) *Until* 1917.—A and B reserves were held, but the A reserve was not calculated on the same basis as was the case with small scale maps.

The A reserve was :—

1/40,000.—5,000 of main area of operations, as far east as Ghent, Peruwelz, Le Cateau; 2,000 of area north and south.

1/20,000.—5,000 of sheets immediately east of trench maps; 2,000 of other sheets as far east as the 1/40,000.

No reserve of trench maps was held by G.H.Q. These were demanded as required and held by Armies.

(b) During 1917.

(b) *During* 1917.—A and B reserve were abolished, as explained above, and the following stocks held :—

1/40,000.—10,000 of 28 Ypres and 51b Arras sheets, on which Armies overlapped; 6,000 of other sheets as far east as Ghent, Le Cateau, Guise, and from Thourout in the north to La Fere in the south (sheets 19, 20, 21, 27, 29, 36a, 36, 37, etc., down to 66d, 66c); 2,000 of the row of 1/40,000 sheets east (Nos. 22, 30, 38, etc.), extending to Termonde, Mons, Maubeuge, Hirson.

1/20,000.—2,000 of all sheets excluding trench maps extending from Dunkerque, St. Pol, Amiens on the west, to Ghent, Peruwelz, Guise, Laon on the east.

(c) In 1918.

(c) *In* 1918.—

1/40,000.—In August stocks were being built up, and had extended as far east as to include Antwerp, Brussels, Charleroi, but with no increase on numbers given above.

In October stocks varied from 15,000 to 20,000 of sheets between Ypres and St. Quentin, and as far east as Antwerp, Brussels and Charleroi.

1/20,000.—During this period the 1/20,000 fell into disuse, owing to the rapidity of movement, and stocks were not increased or maintained.

As many as 70,000 of some sheets were issued, and the situation as to stocks and supplies had to be considered daily.

11. Scales of Issue.

(a) Pre-war.

(a) The scale of issue of maps for the original Expeditionary Force was as laid down in the Training and Manœuvre Regulations. It catered for small scale maps only, the strategical map (1,380,160) being issued in very small numbers, and the tactical (1/80,000 or 1/100,000) on a liberal scale. The 1/250,000, it will be noted, had not yet been published. The issue, for example, of the tactical map to a Battalion (with 30 officers) was 85, and the full issue to an Infantry Division, 1,544. This scale of issue, combined with the large numbers of sheets carried (26), accounts for the great quantity of maps issued to the Expeditionary Force, in spite of its small strength. The total issue for the force of six Divisions and Cavalry Division, with L. of C. Troops, etc., was about 360,000.

(b) 1915.

(b) In the case of tactical maps this scale was soon reduced to the rate of one per officer, and in April, 1915, the issue to a Division amounted to 820.

At the same date the issue of large scale maps was first recognised, and G.R.O. 878 provided for 1/40,000 to all troops at the rate roughly of one per officer, and the 1/20,000 to Staffs, Artillery and Engineers.

In August, 1915, the scale of issue provided for the 1/250,000, which was issued on the pre-war scale. With the addition of various units the total issue to a Division now amounted to 871 for 1/80,000 or 1/100,000, and 1,737 for 1/250,000.

(c) 1916.

(c) At the beginning of 1916 a complete revision of the scales of issue was made, after consultation with all Armies and Heads of Departments. The resulting scale of issue (S.S. 435) was put in force in March, 1916, and continued with slight modifications until 1918. In this the 1/250,000 was cut down to the scale of a strategical map; the issue of the 1/100,000 was increased, and full provision was made for the three scales of large scale maps. This scale of issue included "Sectional maps," which was the special form of 1/10,000 produced for a short time by certain Armies. It was, however, provided that the regular series of 1/10,000 could be issued when the sectional map did not exist.

The following figures will serve for comparison with other scales of issue.

		Battalion.	Division.
Scale of	1/250,000 ...	2	158
Issue,	1/100,000 ...	50	1,146
S.S. 435,	1/40,000 ...	5	221
March, 1916.	1/20,000 ...	36	711
	1/10,000 ...	80	1,421

In October, 1916, as the result of considerable discussion upon the relative merits of the 1/20,000 and 1/10,000 scales, it was decided that Armies could issue which they preferred.

(d) Final Scale.

(d) By the end of 1917 numerous changes in the composition of formations and changed requirements of various kinds made a revision of the Scale of Issue necessary.

A careful revision of S.S. 435 was made, and copies were circulated to all Armies and branches in January, 1918, for remarks and suggestions. The German attack started before all replies were received, and nothing more could be done until the autumn. Complete replies came in ultimately, and a revised scale was made out, but was not put into use owing to the Armistice.

The opportunity was taken immediately after the Armistice, whilst actual experiences were still fresh in mind, to obtain detailed opinions and reports from all formations and units as to the adequacy of map supply and the suitability of the map scales. The analysis of the replies shows that in general the supply was considered satisfactory.

As a result of this and of the suggestions received, a complete revision of the General Scale of issue has been made. It embodies the latest opinions and the results of the experiences of map users in the war, and so may be regarded as fairly representing the needs of the various arms.

This scale is not reproduced in this report, but it will be found, with other full details of all kinds on the subject of map supply, in a file in the Geographical Section, War Office.

For purposes of comparison, the following figures are extracted:—

	Battalion.		Division.
1/250,000 ...	2	......	139
1/100,000 ...	50	......	865
1/40,000 layered	1	......	32
ordinary	8	......	440
1/20,000 ...	50	......	815
1/10,000 ...	50	......	790

(e) Secret Trench Maps.

(e) As explained in Chap. 1, Section III. 8, a secret trench map was, until 1918, considered to be any map showing our own trenches. Under this definition the only secret maps published until the middle of 1916 were on the 1/10,000 scale. Their issue was strictly limited, *e.g.*, one per Infantry Brigade and a total of 15 for a Division.

In 1916 the issue of a secret 1/20,000, showing back lines of our own trenches, was approved, but the issue was limited to three per Army (G.O.C, M.G.G.S. and O.C.F.S.C.) and one each to the G.O.C. Corps and Division. This was increased in January, 1917, in consequence of representations by the Armies, to 10 per Army H.Q. and 10 per Corps H.Q.

In January, 1918, it was decided that secret matter was confined to what could not be detected from an air photograph. From that date the only map published with really secret information was on the 1/20,000 scale, unless in special circumstances an Army authorised the issue of a secret 1/10,000. The scale of issue for the secret 1/20,000 was 20 for Army H.Q., 15 for Corps H.Q. and three for Div. H.Q. Subsequent representations showed that it was necessary for various units and formations in a Division to have the secret map, and the issue was increased to 28. This is the figure included in the final scale of issue mentioned above.

(f) Special Scales of Issue.

(f) Besides the above scales of issue, which were of general application, there were various scales made either for special circumstances or for special maps:—

(i) *Special "Army" scales* were made pending the revision of the general scale of issue, or to provide for special needs.

(ii) *Situation, Battery Position, Enemy Organisation* and various other maps were issued under Army arrangements according to requirements.

(iii) *Traffic Control* and other maps prepared for the Q. branch were usually handed over in bulk and issued by them.

(iv) *Troops transferred to another area* received maps for the move on a special reduced scale.

(v) *Layered maps* (1/40,000) were issued on a special scale laid down by G.H.Q.

(vi) *Allied troops* operating on the British front received maps on a special scale according to requirements.

Full details of all the above will be found in the Report on Map Supply (Geographical Section, War Office) already referred to.

12. Issues.

(a) Replacements.

(a) The principle was followed throughout the war that all issues should be replaced on demand and without query, unless the request appeared on the face of it to be unreasonable. Red tape was avoided as much as possible.

This principle was observed faithfully by Survey units, who recognised that maps are perishable articles, but not always by those through whose hands the maps passed on their way to the troops. It was found on several occasions that demands from units or lower formations had been held up by some subordinate on the mistaken ground that once an officer had received a certain map he was responsible for its maintenance, and had no right to call for another.

This matter has a bearing also on the question of the receipt by troops of the maps to which they were entitled. It has been pointed out that the Survey units made it their business, in spite of great difficulties of transport, to deliver maps to Divisions, though, strictly speaking, they could not be held responsible for delivery further than to Corps H.Q. It was then the business of the Division to distribute to the lower formations, and of the lower formations to distribute to the units. But it was frequently found that units had not received their maps, and that they had been held up by some higher staff. As the maps so held up were kept untouched, it can only be assumed that they were kept for fear that they would not be replaced—a fear for which there was no justification. An example of this is a demand received for the re-issue of a large number of maps "to replace those destroyed by fire at Brigade Headquarters." The maps should not have been at Bde. H.Q.; they should have been issued some time previously to the troops. This holding up of maps and creation of stocks was quite unjustifiable. It was the business of the Survey Units to maintain stocks, which they did in ample quantity, and no difficulties were ever raised about meeting proper demands.

(b) Statistics.

(b) The following general figures have been extracted from records, as being of interest :—

Map Issue to Expeditionary Force, 1914.

The total issue of maps to the original Expeditionary Force, consisting of 1/380,160, 1/80,000 and 1/100,000, amounted to about 335,000, exclusive of G.H.Q. and L. of C. troops. Considering the size of the force (six Divs. and one Cav. Div.), this figure is very high, owing to the large scale of issue and the great number of sheets carried (26).

Map Issue to British Armies, 1917.

The total full issue of maps to the British Armies in France in 1917 (*i.e.*, the total that would have been issued had a complete outfit been required), allowing four 1/250,000 sheets, four 1/100,000, three 1/40,000, two 1/20,000 and two 1/10,000, amounted to about 654,000, exclusive of G.H.Q. and L. of C. troops.

Total Maps Printed and Issued for Western Front.

The total of maps of all scales printed during the war for troops in France and Belgium was :—

By the Ordnance Survey, Southampton	21,703,798
,, Overseas Branch, Ordnance Survey	3,111,132
,, War Office	2,149,450
,, Survey Units (about)	7,000,000
Making a total of maps printed during the war of (in round numbers)	34,000,000

Stocks remaining in December, 1918, amounted to 2,981,000, so that the total issued to troops may be taken as 31,000,000.

Average Issue to Division and Corps.

The total average issue for an Infantry Division was :—

Small scale	5,216
Large scale	4,927
Total	10,143

The total average issue, including all maps, for a Corps of three Divisions was 34,200.

Reserves in France.

The total maps of all kinds held in reserve was:—

In 1917—By G.H.Q.	858,500
,, Armies	410,000
Total	1,268,500
In 1918—By G.H.Q.	1,587,500
,, Armies	830,000
Total	2,417,500

Small Issues by Maps G.H.Q.

The total small issues by Maps G.H.Q. (*i.e.*, other than issues in bulk to Armies) was:—

In 1917	233,600
,, 1918	308,425

Daily Issue, G.H.Q. to Armies.

The average daily issue of maps to Armies by Maps G.H.Q. for typical periods was:—

January, 1917	20,110	
May, 1917	31,162	... Great activity, full issue of large scale.
July 15-October 15, 1918 ...	21,413	... Chiefly forward areas, 1/40,000 and 1/100,000.

The average daily issue of maps to Armies from the Map Depots, L. of C., was 1,176. (These were, of course, nearly all small scale sheets).

Daily Issue, F.S.B. to Troops.

Typical average daily issues of maps to troops by F.S. Bns. were as follows:—

3rd F.S.B., November, 1917	11,110	... Battle of Cambrai.
1st F.S.B., January, 1917...	2,951	... Typical stationary warfare.
2nd F.S.B., May, 1917 ...	19,006	... Preparation for Messines, etc.
4th F.S.B., July, 1917 ...	7,013	... Army very small at this time.

Maximum Printed by F.S.B.

The largest number (of which record has been received) of maps printed by a Field Service Battalion in one month was:—

By 4th F.S. Bn. in September, 1918 (British attack, fourth Battle of Ypres)—432,000.

Average Monthly Issues to Divisions.

The following are examples of the average number of map issues per Division per month in the five Armies. The figures are taken from the first six months of 1917:—

Army.	Number of Maps (all Scales).
I.	 12,958
II.	 10,925
III.	 11,250
IV.	 9,108
V.	 19,833

13. Disposal of Maps.

(a) Types of Map for Disposal.

(a) The large number of maps issued, the frequent editions of large scale maps, and the constant movement of units from one part of the front to another, led to there being considerable numbers of maps for disposal.

These may be classed conveniently under the following headings:—

(i) Obsolete editions.
(ii) Worn out maps.
(iii) In use and serviceable, but no longer required owing to advance or movement.
(iv) Reserve, ditto.
(v) Current secret or special information, no longer required for same reasons.
(vi) Obsolete secret.

Briefly, the disposal was

(i), (ii) and (iii) were collected by units and sent by rail to one of the Map Depots on the L. of C.

(iv) and (v) were collected by Divisions at Div. H.Q., and the F.S.B. informed. Instructions were then issued for their disposal.

(vi) were burnt by the unit responsible.

Orders for the above procedure were contained in G.R.O. 3147.

(b) Handing over to Relieving Divisions.

(b) In order to economise issues, every endeavour was made to transfer current maps from one Division to another when a relief took place in the trenches. Those maps under (iv) and (v) of the preceding paragraph, left by an outgoing Division, were examined by the Field Survey Battalion and as far as possible re-issued to the incoming Division. It was then only necessary to make up numbers to full Divisional issues by the supply of new maps, and consequently a great saving was effected.

Current secret maps and maps mounted together containing special information were handed over direct by the outgoing Division to the incoming one.

(c) Work at Map Depots.

(c) Consignments of returned maps were received daily by the Map Depots, L. of C., and a considerable portion of the time of the Depots was taken up in the examination and sorting of these maps. The small scale (1/250,000, 1/100,000) and 1/40,000 were examined; unserviceable copies rejected and the remainder sorted and packed for re-issue. Many thousands of maps were saved in this way.

Trench maps and large scale maps of current editions were similarly put aside for re-issue. Obsolete trench maps were sorted under editions and put aside in case of future need. This precaution proved to be sound. Many thousands were issued during the German advance in 1918, when we were again on ground for which trench maps had been printed some time before, and returned to the Depots when the 1917 advance took place.

Throughout the war requests were frequently received for copies of particular editions of trench maps. These stocks of obsolete trench editions were of great use for such demands.

After the Armistice units and formations compiling records and writing Histories required copies of old maps of all kinds, and several thousand demands were met from these L. of C. stocks. In addition, the Imperial War Graves Commission was provided with a supply of all trench maps of which stocks existed.

All unserviceable maps were sent to the Army Printing and Stationery Services for disposal as waste paper.

14. Organisation and duties of the Publication and Map Supply Section, G.H.Q.

In May, 1917, a G.S.O. 3 was added to the staff of Maps, G.H.Q., to deal with publication and map supply. Captain Field, who held this appointment, had assisted in this work for seven months previously, in addition to his duties as O.C. Printing Company, but from the date mentioned he was able to devote his whole time to it. His staff was gradually increased until it included 1 officer and 7 other ranks at G.H.Q., with 10 other ranks in the map depots on the L. of C., besides the transport.

(a) G.H.Q.

(a) The duties of the Publication and Map Supply Section included:—

Publication.

Receipt of material from Armies, record, and transmission for reproduction to the Ordnance Survey or O.B.O.S.

Record of all editions, and allotment of numbers and letters.

Maintenance of card index of all sheets of large scale maps.

Supply.

Map Supply in bulk to Armies and G.H.Q. Troops.

Map Supply in detail to all branches of G.H.Q.

Maintenance of necessary reserves.

Receipt and transmission to proper quarter of all demands, printing orders, etc., from Armies.

Records.

Filing of all original materials.

Maintenance of record files of all kinds of maps, and transmission of record copies to England, etc.

Maintenance of indexes to trench maps, etc.

Miscellaneous.

Despatch of material to French and filing of French material.

A stock of maps of the British front of every kind was kept, and also a stock of maps of various kinds of all theatres of war, for issue to the departments of G.H.Q. and also to visiting officers and others.

Record copies of every edition and of all maps published in France were disposed of as follows :—

2 copies filed at G.H.Q.
1 copy sent to M.I. 4, War Office.
1 copy sent to D.G.O.S., Southampton.
1 copy sent to Historical Section, London.
1 copy sent to G.H.Q., American Army (by request).

(b) L. of C.

(b) The Map Depots on the L. of C. were organised as follows :—

Until May, 1916, while there was one L. of C.

Main Depot, Rouen.—Opened August, 1914, closed May, 1916. Staff finally, 7 other ranks.

Advanced Depot, Abbeville.—Opened October, 1914. Staff, 1 W.O. and about 4 other ranks.

From May, 1916, when there were two L. of C.

Northern Depot, Calais.—Opened May, 1916, closed June, 1919. Staff, 1 W.O. and 3 other ranks.

Southern Depot, Abbeville.—This was considerably increased on the closing of the Rouen Depot. Staff finally, 1 W.O. and 9 other ranks. Closed June, 1919.

These Depots were responsible for bulk storage and issues, for small local issues, and for sorting out old maps and editions, and repacking those that were serviceable.

(c) Publication of Editions.

(c) In the publication of editions of large scale maps the following principles were observed.

Editions of the outline (*i.e.*, topographical detail apart from trenches) were known by numbers, and editions of the trenches by a letter. Thus Edition 4B meant the fourth edition of the outline, and the second edition of the trenches issued with that outline edition. When a new outline edition was published, the first edition of trenches issued with it was always given the letter A.

Editions were occasionally given the name "Local" (*e.g.*, Edition 3a Local) to distinguish an edition published in France from those published in England; but as reproduction in France became more common, this practice was dropped.

The original intention was to publish new editions of all sheets of the "trench" scales of a certain area simultaneously; for example, a 1/20,000 sheet and the four 1/10,000 corresponding. It was however found impossible to do this in all cases. Attention had to be devoted in the first instance to sheets on which the front line fell, and there was often no time to revise the rear sheets. Hence it might happen that two 1/10,000 sheets on which the front line fell went through two or three outline editions, while the adjoining two 1/10,000 sheets remained unchanged. In such cases new editions of the corresponding 1/20,000 were as a rule brought out, embodying the later editions of the revised 1/10,000, and the original edition of the unrevised. When it was possible to revise the rear sheets, the whole series, 1/20,000 with its four 1/10,000 quarters, would be published with the same edition number. This accounts for the fact that in many cases, consecutive editions of certain sheets do not bear consecutive numbers, no editions bearing the missing numbers having been published in the case of those particular sheets.

Certain other points may be mentioned in connection with the nomenclature of some of the earlier editions. It was mentioned in Chap. 1, Sect. II. that the maps produced by the first survey in 1915 were not all named "Second Edition." In the case of 27a N.E. and S.E. and 36a N.E., the 1915 survey produced the first map of this area, there having been no previous enlargements of the 1/80,000. The 1915 survey sheets will in these three cases thus be found named FIRST EDITION.

Generally speaking the imprint FIRST EDITION, SECOND EDITION, etc. (the number being in words), is a sign of an early edition. Later the figure was always printed, as EDITION 3, EDITION 4.

"B SERIES" on some of the earlier editions simply means the extension westwards of the series of Belgian maps, to distinguish them from the maps of Belgium proper.

"REVISED SYSTEM OF SQUARING," which also appears on some early maps, refers to the system of squaring used on British maps throughout the war, to distinguish it from a somewhat similar grid which was in use for a very short time on the first introduction of squared maps.

SECTION IV.—DEDUCTIONS.

1. Apparatus for Reproduction.

(a) Uniformity and Standardisation.

(a) The importance of having all reproduction apparatus of uniform type is self-evident, and has been emphasised during the war by the difficulties attendant on the replacement of broken parts, and the unavoidable complication in the supply of stores. It would be of immense advantage in simplicity and economy to have all machines, all power units, and all kinds of apparatus of uniform size and type.

(b) Printing Machines.

(b) The type of machine used throughout the war was the flat-bed. This was because all machines had to be obtained at second hand from the trade, and flat-beds are the commonest type in England; and also because few of our personnel were acquainted with rotary machines, and there was considerable misapprehension as to the suitability of that type for map printing under service conditions.

Since we have had experience in using one of the American direct printing rotaries, it has been proved that machinemen and feeders can be trained to use these machines quickly and efficiently, and that there is no difficulty, after a little experience, in making the necessary adjustments and obtaining as exact register as is possible on a flat-bed.

Rotary machines have the great advantages of compactness and lightness, both of which qualities are closely connected with the question of mobility, which will be dealt with in the following sub-section.

The preparation of the plate for a direct rotary is precisely the same as for a flat-bed, and it appears evident that this type of machine, slightly modified to suit service conditions, should be adopted in the future.

(c) Cameras.

(c) The cameras supplied during the war were mainly 24 in. by 20 in., this size being adopted partly on account of its comparative lightness and mobility, and partly because lenses to cover four times this area are by no means common or easy to obtain. For future requirements provision should, however, be made for cameras large enough to cover a double demy sheet, that is, to take negatives of not less than 28 in. by 44 in. Speed is the essential part of reproduction in the Army. It is only because of the urgency for certain maps that reproduction at Army H.Q. is necessary. The secrecy observed before an attack means that maps are not arranged for until the last moment, and consequently everything should be done to avoid unnecessary steps in reproduction. Hence it should be possible to photograph the whole of the map at once.

(f) Apparatus for Rapid Reproduction.

(f) The reproduction and copying apparatus [illegible]

2. Mobility.

(a) [illegible]

a. The [illegible]

[illegible]

(b) [illegible]

b. [illegible]

(1) [illegible]

(2) [illegible]

(3) [illegible]

[illegible]

(c) [illegible]

c. [illegible]

[illegible]

3. Personnel.

[illegible]

who all had had a scientific training of one kind or other, did excellent work, but it cannot be denied that a very great improvement in methods and organisation took place in 1917 when officers with trade experience were obtained.

For the future a staff of Regulars, both officers and men, should always be maintained, with a view to forming a nucleus for a larger number of trade hands specially retained for service in emergency. However excellent the latter may be as tradesmen, it will take a long time to get them to work together as a "team," under strange conditions, unless Army traditions and customs are at once introduced. With a good leavening of Regulars they will quickly realise how vitally important their work is to the fighting troops, and will see the necessity for long hours of rushed work. The Regular printers should normally be employed with some establishment which is turning out practical work, so as to maintain and improve their skill at trade. But they should be practised annually in working in the field, so far as possible under conditions approximating to active service.

To supplement the Regulars it is very advisable that we should keep in close touch with the trade, and that men suitable for printing officers should in some way be ear-marked or retained, so that they will be available in a national emergency for their proper work, and not absorbed in the Infantry or other branches where their special qualifications are wasted. A similar plan should be adopted for tradesmen, who might possibly be enlisted and passed into the Reserve.

4. Supply of Stores.

It must be admitted that throughout the war the supply of apparatus and stores necessary for map reproduction and printing left much to be desired. The rapid growth of the work, in so many directions which could not be accurately foreseen, have, it is true, made the problem a very difficult one, but at the same time it seems that it should not be impossible to devise a system under which supplies could be obtained far more promptly and sent out in better working order than has hitherto been the case. In a theatre of war supplies, when required, are practically always required very urgently. A new need has arisen, and every day's delay in getting a system to meet that need into working order is a very serious matter.

The cardinal needs of a system of supplying printing stores from England to an overseas theatre of war appear to be as follows:—

(1) A central place in England, with a sufficient staff of officers expert in the various branches, through which all classes of stores for Survey Units would be supplied. Hitherto different classes of stores have been supplied by Ordnance Survey, the S.M.E., the Stationery Office, and direct from the contractors.

(2) A thorough liaison between the Field Survey Units and the source of supply. An officer's time would be well spent in constantly visiting the units with the object of finding out their requirements and difficulties, and in seeing that their needs were being met as promptly and exactly as possible.

(3) A rigorous inspection of all apparatus and stores before despatch. Many machines in the past have arrived incomplete, or there has been failure to supply concurrently some essential accessory to enable the process to be got into action. Survey Units in a theatre of war must be regarded in the same light as a business operating in some distant colony, and the same care should be taken to see that apparatus sent to them is in perfect working order, as would be taken by a reliable firm which wishes to keep its foreign connections.

Packing is of the highest importance, and should be most carefully inspected before despatch. No package must be too heavy for the transport of the country to which it is being sent. It should always be remembered that every package will probably have to be man-handled, so they should be made as light and compact as possible.

(4) Convoy of all important consignments by specially selected N.C.O.'s, or in specially urgent cases by officers. Much valuable time has been lost in the past by consignments being allowed to lie in ports, and cases have occurred where they have been wrongly consigned.

We have learnt a great deal in the course of the war which has just ended, but nothing is more certain than that the next war will give rise to new methods and requirements, the need for which will only be apparent in the course of the war. All our experience has been that new methods are not devised by some all-seeing central power, but that demands arise from the units which have to discover means of coping with practical situations which arise in the course of their daily work. We must, therefore, be prepared with an organisation which will be able to cater for these at present unforeseen needs.

During peace we should maintain as Mobilisation Equipment such machines, cameras and stores as will suffice for the probable immediate needs of whatever Expeditionary Force is likely to leave these shores at short notice. The outfit need not necessarily be lying idle, and might be maintained and used for current peace-time work at a Government establishment. It would at any rate be used annually for training purposes.

At the same time arrangements might be made with various lithographic and process firms who have suitable plant for their apparatus to be taken over whenever required. We should be able to put our hands immediately on exactly the apparatus we shall require to supplement the regular military equipment which we shall maintain. In making these arrangements the importance of standardisation of plant for use on active service should be remembered.

5. General.

In the preceding paragraphs various criticisms and suggestions for improvement have been made in the particular subjects dealt with. It will be well, however, to add certain general deductions and to enunciate one or two broad principles which have been made apparent during the course of the war.

It is of the utmost importance that the experience we have gained up to the present stage should not only be not lost but should be further exploited and developed under the more stable conditions of peace. For this purpose both personnel and money will be required, and a determination that when the next war starts we shall, subject to certain practical limitations, be in a position to supply the troops with all the maps they require, commencing on the very first day of the war.

The experience of this war has shown the vital importance of making ample provision for the reproduction and printing of maps for any force operating in a foreign country, even if that country is a friendly one, and even if it is already well or moderately well mapped. It has shown the impossibility of laying down a definite equipment which would be appropriate to a particular formation under all conditions and in all theatres of war.

In France, for instance, towards the end of the war the equipment which had been collected at an Army Headquarters was able to cope with requirements, backed as it was by the Ordnance Survey. But for an Army acting independently in a more distant theatre of war it would not have been enough. Similarly, in the case of a Corps, the Topographical Section was able, with the Army equipment behind it, to meet most of the Corps requirements, but could not have acted independently at all.

On the whole, smaller formations acting independently require mapping facilities which in France would have been considered out of all proportion to their numerical strength. Even for a single Division in a distant theatre it would be advisable to provide a plant to carry out all the various processes necessary to reproduce and print in colours.

In all cases it is advisable to start operations with as big an outfit as is ever likely to be required for the campaign so far as can be reasonably foreseen. It is better to risk having plant lying idle than to risk a shortage of supply to the troops in the early stage of a campaign, which is always a critical period. Similarly, with the staff of printers and others, if more men are taken than are found to be required wastage need not be made good, and the number will soon right itself.

6. Map Supply.

The various lessons derived from the experience of the war have been referred to in Section III. They may be conveniently summarised here.

(a) Numbers Carried.

(a) Troops should not be expected to carry too many maps. When on the move ten sheets of normal size may be taken as the maximum, of which four are carried on the person and six in the first-line transport of each unit. A reserve should be carried at the H.Q. of the Corps or corresponding formation. Provision should be made for the transport required for this.

(b) Troops on Move.

(b) Troops moving from one area to another should, as a rule, receive the maps they require from the responsible survey unit at their destination. At the point of departure they should be given only such maps as they require for the move.

(c) Transport.

(c) The secret of map supply in the field is transport, which must be ample in quantity and suitable in type. For work near the front probably the lightest type of van is most suitable, supplemented by heavier box-cars further to the rear, and, again, by lorries further back still for deliveries in bulk. Decentralisation of supply from Army to Corps will probably facilitate supply, provided that the staff and adequate transport are available.

(d) Responsibility for Supply.

(d) The remarks made in Chapter I., Section IV., on the subject of responsibility for map preparation apply also to map supply. This should, it is considered, always conform to the military command, in spite of the fact that supply by area would offer undoubted advantages during periods of stationary warfare.

PART II.

ARTILLERY SURVEY.

INTRODUCTION.

The term Artillery Survey is used to include survey work, and work which grew out of the survey organisations, in its special application to the needs of the Artillery. Such work was done during the war by the Field Survey Battalions, but in future it will no doubt be done by the Artillery themselves, when they have had the necessary training.

Artillery Survey includes all work relating to our own batteries, such as fixing position, giving line, making and providing artillery boards and observing for ranging; and all work relating to the fixing of enemy batteries, such as cross observation, sound ranging, and examination of air photos and knowledge of map values in this connection. All the above methods include survey practise and a knowledge of survey as a necessary part of the procedure. Artillery Survey is not in this report held to include screen calibration, as the only connection that this method had with the survey organisation was that it required the Bull recording apparatus (used in sound ranging), and that for this reason, and questions of technical personnel, screen calibration was developed and carried on during the war by the Survey Battalions. Screen calibration is, however, no part of survey, and is therefore dealt with in an appendix.

CHAPTER 1.

SURVEY OF OUR OWN BATTERIES.

SECTION I.—BATTERY SURVEY.

1. Early History.

In February, 1915, a 15 in. howitzer came to take up position in the 8th Divisional area. The arc of fire was to include both Fromelles and Aubers, and the Ranging Section, R.E., was asked to lay out the platform and centre line. In the subsequent report ranges and bearings to all prominent points in German area were given.

Two 9.2 howitzer batteries which arrived shortly afterwards were dealt with similarly, and the practice became popular so quickly that by the end of February most heavy and siege batteries were fixed, and the Battery Commanders had been supplied with information concerning all fixed points. Aiming points were always included in the survey.

Working from a headquarters in La Gorgue, two or three trig. observers were able, at this time, to deal with all heavy and siege batteries on the front.

The issue of this information marked an immediate advance in map shooting, for it showed up areas which were particularly in error on the map, and allowed of a rapid estimation of good line.

Before the Battle of Neuve Chapelle (March, 1915) a quantity of siege and heavy batteries were concentrated for the preliminary preparation. For all of these batteries positions were fixed and line given to aiming points. In the case of batteries which came in at the last moment, the field in which they were to take up position was surveyed and bearings were given from a central point in the field. This work led to the provision of Artillery Boards, which are described in the next section.

2. Extension of Work.

The fixing of battery positions now engaged increasing attention. The preparations for the Battle of Loos (25th Sept., 1915), were carried out by the Ranging and Survey Section, the First Army Topographical Section having been formed only a short time previously. From Laventie to Lorette all heavy and siege batteries were fixed and provided with artillery boards, whilst the field guns and light howitzers were fixed graphically and given tracings (to put over the map) showing all fixed points.

In 1916 the Battle of the Somme put the same severe test on battery survey as it had done on the map supply. Transport again became the ruling factor. It was impossible to continue work from Company Headquarters, and plane-tablers or trig. observers were therefore attached to the H.Q. of Corps Heavy Artillery. Moreover, as every conspicuous trig. point was destroyed the difficulties of survey were enormously increased.

3. Bearing Pickets.

During 1915 an enormous number of points were fixed in connection with battery survey. Reserve and alternative positions, aiming points, etc., were continually being surveyed.

To prevent duplication of work in the Somme neighbourhood it became obvious that permanent marks of iron must be used. Hence in the autumn of 1916 the 3rd Field Survey Company used these pickets everywhere, and lists referring to the numbers which were marked on the tabs tied to each picket were distributed to the artillery. In several cases such pickets were expressly inserted for the convenience, in finding line, of the battery commander concerned.

This was the origin of the present day "bearing picket," though their general use did not follow for some time.

A bearing picket is a permanently marked point from which bearings to several conspicuous points have been accurately determined. These pickets are numbered, and in some cases have the bearings written on the attached tab; but in any case the bearings are published in lists supplied to the Artillery. The object of the bearing picket is to enable the Battery Commander to get accurate line wherever he is. It is unnecessary for him to have his position fixed exactly, as was done whenever possible in the early days of battery survey. He can fix it, approximately, from map detail, and can then, by setting up a director over the bearing picket, give parallel line in any desired direction to all the guns of the battery. This can be done directly if the battery is visible from the picket, or, if it is not, by means of an intermediate station.

The value of a bearing picket is particularly in evidence when the position of the battery is not previously known (as in a hasty concentration) and in the case of a railway gun.

4. Survey of Forward Positions.

A new departure before the battle of Arras was the survey of forward positions, in or close to our own trenches. The regular progression of the barrage is, obviously, a most vital matter, and the survey of forward positions, together with same provision for finding line, is a natural corollary. The advanced positions for the 9th Divisional Artillery were so surveyed, and this previous preparation proved its value in the gain of speed and accuracy.

The same general procedure was followed at the battle of Messines.

5. Battle of Cambrai and Surprise Attacks.

The battle of Cambrai (20th Nov., 1917) began a new era. The tendency to rely for success on a complete artillery surprise was, of course, natural and inevitable. A complete surprise means, however, map shooting and no previous registration. This in turn implies the most careful preparation for line and to a slightly less extent for position. The survey preparations for this battle were, therefore, most thorough, and included the insertion of a bearing picket sufficiently close to each battery to allow of easy reference. Every battery, heavy or siege, which took part was visited by an officer of the Field Survey Battalion.

From this time onwards bearing pickets became a recognised feature of the preparation for attacks, and lists of them and of bearings from them were distributed to all gunners concerned. Short courses were held at each Field Survey Battalion to explain their use.

The Canadian and Australian attack in front of Amiens in 1918 owed a large measure of its success to the complete artillery surprise, and an examination of the German battery positions after the attack showed how successful and accurate the shooting had been. A considerable part was played by screen calibration, but much is due to the proper use of survey methods in obtaining line.

Before the attack the position of many of our own batteries was taken from air photographs. Line was found, however, invariably by some direct survey method. Sun azimuths were observed in cases where more simple methods were impossible.

6. Preparations for Defensive.

At the beginning of 1918 we were definitely on the defensive. Naturally the survey preparations for a defensive battle are more extensive than those for an attack. The number of alternative and reserve positions is much larger and a considerable area in depth has to be allowed for. Trig. points and bearing pickets were fixed and marked throughout the zones in which fighting was anticipated.

7. Battery Survey during Operations.

It is during the course of operations that the real difficulties of battery survey begin.

The necessity for pushing forward the trig. skeleton, the congestion on the roads and the heavy reaction from the enemy's artillery are all contributory causes, whilst perhaps the greatest trouble of all is the difficulty of getting information as to the movements of batteries. The battle of Passchendaele introduced extraordinary difficulties in all these directions.

During the German offensive in 1918 little could be done to help batteries. The difficulty of finding them and the frequent change of position made any attempt almost hopeless, but it is also doubtful if survey can help at all in these circumstances. There is little counter battery work and targets are mostly under direct observation.

During the preliminary battles of the counter-offensive the bearing picket resumed its importance. When the advance began survey was carried on until the last stages. Naturally, however, as conditions became more and more mobile, transport difficulties intervened and the necessity for survey diminished. Positions were fixed up to the last, but bearing pickets and artillery boards were not always available.

In one Army a return was made to the practice of earlier days in issuing boards with a skeleton grid and the trig. points plotted on it. The Battery Commander himself inserted his position on his board, and used a protractor in place of a paper arc.

8. Technical Methods.

It is not proposed in this account to enter in detail into the technical methods employed in fixing positions and giving line, as they may be studied in the pamphlets and handbooks on the subject, which will be found enumerated below. It will be sufficient to indicate the methods used and to point out their practical value.

(a) Position.

(a) Battery positions were nearly always fixed by resection (sometimes called interpolation) from trigonometrical points. The resection, in the case of heavy artillery, was usually instrumental (that is, obtained by measuring a round of angles with a theodolite or director), and graphic (that is, by the plane-table) for field artillery. The observations for instrumental resection were usually sent to the F.S.B. Hd.Qrs. for computation, but were occasionally computed at once in the field.

As resection must be done from a position from which trig. points are visible, and battery positions are usually concealed, the process of battery fixing generally combined two operations, namely, resection of a point and running a short traverse with instrument and tape to the battery position.

When resection was impossible owing to lack of time, personnel or trig. points, batteries were occasionally fixed solely from map detail. To have any useful result this procedure requires skill in map reading, some survey experience, and a knowledge of the value of the map detail in that neighbourhood.

(b) Line.

(b) Later, when more attention was paid to giving accurate line than to the fixing of actual position, battery fixing became less common, giving place to the fixing of bearing pickets, which was, of course, always done instrumentally. The position of a bearing picket being known, it is easy, if there is a surveyor in the battery, to measure a direction and distance or to run a traverse, and thus get the position of the battery exactly, if it is desired to do so.

(c) Astronomical Methods.

(c) In certain circumstances, as, for example, when the gun was concealed in a house or enclosed courtyard, methods had to be employed for determining line which were independent of trigonometrical or map detail. In these cases line could be obtained by the observation of heavenly bodies, or by the compass. In the former method the simplest way was to observe a heavenly body (sun, moon or star) at a certain instant, while at the same instant its bearing was measured from a survey post or other fixed point. This implied telephonic communication between survey post and battery, which could usually be arranged, or it could be done by careful synchronisation of watches, and taking the mean of several observations at pre-arranged times. This method was employed with the telephone on several occasions, but not by watch-time, so far as is known. Another way was to observe an azimuth by the usual methods. This required more time and previous knowledge. It was employed on more than one occasion.

In this connection it may be mentioned that the Groupe de Canevas de Tir of one French Army published a list of the bearings of the sun and certain bright stars at certain times within a short interval of their rising and setting. This practice appears to offer possibilities, and might be developed.

(d) Compass.

(d) Obtaining accurate line by the compass when better methods are impossible is quite feasible, given proper precautions, and instructions were issued to enable this to be done. The points on which emphasis was laid were the accurate determination of the error of the compass, the avoidance of disturbing influences (such as masses of iron), and the multiplication of measurements in order to obtain a reliable mean.

It was found during the war that very little knowledge existed among the Artillery about accurate methods of obtaining position and direction, and that there was widespread ignorance on the subject of the uses and limitations of the compass, combined with, in many cases, a blind belief in its efficacy in all circumstances. Hence it became particularly important to spread education on these subjects.

In this connection Appendix V., on Magnetic Bearings, may be studied.

(e) Technical Publications.

(e) Notes dealing with the problems involved were published at various dates by most of the Field Survey Battalions and elsewhere. Of these the following are the most comprehensive :—

Notes on Survey methods of setting out line for Batteries (*3rd F.S.B., June,* 1918).
Survey Aids to Gunnery (*General Staff, January,* 1919).

A pamphlet intended to supersede other publications and to establish uniformity of practice was prepared with considerable care in 1918 by Maps, G.H.Q., in conjunction with the Artillery, but so far as is known it has never been published.

Useful notes on the problem of resection are :—

Notes on Trigonometrical Interpolation (3rd *F.S.B., August,* 1917).
The Resection Problem (*General Staff, I.* (*c*), *G.H.Q.*).

9. Personnel and Transport.

The personnel available for survey in a F.S.B. was, by establishment, one or two officers (one of the subalterns could be, and was usually, employed on this work), ten topographers, two computers, six observers and assistants (all at H.Q.), and three topographers with each Corps Topo. Section. These numbers, in the case of H.Q., were as a rule exceeded in practice.

The whole of the above personnel was not available for battery survey, as there was always some map revision and other survey work to be done; but during preparations for operations it was generally necessary to concentrate every one on artillery work, unless other work was of sufficient urgency to prevent this.

In addition to field hands, draughtsmen were required to prepare artillery boards. As a rule half a dozen men were employed on this work. In early days one or two carpenters were also employed in various Companies on board construction.

One of the chief difficulties was lack of transport. It is obvious that one box-car (probably all that was available) could not transport all the field hands to all parts of the front. The difficulty was met to some extent by attaching the surveyors to the H.Q. of the Corps Heavy Artillery. The carriage of artillery boards to and fro made additional demands on transport.

Theoretically the H.Q. personnel attended to Heavy Artillery and the Corps Topo. Sections to Field Artillery. The decentralisation of survey of Field Batteries to Corps Topo. Sections, though theoretically sound, failed owing to lack of supervision, of sufficiently trained staff, and of transport, and resulted as a consequence in almost completely stopping the application of survey principles to the work of Field Artillery. The O.C. Corps Topo. Section had so much office work to do that the proper supervision of his plane-tablers was impossible.

It will be readily seen what advantages would result if the Artillery were completely independent in these matters, if every battery had personnel able to take all necessary observations and to prepare boards, and every brigade at least one officer thoroughly competent to check and supervise all Artillery Survey work. All the harrassing lack of personnel and transport would be saved, and battery survey would be decentralised on sound and efficient lines.

SECTION II.—ARTILLERY BOARDS.

1. First Supplies.

The accurate fixing of battery positions and other features led to a demand for the provision of this information in graphic form. Some of our batteries at the extreme south of our front came into contact in 1915 with the Groupe de Canevas de Tir of the 10th French Army, and were provided by them with "planchettes," or map boards. These were very handy for practical use, and gave rise to a demand for similar provision for ourselves. At about the same date the "Second Edition" maps, the result of the first 1915 survey, appeared, and in all those cases where the arc of fire fell on Fortress Plan Directeur material (at that time the only good map existing of forward areas in France) the combined effect of a good map and well-fixed position and line became at once apparent. The Topographical Sections therefore undertook the preparation and supply of artillery boards for our batteries. The first issues were made in the Third Army in August, 1915. These boards were originally supplied to Heavy Artillery only, but at a later date the issue was extended to Field Artillery. The first 1/10,000 scale boards were supplied to Field Artillery in the Third Army in October, 1915.

2. Necessity for Special Form.

Artillery boards are provided for three reasons :—

(1) The necessity for having the requisite information in graphic form.
(2) Convenience in using the map.
(3) Avoidance of inaccuracies resulting from the use of an unmounted or badly mounted map.

The requirements under (1) and (2) could be met by maps mounted in any fashion and on any kind of board; but those under (3) can only be provided for by specially constructed boards, and special methods.

Paper varies by at least one per cent. in linear dimensions with changes in the amount of moisture in the atmosphere, and the change is usually different in different directions, or even in the same direction in different parts of the sheet. Hence the scale values are changed, and angles are distorted. Such changes are greatly magnified when a map is wetted, as during the operation of pasting, and the consequent distortions are rendered permanent by sticking the map on a board. Wood also alters in dimensions with changes in humidity.

To meet all the requirements of an artillery board we must therefore have a board of special material or construction, with the map mounted on it in a special way.

3. Definition of Artillery Board.

An Artillery Board may thus be defined as a board of such construction and on which a map is mounted in such a way, that distances and angles are represented accurately, and remain so in spite of changes in atmospheric conditions; and which is provided with all the information required by the Battery Commander (such as position of guns, aiming point, etc.), and with convenient means for measuring distances and bearings accurately.

4. Early Forms.

The first artillery boards supplied to our Army were wooden boards, on which a sheet of zinc was nailed. On this zinc a sheet of stout drawing paper was pasted; and on this paper the map grid was drawn, and the positions of gun or guns, aiming point, and various conspicuous points plotted, and a "zero" line was drawn from the directing gun. On the earliest boards this was all the information given, but before long an arc was drawn, of radius greater than the range of the targets, and divided to read to 10 minutes. To save the labour of drawing, arcs were very soon printed and supplied in quantity, so that they could be cut out and pasted in position on the board.

The earliest boards were thus simple skeletons, showing hardly anything but the grid and a few plotted points. They were often prepared for a special operation, and the positions of certain cross roads, trench features, or other targets for which the battery in question was specially detailed, were fixed by observation and drawn on the board. The idea was that, following the example of the French, the Battery Commander could either fire on the square position which he could obtain from the map; or he could trace the detail from the map and transfer it to the board, locating its position either with reference to the trig. points or the map grid. A demand soon grew however for the provision of more general detail on the artillery board.

It will be remembered that at this date the maps of the forward area were mostly in a very imperfect state. They could not therefore be used for the preparation of artillery boards without giving some indication of the nature and extent of the errors they contained. Various methods were tried to provide the Artillery with the fuller detail which they required. In some cases the detail was laboriously drawn by hand. In others, portions of the map were pasted on to the board in the target area, based on such trig. points as were accurately shown. The true positions of inaccurate points and prominent features were then plotted correctly on the map, and the difference between the true and false positions indicated the map error in that locality, and ranges and bearings to topographical features had to be corrected accordingly. In other cases again the trig. points were cut out of the map, leaving small holes through which the correct positions of the points, plotted on the board, could be seen. The map was then pasted on in pieces, the detail being adjusted to the position of the nearest trig. point.

5. Later Forms.

As the map improved in accuracy it was increasingly used for the construction of artillery boards, and at the same time the boards themselves were altered somewhat in form. Zinc became difficult to obtain, the number of boards required increased enormously, and it was found that good 3-ply wood gave equally satisfactory results, except for the largest boards. The latest form of artillery board supplied by the Ordnance Survey was therefore usually constructed of thin 3-ply wood, about quarter inch thick, mounted on a braced framework of deal of about ½ x 1½ inch section. These boards were very satisfactory and had the advantage of lightness.

At a later date, 3-ply wood becoming difficult to obtain, experiments were made with boards of plain half-inch deal, stoutly braced with battens about ¾-inch thick, let into the board across the grain, and screwed to it. These boards barely came within the limits of rigidity required for artillery boards.

On the wooden boards drawing paper was pasted, and on this the map grid was drawn. The map was then cut into small sections, usually about 2,000 yards square, and pasted carefully into position on the grid. The expansion of the paper due to the wetting with paste caused a slight overlap sometimes, but this could be avoided by slightly paring the edges.

Circles were struck at the proper radius for the various arcs required, and the paper arcs, which were printed in different colours to distinguish them, were pasted to these. To avoid errors due to expansion it was found necessary to cut these arcs into small portions and paste each in position. As a control the chord for a certain angle was calculated, and the length printed on the paper arcs. The arc when pasted was made to fit to this length.

Finally the grid bearings from the gun position, or from the nearest bearing picket, to various points, were written in a convenient position on the board, together with the trig. co-ordinates of important points, and any other information that might be useful in obtaining range and bearing.. When the position was known and the board prepared beforehand, small sketches of the aiming points were often made and put on the board. This enabled the gunners, on arriving at the new position, to pick up their points easily.

Boards were also supplied when possible for forward observing officers. These were however of much simpler form and usually consisted of a small board bearing the portion of the map covering the target, and with the position of the O.P. plotted. A hole was made in the board, to hang it up in the O.P.; and sometimes the board was cut somewhat in the shape of a grid-iron or square frying pan, the hole being at the end of the handle, and representing the gun position.

6. Size and Scales.

The great majority of artillery boards issued by the Field Survey Battalions were intended for the 1/20,000 scale, and the usual size was 28 in. by 23 in., which allowed of ranges up to about 14,000 yards, with an arc of fire extending over about 50 degrees.

For the Field Artillery boards were issued in most cases, but not universally, with detail on the 1/10,000 scale.

Special provision had to be made for long range guns. At first, boards of 1/40,000 scale were provided, but as the 1/40,000 map was not up to date, they were made up with bromide reductions of the 1/20,000 sheets. When large boards (30 ins. by 36 ins.) became available, the 1/20,000 scale was used and boards of this pattern were provided for the 6-in. and short 9.2-in. guns. For the 12-in. and long 9.2-in. guns, 1/40,000 scale boards were made, but in the case of these very long range guns the Artillery were encouraged to work by calculating range and bearing rather than to use graphic methods.

7. Official Pattern.

It was suggested in 1916 that artillery boards should be made an official Ordnance supply, so that every battery should automatically possess at least one board among its battery stores. A design was got out for these boards by Maps G.H.Q. in conjunction with the M.G.R.A. This design followed closely the pattern of a German artillery board that had been captured, the chief feature of which was the provision of a metal pivotted scale and a metal arc, both of which could be fixed to the board to suit any gun position.

The British boards were made in two patterns.

(1) Heavy Artillery—Rectangular, 24 ins. by 30 ins.

(2) Field Artillery—Sector shaped, 15½ in. radius and allowing of an arc of fire of 120°.

Each was designed for the use of the 1/20,000 scale, and, except for the difference in shape, they were similar in construction and fittings. The latter were carried in pockets in the back of the board, and consisted of a scale, divided in yards, a pivot, containing a central hole through which the gun position could be seen; and an arc reading to half degrees. These fittings were of white metal, and the pivot and arc could be fixed in any position on the board by drawing pins, a supply of which were carried in a pocket.

The following criticism may be made on the official pattern boards. They were unnecessarily stout and heavy, the three-ply wood being ⅝ in., that is about twice as thick as that used on the F.S.B. boards. The surface wood was too hard to receive drawing pins conveniently. The arc should read to at least ten minutes, and should cover a wider angle; this could be managed by making it of shorter radius, or by having a second shorter radius arc for use when required. The Field Artillery board might well be larger, and it is questionable whether the sector shape is an advantage; it certainly makes it harder to draw a grid. Finally, it might be possible to devise some means (such as a light wooden cover) of protecting the surface, which at present is liable to get dented and damaged.

The supply of these boards came along slowly, and to the end of hostilities the F.S. Battalions continued to supply large quantities of boards made by the Ordnance Survey.

8. Construction of Boards.

The method of mounting the map on the boards has already been explained. Certain matters in connection with the construction of the original boards may be referred to as having interest and a possible bearing on future design.

Difficulties were experienced with the early boards on which the zinc sheet was nailed to the wooden base, as the movement of the wood with changes of humidity caused buckling. It was found necessary to allow for expansion and contraction, and this was arranged in various ways. One method was to cut slots in the metal sheet through which the screws which fastened it to the board were passed, and which thus permitted free movement of the sheet. Another was to fasten the sheet by one nail only, in the middle, and to paste linen on to the sheet, turning the edges under the board and fastening them there with small nails.

On the later Ordnance Survey zinc-covered boards the sheet was fixed by tacking the linen under the board and without any other kind of fastening; and this was the simplest and most satisfactory method of all.

Some trouble was experienced with the later three-ply boards owing to buckling. This, however, it is thought, was due to the fact that as time passed it was almost impossible to get any properly seasoned wood. Both the three-ply wood and the framed backing were probably green. It has been mentioned that the official pattern of board was made unnecessarily heavy. It is possible, however, that the thickness of the three-ply wood used on the F.S.B. boards might have been slightly increased with advantage; and it seems probable that if future boards were made of somewhat stouter stuff, both board and frame being thoroughly seasoned, they would be satisfactory in every way without losing the great advantage of lightness.

An excellent feature of the boards made by the Ordnance Survey was the attached American cloth cover, and the handle for carrying.

9. Preparation of Grid.

An important point in connection with the preparation of the board for use is that of the drawing of the preliminary grid, which serves as the framework to which the map is fitted when pasted down in sections. During the war this grid had to be drawn on every board, entailing a large amount of extra labour which it should be possible to save in the future.

It is of interest to note here the practical bearing of the grid used on British maps on the question of battery survey during operations. Owing to the fact that our grid was based on the *sheet* and not on the *area of operations*, combined with the fact that it did not fit the sheet, the grid was not continuous, and there was an interruption, or "overlap" at the junction of two 1/40,000 sheets. Hence it was impossible to issue a board for universal use, such as would have been extremely useful at any time, and invaluable during a period of rapid movement; because no one could say where a battery would be situated with reference to the edge of a 1/40,00 sheet. As an attempt to meet the difficulty, boards were issued with the grid overlap plotted at one third of the width of the board, and on these the positions of most batteries could be plotted with a fair amount of convenience; but the method is evidently a makeshift. The point is of considerable importance as showing the far reaching practical effect of a question which was at the outset thought to be a matter of theoretical interest only.

With a continuous grid, such as the French used throughout the war, and we adopted at the end, and such as it is hoped will always be used in future, there is no reason why boards should not be issued with the grid already printed or engraved on them.

10. Numbers Supplied.

The number of artillery boards required for use varied considerably according to circumstances. In the first place, every battery required at least one board for use, and, if possible, an additional one at the O.P.; and if it was split up this number had to be doubled or trebled. Then there was the question of second or alternative positions, which might be either reserve or advanced, according to the nature of the operations. In either case it was often necessary to have at least one other board ready prepared.

On the whole, it would seem from the experience gained in the war that the normal equipment of any battery should be at least four boards, and that something like a 25 per cent. reserve should be held at the nearest Artillery Headquarters.

The actual number of boards supplied during the war by the Ordnance Survey was 11,379. Figures for those made locally are not available, but as a rough estimate we may take it that a quarter of the above number were produced in addition in France, making a total of about 14,000 boards of various sizes supplied to the Artillery.

Of the boards supplied by the Ordnance Survey, 6,399, or 56 per cent., were 28 ins. by 32 ins., and 3,201, or 28 per cent., were 30 ins. by 25 ins.

CHAPTER 2.

CROSS OBSERVATION.

SECTION I.—DEVELOPMENT OF UNITS.

1. Early History.

Before the end of 1914 the question of battery fixing, or "Flash Spotting," as it is commonly called, had come into prominence, and various organisations were formed independently in order to deal with it. Probably every Corps devised some means of trying to fix enemy batteries, with varying degrees of success. One of the earliest and best organised of these units was the Flash Spotting Section of the II. Corps Artillery, which was established on the front from Hill 63 to the southern outskirts of Armentières, under the command of Lt.-Col. Pottinger. It was equipped with alidades mounted on sectors, but "Instruments, Observation of Fire," were introduced in December, 1915. This Section worked as an artillery unit during 1915 and until observation was taken over by the Survey organisation. In November, 1915, the Second Army decided, however, in consequence of the frequent moves of Corps, to organise flash spotting on Army instead of on Corps lines.

In the Third Army the first organised unit for battery fixing was the Artillery Survey Detachment, which was formed in October, 1915. This was an R.A. unit, though it included among the rank and file certain trained scouts who were not R.A. The officers were R.A. subalterns. This unit was placed for administration and tactics under the R.A., and for training and technical methods under the O.C. Third Army Topographical Section. Before long, however, this dual control was abolished and the Detachment put entirely under the O.C. Topographical Section. It consisted of seven observation posts spaced along the Army front, each manned by one officer, six observers and telephonists, and one cook, the H.Q. and collecting centre being at the Topographical Section. It was equipped with directors and observation of fire instruments.

It was soon found that a single section dealing with the whole front was too cumbersome, and in April, 1916, it was split up into Groups of three or four posts, each Group being under an officer.

Shortly after the formation of the Third Army Artillery Survey Detachment, and following on a conference held by the B.G.I., the First Army formed a Flash Spotting Section. In this case the personnel were selected from officers and men who had experience of survey and the use of instruments in peace time, but who included at first no gunners. The instruments used were theodolites reading to 10 seconds. The section worked in groups of two Observation Posts each, and for some time there was no proper co-operation between the groups. It was placed under the control, technical and otherwise, of the O.C. First Army Topographical Section, but it should be stated that the equipment and organisation had been decided before he took charge.

There is no doubt that the First Army Flash Spotting Section was formed on unsound lines. The decision of the Army that no R.A. were to be employed (though rescinded in January, 1916) resulted in a loss of touch with the Artillery and a want of confidence in the unit, which it took a long time to remove. The instruments were quite unsuitable, being too fragile for rough work, and of a wholly unnecessary degree of accuracy for the purpose in view. The employment of groups of two posts was radically unsound, and enough insistence was not made on the necessity for co-operation, which is so essential to success. Lastly, posts were ordered to report individual flashes to the R.A., thereby destroying all chance of obtaining a location.

In spite, therefore, of the fact that at the close of the war the First Army battery fixing was among the best we had, it took a year and a half for flash spotting to live down its early mistakes in this Army.

2. Observation Groups.

In the meantime the question of observation along the whole front, with a view to the fixing of position of targets, and especially of batteries, was being considered at G.H.Q., and it was decided that in the interests of uniformity of method and control this work should be definitely incorporated in the Survey organisation. Consequently, on the formation of the Field Survey Companies in February, 1916, an "Observation Section" was included in the establishment (No. 239, d/11/3/16). The idea originally was that, though the Observation Section was divided into Groups, the controlling and co-ordinating centre for *observations* was to be at the F.S.C. H.Q.

The Observation Group, however, speedily developed into a highly specialised and organised body, and all co-ordination of observation and location within the Group was done there, though the F.S.C. or F.S.B. H.Q. remained throughout the controlling and co-ordinating centre for *results*. In the First Army the complete centralisation of work at the F.S.C. H.Q. continued for much longer than in the other Armies, mainly owing to the fact that there was direct telephonic communication between the Company H.Q. and all the posts.

In this earliest establishment of the Observation Group, consisting of a H.Q. and a number of Survey Posts, it will be seen that no provision was made for any office work at the Group H.Q. The Group H.Q. consisted of one officer and two o.r. (batman and driver), with a sidecar combination or light car; while a Squad (for a Survey Post) consisted of eight o.r., including one driver for a two-wheeled cart.

This continued until Dec., 1916, when a new establishment allowed for a Group H.Q. 2 officers and 14 o.r. (including 2 batmen and 2 drivers), with a light car, a motor cycle, and a 2-wheeled cart, while the Survey Post Squad was increased by 4 o.r. to a total of 12. At the same time each F.S.C. was allowed to maintain one squad in excess of the actual requirements for manning their posts.

When the Field Survey Battalions were authorised in 1918, the Group H.Q. establishment was increased by 1 officer (making 1 Captain and 2 Subalterns), but no other change was made, not because it was not desired, but owing to lack of personnel.

3. Method of Forming Groups.

The responsibility for the formation of Observation Groups, for the number required to cover the front, and the number of posts required in each group, was left entirely to Armies. The total number of groups formed was 29. Of these two (Nos. 25 and 29) were sent to Italy, one (No. 26) to Salonika, and one (No. 28) to Egypt; while one (No. 22) was employed as a Screen Calibration Section. The maximum number employed on the Western Front was therefore 24, which was just enough to cover the front without any reserve.

At first each F.S. Company named or numbered its own Groups, but this caused confusion owing to the frequent changes of units from one Army to another, and in 1917, by order of G.H.Q., all Observation Groups were allotted numbers which they retained permanently thereafter.

4. School for Observers.

Instruction of personnel for employment in Observation Groups was carried out in various ways by all F.S. Companies from the time they took over responsibility for this work. Both the 2nd and 4th F.S.C. arranged small instructional courses; but the most complete school was that started in the 3rd F.S.C. in March, 1916, and which worked at Beaumetz (and for a few months at Dainville) until it was taken over by G.H.Q. in 1917. This school was organised on highly efficient lines, mainly by Major W. Newbold, R.G.A., and its equipment and accommodation were so good that arrangements were made to send observers to it from other Armies for courses of instruction.

On the formation of the Depot F.S. Company in April, 1917, the 3rd F.S.C. school was transferred to G.H.Q. and absorbed by that unit. The establishment then authorised was 1 officer (Captain) and 10 o.r., of whom 7 were instructors or administrative staff.

When the Depot F.S. Battalion was authorised in 1918, the establishment of the School for Observers was increased to 3 officers (Major and 2 Subalterns) and 23 o.r., of whom 15 were instructors and 5 administrative, etc.

5. Final Establishment.

During the later stages of the war it was found that, to make an Observation Group thoroughly efficient, an increase in the H.Q. strength was necessary, and an increase and change in the transport. This was not possible during hostilities; but when the advance into Germany took place, advantage was taken of the fact that a number of Groups would be left behind and would be unlikely to be required for service again, to increase the W.E. of those going forward. The "Higher Establishment" then approved represents very nearly what the experience of the war showed to be necessary for a completely efficient Group, capable of action in both stationary and mobile warfare. It was not exactly what theory demands, because it was still necessary to limit the establishment to numbers and material actually existing, so that the transport is not what would have been included had there been complete freedom of choice, and the personnel requires some addition, chiefly in linemen.

Apart from numbers, the difficulty of dealing with a unit whose strength was indeterminate had long been felt. An Observation Group consists of a H.Q. and a number of posts. This number must be at least three; it was usually four, but it was occasionally convenient and economical to include a fifth post, and so bring in a wider range of country with no increase in the H.Q. staff. But there were administrative difficulties in dealing with units whose strength was variable, and the A.G. branch objected to an establishment which they were powerless to check. Hence it was decided to give the Observation Group a fixed establishment sufficient for a H.Q. and four posts, leaving it to internal arrangements to provide for a fifth post if it was found necessary.

The higher establishment approved in W.O. letter 121/France/3507 (S.D.2), d/15/3/19, was 3 officers and 79 other ranks. Deducting 12 for drivers, batmen and cook, this left a C.Q.M.S. and 66 tradesmen, made up of 53 survey post observers, 12 linemen, and 1 carpenter. The transport, etc., was 1 30-cwt. lorry, 1 light car, 1 motor cycle, 5 2-wheeled carts, 2 riding horses and 6 bicycles.

The above strength was intended to provide four posts of the usual establishment, namely 11 s.p. observers and 1 driver, with a 2-wheeled cart.

The only changes which it is desirable to make in this establishment are to add 5 linemen (making 4 per post and 1 at H.Q.) and to substitute a 3-ton lorry for the 30-cwt. (to carry cable); a 15-cwt. box-car for the light car; and a G.S. wagon (for H.Q. stores) for one of the 2-wheeled carts.

The establishment would then be :—

Personnel.—3 officers, 84 other ranks.

Transport, etc.—1 3-ton lorry, 1 15-cwt. box-car, 1 motor cycle, 1 G.S. wagon, 4 2-wheeled carts, 2 riding horses, 6 bicycles.

If Groups were provided with C.W. wireless sets, 2-wheeled carts would have to be replaced by 2-horse limbered wagons.

SECTION II.—TECHNICAL.

1. Functions of the Observation Group.

An Observation Group is a unit organised and trained for the purpose of fixing objects by cross observation, or, in other words, by the intersection of visual rays, and especially of fixing the positions of guns or shell bursts by observation of their smoke or flashes. The duties of Observation Groups, as laid down on their formation, included watching all ground to their front, and fixing and reporting the position of any target or unusual occurrence, but by far their most difficult and important duty was that of fixing guns, or "flash spotting," with its corollary, observing shell-bursts for ranging.

The duty of an Observation Group may thus be briefly defined as to provide accurate three or four-line observation for both location of targets and observation of fire.

With that in mind, we will trace the development of the methods employed to attain these ends.

2. Early Methods.

The problem of flash spotting may be said to consist in training observers to observe flashes, and directing them on to the same flash. When, as was usual in France, the number of flashes is great, and enemy guns are close together, or in positions extremely difficult to observe (such as behind hills or in woods or buildings), it is evident that for flash spotting to have any real practical valu it must be carried out by a highly organised unit employing the most accurate methods.

It was for this reason that the earlier attempts at flash spotting either failed altogether or did not produce the best results possible. An axiom in the fixing of positions by intersection is that the positions of the observation posts must be accurately known, and that the direction of the observation rays must be as accurate as the nature of the observation will permit. The early observation posts were usually fixed from map detail alone, and in those days the map was not accurate, while rays were often magnetic or referred to magnetic north. It is not difficult to understand that observations made in this way, even to stationary and easily observed objects, would produce doubtful and inaccurate results; and when the great difficulty is added of observing a large number of obscure flashes, it is not surprising that, although a great many intersections of rays were obtained, many of these were false intersections, and the results bore little relation to the true positions of the enemy guns, and that counter-battery work in the early days was consequently ineffective.

When observation was taken over by the Survey Units the positions of all observation posts were naturally fixed exactly, and the measurement of bearings was done by accurate methods, so that errors due to uncertainty in these respects were eliminated. The problem of flash spotting was not, however, solved thereby, for there remained the difficulty of ensuring that observations were being made to the same flash. This problem resolves itself into one of synchronisation; that is, either of directing observers on to a flash which appears at a given moment, or of picking out those observations which are made at the same moment, and so ensuring that they are on the same flash.

The first method adopted was to time all observations. This entailed the laborious comparison of watches at intervals during the day and the booking of every observation to the nearest second, and it also meant subsequent comparison of all these timed observations, with a view to selecting those which referred to the same flash. A very useful check could be obtained by timing the interval from flash to report, and this was usually done.

Attention was soon directed to providing some means of recording the times of observations automatically, or of transmitting a convenient signal to Group H.Q. at the moment of observation. Forms of chronograph were considered, but nothing satisfactory was produced. A "drop-shutter" exchange was tried at the H.Q. as a means of signalling and ensuring coincidence of observation from the posts, but it proved too slow in action, and, moreover, gave trouble, due to short-circuiting. Finally the "Flash and Buzzer Board" was designed by Lt. Hemming, and provided a satisfactory instrument for synchronisation, which was used till the end of the war.

3. Flash and Buzzer Board.

The idea of an exchange showing lights by which observations could be synchronised originated with the French, who were experimenting with such a board in February, 1916. Lt. (now Major) Hemming took this idea, modified and improved the design of the exchange, and introduced the important feature of buzzers. Lt. Hemming's design was produced in May, 1916, and the first flash and buzzer boards were supplied in November of that year.

The flash and buzzer board is a telephone exchange for communication between the Group H.Q. and the Survey Posts, and provided with certain arrangements for assisting synchronisation of observations. The first pattern was a 4-line ringing exchange, but the later pattern was a 6-line exchange working by buzzer. By means of this exchange the Group H.Q. can speak to any post singly or to all at once. The face of the board is provided with four (or six) small lights, in connection with each of the Survey Post lines, and so arranged that the survey post observer can, by pressing a key at the post, cause his light to glow. A buzz can be made to sound simultaneously with the light by pushing down a key. A buzzer sounded by any observer can be heard by all the others. This is an important feature, as will be evident from the description of working given below.

The whole board, the construction of which was carried out by the General Post Office, is very compact, and is contained in a box measuring 13¼ by 10 by 16½ ins. high, which also carries the operator's telephone.

The method of working usually adopted in the F.S. Battalion was as follows. A "leading observer" was told to pick up a certain flash and observe it. Each time the flash appeared in his telescope he pressed his key, sounding the buzzer. The other observers, watching through their instruments, could hear the buzz, and by this means were greatly aided in picking up the right flash. They in turn observed and pressed their keys, but in their case the operator at H.Q. cut off the buzzers so that the lights alone indicated the observation. Finally the leading buzz was cut off, and the last lighting of lamps had to be done with no help from any outside source. When the operator was satisfied that all were on the same flash, he told the observers to book and report their readings.

Working by buzz alone was sometimes resorted to when, owing to faulty lines or other causes, the F. and B. Board would not work, and D3 telephones had to be used instead. In such cases each D3 telephone was tuned to buzz at a different key, and the operator could recognise each post by its characteristic buzz.

The method of observing with the aid of the "buzz" from the leading observer was peculiar to the British service, and there is no doubt that it helped to obtain a large number of intersections.

4. Work and Equipment of Group Headquarters.

The duties of the O.C. Group and Group H.Q. were generally to administer and control the Group, to work for and with the local Artillery, and in conjunction with their neighbouring Groups and S.R. Sections.

Officers had to arrange for the day's programme of calibration or ranging shoots, to fix the positions of new posts, to visit posts by day and night, to render reports of all kinds—routine, special, administrative, etc.—to maintain the Group telephone lines and instruments, and to carry out moves when necessary.

At the Group H.Q. there was always a good deal of administrative work, there being some 62 men to look after, distributed in small detachments at a distance, and seven horses, besides carts and mechanical transport. Besides this there was the technical direction of observation and the plotting of locations.

It may be noted that the work of an Observation Group extended over both night and day. Night was the best time for fixing defiladed enemy guns, because it was only then that the flashes could be seen. When there was sufficient command to allow of seeing the flash directly, day work was, as a rule, the more accurate, as the flash appeared as a minute point of light. The bulk of gun-fixing was done at night, but much valuable work was done by day by all Survey Battalions at various dates. Most ranging was, of course, done by day, because the smoke of the shell-burst made a good object for observation.

An important duty at the Group H.Q. was the estimation of the accuracy of a location. Accuracy was classified as P, Q, or R. P meant that the error of the location might be taken to be not greater than 50 yds., Q not more than 100 yds., and R not more than 150 yds. (It was agreed at the end of the war that R ought to mean 200 yds.) This classification was not intended as an absolute guarantee, as it was impossible to give this; but it was intended as a *reasonable guarantee*, so far as the judgment and experience of the Group Commander and his knowledge of the conditions of observation could give it, that the true position was within the limits of error indicated.

The equipment of the Group H.Q. consisted of the flash and buzzer board, a small telephone exchange for outside communication, plotting boards on both small and large scales, drawing instruments, logarithms and other books, carpenters' tools, and, when possible, a small theodolite.

5. Work and Equipment of Survey Post.

The duties of a Survey Post were to watch the front generally and to make such observations for location as were required. The latter usually took the form of fixing guns and observation for ranging. Towards the end of the war the Artillery duties of the Observation Groups became so heavy that watching of the front was often impossible, except in the most desultory fashion.

Of the eleven Survey Post Observers on the establishment it was rarely that more than eight were available, owing to casualties, leave, sickness, or lack of reinforcements. Two men had to be on duty continuously, one was required to cook, while it was seldom that one man at least was not required for work on lines.

Observers got to know their fronts intimately, and it was common for newly arrived batteries or other units to send officers to the Survey Posts in order to familiarise themselves with the chief features in the landscape.

The equipment of a Survey Post was an observing instrument, telescope, field-glasses, stop-watch, breastplate telephone transmitter with headpiece, and a supply of maps and panoramas. The observing instruments varied in pattern, and will be described in a later paragraph. Telescope and field-glasses were for general watching, but with improvements in the observing instrument the former became unnecessary, though field-glasses were always useful. The stop-watch was for timing flash to report intervals. The breastplate telephone outfit enabled an observer to speak to H.Q. while at the same time observing and having his hands free. It was a most useful addition.

6. Ranging.

Observation for ranging guns is an evident corollary of the work of an Observation Group, for the accurate fixing of the position of a shell-burst offers no difficulty to a properly equipped unit. Ranging may be done for two purposes—to calibrate the gun or to get on to a target. The former is done by observing bursts on the ground, the latter by fixing bursts either on the ground or in the air.

Towards the end of the war observation for ranging assumed such importance—as it was obviously better to hit such targets as we knew than to be continually searching for fresh targets—that many Groups were employed on that work to the exclusion of practically all other. Proposals were also made on various occasions for the formation of small groups or detachments for this purpose only.

These did not materialise officially, but a number of unofficial groups were formed in various armies. In the Third Army, for example, from February, 1918, till the end of hostilities three posts in each Observation Group were duplicated. The duplicate posts were manned by a detachment of Artillery consisting of two officers and about twelve other ranks. These detachments were called "Ranging Sections," and were administered and controlled technically by the Observation Group to which they were attached. The result of this increase of personnel was a decided improvement in results. The Artillery took a greatly increased interest in ranging and calibration by cross observation, while the Group, owing to the absence of distractions, were able to secure a much larger number of daylight locations. Similar ranging detachments were formed in the First and Fifth Armies with R.A. personnel at a later date, but owing to operations, lack of transport and equipment, etc., they did not become a practical success, though they did some good work.

It may be noted that the combination of R.A. and R.E. personnel had nothing to do with such success as was obtained by these Ranging detachments. The essential point was the need for extra personnel to do the extra work. This personnel could not be obtained from the R.E., so was supplied by the R.A.

(a) Ground Burst.

(a) The earliest observation for ranging on the ground burst was done in the Second Army. It was also foreseen in the Third Army as one of the duties to be done by an Observation Group, but it was not until the middle of 1916 that the question was taken up at all generally, and that its capabilities began to be realised by the Artillery.

Observation for ranging on the ground burst resolves itself into a question of reporting the result quickly and accurately to the Artillery in the correct manner; that is, in terms of yards short or over, minutes right or left. The observation of the burst is a comparatively simple matter, as, given a good burst, it is an easy object, and there should be no difficulty in getting a first-class intersection. The rapid determination of the position of the shell burst with reference to the target and the line of fire involves the previous preparation of graphs, and various methods were devised which will be described below.

By the middle of 1916 a number of Groups had graphs ready for various datum points and targets. At this period German Artillery tactics included the construction of clearly defined heavily protected positions, which were easily visible on air photographs, and which continued active for months. Observation for ranging upon these could be undertaken at any moment if they were visible from the posts.

(b) Air Burst.

Ranging on the air burst came into use in the British Army in the autumn of 1917, but at that date it was already common in the French and German Armies. The British Artillery were at first handicapped by the lack of the necessary time-fuse for high explosive shell, but in spite of this fact this form of observation grew gradually into favour. Considerable impetus was given to it by the excellent arrangements and the quick reporting introduced by Capt. Coburn (of the 4th F.S.B.) during his period of duty at the Overseas Artillery School, Salisbury Plain.

The theory of air-burst ranging is simple. It is desired to range on a target which is invisible from the observation posts, but whose map position is known. A projectile is fired at approximately the correct range and bearing, and timed to burst at some point in its trajectory where it is visible from the observation posts. It is then possible from the known laws of the trajectory to determine where the shell will strike the ground; or it is possible, by suitably lowering the angle of sight, to cause the shell to strike the ground at a point vertically below that at which it was observed.

Either of these methods may be employed. The former is called "ranging on the trajectory"; the latter "ranging on a point vertically above the target." As far as the Field Survey Battalions were concerned, it was immaterial which method was adopted, and at first both ways were tried. Later it was decided by the Artillery, for various practical reasons, that the latter method—ranging on the point vertically above the target—should be adopted exclusively.

The Observation Groups were well situated for carrying out observation for position in the horizontal plane, but their instruments were not adapted for measuring vertical angles with the necessary accuracy, on account of the inferiority of their levels. They had, therefore, to be supplemented by theodolites for this purpose, until the provision of the Theodolite Flash Spotting, with its later and more accurate form of level.

As in the case of ground burst ranging, the chief difficulty was really the quick determination and reporting of the position of the burst.

It will be noted that, as the target cannot be observed, the method depends for success on the accuracy of the map.

(c) Plotters.

As mentioned above, in order to make the accurate work of the Observation Group of real practical utility, it was essential that there should be no delay in determining and communicating the results. In this respect the Observation Groups had to compete with the Artillery Forward Observer, who sent his report over the telephone within a second or two of the fall of the round, and, though it was admitted that the Groups might be more accurate, there was much doubt at first whether they could give their results quickly enough to be of use. There was also the question of preparation for observation. If the Artillery could not call on an Observation Group at short notice, it was unlikely that they would view the new methods with favour.

It was evident from the outset that there were three requirements to be fulfilled in the method of determining the fall of the shell with reference to the target:—

(i) In order to be sufficiently quick, the method must be graphic.
(ii) In order to be sufficiently accurate, it must be done on a large scale.
(iii) In order to avoid delay in previous preparation, it must be readily adaptable to any positions of gun, target and observation posts.

The third requirement was really the crux of the problem. At first the position of gun, target and observation posts had to be plotted on a large scale, and this process, which even when the personnel had become expert took half an hour, had to be repeated for every change of gun, target or observation posts. Attention was consequently directed to the design of graphs or "plotters," which could be readily adapted to varying positions and conditions. It is probable that every Observation Group devised some means of dealing with the problem, but all were not suitable for general use. Capt. (now Major) Jessop, for example, produced an elaborate mechanical device known as the "Jungle Plotter, which was satisfactory while in use, but was too heavy and too complicated for manufacture in numbers.

Of the plotters readily adaptable for general use, two may be mentioned.

Percival Plotter.—Lt. Percival, while an Instructor at the School for Observers, designed a graph by which the rays from a Survey Post in any position could be plotted on the scale of 1/5,000. The graphs were printed on tracing paper, and one was pinned in position for each Survey Post from which observations were to be taken. The rays from the Survey Posts could be plotted (with weighted threads) in a few seconds, and, by means of a suitable graph also provided for the target, the position of the intersection with reference to the target could be determined very quickly. The plotter fulfilled the necessary requirements admirably, the whole process of previous preparation and reporting the round taking a very short time. It was an ingenious arrangement, for which the designer deserved great credit. The objections to it were that the graph sheets were rather large, and consequently required a good deal of room, and were liable to be torn.

Coburn's Transparent Grid Plotter.—Capt. (now Major) Coburn designed graphs for plotting at about the same time as Lt. Percival, but independently. His graphs showed rays from an observation post drawn at various distances. The suitable graph for each post was chosen according to its distance from the target. The graphs were printed on tracing paper in various colours, so that the different posts could be distinguished, and were used over a sheet of glass and read by transmitted light. A large stock of graphs had to be carried, and it was not always easy to see through the tracing paper and distinguish the intersection; but the Coburn plotter was much quicker to use than the Percival, and judging by results it seems to have been the most practical, for at the end of the war it was in use in about half of the Groups, the other half using various kinds, including the Percival.

Smellie's Protractor.—Capt. Smellie designed a protractor, which was really an adaption of the Percival plotter, for setting off scales whereby rays could be plotted. Instead of using the printed graph the scale was drawn in the board (which could be done quickly with the aid of the protractor). This had the advantage that less room was required than for the Percival plotter, and it was rather more convenient for operation.

7. Liaison with Artillery.

As the efficiency of Observation Groups developed and their Artillery work came into prominence, the great importance of close liaison with the Artillery became more and more evident. It was realised that intimate co-operation was quite as important as intensive technical training, and that it was essential to the practical utility of the Observation Groups that there should be the closest touch with the Artillery generally, both with the Counter Battery office and with the battery. In the early days of the war the dearth of Artillery officers led to the rule being made that none could be spared for work in the Survey units, consequently few of the Group officers belonged to the Artillery. This did not facilitate the establishment of a good liaison, in work in which acquaintance with Artillery methods and practise was so important. To meet this difficulty Group officers were frequently attached to batteries for a period; courses of instruction in flash spotting were given to R.A. officers and men; lectures were given at Artillery Schools, and every effort was made to extend observation for calibration or ranging.

8. Observation Groups in Mobile Warfare.

8. Observation Groups were developed in a period of stationary warfare, and for some time were considered to be suitable only for work in such conditions, and statements to this effect were made in several official documents. Actual movements of the line, however, necessitating movements of Groups to conform, and the continual increase in their efficiency, showed that, given proper equipment, Observation Groups were capable of a high degree of mobility while at the same time maintaining their usefulness. Much attention was given to this subject and to the role that Observation Groups must fill in open warfare, with the result that their mobility increased to a remarkable degree. But there is no doubt that their usefulness in this direction is capable of great extension and that the subject is still in its infancy.

(a) 1916.

(a) The battle of the Somme was the first test of the ability of all geographical methods to meet mobile conditions. It was, naturally, impossible to arrive at a sound tactical programme without such experience. Different ideas on the handling of Groups at once became apparent. On the one hand, in one Group, under the orders of an old regular gunner everything was sacrificed to mobility, the Group was moved forward without due regard to the possibility of maintaining the essential communication between H.Q. and the posts or between H.Q. and the Counter Battery office, and it became a mere collection of individual independent posts. On the other hand, another Group, by moving forward one or two posts at a time, was able to continue in action with but little interruption, though lack of trained personnel and inadequate equipment made the advance too slow and the results of their work somewhat meagre. There is little doubt however that the style of this battle with its succession of local objectives lent itself to an advance post by post, and that this policy was the best in the circumstances and achieved far better results than the other.

(b) 1917.

(b) The battles of 1917 were not responsible for any marked advance in methods or tactics. Advances were too small to give much practice in mobility, and the change in German artillery tactics—the introduction of alternative positions, wandering guns, and the value given to concealment at the expense of protection—brought many new difficulties.

(c) 1918.

(c) During the operations in the spring of 1918 the retreat on the extreme south of our line was too pronounced and continuous to allow of much flash spotting. Artillery work generally was on visible targets or on cross roads and communications, and locations would not have been of great value. Groups were assembled in rear and formed part of "Carey's Force" for the defence of Amiens, suffering fairly heavy casualties.

On the 3rd Army front however movement was more methodical and much less rapid. Groups were able to keep in action, changing bases every day and keeping touch with the nearest heavy battery or brigade. Here, as always in mobile operations, the chief difficulty lay in keeping in touch with someone who could exploit the information gathered.

On the Lys front the experience of the German offensive followed very much on the same lines, with added difficulties of topography; for the country, flat, heavily timbered, and closely intersected with hedges, affords extremely few good observation posts. Touch was completely lost with C.B.S.O.'s as it had been in the south.

As the line steadied Observation Groups took up their ordinary duties again. The numerous and accurate locations in the Lys salient and from the Vimy Ridge were perhaps the most noticeable feature in location, whilst calibration and observation for all sorts of shoots continued to a greater extent in the south, where muzzle flashes are rarely visible by day.

During the last offensive, on the north of the line the advance was at first so rapid, and the road communication so bad, that Groups could not keep up and were for a time out of action. East of the Messines Ridge however conditions were easier, and Groups had no difficulty in keeping up with the heavy artillery, though unfavourable ground and weather prevented their effecting many locations. In this advance it was clearly shown that a Group moving along a road can deploy and get into action in 3 to 5 hours from the time of arrival at the point of deployment. Other deductions from the experience of this advance are embodied in the conclusions at the end of this Chapter (Section III).

From Amiens to Arras, however, the advance, occasionally in bounds of ten miles at intervals of several days, occasionally in bites of two or three thousand yards daily for a week or so, gave ample opportunity for experience and deduction.

At the end of the period Groups were thoroughly efficient. Advancing along a signal route, in close touch with some Heavy Artillery Brigade, occupying a small base (3,000-5,000 yards), continually studying the topography ahead and sufficiently served by transport, they averaged as many locations as in quiet times, and showed that the Observation Group is not a purely siege warfare unit, but is a necessary and indispensable adjunct to the artillery work of a large army.

9. Training.

(a) Observation.

(a) Training in observation and the work of a Group was carried out first by the Third Army School, and later by the School for Observers at G.H.Q., the officers immediately responsible for instruction being first Capt. (now Major) Newbold, and later Capt. (now Major) Robinson. There were usually from 100 to 150 pupils under instruction at a time, made up of recruits from the base and men from the F.S. Battalions undergoing Preliminary or Advanced Courses.

Recruits for Observation were obtained by the selection of likely men from the Base (where much help was given by the D.A.G.) or from the Armies. It was found that men who had had no experience at the front were of little use for several months, however suitable they might be otherwise. The ordinary conditions of life in the Observation Group appeared to them hard, whereas the man from the trenches welcomed the comparative relief, and was besides already educated to the sights and sounds of warfare.

Courses of instruction for S.P. Observers were either Preliminary or Advanced. The former, through which all recruits were put, lasted three weeks, and included instruction in—

Organisation of F.S.B.
Work of Group.
Measurement of angles.
Use of instrument.
Fixing batteries.
Maps and map reading.
Use of stop-watch.
Nature of Artillery and shells.

The Advanced course lasted three weeks, and included—

Map construction, co-ordinates, etc.
Observation, other instruments, etc.
Information about other units, such as S.R. Sections and Balloons.
Work of Group and Post.
Telephones, electrical connections, etc.

Courses of instruction were also given in computing, in order to provide at least one man in each Group capable of dealing with the computations necessary for rapid surveys and ranging.

The detailed syllabus of these courses will be found in Appendix IV.

For instruction in flash spotting an elaborate dummy range was provided in which gun flashes were simulated by electric lights, and gun smoke by smoke puffs from "bee puffers." A complete Group was installed, with H.Q. and four posts, and all instruction was carried out in the most practical manner. For general observation, the 3rd Army School when at Beaumetz had the advantage of a post from which a view over the trenches could be obtained; while the G.H.Q. School had one overlooking the sand dunes and a big stretch of country in which troop movements, tanks, machine gun manœuvres, aeroplanes, etc., could be seen. In 1918 the use of a 6-pr. gun was obtained on which to practise observation for ranging.

(b) Mobility.

(b) The first definite training for mobile warfare was given in the 3rd F.S.B. early in 1917. With the lessons of the battle of the Somme in mind, courses of instruction in mobile warfare were held in preparation for the battle of Arras.

A Group of three mobile posts, with a forward and rear Headquarters, was the organisation chosen. Speed of construction of lines, of fixing positions graphically, and of subsequent computation, organisation of transport, and packing were all practised. These courses were most valuable and taught many lessons.

Subsequently much thought was devoted to the mobility of the Group. "Mobile courses" were held at the School for Observers. In these an effort was made to make all affairs of detail into a routine or drill which should follow automatically, whilst educating N.C.O.'s i/c Posts to select and fix their own posts and generally to use intelligence and initiative. These ideas were not accepted everywhere, though there can be little doubt that the original Third Army course and the subsequent mobile courses at G.H.Q. were on sound lines. It was, however, difficult to arrange for real "team" training, because the number of Groups never allowed for more than an occasional reserve Group, whilst most Groups remained continuously in the line from their formation.

(c) Survey.

(c) Courses in survey were held in order to instruct officers in the knowledge necessary to fix their positions from trig. data.

10. Observation Instruments.

A variety of observation instruments were used in different places and at different periods during the war.

(a) Theodolites.

(a) Theodolites of ordinary surveying pattern were used for the observation of horizontal angles in the original Flash Spotting Section of the First Army. A common theodolite is not, however, suitable for this work, for which a strong instrument is required, with good telescope power and a wide field of view, and which need not read to less than 1 minute of arc.

Theodolites were used later for the observation of vertical angles, for the special purpose of air-burst ranging.

(b) Instruments, Observation of Fire.

(b) These instruments, designed, as their name shows, for the purpose for which Observation Groups were formed, were found to be in possession of all Heavy and Siege Batteries, but were not used by these units. They are in many ways admirably suited for their purpose. They are very strong, easily manipulated, and are provided with means of illumination for night work. Their defects are unnecessary weight and a telescope that is optically inferior and has too small a field of view; but they proved invaluable for the work of the Observation Groups, and were widely used until replaced by better instruments.

(c) Directors.

(c) The latest pattern of Artillery Director used by the Observation Groups —the Mark V.—has the advantages of the Observation of Fire Instrument without its undue size and weight. The arc is, however, graduated on the vicious artillery system of 180° right and left, instead of round the circle from 0° to 360°; and its optical qualities are perhaps inferior. These instruments were preferred to the Instrument Observation of Fire, except for purely stationary warfare, but they were a good deal harder to obtain, being wanted for use by batteries. Practically all posts were, however, equipped with them before the introduction of the French telescope and the flash spotting theodolite, and the great bulk of battery fixing during the war was done with these instruments.

(d) Theodolite F.S. and Longue-vue monoculaire.

(d) The attention of both the French and ourselves had for some time been directed to the design of a suitable instrument for use in the Observation Groups.

The British produced first the "Trench theodolite," which was a small prismatic telescope, the design of which, with its mounting, was based on that of a captured German instrument. A few of these were tried, and then an improved instrument, called the "Theodolite Flash-Spotting," was designed by Major Henrici, R.E., embodying various modifications. Both these instruments were arranged to measure vertical angles as well as horizontal, and their chief feature for this purpose was that the level was attached to the telescope, and that vertical angles were read on a graticule in the field of view. The Theodolite Flash Spotting is a compact and handy little instrument, with power 6½ and field of view about 6½ degrees, and is carried on a simple well-designed mounting, with circle reading to one minute.

The French had previously designed two instruments—the longue-vue monoculaire, for use by day, and a binocular for night—both fitted to work on the same mounting, which had a circle divided in milliemes. The longue-vue monoculaire was a prismatic telescope of excellent optical quality, with a 3-in. object glass and a triple eyepiece (powers 32, 23 and 16).

The Service Géographique, who had the supply of these instruments in hand, informed us that they had placed a large contract, and that they could provide for our wants also if we so desired. We welcomed the opportunity, and it was decided to take enough of these telescopes to equip all our Observation Groups and to fit them to be carried on the mounting of the Theodolite Flash Spotting. During 1917 a certain number of these telescopes, complete with the French mountings, were obtained and used, but in the winter of 1917-18 a large number were fitted to the British mounting and were also provided with graticules, and by June, 1918, all Observation Groups were equipped with them.

The new outfit was in most respects a great improvement on previous equipment. The French telescope was excellent and acknowledged to be superior to any of similar size previously used by the Groups, and the little theodolite for night work was agreed to be first-rate. The one rather serious defect in this equipment was that the mounting, designed to carry the flash-spotting theodolite, was too light to take the big telescope, with the result that the instrument for day use was not sufficiently rigid, and a considerable amount of play developed early.

(e) Coles' Instrument.

(e) In the autumn of 1917 Sergt. Coles designed an instrument for observation and flash spotting which embodied a really original idea. It consisted of a theodolite in which an image of the divided arc was projected, by means of a prism, into the field of view of the telescope, so that objects could be observed and bearings read over a fairly wide field without moving the telescope and without taking the eye from the eyepiece. The advantage of such an instrument for the difficult work of flash spotting, for observing shell-bursts, or any rapidly-moving target, are obvious.

The construction of this instrument was put in hand in May, 1918, being entrusted to Messrs. Watts & Son. Certain practical difficulties mainly connected with the optics were encountered, and this delayed the production of a model instrument, and hostilities ceased before the design could be sufficiently perfected to allow of construction in quantity. The instrument was therefore never put to practical use in the field, but it was agreed by all who tested it that it constituted an immense advance on anything previously used. Construction is being continued, and it will no doubt form the equipment of future Observation Units.

(f) Other Telescopes.

(f) The instruments described above are all designed for angle measurement. Besides these, field-glasses and telescopes were used for ordinary observation. Field-glasses were all of prismatic pattern. Telescopes were as a rule "signalling" pattern, but others of a model called "S. 3" were supplied. There was little to choose between these, and they were satisfactory until superseded by the better longue-vue. When the demand for good telescopes was made by the Army generally in the early days of the war a large number were purchased in England from the various makers of optical instruments and sent to France, and of these some found their way to the Field Survey Battalions. They were mostly of astronomical pattern of long focal length, and though excellent telescopes in themselves, were entirely unsuitable for use in a confined observation post.

Mention must be made of the telescopes supplied by Colonel Gifford. This officer is an optical designer of some note, and also the possessor of a quantity of Jena glass. He constructed a large number of telescopes which he presented for the use of the troops. A number were sent to the Artillery, and eventually four or five to each F.S. Battalion. His telescopes were of first-rate optical quality and were most valuable. Colonel Gifford paid a visit to G.H.Q. by invitation in 1915, and after a visit to some of the Observation Groups set about the design of a small telescope for use in confined posts. Various delays were encountered in manufacture, and by the time construction could have been undertaken the Observation Groups were well provided otherwise. Colonel Gifford's name should, however, be remembered for the generous way in which he provided a large quantity of telescopes at his own expense for the use of troops at the front.

SECTION III.—DEDUCTIONS.

1. Role of the Observation Group.

The experience of the war shows that the real duty of the Observation Group is to provide accurate three or four-line observation whenever required for both location of targets and observation of fire.

To this end it must be self-contained and mobile. It must be capable of doing all work necessary to its installation, such as survey and erection and maintenance of lines, without outside help, and also be completely independent in matters of interior economy, such as fetching and distributing rations. It must be capable of moving 10 miles a day and of coming into action within six hours of arrival, and it must move and keep in touch with some artillery formation.

The above implies a highly organised skilled body whose value lies in team work. It is obviously absurd to split it up in mobile warfare into independent posts on the Lovat Scout principle, as was once proposed, and it is equally unsound to leave it behind for some days during an advance, and thereby lose its services just as hostile batteries begin to come into their new positions.

Command of the Group from the Army is, in mobile operations, impossible. Tactical instructions to the R.A. issue from the Corps. The Group should receive its instructions from the same source.

2. Personnel.

(a) Officers.

(a) A good grounding in gunnery is an essential qualification for an Observation Group officer. As the Groups of the future will be Artillery units, it is not necessary to emphasise this point.

Every officer must also be thoroughly trained in survey. Map reading is, of course, important, but far more is needed. The ordinary simple methods—intersection, resection, traversing and plane-tabling—must be familiar to him. The simple calculations involved must also be so familiar that he can direct and check the Group Computer even if he does little computation himself.

The third essential is a practical knowledge of signal work and a thorough grasp of the electrical connections and instruments necessary to the running of his Group.

(b) Other Ranks.

(b) A large proportion of the rank and file must be skilled observers. There must be an ample staff for the maintenance of lines and instruments, and this staff must be sufficient to allow of picking up an old base simultaneously with laying out a new one; otherwise delay will be caused which will be fatal to the successful employment of the Group in mobile warfare. It may be noted that one of the great advances in efficiency of the Observation Groups took place when they undertook the erection and maintenance of their own lines, instead of relying on outside sources. The H.Q. must include a surveyor, or computer, and skilled "board" N.C.O.'s, who plot results as they come in from the posts. It must also include such tradesmen as are necessary to make the unit independent, such as a carpenter and bootmaker.

3. Equipment and Transport.

It is unnecessary to go into all details of the equipment here, but a point that is intimately connected with the number of personnel necessary and the amount of transport is that every Group should be provided with enough wire for two complete bases, with, as mentioned in the previous paragraph, enough men to pick up one base and lay out another simultaneously.

The transport allotted must be ample and suited for any kind of country. The transport available during the war was quite inadequate. Having started with the idea that an Observation Group could be employed in stationary warfare only, it was realised later of how great value it could be during movement, but by that date the situation with regard to transport made any increase impossible to obtain. But for future organisation special attention should be paid to this point. The details of what is necessary have already been given in Section I.

4. Training.

Training should be directed not only to making the unit efficient technically, but also to making it work together as a team, both when stationary and when on the move. For this purpose mobile courses such as were held during the war are most valuable, and also because they keep alive the *esprit de corps* of the men and make them realise that the unit is an active one. It is, however, important to guard against a danger into which units which have to combine technical with military efficiency are apt to fall. If the Observation Groups of the future develop into units whose chief ambition is to pack up in the shortest possible time and gallop to another site, their value will disappear. Technical efficiency must be the first and the chief object; and when that is ensured it must be combined with military rapidity.

5. Questions for the Future.

There are several questions which affect flash spotting which have not yet been solved The first of these is the automatic record of all flashes.

(a) Automatic Record.

(a) In the earlier days of sound ranging the human observer was used, whose duty was to tap a key when he heard the report of a gun. The human observer soon gave way to the microphone. Similarly in flash spotting the time will probably come when the human observer will gave way to a photographic record. So far the difficulties of finding a plate sensitive enough for the purpose have proved insuperable. To be of value the camera must be able to record the glow or reflection of a flash from a gun defiladed from direct view. Most location by flash spotting is done upon the glow and not upon the muzzle flash. Should the camera succeed in replacing the observer, the personnel could be cut down and the length of the base could be much reduced, because of the great accuracy of plotting which can be obtained on a plate.

(b) Wireless Transmission.

(b) The second point is that of communications. It is one of the hardest problems to get information back from the Group H.Q. to the gunner. This difficulty should be largely solved by the introduction of wireless telegraphy. Either C.W.W. or Sparking Sets could be used, but whichever type is employed must be such as is used by the batteries themselves.

Wireless will also solve the problem of warning all other location units of the area in which activity is suspected, so that confirmatory evidence may be got at once. It may also do away altogether with the necessity for laying internal communications in the Section itself.

CHAPTER 3.

SOUND RANGING.

SECTION I.—DEVELOPMENT OF UNITS.

1. Initial Steps.

The possibilities of Sound Ranging were first investigated by the French, who had several Sections working early in 1915, including two adjoining the British front, at Arras and north of Ypres. The subject attracted attention in the British Army, Generals Uniacke and Phillips being among the R.A. Officers who were interested. The latter had actually proposed as early as 1914 that the possibilities of fixing position by sound should be investigated. Colonel Blandy, R.E., wrote a report on Sound Ranging as he had seen it in Paris in March, 1915. In April, Colonel Hedley, R.E. (Geographical Section, G.S., War Office), was so impressed by what he saw and heard on a visit to Paris, that he went at once to G.H.Q. and reported on the subject to various senior officers. The result of this was the despatch of a Committee of three to report on French Sound Ranging. The Committee consisted of Major Winterbotham (Survey Expert), Capt. Lefroy (Electrical Expert), and Major Dreyer, R.A. The last named returned to G.H.Q. very soon, but the two R.E. officers continued their investigations, and in due course reported on the question. Considering how little was known of Sound Ranging at that time, and in what a crude state the French system was, it is a great testimony to the ability and foresight of these two officers that the report and recommendations they made hold good to this day, and have been amply justified by the event. The gist of their report was that :—

(1) Sound Ranging, though in its infancy, was a practicable proposition, and would give valuable results.

(2) The Bull system was the best.

On receipt of this report the Committee was sent on a second visit to see the working of a French Sound Ranging Section at the front. Their second report confirmed the first.

The matter was put before the Experiments Committee at G.H.Q., but they decided against ordering any apparatus, on the ground that the method had not yet reached a sufficiently practical stage. After some further representations, however, they yielded, and authorised the purchase of one experimental set. This set, made in Paris by Mr. Bull, was ordered in June and delivered in October, 1915.

2. First Sound-Ranging Section.

To superintend the work of the first section, and conduct initial experiments, Colonel Hedley secured the services of Lieut. (now Major) W. L. Bragg, Liec. R.H.A., a young scientist with a considerable reputation. Lieut. Bragg arrived in France in August, 1915, with an assistant, Lieut. H. Robinson, R.G.A., who was an expert mathematician, and two men (an electrician and an instrument maker). After a preliminary visit by the two officers to a Bull Section working on the French front, the first British Section arrived at the front on 18th October, 1915. It consisted of the above-mentioned two officers and two men, and its transport was a specially equipped lorry containing the apparatus, and two Singer light cars; making a total, with drivers, of two officers and six other ranks. A fortnight Lieut. Bocquet, R.G.A., was sent to the Section as Advanced Post Officer, and a lineman was lent to it by a neighbouring Signal unit. Lieut. (now Captain) Bocquet is an electrical engineer who had himself made some original experiments in Sound Ranging while with his battery. His previous experience in the line was of great value when practical details of the establishment of a Sound-Ranging Section were, at a later date, being considered.

In allotting so small a personnel to the first Section the idea was that the erection and maintenance of lines would be done by Corps Signals, so that the personnel of the Section would only be concerned with the working of the apparatus at headquarters. This was, however, found to be impracticable, on account of the delays involved in getting help from Signals whenever a line was cut. In spite of preliminary difficulties, the first location was made by this Section on 2nd November, and by December the results were considered sufficiently promising to justify the formation of seven more Sections, making in all two Sections for each of the four Armies then in the field.

3. Formation of Seven New Sections.

The establishment (No. 239, dated 11-3-16) authorised for the new Sound-Ranging Sections consisted of 3 officers and 18 o.r., including 1 sergeant, 1 instrument repairer, 1 photographer, 3 linemen, 2 telephonists, 3 forward observers, 3 batmen and 4 M.T. drivers; and the transport consisted of 1 30-cwt. lorry, with special body for apparatus, 1 15-cwt. box car, and 1 light car. The box car was fitted with a C.A.V. Dynamo, and the intention was that the charging of accumulators for lighting the lorry and apparatus should be done from this car.

Sound-Ranging Sections were now designated by letters starting from the end of the alphabet. The first eight Sections were called Z to R (omitting U), the original Section being named W.

Officers for the new Sections received one week's training at the original Section at Mt. Kemmel. As each set of apparatus was completed at the Institut Marey, the O.C. Section was sent to Paris to bring it up by road in its lorry. The new Sections were installed where they could be most useful, as there were not enough to cover the whole front. Survey was done by the Field Survey Company to which the Section belonged, and lines were erected by Signals. Owing mainly to the time taken to put up the air lines, Sections took a long time to get into action. Three or four weeks was about the average period, from surveying the base to getting the first result, and in some cases it ran into two or three months. This may be compared with work at the end of the war when with larger bases and in much more difficult conditions Sections came into action in two or three days.

The new Sections started work in April, May and June, 1916. The two southern Sections, R and S, became involved in the battle of the Somme, and were unable to do much work, though S succeeded in getting some locations before the battle.

Meanwhile progress was made on quieter fronts. At first a certain amount of incredulity, quite natural under the circumstances, prevented the results obtained from exerting their proper influence. It happened at this time, however, that German Battery Positions on the quieter fronts were very conspicuous, and the accuracy of the sound-ranging locations was, therefore, readily checked.

It became apparent, too, that sound-ranging was the only accurate method of location in times of bad visibility. Lectures were given and visits invited, and by December, 1916, most Counter Battery Staff Officers were convinced.

In June, 1916, the Tucker microphone was invented, and all Sections were equipped with it by September.

4. Increase of Sections and Establishment.

In August, 1916, it was decided to increase the number of Sections in order to provide a total at the rate of one per Corps; and at the same time proposals were put forward for an increase of establishment, which was approved (with the new establishment for a Field Survey Company) in December, 1916 (Nos. 407, dated 7-12-16 and 501/42, dated 3-4-17).

This establishment comprised 3 Officers and 33 O.R., the tradesmen being 1 instrument repairer, 2 photographers, 5 linemen, 3 telephonists, 2 computers, 1 carpenter, 1 cook, 10 forward observers, while the batmen, drivers and transport remained as before. A change was, however, made in the form of the 30-cwt. lorry, which was no longer fitted with a special body. Experience showed that it was nearly always necessary to put the apparatus in a dug-out, and apart from that most officers preferred to get it out of the lorry and dispose it in more roomy quarters. It was, therefore, decided to dispense with the special bodies, and have ordinary lorries for transport purposes only.

Training was carried out at Mt. Kemmel by W Section during the autumn of 1916, and in the winter of 1916-17 twenty Sections in all were in being. The whole front was well covered, with the exception of the Somme area and the Ypres salient, in which two areas there was considerable difficulty in working. During that winter the weather for Sound-Ranging was good, and all Sections obtained numerous results. For the first time Sound-Ranging took its proper place with other means of battery location, and it was found that in certain conditions it was much the most fruitful source of location.

At the same period—late in 1916—the location of our own shell-bursts for the purpose of ranging was begun.

5. Experimental Section, Salisbury Plain.

Up to the end of 1916 all experimental work had been done by W (the original) Section at Mount Kemmel. The Section had in August been given extra personnel to enable it to do this work, but the difficulty of carrying out research so near the front was great. Apart from this, the Overseas Artillery School was just being started in England, and it was considered advisable to have a Sound-Ranging Section at the School to work with the Artillery and convince them of the efficiency of Sound Ranging.

Consequently in November, 1916, Lieut. Tucker was sent to England with a nucleus of trained men, and the Experimental Section on Salisbury Plain was formed.

6. Experimental Section and Sound-Ranging School, G.H.Q.

W Section, in addition to doing experimental work and the work of an ordinary Section on a front which was continually becoming more active, had trained the personnel of the first 20 Sections. It became impossible for it to continue this work, and in March, 1917, the nucleus of an Experimental Section, consisting of Lieut. Bragg with one officer and five men, was transferred to G.H.Q. On the formation of the Depot Field Survey Company in the following month an establishment of four officers and twenty-six other ranks, with a motor-car and box-car, was included for this Section, but for various reasons it did not actually join the Company until July. Between March and July the Section trained various officers and men and gradually collected machines and staff for a workshop. In the winter of 1917 the Section moved with the Depot to Campigneulles-les-Grandes, and was given proper accommodation for classrooms and a workshop.

This Section had three different functions : (1) Experiments on apparatus and methods, (2) Upkeep of existing apparatus and construction of new (such as automatic developers), (3) Instruction.

Though the Section remained to the end of the war the "Experimental Section," there was in practice a separation between the Experimental and Workshops portion and the School of Instruction, as each occupied the whole attention of a separate staff.

(a) Workshop.

(a) The workshop was in charge of a specially selected officer, Lieut. Cooke (of Princeton University), with a permanent staff of sixteen workmen, to which could usually be added half-a-dozen reinforcements working in the shop while waiting to be posted as instrument repairers to a Section. By the end of 1917 the tools consisted of two screw-cutting lathes, five small bench lathes, one milling and one drilling machine. The lathes were driven through shafting by a Blackstone engine, which also worked a dynamo, and together with a lighting set, supplied the electric light for the Depot and charged the accumulators required for the instruments. To the shop was attached a large test room in which ten Sound-Ranging instruments could be set up together for testing.

The work of the shop was mainly as follows :—

(1) The testing of new apparatus and the carrying out of necessary alterations before sending it out to the Sections.

(2) The repair of apparatus and the supply of spare parts, including "harps" ready strung for Sections in the field.

(3) The alteration and remodelling of the old Bull-type instruments returned from Sections.

(4) The actual construction of quantities of a number of the smaller articles required by Sections, such as microphone holders and weights and eyelets for plotting boards.

(5) The construction of plotting boards.

(6) In addition to Sound-Ranging work, the workshop carried out the simple repairs to flash-spotting instruments, overhauling and cleaning flash and buzzer boards, observation of fire instruments, directors, etc., and undertook such repairs as were possible to theodolites, besides which there were always a number of experimental instruments and "gadgets" in course of construction for all branches of Field Survey Battalion activity.

(b) Sound-Ranging School.

(b) The Sound-Ranging School had a staff, from January, 1918, onwards, of three officers and four N.C.O.'s. At this date instruction on a larger scale was begun to provide for the many Sections being formed, and until May there were as a rule ten or twelve officers and about forty other ranks being trained as computers, sound-ranging operators and forward observers. In May the reduction in the number of Sections rendered further training unnecessary. Courses of instruction in "mobility" were also held.

7. Formation of Sections for Overseas and new W.E.

In December, 1916, the W.O. ordered the formation of three extra Sections for service overseas, of which one was cancelled later. The formation of these two Sections was delayed owing to extensions of our line and the consequent extra requirements. In November, 1917, the W.O. ordered the formation of another 12 Sections over and above those required for France. Consequently 34 Sections in all were formed in France, of which two (Q and X) were sent to Salonika, two (N and V) to Egypt, and one (E) to Italy, leaving 29 Sections in France during the winter of 1917-18. This was the maximum in existence on the Western Front at any one time.

The new Sections were formed on the new establishment included in that for a Field Survey Battalion, which was approved in August, 1917. This establishment comprised four officers and thirty-nine other ranks, the tradesmen being two instrument repairers, three photographers, five linemen, three switchboard operators, six computers, one carpenter and ten forward observers. The increase was not nearly so large as was required, but unfortunately the situation did not permit of any greater numbers.

With 29 Sections available it was possible to have four or five Sections in reserve and allow those in the line to get an occasional much-needed rest.

8. Final Establishment.

As in the case of the Observation Groups, a "Higher Establishment" was approved for a Sound-Ranging Section when the advance into Germany took place, the personnel being found by reducing the Sections left behind. This higher establishment shows, with the same reservations as to transport (which was limited to what was actually in possession at the time), practically what the final experience of the war showed to be necessary to make an efficient Sound-Ranging Section capable of action in both stationary and mobile warfare.

The "Higher Establishment" was 4 officers and 63 other ranks. Deducting 10 drivers, batmen and cooks, there remained a C.Q.M.S. and 52 tradesmen, including 6 computers, 8 sound-ranging operators, 12 forward observers, 25 linemen and 1 carpenter. The transport was 1 Ford or similar light 4-seater car, 1 15-cwt. box-car and 1 30-cwt. lorry.

Additions to the above which it is considered should be made are 3 forward observers and two 2-wheeled carts, making the total personnel (other ranks) 68.

SECTION II.—TECHNICAL.

1. Early History.

(a) Nordmann's Experiments.

(a) The possibility of locating a gun from a record of the times at which its report reached various fixed positions appears to have been discussed many years ago in Austria, but no arrangements had, so far as is known, been made, prior to the outbreak of this war, by any country for the practical application of "sound ranging."

In the French Army experiments in sound ranging were commenced very soon after the war started. The first to give practical shape to the idea was Professor Nordmann, of the Paris Observatory. He conceived the idea at the front, and obtained permission to go to Paris in September, 1914, to experiment. His first idea was to work on a measured base with three men, each with a stop-watch, who would record the instant the sound reached them. In case sufficient accuracy were not attained by this method he had foreseen the use of microphones and a graphic means of registration. As he had no technical knowledge he consulted Mr. Lucien Bull, Sub-Director of the Institut Marey, as to the best means of doing this, having heard at the Sorbonne that Bull had done work on sound registration. Mr. Bull is a British subject resident in Paris, and an expert in optics and mechanics.

(b) Co-operation with Bull.

(b) Bull thought over the problem and proposed the use of the string galvanometer. He also proposed that Nordmann should make his experiments at the Institut Marey, where he would have the advantage of Bull's workshop and technical knowledge.

During the following month work was carried out on three schemes:—

(1) Men with tapping keys, working electro-magnetic markers, which registered on a smoked cylinder side by side with a time marker.

(2) Microphones, with or without relays, registering in the same way.

(3) Experiments with the Einthoven galvanometer.

Experiments on the first scheme were conducted personally by Nordmann. He educated his "tappers" to a remarkably high degree of efficiency.

Those on the second were conducted by Bocquet, Nordmann's assistant, who was an electrician in private life. These experiments were not immediately successful, but at a later period they led to the "T.M." method. This is the method adopted officially by the French Army, which employs special microphones of the carbon granule type, and a recording apparatus in which styles register on smoked paper.

The third series of experiments were conducted by Bull. He used three carbon microphones of the long distance telephone type, fitte with gramophone horns to increase their sensitivity. These were connected to three strings specially fitted to the large laboratory Einthoven galvanometer.

(c) Test of Systems.

(c) The first and third methods gave promise of ultimate success, and a base was mapped out consisting of three stations, the central of which was on the Institut Marey, and having a total length of 4,500 metres. A test was arranged to take place on 17th November, in the presence of three French Generals, on two guns firing three rounds each at a point about 4,000 metres away. The meteorological data for corrections were supplied by the Eiffel Tower.

The guns were successfully located to 20 metres for line and 40 metres for range. The time intervals recorded by the tappers did not vary by more than 1/20th second from those measured by the microphones. The French authorities were convinced that there was something in sound ranging, and Nordmann was sent to the front with his tappers for work in the field. It is interesting to note that at about the same date (January, 1915) a Section working with stop-watches was installed on the Arras front under Captain Bougier of the French Engineers, whilst a similar Section took up its position on our left to the north of Ypres. It is not known whether Capt. Bougier had any knowledge of Nordmann's experiments, but it is certain that both worked simultaneously at the problem of sound ranging with human observers, but with different apparatus, that used by Bougier being improvised at the front.

(d) Development of Bull and T.M. Apparatus.

(d) Bull was asked to carry on with the galvanometer method, and he built a 5-string Einthoven galvanometer. The whole apparatus was made more portable, and a motor lorry was fitted up as a dark room with all the instruments inside. The microphones were made more sensitive, and protected from the wind by placing them in large cones.

On 6th January, 1915, the Marey Institut outfit was sent to the front at Tracy le Mont, near Compiègne. It was in charge of Lieutenants Taris and Ferre, of the 8e Section du Génie. Professor G. Weiss and his son, who had helped in the laboratory on the mathematical side of the system, formed part of the expedition. The apparatus was at one period known as the Bull-Weiss, but Weiss's connection with it was slight, and all the technical details had been worked out by Bull.

The expedition remained at the front for a week, during the whole of which the wind was adverse. No good records of enemy guns were obtained, partly for this reason and partly owing to ignorance of the existence of the "onde de choc" or shell-wave. The shell-wave is the sound made by the shell travelling through the air, and in the case of a high velocity gun this sound travels in advance of the true sound of the gun discharge, and the sound record gives a false position.

French batteries and the bursts of enemy shells were, however, located with great success, and the conclusion arrived at was that the microphones were not sufficiently sensitive. On his return Bull carried out a number of improvements, and in the spring sent a report on his method to the Service Géographique, pointing out the advantages of the galvanometric method and advocating the use of a regular rectilinear base. Shortly afterwards the Service Geographique ordered three sets of apparatus from the Institut Marey.

At the same time the 8e Section du Génie at St. Cloud, where Bocquet was working, carried on experiments with the microphones and smoked paper recorder, and ultimately developed the T.M. method.

It is interesting to note that both the Bull system (officially adopted by the British and American Armies) and the T.M. system (officially adopted by the French Army) originated in the experiments carried out at Nordmann's instance at the Institut Marey.

(e) Other Systems in France.

(e) In the early part of 1915 a number of workers in France attacked the problem of sound ranging, with different methods. M. Dufour, of the École Normale, developed a photographic recording system, with 5 oscillographs in place of the Einthoven galvanometer, and a form of "rupteur" as microphone. This system he afterwards developed to a high pitch of excellence, employing an electro-magnetic microphone in place of the rupteur. MM. Cotton and Weiss developed a system which worked on a different plan from all the others, and was used by one of the French Armies up to the end of the war.

This system depended on the use of "rupteurs," two of which were placed at either end of a base of 200-300 yards in length, and formed part of a Wheatstone bridge circuit. A flux-meter was placed in the same position as the galvanometer in the Wheatstone bridge. When a sound-wave reached one rupteur the circuit in that arm of the bridge was broken and a current flowed through the fluxmeter. This current ceased when the circuit was broken by the arrival of the sound-wave at the other rupteur. The reading of the fluxmeter provided a measure of the time interval between the arrival of the sound at the two rupteurs and from this the direction of the source of sound could be calculated in the usual way. This system was simple, easy to instal, and required little wire; on the other hand it gave no permanent record, and usually answered to the shell-wave and not the gun-wave. It was not equal to the Bull, T.M. or Dufour systems, but it had points, and for certain purposes (possibly for trench mortars) it might be useful.

M. Claude designed the "Orthophone," an arrangement of two ear trumpets similar to that used for locating aircraft (see below, paragraph 3 (d)).

In the British Army several investigators took up this problem independently, and proposed schemes for dealing with it. None of these, however, reached the practical stage, nor did any of them offer hope of competing successfully with the Bull method.

(f) Other Systems in England.

(f) In England the question also received, at a somewhat later date, entirely independent consideration. The experiments made proved abortive, but have some historical interest. In the summer of 1916 Lieut. A. Anderson, in conjunction with Mr. Irwin, carried out a number of experiments, under the auspices of the Munitions Inventions Department, and produced an apparatus for sound ranging. This apparatus included microphones based on the rupteur principle, having a rubber diaphragm, a recorder consisting of a modified Brown telephone receiver on which a small mirror was mounted, and a cinematographic camera which received on its film a spot of light reflected from the mirror. Results were computed by a special method which is described in paragraph 7.

G.H.Q. France was notified of the production of this apparatus, and, it being considered that the recorder offered distinct possibilities, it was proposed that it should be tried in the field. Lieut. Anderson came to France later, and, having seen the Bull apparatus, did not press for the trial of his own, being apparently satisfied that it could not compete. The Anderson-Irwin apparatus was thus never used in the field. The chief lesson to be learnt from these experiments is the futility of attempting to perfect an apparatus without studying the practical conditions under which it will have to work. The apparatus included some good points, but all the experiments in England were carried out at short range and under peculiarly favourable conditions, and when Lieut. Anderson reached France he did not even know of the existence of one of the prime difficulties of sound ranging, namely, the shell-wave.

2. Preliminary Experience with Bull Apparatus.

On the arrival of Lieuts. Bragg and Robinson in France, these two officers were sent to a Bull Section on the French front in the Vosges to get experience. At this time (September, 1915) this Section was getting practically no results, owing to the type of microphone used. This was an ordinary telephonic microphone (Paris-Rouen model), to the carbon diaphragm of which a light paper horn had been gummed in order to increase the sensitivity. This microphone was much more sensitive to the shell-wave than to the gun report; in fact, it recorded the latter only in exceptional circumstances. It was sensitive to all ordinary noises, such as speech and rifle shots, and was easily affected by the wind. The character of the record was the same for every type of sound recorded, being made by a continuous vibration of the galvanometer string. This made it yery difficult to read the records.

In quiet conditions a howitzer could be recorded and its position fixed satisfactorily. In the case of a gun, the shell-wave alone was recorded, and "caustics" were used to work out its position. The normals to the shell-wave, instead of meeting in a point, outline a curve corresponding to the "caustic" in certain optical experiments, hence the use of this term in sound ranging. The caustics for German guns were calculated mathematically from their range tables, when these were available, which was only the case with the more common types. By fitting these caustics to the intersections in the board, the gun position could be found. The method was very uncertain. The shape of the caustic varies with the type of the gun, with the range, and with the muzzle velocity of the shell. The position of the gun had always to be found by a series of approximations. It had some success, however, as in those days few types of guns were used by the Germans.

Locations were plotted on a board on the scale of 1/20,000. The microphone bases and right bisectors were drawn on this board, and the angles which the asymptotes made with the right bisectors were calculated by logarithm tables for each time interval. These asymptotes were then ruled out on the board by using a large protractor.

The Section had six microphones wired to headquarters by cable, which was supported on trees and posts. The country in which it was operating was very mountainous, and it was necessary to place the microphones on the summits of convenient peaks, so that the base was far from regular.

This was the state of Sound Ranging in September, 1915, when we took it over from the French. It showed promise, but it could not be claimed that it had yet given results of any real value.

3. Early Experiences on the British Front.

(a) First Section.

(a) The first Sound-Ranging Section was installed on a base between Dickebusch and Mont Kemmel. The intention had been to have a 5,500 yard base, but as the Section was dependent on the Signal Service for the erection and maintenance of its lines, and the Signals foresaw difficulty in keeping up the lines for the greater length, it had to be cut down to 3,000 yards.

Apart from the handicap of this extremely short base, which made it difficult to obtain good intersections, this Section, which had to experiment with a view to improving methods, and at the same time procure results to justify its existence, experienced every kind of difficulty. The standard of accuracy required in fixing the microphone positions was not realised, and there were large errors, locations depended on the use of "caustics," corrections for wind and temperature were rough, and the personnel was absurdly inadequate.

Locations made at that time were limited to indicating the sub-square of the map from which the gun was firing. Nevertheless, guns were located which had previously been unknown, or only suspected, and, as already stated, results were considered sufficiently promising to justify the formation of new Sections.

(b) Early Sections.

(b) The seven new Sections formed in the spring of 1916 encountered the same difficulties due to the unsuitable microphones and the shell-wave, but they were able to profit by experience in having their bases lengthened to 5-6,000 yards. The front at that time was very quiet as compared with 1917 or 1918, and it was possible, except during a battle, to maintain the lines with the limited personnel. With these conditions howitzers were located with considerable accuracy, and even field batteries were fixed to 100 or 200 yards by means of the caustics.

(c) Stop-watch Method.

(c) While sound ranging was being developed on the above lines, certain experiments were made with other methods. Mention has been made of the French "stop-watch" section, which was established early in 1915 on the Arras front. This Section had given many good results, and had created a belief in the possibilities of sound ranging which stood the new British Sections at the South end of the line in good stead. The French personnel was excellently trained and the officers shrewd, knowledgable men, who were not above drawing bold (and generally justifiable) conclusions on scanty evidence. An attempt was made in the Third Army to raise similar Sections to fill the gaps between our microphone Sections, but experience showed that long training and practice are necessary before any reliable results can be obtained by this method, and the British stop-watch Sections came to nothing, being, moreover, soon rendered unnecessary by the increase of the regular Sections.

(d) Orthophone.

(d) Another device which was being used on the French front—the Claude Orthophone—was tried. It may be noted that the "Murray" apparatus, which was sent from England for trial, was merely a copy of the Claude, being constructed from reports and descriptions of the latter instrument. The device consists of two ear-trumpets fixed, 10 feet apart, to either end of the horizontal member of an iron T made of gas-pipe, which is supported so that it can be rotated round its central vertical axis. The base of the T is in a dug-out, and is provided with an arc and pointer; the top projects through the roof. Two tubes lead from the ear-trumpets down the gas-pipe to a stethoscope head-piece, which is worn by the observer. By rotating the whole until the sound appears to be "in front," or, in other words, of equal intensity in each ear, the approximate direction of the sound can be obtained. This instrument was soon given up by both the French and by ourselves. The shell-wave introduces insuperable difficulties in locating guns (though not howitzers) by this method, and the results obtained suffer much in comparison with those obtained by our regular system. The Germans continued, however, to use an instrument of this description, and appear to have been satisfied with the locations so obtained.

(e) Research.

(e) While personnel was being trained and new Sections formed, the officers of W Section, with some later arrivals who were suited for research, were constantly considering the various problems which had to be solved, and the improvements which it was necessary to make, in order to put sound ranging on a satisfactory footing. Of these questions the most pressing was that of the microphone. Early in 1916 Lieut. Bragg set to work, with the aid of Lieut. Tucker, to attack the problem, and in June, 1916, Lieut. Tucker invented the microphone which afterwards bore his name.

With the solution of the microphone problem it was possible to devote attention to other faults of the system, and from this time a number of improvements were introduced whose combined influence greatly increased the efficiency of the Sections. It will be convenient to follow the development of improvements in each particular line independently, though actually they took place to a large degree concurrently and in many cases were interdependent.

4. The Tucker Microphone.

The faults of the existing type of microphone were, of course, obvious, and experiments were being made with various other forms. The line which experiment should take was indicated by the results which a French physicist, Professor Esclangon, had obtained at L'Orient. He had recorded the firing of large guns by means of an instrument similar to an aneroid barometer, and discovered that the shell-wave consisted of very rapid oscillations of pressure of no great amplitude, whereas the gun report was a long wave, with which large changes of pressure were associated. The ideal microphone was one which would respond well to the long waves while ignoring the short ones.

In the Tucker microphone an air-tight container, of 20-30 litres capacity, has a small window pierced in it. Across this window is stretched a fine platinum wire, which is heated to red heat by an electric current. When the sound wave reaches the microphone the difference between the pressure inside and outside the container causes a current of air to pass through the window, and this cools the platinum wire, thus causing its resistance to decrease. The wire is in one arm of a Wheatstone bridge, or some similar electrical arrangement, and the change in resistance of the wire allows a current to flow through the corresponding string of the Einthoven galvanometer.

The free period of the Tucker microphone of the type usually employed is about 1-15th second, so that it gives a maximum response to sounds whose frequency is of the order of 15 a second. Sounds of high frequency, such as speech or noises of traffic, do not affect it at all, and even rifle shots have no effect when at a distance of more than a hundred yards; yet it will respond well to guns which are hardly audible. It has another great advantage in that it responds to the same kind of sound in the same way, a property not possessed by microphones of the contact type, and the importance of which, as giving an indication of the kind of gun firing, is obvious. It is also well damped, and records clearly and distinctly sounds which arrive within a very short interval of each other. While not ignoring the shell-wave, it responds less to it than the gun-wave, and owing to the good damping differentiates between them. At first considerable trouble was experienced in shielding it from the wind, but this was overcome by erecting brushwood o camouflage screens around the emplacement.

The new microphone was an immediate success. Its manufacture in quantity was undertaken by the General Post Office, and by September, 1916, all Sections were equipped with it. From the date of its introduction Sound Ranging may be said to rank as an exact method of location.

5. Wind and Temperature Corrections.

(a) Early Methods.

(a) After the microphone the first question to be considered was that of corrections for wind and temperature. It was arranged that the Meteorological Section (usually known by its telegraphic address "Meteor") should report the wind and temperature at regular intervals during the day to all S.R. Sections. The corrections were applied with more care, and greatly improved the accuracy of results. It was realised that the effect of wind and temperature was still uncertain, but empirical rules for calculating their effects were devised, and these were a great improvement on the older methods.

(b) Wind Sections.

(b) The Experimental Section on Salisbury Plain, which was started at the end of 1916, made various experiments on the determination of wind and temperature corrections, and as a result, mainly of the able investigation of these questions by Lieut. Gray, it was decided to establish "Wind Sections" along the front.

A Wind Section is a S.R. Section which has a series of microphone bases established on concentric semi-circles of different radius, such as 5,000, 7,000 and 9,000 yards. By exploding a bomb at a central point the rate at which the sound spreads from this point can be measured in all directions in which the sound from an enemy gun is likely to travel. It was anticipated that the results obtained by one Wind Section would apply over a fairly wide area, and the intention was to establish about four of these Sections in rear of the British front.

The results obtained by the first Wind Section greatly improved the accuracy of the neighbouring Sections, and showed that corrections based on ground wind and temperature were very misleading, especially at night. Other Wind Sections were installed with similar results. For a period of several months the results obtained by the Wind Sections in each Army were compared with those furnished by Meteor in the same Army, and a large quantity of comparative data was thus obtained.

The Wind Section improved Sound-Ranging locations immensely, but they had one great drawback. They were slow and costly to instal and very immobile. The area covered by an installation is about 35 square miles, and about 48,000 yards of air-line have to be erected. Consequently when movement began in 1918 it was out of the question to re-establish Wind Sections that had been put out of action.

By this time, however, the mass of information that had been obtained made it possible to establish reliable rules for estimating the effective wind and temperature from the data furnished by Meteor.

Hence, though Wind Sections were employed for about six months only, and are not likely to be formed for use in active service again, the results that they obtained during that period are invaluable. These results consisted briefly in the establishment of the fact that the effective wind and temperature for sound ranging are those between the altitudes of 250 feet and 500 feet, and in providing valuable information about the behaviour of the sound wave.

(c) Final Methods.

(c) When Wind Sections were abandoned a sound-ranging officer and six men were attached to Meteor in each Army. Observations were taken periodically, and from these the effective wind and temperature were deduced and data were sent to the Sections every hour by telephone. The scheme worked very satisfactorily and gave good accuracy of location. Sound-Ranging personnel was used for this purpose because the existing Meteor Staff could not cope with the extra work.

6. Regular Base.

The advantage of having a regular base had been foreseen by Mr. Bull, who proposed it to the Service Géographique in 1915. A regular straight base was adopted by X Section (Capt. Lloyd Owen) in front of Armentières in July, 1916. In November, 1916, W Section tried a regular circular base, the microphones being spaced at equal intervals on the arc of a circle of 8,000 yards' radius, which had its centre in the region of the German batteries. The advantage was at once apparent, and all Sections were thereafter urged to use regular circular bases. The idea at first met with considerable opposition, due in part, no doubt, to misapprehension as to the effect of local conditions on the microphones. It was thought for some time that small local irregularities, such as houses, banks and woods, would affect the microphones, and that rigid adherence to a regular base might consequently entail disadvantages due to bad positions. Experience proved, however, that this objection was ill-founded. In the first place it was nearly always possible to select a regular base so that all microphones were well placed; in the second it was found that small local irregularities had little effect on the microphone.

The difficulty of fitting a regular base to the terrain is, in fact, far more apparent than real. In operations in the latter half of 1918 most of the Sections installed from six to twelve bases each. In nearly all cases a base with 4½ secs. sub-base and 35 secs. radius was chosen, and the occasions when difficulty was found in making the microphones fall in suitable places were very few. Seeing that it is not necessary to adhere to this particular form of the regular base, it may be said that in open country, with no variations in height greater than 200 or 300 feet, a regular base is always possible.

The advantage of a regular base is that the breaks on the film fall on a regular curve, and that it is consequently much easier to read the film and to pick out a gun record from a number of other sounds. This advantage is enhanced when a Section moves. A computer may become expert in reading a particular irregular base, but when he moves to another irregular one he has to re-learn the characteristic appearance of the gun records from various directions. With a regular base a man accustomed to reading films on one can read them with equal ease on any other of similar form. Another advantage is that plotting boards can be standardised, and the time required to prepare a new board thereby saved. During the war plotting boards for the normal type of base were printed instead of being drawn by hand, and were used with great success by the Sections.

By April, 1917, all Sections had adopted the regular base, and thereafter never used an irregular one if it was possible to avoid it. The circular form was almost invariably adopted.

7. Methods of Plotting.

(a) Asymptote.

(a) The method of plotting locations found by experience to be best was that of using weighted threads to represent the asymptotes of the hyperbolæ. In the early days cotton or silk threads were used, attached to pins at the mid-points of the sub-bases, but these threads were too coarse, and were apt to stick together. Copper wire was tried, but broke too easily. Finally fine gut was used, and proved quite satisfactory. The gut threads were passed through holes at the centre points of the sub-bases (the holes having previously been fitted with smooth metal sockets), and were kept taut by a small weight below the board and kept in place by rubber-soled weights on the board. Each sub-base was given a colour, and the time scales and weights were coloured accordingly. A table of corrections was used to allow for the difference between the asymptotes and the hyperbolæ, but it was usually only necessary to apply this for the location of bursts nearer than 1,500 yards.

(b) Hyperbola.

(b) Two other methods which were used or tried may be mentioned.

In the first the hyperbolæ themselves are plotted on the board. For each sub-base a family of hyperbolæ is drawn, at time intervals differing usually by 1-10th of a second. The intersection is obtained by interpolating by estimation between hyperbolæ drawn on the board. This method appears to have been used by the Germans, and was employed by one of our Field Survey Battalions. It is, however, greatly inferior to the asymptote method for several reasons. Five families of hyperbolæ drawn on one board are very confusing to the eye, even if drawn in different colours; it takes much longer to interpolate between two hyperbolæ than to lay a thread across a given scale division, and errors of interpolation are liable to occur. A hyperbola board takes a very long time to draw, and the labour required is out of all proportion to the results obtained.

(c) Anderson's Circles.

(c) The second method is that proposed by Lieut. Anderson and mentioned in paragraph 1. In this method the microphone positions are plotted on a large scale, usually 1/5,000. Suppose that when a record is obtained, No. 1 microphone is the first to get the sound. The instant at which No. 1 receives it is taken as the origin of time, and time circles are drawn round the other microphones. Each time circle has a radius representing the distance travelled by sound in the interval between the record of its microphone and that of No. 1. If now a circle be drawn which touches all these time circles and passes through No. 1, its centre will be at the origin of the sound. Lieut. Anderson had sets of circles etched on sheets of plate glass, on a scale of 1/5,000, and at intervals of 20 metres radius. The glass sheet was placed on the plotting board, and by trial and error a circle was found which touched the time circles and passed through No. 1. Its radius then gave the distance of the gun from various microphones. The actual position was found by calculating, from the side lengths thus obtained, and the base length, the triangle formed by the two flank microphones and the gun position.

This method was at first thought to possess various advantages, and it is certainly sound from the scientific point of view. It has, however, the serious practical disadvantage that it entails the carriage of a number of heavy glass plates, which have to be packed in a special case. These plates were of an inconvenient size for the bases used in 1916, and for the long modern bases of 8,000 yards or more they would become quite unwieldy and unsuitable for use in the field. Experience, moreover, showed that the method is much slower than the asymptote system, and that no practical advantages ensue. The circle method was therefore never used in the field, except for the special case of locating a shell burst nearly in the line of the microphones. In this case it was usual to draw circles on tracing paper, but a small circle plate might well be carried for this purpose.

8. Ranging.

As in the case of visual observation, ranging of our own guns forms an obvious corollary to gun fixing, since, if the shell burst be sufficiently loud, its position can be fixed as well as that of a gun. Ranging of our own guns was therefore frequently carried out with success.

Location of the shell burst was begun late in 1916. The subject was studied and developed, and the "differential" method was brought to a satisfactory degree of efficiency.

Observation for ranging by sound can be done in two ways :—

(a) By ranging on the map—the direct method.
(b) By ranging on a battery which has just fired—the differential method.

(a) Direct Method (Map).

(a) Ranging on a map-point consists in determining the position of the shell burst and reporting it in the usual terms to the battery. Sound ranging is not very suitable for this method, because it is seldom that conditions are so good that a perfect intersection is obtained. The nature of this intersection is sufficiently accurate for gun fixing, and in any case can for that purpose be repeated and a mean obtained; but for fixing a shell-burst reliance has to be placed on a single intersection, and this in general is not sufficiently accurate for the purposes of ranging.

Ranging on the map was therefore resorted to only when visual ranging was impossible and sound-ranging conditions good.

This combination of circumstances usually occurred in foggy weather, and not infrequently at night, and on these occasions ranging by sound on the map was sometimes carried out with success.

As in the case of visual observation, a great part of the problem was to get the results out quickly. For this various forms of graph were used.

(b) Differential Method.

(b) If fire be opened on an enemy battery which has just fired, and a sound-ranging record be taken of both enemy guns and the bursts of our own shell, the two records will be subject to practically identical atmospheric conditions. Errors due to these conditions will therefore cancel out, and all that is necessary is to determine the *difference* between the shell record and the gun record, expressed in the usual terms of yards and minutes from the target, and correct fire accordingly. It is evidently unnecessary in this method to know exactly where the enemy battery is; it may be one that has never fired before. This "differential" method of ranging by sound is considerably more accurate than the other, and was frequently employed with great effect.

To enable the relative positions of shell and target to be determined quickly from their records, a special form of graph was designed by Major Bragg, and it was later developed by him in a mechanical form.

Many cases occurred when ranging by this method was carried out most successfully. On one occasion, opposite Bethune, a German 8-in. howitzer which had been brought close up to the line in a fog was stopped after the second round and compelled to move. On another occasion, on the Ypres front, in July, 1918, a direct hit was obtained after the third round.

(c) Long-Distance Ranging.

(c) Sound-Ranging Sections using our usual length of base cannot as a rule locate shell-bursts accurately at a greater distance than about 12,000 yards (*i.e.*, about 9,000 yards from the front), on account of the combined effect of acute intersection and the greater errors experienced at that range. A Section can, however, fix direction or "line" with sufficient accuracy up to a much greater distance. Sections were employed once in this way with great effect. Three Sections gave "line" for the fall of our rounds when shooting at the famous Courrieres gun, and the intersection of the lines, combined with some rays obtained by two Observation Groups, was used as the location. This ranging, at a distance of 20,000 yards from the front line, was eminently successful.

(d) Ranging for Calibration.

(d) Another form of ranging was done for purposes of calibration. Sound-ranging results are always less accurate in range than in director (or line). Hence ranging by sound for the purpose of calibration was, as a rule, impracticable if the guns were firing directly away from the sound-ranging base. But if it could be arranged that the guns fired across the front of the sound-ranging base, calibration could be done with good effect, for in this case the direction of the shell-burst, which could be determined accurately by sound ranging, gave a line at approximately right-angles to the line of fire, and hence fixed the range from gun to shell-burst with sufficient accuracy. Calibration was thus done on many occasions, but sound ranging is not really suitable for this class of work, and the method did not develop, as it would not compete in accuracy with the work of the Observation Groups and with Screen Calibration.

9. Determination of Calibre.

A very strong point of sound ranging is the accuracy and certainty with which the calibre of the gun or howitzer can be determined. Generally speaking this can be obtained from the time of flight between the discharge of the gun and the explosion of the shell, the exact position of each and the time interval having been determined by sound ranging.

It has been mentioned that a great advantage of the Tucker microphone is that it as a rule responds to the same sound in the same way and so produces "characteristic breaks" on the film. The shape and size of these breaks depend largely on the form of the container in which the microphone is fixed. It was hoped to design a container which would make the breaks so distinctive that it would be possible to determine the nature of any gun or howitzer recorded, and careful experiments were made on Salisbury Plain with this end in view. A distinct relation was established between certain types of break and certain calibres, but so far it has not been found possible to do more than determine broadly from the break to what class of ordnance the gun or howitzer belongs.

Sound ranging is, however, from the other evidence which it provides, the most reliable source of information on the calibre of enemy guns.

10. Recording Apparatus.

(a) Bull.

(a) The recording apparatus used by the British Army owes its design entirely to Mr. Bull. It includes an Einthoven six-string galvanometer, a lantern, time wheel with tuning fork, a cinema lantern, and various relays and resistances.

Each string of the galvanometer is connected to a microphone. When a sound wave reaches a microphone the electrical balance is upset in the manner already described in paragraph 4, and a current passes through the corresponding wire in the galvanometer, and thus causes the wire to move. The shadows of the six wires are thrown by the lantern on to a cinema film, and so long as the wires are stationary these shadows are reproduced on the moving film as a straight line. When a wire moves its shadow is broken or sharply displaced. The time wheel revolving in front of the lantern, and controlled in rate by the tuning fork, produces on the film a series of cross lines, which represent time intervals. The film thus provides a complete record of the time at which any sound wave reaches each microphone.

In order to read the film it has to be developed. In the earliest form of apparatus a dark room, adjoining the instrument room, was provided for this purpose in the special lorry. The camera was fixed close to the wall and the film was passed into the dark room through a light-proof door.

In the autumn of 1917 and afterwards, bromide paper was used instead of film. It proved equally good for practical purposes, took less time to develop, and cost about one-half the price of film.

The photographic record, though practically perfect for the purposes of accurate record and measurement, has the disadvantage that time is required for developing. From an early date efforts were made to reduce this time as much as possible. Experiments were tried with various kinds of developer at varying temperatures, and in this matter Captain Field, then O.C. Printing Company, did good work; and the actual process of developing was reduced to a matter of a few seconds. There was still, however, the delay due to cutting off the film and putting it into the bath, and to get over this an automatic developer was designed, which will be described later.

The apparatus for the first twenty Sections, with a number of spares, was made under Mr. Bull's superintendence at the Institut Marey. At first it was designed to go in the special lorry, but when this was abolished it was carried in a case, and erected on a strong baseboard when required for action.

(b) C.S.I. Company.

(b) Partly in order to be independent of foreign manufacture, and partly to quicken production, the order for later sets was given to the Cambridge Scientific Instrument Company. The Company was provided with complete working drawings and Mr. Bull visited them before they began manufacture. The Cambridge Company spared no pains in the construction of the apparatus and introduced various slight modifications in the design, some of which were undoubtedly improvements in the direction of making it more robust; but it must be admitted, in justice to the excellence of the design and workmanship of the original apparatus made in Paris, that none made at any later date lasted better or gave less trouble in the field.

(c) Automatic Developing Apparatus.

(c) The idea of an automatic arrangement for developing the film originated with M. Dufour. It was taken up by us, and apparatus on the lines suggested was constructed, with various modifications, in the S.R. workshop. It was found impracticable to develop film automatically, but bromide paper solved the difficulty, as its development is so much more rapid. The automatic developer was introduced towards the end of 1917, and nearly all the Sections used it during 1918.

In this apparatus the paper is passed direct from the camera through the necessary baths and appears developed and fixed without any check in its movement.

At first the apparatus gave a great deal of trouble, and to the end of the war it was not wholly satisfactory; but there is no doubt that automatic development is a necessity, as development by hand cannot keep pace with a rush of records on a busy day, and there should be no great difficulty in overcoming the mechanical troubles and developing a satisfactory type.

11. Conferences and Technical Papers.

Sound ranging being a highly technical service in which new methods were constantly being proposed, it was arranged that sound ranging officers should meet periodically to confer and discuss technical questions. The first of these conferences was held by officers commanding Sections in January, 1917, at Armentières. They were held at regular intervals after that, and at a later period officers commanding Field Survey Battalions made a practice of attending.

These conferences were of great value in increasing the efficiency of the Sections. The officers had an opportunity of discussing among themselves the results they had obtained and the devices they had found useful. Since the science of sound ranging was of such recent development, all Sections had been working more or less in the dark, and knew little of what other Sections had achieved. The immediate effect of the conferences was to stimulate competition.

Another means of disseminating information was the publication of technical papers. These latterly took two forms :—

(1) Technical papers, written by officers or men, and which contained proposals, discussions, and criticisms on any technical subjects.

(2) Sound ranging circulars, which were issued by G.H.Q. and contained definite instructions, laid down principles for guidance, and issued orders.

Technical papers previously issued often formed the subject of discussion at the ensuing Conference.

12. Work and Equipment of a Sound Ranging Section.

A Sound-Ranging Section at the end of the war was installed with a base at least 8,000 yards in length, at a distance of from 3,000 to 5,000 yards from the front line; that is to say, just behind the area where our active field batteries were placed. The bases were nearly always arcs of circles of 35 secs. radius (*i.e.*, the distance traversed by sound in 35 seconds, or about 11,800 metres), with microphones equally spaced at 4½ secs. interval. S.11 cable was used, laid on the ground or in trenches.

The situation of the advanced posts, from which the forward observer set the apparatus in motion, had to be such that a gun report would reach them at least 2 seconds before reaching the nearest microphone. This meant about 1,000 yards in front of the base if two posts were used, or more if there was only one post.

Headquarters were placed as near as possible to the centre of the base, but as the accommodation for an apparatus room, computing room, 4 officers and about 60 men was not always easy to find, it was often necessary to locate them at some little distance. Occasionally advanced headquarters were established near the base, with rear headquarters for transport and men who were resting.

Forward observers were equipped with maps, good field glasses, and stop-watches. An important part of the forward observer's duty was to establish the connection between a gun that was firing and the area that was being shelled, and it was, consequently, necessary for him to be able to examine the country in rear.

There were 10 forward observers in a Section, and if, as was usually the case, there were two posts, this number was none too great to allow for the necessary reliefs, cooking, casualties, etc.

At the headquarters there was, besides the sound-ranging apparatus and plotting board already described, a petrol electric set for charging accumulators, a full equipment of drawing instruments, and the usual equipment for linemen. The charging set adopted as standard was constructed by the Austin Motor Co., Ltd. The engine was a 1½ h.p. single cylinder, and the dynamo gave 700 watts.

The normal average consumption of paper or film for recording purposes was, per Section, about 40 rolls, or 15,000 feet, a month ; say 500 feet a day.

A section required about 30 miles of cable for its installation. Metallic circuits were always used. An attempt was made to use earth returns, but it was found that this could not be done with our apparatus without introducing various troubles, so that this method was not continued.

When stationary the work of a Section consisted of locating batteries, observing for ranging or calibration, patrolling the lines, keeping apparatus in order, making reports, etc. An estimate was always given of the accuracy of a location, in the same way as has been described in the case of flash-spotting locations, by classifying it as P, Q, or R (within 50, 100, or 150, later increased to 200 yds.). This, as explained in Chapter II., implied a reasonable guarantee that the location was within the limits of error indicated.

The O.C. had the general controlling and administrative work to do; one officer was usually in charge of the instruments; the Advanced Post Officer superintended the work of the forward observers and linemen.

13. Sound Ranging Sections in Battle.

The experiences of the Sound-Ranging Sections in the earlier days were limited mainly to overcoming technical difficulties and learning the work of a Section in fixing gun positions. It was not until the front became more active that the real difficulties of working a Section were realised.

(a) Somme Battle.

(a) Of the first eight Sections formed, S Section alone was installed in time to be of use in the Somme battle. This Section got into action three weeks before the offensive began, and located a number of batteries. R Section, the only other in this area, got into action after 1st July, and the noise of the battle prevented all work. S Section made several attempts to get into action during the autumn of 1916, when the Somme fighting was still going on. The upkeep of the lines was immensely difficult, because the strength of the Section was so small, but a number of locations was obtained.

(b) Arras and Messines Battles.

(b) In the Arras and Messines battles the organisation of the Sound-Ranging Sections was severely tested. So far sound ranging had developed entirely on trench warfare lines. The installation of a Section was very slow, and it was not considered excessive if it took three weeks to come into action. Methods were in vogue that were quite unsuitable for active operations; for example, it was the custom to use air-lines to the microphones. Air-line has a low resistance, good insulation, and is not meddled with by other units; but it takes a long time to erect, and it is very vulnerable. It was obviously out of the question in a battle. The experience of the Arras and Messines operations showed that the only method which could stand against the shell-fire and the traffic of a battle was to use cable lying on the ground, and also that a Section must be prepared to lay its own lines. The Signal Service are too busy in an action, and if a Section depends on them for laying lines delay is bound to ensue. For the same reason the Sections were very slow in getting installed on the new line after the German retreat to the Hindenburg Line in 1916.

The lessons of these battles were thus that a S.R. Section must use cable laid on the ground; that such cable could be laid quickly by the men of the Section, and that it was quite possible to maintain it. Enquiries were, consequently, made for a cable of good insulation and low resistance, and in April, 1917, a supply of S.11 cable was allotted by the Signal Service for sound ranging. The resistance of this cable is about 20 ohms a mile, and its insulation is good. It was used until the end of the war and was excellent in every way.

(c) Third Battle of Ypres.

(c) Attempts to do sound ranging during the battle for the Passchendaele Ridge were an absolute failure, partly owing to inexperience, but mainly to adverse conditions.

The Section operating just north of Ypres had only come into action a few weeks before the attack, and so had not even the advantage of local knowledge. The wind for three months was steadily in the west, the ground was covered with shell holes full of water and crossed in all directions by traffic, all lines were under heavy fire and it was exceedingly hard to find headquarters. In addition to this the greatest difficulty was found in surveying bases owing to the destruction of all trig. points. The experiences of the Passchendaele battle did a great deal to discredit the capabilities of sound ranging in a battle.

14. Sound Ranging Sections in Mobile Warfare.

The distinction between the operation of S.R. Sections in the battles mentioned above and in semi-mobile or mobile warfare may not appear to be clearly marked, but there is a difference. Until 1918 attacks were confined in area. It was possible to concentrate on those Sections that were engaged and supplement them; and as a rule all that was asked of them was establishment in a new position where they were likely to remain for some time. But the moment that movement became more or less rapid and general it was found that the S.R. Section that was not self-contained and mobile could not be considered completely efficient, whether it was merely a matter of moving, as in a retreat, or a question of taking up a new position.

The question of mobility was studied on the southern part of our front with great care after the experiences of the Somme battle. Arrangements in the 4th F.S.B., made on the

Corps principle, failed on account of lack of transport and of indifference or negligence on the part of Corps. Those in 3rd F.S.B., made on the Army principle, failed because the Army command would not allow an immediate advance after an attack.

These arrangements were however gradually improved until at the battle of Cambrai (November, 1917) they were allowed to materialise by the higher command. This was the first ocasion on which real mobility was attained by a S.R. Section. H. Section (Capt. Ash), of the 3rd F.S.B., then got into action 56 hours after zero, in country which had previously been in the hands of the enemy.

G.H.Q. began to intervene in the matter early in 1918, and the mobility subsequently displayed is largely due to the training in mobile methods given at the courses held for that purpose. Special mention should also be made of the 5th F.S.B., who prior to the final offensive of 8th August made complete dispositions for following up the attack, and carried them out with great ability.

The following remarks deal with the period when movement became more or less general, and practically all Sections were affected.

(a) Retreat in 1918.

(a) In the German attack in 1918 the retreat of the Fifth Army was too fast and continuous to offer any possibility of getting into action after leaving the Bases which had been occupied. All important instruments and documents were got away safely, and little information of any value was left to fall into German hands, but a good many stores had to be abandoned. Together with the Observation Groups, Sections formed a considerable part of "Carey's Force" in front of Amiens, and suffered severe casualties.

In the Third Army area, where movement was less rapid, Sections were withdrawn during the German offensive, but came into action again directly the line steadied.

In the interval, Sections from both Armies were sent back to G.H.Q. to get reinforcements and fresh equipment, and the same thing happened later in the case of the northern Armies.

There were no particular tactical lessons to be gathered from these operations, but it was easy to see that Sections had been carrying too many stores and had gone in for far too many "gadgets," which caused confusion and delay both in getting out of, and into, action.

It was partly due to having learnt the above lesson and partly to the presence of reserve Sections that moves were made with such efficiency on the Ypres Salient during the German offensive of April. In one case a Section was only out of action for 5 hours, whilst shifting backwards 7,000 yards from a forward position to a base which had been prepared and wired up for it behind. In another case a Section was in action till 12 noon when it received orders to reel up wire and return to a reserve position. At 4.30 p.m., the Section reported all ready and packed for the move. In a third case a Section was again in action in less than 48 hours.

(b) Final Advance.

(b) By the time that our counter-offensive started a great deal of experience in various degrees of movement had been gathered. Prior to the beginning of the attack, however, opinions varied as to whether sound ranging could be carried out in such times, or whether it would not be wiser to park Sections in rear and send them forward only when the enemy had prepared a stubborn resistance on a well entrenched line. The question was complicated by the transfer of tactical control to the G.O.C., R.A. of the Army, which resulted in many different opinions.

These divergencies of thought led to three solutions, which were tried at various times, but which may be condemned at once:—

(i) To call in all Sections and park them in a central place.

To do this implies long and unnecessary marches, both in the concentration and in the getting into action again, and offers no corresponding advantages.

(ii) To leave Sound Ranging Sections behind and to move them up after the line had stiffened.

This means delay again, By the time Sections had got into action movement was probably just commencing, and the valuable information which might have been got in the first day or two was lost.

(iii) To use part of the personnel of one Section to reinforce another Section or Group.

It was found that a Section once split up loses its identity and suffers much when it is reassembled.

In the final advance the experience was as follows:—

In the northern half of the front the consecutive large German withdrawals made sound ranging next to impossible. It was difficult to get up even the bulk of heavy artillery quickly, and there was insufficient transport to tackle the movement of Sound Ranging Sections until some time after the line had steadied. Some sections got into action very quickly and efficiently, however, when they eventually received permission to advance.

At the South end of the line conditions were more interesting and provided more useful lessons. The experience of the battle of Cambrai was confirmed, and it was proved that Sections could be in action 48 hours or less after receiving orders to move, and that, like the Groups, they are real tactical units capable of accompanying the movements of any large Army, and able to come into action whenever counter battery work is called for.

The above is only true, however, when—

(1) The officer in immediate tactical control (in the past the O.C., Field Survey Battalion, or the O.C., Artillery Section) is closely in touch with the tactical situation, and can gauge accurately the time at which to put in the S.R. Section.

(2) Sufficient transport is available for the stores, men and cable.

(3) The Section is entirely self-sufficient, and can survey its own base and construct its own lines.

During the advance of the Third and Fourth Armies the above conditions were gradually fulfilled. Sections continued, therefore, to play a real and important rôle, and the future utility of sound ranging in any war in which powerful artilleries take part is assured.

The first advance was made in front of Amiens and proved a triumph for the Field Survey Battalion. German batteries had been moved back some eight days before owing to a minor Australian attack. The weather in the interval was misty, but favourable for sound ranging, and the Sections obtained a number of locations unconfirmed by any other source of information. These were engaged by our batteries on the day of the attack, and an examination of the ground afterwards showed how effective in every case the counter battery work had been. Sections were all established on a new line two days after the attack. As we pushed forward still further they were brought up again, and were in action in a third position five days after the first attack.

This was the first time that anything like this had been done on a large scale, and it was repeated many times in the ensuing months. It was found that in this kind of warfare, where the retreating enemy put up a fight on one line after another, Sections could always be got into action in less time than it took to bring up heavy batteries and sufficient ammunition to make the next attack, and the number of results obtained amply repaid the work involved.

15. Training.

(a) Technical.

Officers.—The course of instruction given by the Sound-Ranging School in the latter part of the war lasted 17 days. A fair standard of mathematical and electrical knowledge was assumed, and was usually possessed by those who went through the courses. The bulk of the time was devoted to film reading, as this is always the most difficult thing to pick up. Practical instruction went on concurrently with theoretical, and at the end an examination was held.

The following is an abstract of the syllabus, full details of which will be found in Appendix IV.:—

Object of sound ranging, history, etc.
Method of working.
Corrections required (asymptote, wind, temperature).
Calculation of formulæ for corrections.
Times of flight.
Film reading.
Shell-wave, Bertrand's graphs, etc.
Types of break on films.
Accuracy of location.
Ranging.

German artillery and shells.
Details of apparatus, microphone, etc.
Maps, system of grid, etc.
Preparation of plotting board.
Organisation and work of Section in action.
Upkeep of lines.
Hostile Battery maps.

Computers.—The course lasted a fortnight, and the syllabus was similar to that of the officers' course. The subjects were treated in a more elementary manner and less time was devoted to the instrument. "Action practice," or practice in quickly applying corrections and laying out strings when a series of readings is called out, was carried out daily.

Sound-Ranging Operators (formerly called instrument repairers) were trained in the workshop. They were taught elementary ideas of electricity, the corrections and the details of the Sound-ranging apparatus, likely faults and how to repair them, stringing of harps, care of accumulators, etc. At the end of the course tests were given. The class of men taught usually knew little or nothing of electrical apparatus or of scientific instruments, many having been employed in watch making or similar work, and the course had to be designed to suit such men.

Forward Observers.—The course lasted for a week, since an observer's real training must, by the nature of his work, be done at the front. The course was mainly selective in character, and aimed at discovering men who were naturally quick and observant, training them in map reading, cable laying and repairing, the recognition of the various types of hostile artillery from the report of the gun, the noise made by the shell, and so on, with elementary ideas on the subject of the shell-wave.

(b) Mobility.

(b) The experience during the retreat of the spring of 1918 showed that Sound-Ranging Sections were not, generally speaking, mobile enough, and lacked the organisation necessary for getting in and out of action rapidly.

The mobile course was instituted in order to afford practice in the speedy and efficient installation of a Section on a new base. It aimed at giving N.C.O.'s and men practice in carrying out intelligently and quickly the wishes of the O.C., rather than at laying down a hard-and-fast routine; but it must not be forgotten that a certain amount of standardised routine in matters of detail is an essential point of good organisation, and should always be followed.

Sections in turn were brought down to St. Josse for rest, and during that time the linemen and observers were trained in line laying, the construction of pole crossings, buries etc., and particularly in map reading and in the laying of a line to a certain point and by the route marked on the map. The N.C.O.'s of the Section were trained in choosing suitable routes for cables and in taking charge of parties of linemen, who had to lay a series of cables rapidly to given points. The computers were trained in calculating the co-ordinates of the microphones, being given a map with the base marked on it and the co-ordinates of the flank microphones, and in putting the appropriate grid on a standard plotting board. The sound-ranging operators were trained in putting up and taking down the apparatus quickly, stress being laid on the preparation of proper connections beforehand.

At the end of a course a test was held. The Section was given a complete set of stores, a headquarters, transport and cable. A full-sized microphone base was marked on the map, and the Section had to bring up its stores and men to the headquarters, instal the instrument, lay out cable to the microphone positions, construct the emplacement, and get a record showing all the microphones in action in the shortest possible time. At the end of the test the O.C. School and O.C. Section went over the work together and discussed the various points in which improvements might have been made. It was found that the Sections derived considerable benefit from the course, since each man learnt to know what his particular work was in the case of a move. The results were surprising, as some Sections carried out these operations (which included the whole process of installing a Section, except the Survey) in five hours from the time of starting, and the average time taken was under nine hours. It is interesting to compare this with the ten days or so which had usually been found necessary for the erection of lines at the front when the Sections depended on outside help.

(c) Survey.

(c) It had been found that one of the main sources of delay in installing a Section was the time required for the survey of the base, and it became evident that if sound ranging were ever going to be of value in mobile operation it was essential to have at least one officer in each Section capable of carrying out the survey. With this end in view courses were started at the Depot in May, 1918, under a trained survey officer. Each course lasted a month, and five courses were given in all, a total of 37 officers being trained. With the material available, nearly all the officers being fairly good mathematicians, it was found that a course of this length was enough to give them a thorough grasp of the theoretical principles and a good knowledge of the instrument, while subsequent practice enabled them to lay out a sound-ranging base quickly and accurately. The fact that at the beginning of the advance in August nearly all Sections had an officer capable of surveying a base was of the greatest value in the operations that followed.

16. Research.

Experiment and research were carried out during the war mainly by W Section, by the Experimental Section, Salisbury Plain, and by the Experimental Section, G.H.Q. Valuable work was also done in certain special directions by the General Post Office, the Munitions Inventions' Department, and the Signals Experimental Establishment.

(a) W Section.

(a) On W Section, as already mentioned, fell the burden of all early investigation and experiment. It was in this Section, in its cramped and inconvenient quarters on the slopes of Mt. Kemmel, that the problem of the microphone was attacked and the Tucker microphone invented, and it was here that all the first investigations were made into the effect of wind and temperature, and the various practical problems considered in connection with the work of a Section in the field.

(b) Experimental Section, Salisbury Plain.

(b) The Experimental Section on Salisbury Plain, which started work late in 1916, was able to devote more time to research, and in most respects worked under better conditions.

In the programme of research for this Section were included the improvement of the microphone, the standardisation of the container, the elucidation of the wind and temperature effects, the investigation of the accuracy of Sound-Ranging locations, and the development of ranging our own guns by sound.

The Section had considerable difficulty in getting results for the first few months, owing to errors made in the survey of its bases. For this reason no satisfactory data relating to accuracy were obtained. On the other hand, the wind question was worked out very thoroughly, and led to the establishment of Wind Sections. In addition, the Section was asked, soon after its installation, to help in determining muzzle velocities by the screen method, and this afterwards led to the formation of Calibration Sections. The Section also carried out experiments on the size and shape of the microphone container, which had valuable results in establishing a standard pattern.

(c) Experimental Section, G.H.Q.

(c) The Experimental Section, G.H.Q., continued investigations of various questions, mainly connected with practical details of apparatus. Its chief work was the improvement and standardisation of the plotting board and the production of the automatic developer.

(d) G.P.O.

(d) The Engineering Branch of the General Post Office took the liveliest interest in the work of the Sound-Ranging Sections, and the most valuable advice and assistance were given, under the direction of the Chief Engineer, Mr. Preece, by his assistant, Mr. Pollock. Besides organising the construction of the Tucker microphone in quantity, they made various improvements in details. They also conducted a series of experiments on the construction of a recording apparatus which would avoid the necessity for photographic development, while preserving the other advantages of the Bull system. These experiments did not, however, succeed in producing anything which could replace the Bull apparatus.

(e) M.I.D.

(e) In the Munitions Inventions Department, Mr. Irwin (who was associated with Lieut. Anderson in the production of the Anderson-Irwin Sound-Ranging apparatus) carried out a long series of experiments with a view to producing a satisfactory pen-recording apparatus. A good pen-recorder was designed, but it was not considered that it could compete advantageously with the photographic record, though it would probably have been most suitable for sections for fixing trench mortar positions had it been possible to form these.

(f) Wireless Transmission and Earth Tremors.

(f) The Signals Experimental Section carried out experiments in the application of wireless transmission to Sound Ranging, and various investigators considered the question of gun location by earth tremors. These subjects are dealt with in the two following paragraphs.

17. Application of Wireless Transmission.

For some months in 1917 experiments were carried out with a view to determining whether the impulse from the recording microphone could not be transmitted to the registering apparatus by wireless in such a manner as would enable it to be used for sound ranging. Were that possible the construction and maintenance of lines would be comparatively trivial, and much time would be saved. Unfortunately it turned out that wireless is still unable to solve the problem without large and cumbersome installations at each microphone and other disadvantages. Probably wireless will one day replace cable, but it is not able to at the moment. The Signals Officers who investigated the problem did very valuable and efficient work, however, and succeeded in producing a system of the relay type. When the gun affected the microphone a "trigger" valve was set in oscillation, and this affected a relay valve at headquarters, and set up a vibratory current in one of the Einthoven strings. Apart from the drawbacks of the size and weight of the installations at each post and the staff necessary to maintain them, the method gave records which had no character. All sounds above a certain intensity caused the string to vibrate in the same way, and it would be almost impossible to work with such records at the front, as it is most important to have a system which produces a record to some extent characteristic of the sound. The work of the Signals Experimental Section is a step towards achieving practical sound ranging by wireless, but in the present state of our knowledge the difficulties would seem to be great. The best policy would be to watch carefully the development of wireless telephony, as the problems are similar, and any great advance in wireless telephony could be immediately applied to sound ranging.

18. Location of Wire Tremors.

The possibility of locating sounds by means of earth tremors has attracted a good deal of attention, because the method would be independent of meteorological conditions. In England experiments were conducted by Mr. H. Shaw and others, and the French and Germans have tried the method, but all would seem to have arrived at the conclusion that it is not possible to locate a gun by this means. Owing to the fact that the shock of recoil on the discharge of a gun is taken up in the mounting and not communicated directly to the ground, the shock given to the ground is not sufficiently strong to be distinguished at 9,000 yards from other earth tremors. The Germans state (in a document found at Wahn) that they had some success with trench mortars, being able to pick these up at 2,000 yards distance. All agree in saying that the burst of a shell in the ground can be distinguished at a great distance, and the French tried during the war to range guns in this way. It is almost certain that a method for doing this could be devised, if it were worth doing. This is rather questionable, for the method would only be capable of comparative results; that is to say, it could only enable ranging to be carried on if the first burst had been located by some other means, for the variations in the speed of sound in the ground preclude an absolute method.

Correspondence on this subject will be found in a file, "Seismic Method of Sound Ranging," in M.I.4, War Office.

SECTION III.—DEDUCTIONS.

1. Chief Lessons.

The chief lessons on the subject of Sound Ranging to be learnt from the experience of the war are as follows:—

(1) The organisation and training must be such as will fit Sections for the greater difficulties of mobile operations rather than for the lesser difficulties of stationary warfare.

(2) For this purpose adequate personnel and transport must be provided.

(3) The tactical handling must be efficient.

2. Organisation and Training.

A Sound-Ranging Section must be independent of outside help. It must contain within itself the knowledge and the appliances necessary to its work in all circumstances. Its training must therefore include, besides the technical work of sound ranging, instruction in survey and the erection and maintenance of lines. It must be practised in team work and mobility, and learn to combine rapidity of movement with technical efficiency.

3. Personnel and Transport.

The personnel and transport required have already been dealt with in Section I. If sound ranging is to be efficient, the mistake of starving this service must not be repeated. Repeated instances could be given of the way in which Sections were prevented from being of full utility owing to this continued shortage. For example, there were never more than five linemen on the establishment. These men were supposed to lay from 30 to 40 miles of cable, weighing five tons, maintain it, reel it up, march forward and lay it again every few days during an advance. Again, the transport allowed for a Section (a lorry, box-car and light car) proved quite inadequate for mobile warfare, but even this amount was not available, because the Field Survey Battalions were themselves so short of transport for H.Q. that the Sound-Ranging Sections were robbed.

4. Tactical Control.

The possibilities of Sound Ranging were never properly appreciated until the advance of 1918 showed what could be done under good tactical management. Instances have been given, in Section II., 14, of tactical mishandling. This was due to several causes. There was, in the first place, much ignorance of the capabilities in movement of a S.R. Section, an ignorance by no means confined to those outside the Field Survey Battalions. It was not until the combined effect of experience in movement at the front and courses in mobility at G.H.Q. showed what Sections could do with proper organisation and attention to details that it was realised that a S.R. Section is perfectly capable of taking part in movement at least as quickly as heavy artillery. Another cause of bad tactics was that until late in the war the control was too far in rear. Control must be in the hands of someone on the spot closely in touch with the tactical situation. There was a marked improvement in this respect when Artillery Section Commanders were appointed, but these were only a compromise for the real need, which was a Technical Commander with each Corps. This did not eventuate during the war, but will, it is hoped, be the system in any future big war. With a Commander at the Corps H.Q., himself (as he will be in the future) an Artillery officer, and closely in touch with the Artillery situation, there should be no difficulty in ensuring that the Groups and Sections are always in their proper place in a forward movement; that is to say, well to the front, in a position to secure the earliest information possible.

The old idea that obtained for some time during the period of stationary warfare that a Sound-Ranging Section was a territorial unit and should serve an area rather than a formation was of course exploded long before the end of the war. It is mentioned here as a matter of historical interest. The needs of mobile warfare, and the great importance of the personal element in conducing to confidence, far outweigh the slight loss of efficiency which may occur after a move and before the Section learns the local conditions. A S.R. Section must serve a particular formation and move with it wherever it goes.

5. Selection of Officers.

In the early days of Sound-Ranging officers were selected from those with the highest scientific and mathematical attainments, and the idea has obtained generally that all sound rangers must be scientific experts. This idea is wrong. A large proportion of pure scientists was useful in the beginning, but now that Sound Ranging has reached the practical stage, and has to take its place with other weapons of war in the field, the practical side, the organisation, the efficiency of the apparatus, the care of the men and transport are all as important as a knowledge of physics. On the other hand, it is equally wrong to say that Sound Ranging is as simple as working a field gun, and that science is required only in experimental sections at the base.

Sound Ranging, in its present stage, requires a certain proportion of specialists, and a section which has not got at least one officer who is a first-class computer will never get the best results. The difference between a good and medium computer is enormous. The one will tackle records as they come in and get location after location from them, while the other, with exactly the same records, will not be able to work out a single battery. It was found in the war that a man who had a first-class scientific education and had passed through the Sound-Ranging School required at least six months' experience before he could be considered completely efficient as a computer. The difficulty does not lies in the mathematics involved, which are of the simplest order. The qualities which make a successful computer are those which make a good experimenter in any science—namely, the power of getting quickly the best results from a series of imperfect observations and of estimating honestly the error of the final result. The computing work is the most specialised part of Sound Ranging, and to be successful must be done by the right type of man. But so long as he has the requisite qualities there is no occasion for him to be a mere laboratory scientist. The experience of this war has shown that many men with the highest scientific attainments are as keenly alive as anyone to the practical side of things.

The officer commanding should be a good practical organiser and director, his scientific knowledge being of secondary importance.

One officer in the Section should be competent to look after all electrical apparatus, while the fourth must be able to superintend the work of the linemen and forward observers.

Two officers at least should be capable of doing all the survey required in installing a Section.

Needless to say, all officers must be interested in the work. However practical and able, it would be absurd to have officers in a S.R. Section to whom science is abhorrent. Generally speaking, the type of man required is the electrical engineer with a taste for, and some knowledge of, physics. The ideal Section would be composed of such men, one of whom was an expert physicist and experimenter.

No mention has been made of Artillery knowledge, as it is assumed that in future this will be possessed. It is, of course, essential.

6. Technical Development.

Generally speaking, the technical methods employed at the end of the war were satisfactory. They were the result of intensive practical experience and it is not easy to see how to make many improvements in the accuracy of results, the method of getting wind and temperature corrections, ease of reading the records, or speed of obtaining the record and plotting the result. The apparatus has been improved to such a pitch that it could hardly be made more efficient. The results obtained by a Section depended almost entirely on the skill of the officers who computed.

(a) Recording Apparatus.

(a) With regard to the Bull apparatus, as there is no finality in anything it would be absurd to suppose that nothing better will ever be devised. It is, however, difficult in the present state of knowledge to imagine an apparatus which will more completely fulfil the functions required. The impulse of the sound-wave is transmitted to the record without the intervention of any moving part, and it cannot be easy to improve on that. The one objection to the apparatus which can be urged with any degree of seriousness is that the record is expensive. Bromide cost, at the end of the war, about 0·7d. a foot of strip, so that the paper alone used by a Section in a normal day (500 feet) cost nearly 30s. It would be an advantage if this could be reduced, as there would then be no objection to running the apparatus continuously, as is done by the French Sections. If a "pen reading" apparatus could be devised which was in no way inferior to the Bull apparatus it would have this advantage of economy. So far, in spite of several attempts by competent investigators, no such apparatus has been produced; and in view of the remarkable efficiency of the existing method, and the comparatively small advantage to be gained by any change, it is doubtful whether it would be justifiable to expend much time and energy on the problem. It is at any rate not a pressing need.

In other directions there is however an ample field for research and improvement.

(b) Microphone.

(b) The chief objection to the Tucker microphone is that it requires a very low resistance (250 ohms for each circuit) and that this necessitates the use of a heavy cable. The S.11 cable which was used weighs about 5 tons for the 30 miles required by a Section. If it were possible to use a cable of higher resistance the weight could be reduced to one-third or one-quarter of this amount, which would mean a reduction of linemen and of transport, both most important considerations. Future experiment should therefore be directed to improving the Tucker or devising a new form of microphone which will give equally good results and can be used with a microphone circuit of 1,000 or 2,000 ohms resistance.

It must, however, be remembered that the Tucker microphone and S.11 cable have stood the test of use at the front in every conceivable circumstance, and hence that they should not be replaced by anything that does not prove itself superior under equally severe tests.

(c) Automatic Developer.

(c) A satisfactory and fool-proof automatic developer should be designed. This should not offer great difficulty.

(d) Application of Wireless.

(d) The development of wireless telephony should be carefully watched, as the problem is similar to that of sound ranging, and further experiments in the application of wireless transmission to sound ranging should be made whenever an advance in wireless telephony holds out some prospect of success.

CHAPTER 4.

CO-ORDINATION.

SECTION I.—THE COMPILATION SECTION.

1. Early History in Third Army.

The Compilation Section had its origin in the 3rd Field Survey Battalion. It was due mainly to the efforts of Lt.-Col. (then Major) Winterbotham that the problem was correctly apprehended and tackled in the right way, while the sympathetic attitude of the Third Army Staff contributed to the excellent co-ordination of effort and to the great success which the Compilation Section had in this Army.

(a) Origin.

(a) Before the formation of the Artillery Survey Detachment in October, 1915, a good deal of thought was given in the Third Army to the use which should be made of the results and locations which it was hoped to obtain.

While it was anticipated that there would be little difficulty in arranging survey posts and in training the staff, it was felt that the problem lay in the proper collation of all results, i.e., air photographs, R.F.C. reports, Corps Intelligence summaries, R.A. observation reports, as well as such locations and reports as might result from the work of the Artillery Survey Detachment.

Information concerning the movements and organisation of the enemy had always been dealt with by the General Staff (Intelligence), but the location of German Batteries had been the subject of a number of periodical lists emanating from R.A., R.F.C., and General Staff. These lists differing widely from each other, and in no case getting very close to the truth, had resulted in a distrust of any and all lists, and a reliance on the necessarily crude and insufficient knowledge of the gunner concerned. To compare, to sift, and to analyse into a really reliable list was therefore regarded as the function of the central office of the Artillery Survey Detachment.

For some time this work was carried out by two specially chosen N.C.O.'s under the personal supervision of the O.C. Topographical Section, but the work grew so quickly and assumed such dimensions that a special section called "The Compilation Section" was started in December, 1915.

(b) First Compilation Section.

(b) In each Army Staff a special officer was allowed for the study of air photographs, and the officer chosen for the work in the Third Army, Lieut. Goldsmith, was attached to the 3rd Topographical Section. His duties were defined in the following terms:—

> "To extract from reports and summaries all evidence as to position, whether of batteries, dumps, observation posts, railways, earthworks, obstacles, etc. To file the same in a logical and handy way for reference.
>
> "To study the interpretation of air photographs, and to that end the system and type of enemy works.
>
> "To issue the Intelligence Summaries of the Survey Posts and to provide them with lists of points to be cleared up."

(c) Enemy Organisation.

(c) Whilst the General Staff (Intelligence) was and is responsible for information concerning the strength and disposition of the enemy, a mass of topographical evidence connected with this subject has to be plotted accurately on the map.

In the first new and good large scale maps the enemy's tracks, light railways, machine-gun emplacements, etc., appeared on the trench plates. The bulk of the air photograph work was done by the Topographical Section or its descendants, the Field Survey Company and Field Survey Battalion, cases of doubt being referred to the General Staff (Intelligence).

The Compilation Section dealt therefore with all those cases of air photograph interpretation which affected maps as well as with battery location. A skilled topographer plotted positions on the map.

At this period (early 1916) photographs were beginning to come in in considerable numbers, the average number on a good day being about 50 for the Army front.

(d) Battery Positions.

(d) During the early surveys and the plotting of the first good maps many features of interest were fixed.

Such features were prominent trees, houses, etc., and all well-defined earthworks, inclusive of prepared artillery emplacements. Lists were printed for each sheet, giving the co-ordinates and map-square locations of all such fixed points. These lists were called "Positions Determined," and gradually became a statement of the known and plotted battery positions in each sheet, irrespective of whether these were or were not active.

(e) First Active Hostile Battery List.

(e) In order to reduce the number of competing lists, and to ensure the loyal co-operation of all units, conversations had been taking place between the General Staff (Intelligence), Royal Flying Corps, and the Topographical Section.

Towards the end of February the final arrangements were made for a list, issued by the Major-General, General Staff, entitled the "Active Hostile Battery" List, embodying all location reports and prepared by the Field Survey Company.

The counter battery information was therefore from the end of February, 1916, provided in the following forms:—

(1) A weekly list of Active Hostile Batteries inclusive of Royal Flying Corps and Field Survey Company locations.

(2) Intermediate direct reports from Royal Flying Corps and Observation Section during the week, which were automatically confirmed or cancelled by the weekly A.H.B. lists.

(3) Lists of "Positions Determined" as before, which dealt only with emplacements (not necessarily batteries) whose position was known, and which were, or could be, accurately placed on the map.

(f) Conferences.

(f) In order that the Active Hostile Battery List should really represent the studied opinion of those able to judge, conferences were held at which the G.O.C., Heavy Artillery, the G.O.C., R.F.C. Brigade, General Staff Intelligence of the Army, and the O.C., Field Survey Company, were present.

(g) Counter Battery and Target Maps.

(g) Just as the lists of positions and bearings made in battery survey had to give way to the artillery board, on which information was shown graphically, so the active hostile battery list and the lists of targets had to be printed on maps. Counter battery and target maps were started therefore in May, 1916. The first issue showed batteries which appeared on the active hostile battery lists, and included their arcs of fire, for the German Artillery tactics of that day were such as to allow of exact knowledge of their positions and arcs.

2. Compilation Sections in Other Armies.

The establishment of Field Survey Companies in February, 1916, raised compilation sections automatically in other Armies. Their work varied widely, however, from that of the 3rd Field Survey Company.

The latter inherited from the Ranging Section and the Ranging and Survey Section a record of close and intimate co-operation with the Artillery. This was fostered by the institution of the Artillery Survey Section and by the subsequent growth of the position of the O.C. as technical adviser in matters of survey to the M.G.R.A., whilst the Third Army Staff made the work of the Compilation Section an integral part of the Army Headquarters.

In the First Army the compiling officer was not so used by the Army, but remained a recorder of the results of the First Army Observation Section. As these results continued for months to be a negligible quantity the Compilation Section had little to do, and remained for the next year without interest or influence.

In the Second Army the compiling officer continued to be the official recorder of the doings of the Observation Section. He had, in fact, belonged to the old Second Army R.A. Flash-Spotting Section, but his work resembled that done by the Third Army much more than was the case in the First Army. Even in the scope of his Artillery Intelligence work, however, the beginnings were nothing like so general or far-reaching.

The 4th and 5th Field Survey Companies were raised some time after the introduction of the Compilation Section in the 3rd Field Survey Company. Their Compilation Sections were modelled upon and worked on the same lines. Certain modifications were, however, made. In the Fourth Army, for example, the list of "Positions Determined" was discontinued, the A.H.B. list being divided into two parts—(1) positions believed active, (2) believed unoccupied. "Battery Maps" were first published by the 4th Field Survey Company soon after the beginning of the Somme battle. The 4th Field Survey Company had time to settle down to a regular routine, but the 5th had not, before the Battle of the Somme brought up a number of new problems.

By this date the first eight Sound-Ranging Sections had been formed, and their results were beginning to come in.

3. Appointment of Counter Battery Staff Officer.

During the Battle of the Somme in 1916 German artillery tactics changed considerably. Protection gave way to concealment, and positions changed with a rapidity which made an Army compilation out of date almost as soon as lists or maps could be produced.

The appointment of the Counter-Battery Staff Officer was instituted to deal with the problem, and the Counter-Battery Staff Officer had a compilation office for his counter-battery area.

The Field Survey Company compilation, in these circumstances, became a more studied Army view of the same problem, useless for action which had to be taken at once, but useful as a help in doubtful points, as a guide on matters of location for the M.G.R.A., and as a check on the technical work of the Groups and Sections.

The lesson of the Somme battle spread quickly. Counter-Battery Staff Officers and R.A. Reconnaissance Officers were everywhere installed, and in the Third Army area the Field Survey Compilation office became the source from which the Army R.A.R.O. drew his facts for the M.G.R.A., whilst it provided the O.C. with a check on technical location. The Active Hostile Battery List continued to be published weekly and was supplemented by daily lists from the Corps.

4. Progress in First and Second Armies.

Meanwhile the Groups and Section in the First Army were rapidly improving and a good compilation office was established. The advance over the Vimy Ridge was the only movement which affected the First Army in 1917, so that no difficulties resulted from the centralisation of that compilation at F.S.B. Headquarters. A daily list was issued, and although the Corps issued their own lists the Field Survey Company data were of considerable use to the R.A. at Army Headquarters.

In the Second Army the compilation office was sent up to the Army Location Report Centre far from Army H.Q., and issued its lists from there. Such a procedure appears unsound. A tabular statement of the locations made by Groups and Sections can only be of value to the O.C. Field Survey Company, since each location is reported by telephone to the Counter Battery Staff Officer directly after it is made. On the other hand Counter-Battery Staff Officers make their own analysis of the work of the different branches, and have never shown much enthusiasm for an Army list. It is, therefore, at Army H.Q. that such a list should be produced.

5. Growth of Work.

The number of photographs received constantly increased both in number and in areas covered. Investigation of the evidence they gave of the intentions and organisation of the enemy increased proportionally, and the volume of work soon necessitated an increase of staff and a separation into counter-battery and enemy organisation sides. It will be noted that the former is purely artillery work, but so wa much of the work done by Field Survey Battalions during the war. Enemy organisation, on the other hand, is the business of the General Staff Intelligence. Both, however, are necessary to the preparation of the map, and it is the man who deals continuously with a circumscribed area and the photographs dealing with it who is generally the first to spot new material for the map.

6. Relations with the Artillery.

The increasing importance to the Artillery of the work of the Compilation Sections led to a demand that they should work at the R.A. Headquarters under the direct control of the M.G.R.A.

From the summer of 1917, therefore, that part of the compilation office which dealt with purely artillery matters was detached in three Armies from Battalion Headquarters, and became virtually a part of the M.G.R.A.'s office. In the Third and Fourth Armies this was not done, but in the former the M.G.R.A. and the F.S. Co. were located in the same building.

The examination of air photographs for matters of "organisation," *i.e.*, light railways, tracks, deviations, dumps, etc., remained, naturally, at the Battalion Headquarters in all cases.

7. Function of the Map.

The first 1/10,000 compilation maps on the Third Army front were quickly followed by good mapping of a similar sort along the whole front. Cases did happen here and there of distortion, but on the whole these maps were good, and it was not often that serious errors could be detected.

Results obtained by flash or sound location were of an order of accuracy inferior to that of the maps. In the British Army, therefore, the final arbiter of position was the map, and the plotting on it from an air photo.

This is a point worthy of note because German procedure differed essentially. The German Manual for flash spotting and sound ranging lays down that in many cases locations thus obtained may be taken as a sort of fourth order triangulation, and accepted in preference to the map. This ruling follows rather naturally from the inferior order of topography observable in their maps.

If, however, it is possible to turn out a map of such accuracy that it may be regarded as the final arbiter, it obviously lightens the task of the compilation office, and affords a base on which all other results may be plotted and compared.

There is no question that our locations were of a much higher order than the German, and probably the same applies to French results also.

In the light of our four years experience, however, it is clear that we might have improved not only the maps themselves, but the plotting from air photographs upon them, if we had made a sort of fourth triangulation from air photographs. Cross roads, corners of woods, hedge ord itch junctions or corners, abandoned tanks, and, in fact, any natural or artificial subjects might have been included. Lists of the co-ordinates of such points would have materially improved and assisted the plotting not only in Field Survey Battalion drawing offices but in Counter-Battery Offices also.

8. Strength and Duties of a Compilation Section.

Taking the case of a compilation office which was not split up in order to detach Artillery work to the M.G.R.A.'s office, the strength found necessary was 3 officers, 10 N.C.O.'s and men. Their duties were—

(a) Examination of all air photographs received.

(b) Identification and plotting on the map of all Battery Positions, whether active or inactive.

(c) Preparation of "enemy organisation" map for M.G.R.A. and G.S.I. approval.

The number of air photographs which arrived for investigation varied from 300 to 400, after a fine clear day, to 100 on an average day. It very rarely happened that none were taken at all.

The maps produced as the result of the work of the Compilation Sections bore various names in the different Armies, such as Target, Harassing Fire, Enemy Battery, etc. Finally, they were standardised and reduced to two types; Hostile Battery Positions and Enemy Organisation. The showing of "activity" of batteries on the map was discontinued.

9. Future Methods.

Battery location units will in future be under the Artillery, and with them will go the compilation office. With the decentralisation to Corps which will almost certainly take place the bulk of the work that was done by the Field Survey Battalions at Army Headquarters will in future, no doubt, be done at the Corps.

Experience has shown, however, that some such unit is required at Army Headquarters, and it seems probable that a Staff officer dealing with all matters of location will form part of the Staff of the M.G.R.A. of an Army, and that he will co-ordinate the work of the compilation offices in the lower formations. Such a Staff officer will, it is hoped, include balloons under his control.

The Survey Headquarters will presumably remain the final authority on exact positions, that authority being expressed through the medium of the map; that is to say, that R.A. locations will in cases of doubt conform to the map, rather than the map to R.A. locations.

The position of such emplacements as are topographical features will as a rule be fixed and published by the Survey units, while all "battery" information (such as occupation, non-occupation, activity, and positions of invisible emplacements) will presumably be published as required from data supplied by the Artillery.

SECTION II.—CO-OPERATION.

1. General.

The account in Section I. of the work of the Compilation Sections shows how the results of the Observation Groups and Sound-Ranging Sections were combined, and also that the Compilation Sections had to take into account other means of location, such as air photographs, aeroplane and balloon observation, and various reports.

In dealing with the question of co-operation one is led inevitably from the consideration of co-operation between the sub-units of the Field Survey Battalions to that between these sub-units and other means of location.

Broadly speaking, methods of location may be divided into two classes, terrestrial and aerial. The former, of which the Field Survey Battalions were the chief exponents, is by its nature precise and independent of the map; the latter is comparatively approximate, and is dependent upon the map and map-reading. As a general rule, terrestrial location is slower, and is the chief agent for fixing positions; aerial observation is quicker, and is the principle means of reporting activity.

The ideal system would co-ordinate and combine the whole.

In the following paragraphs an account is given of the co-operation between Groups and Sections, and after that the various attempts at co-operation with other sources of location are described. In a final paragraph deductions are drawn from the experience of the war.

2. Co-operation between Groups and Sections.

In the early days of flash spotting and sound ranging, when each branch was chiefly concerned with getting over initial difficulties and improving technical efficiency, it was only natural that each should think theirs the chief agency for battery-fixing. As time went on, however, it became evident that the two were but parts of one system for locating batteries, and that they were inter-dependent. Flash spotting and sound ranging are entirely complementary means of fixing guns. Each can do certain things which the other can not, and each can aid the other in various ways.

The importance of co-operation and a good knowledge of each other's work led to the excellent practice in certain Field Survey Battalions of attaching Group Officers to a Sound Ranging Section, and *vice versa*, and even of making them exchange duties for a time. Instructions were also issued from G.H.Q. that wherever possible Group and Section H.Q. should be situated together. The results were most beneficial in broadening outlook and increasing efficiency.

Another measure that tended to general efficiency was the Battalion conferences held weekly in most Field Survey Battalions to discuss methods of location. These brought Flash-spotting and Sound-ranging officers together and inculculated the idea that they were working together to a common end.

Direct co-operation between these units was also practised in various ways. When the 4th Field Survey Company was on the coast, in the winter of 1917-18, the question of co-operation between Groups and Sections received close attention. At this time the Sound Ranging Section in that area was having difficulty in maintaining the line to its Advanced Post. A direct line was laid between No. 6 Group and S Sound Ranging Section, and a man on duty at the Group started the sound-ranging apparatus (when conditions were favourable) when he saw a light on the F. and B. board, thus acting as the Forward Observer for the S.R. Section. This was found most useful for checking sound ranging results, and in locating H.V. guns firing at long and irregular intervals. Later, when the Company was transferred to the Ypres front, special attention was devoted to co-operation between Groups and Sections with the idea of obtaining simultaneous location by flash and sound. The same had been attempted by the 3rd F.S.C. on the Bully Grenay-Roclincourt sector in 1916. The results were not in either case so good as had been hoped, but the necessity for developing this co-operation was demonstrated by an examination of captured positions after 28th September, 1917, when strong evidence was obtained that the enemy had been successful in deceiving the Groups with dummy flashes.

3. Proposal to Combine Groups and Sections.

As a result of his experience in the co-operation of Groups and Sections, the O.C., 4th Field Survey Battalion proposed that in a future reorganisation acoustic and visual observation should be combined in one unit, to be called an Observation Section, which would carry out both flash spotting and sound ranging. There is certainly much to be said for this proposal.

It evidently implies the employment of equal numbers of Groups and Sections of these units. The question of relative numbers was discussed towards the end of the war, and the balance of opinion, though not by any preponderating majority, was in favour of having rather more Groups than Sections. This was on the ground that the Group is more mobile than the Section, and hence more useful in moving warfare. This is quite true, but insufficient weight was apparently allowed for the fact that the Sound Ranging Section, though somewhat less mobile, is more economical. An analysis of the results obtained by six Observation Groups and six Sound Ranging Sections in average conditions during the period December, 1917, to September, 1918, shows that the Groups got 7,540 locations and the Sections 11,315. No doubt the Groups during this period did more ranging of our own guns than the Sections; but, on the other hand, the strength of a Section was two-thirds that of a Group, and there can be no doubt that, man for man, the S.R. Sections were more productive of results. Furthermore, throughout the war practically the same number of Groups as of Sections was found to be required to cover a given front; and if there are, say, one each of these units serving a particular formation, as a Corps, it is not likely to serve any useful purpose to push in extra ones as soon as operations become mobile. They would probably be in the way.

The conclusion is that the same number is required, and that the rate is, as the experience of the war showed, one of each per Corps of (on an average) three Divisions.

If this Group and Section in a future organisation form part of a Corps Company, with a common O.C. and H.Q., this comes to practically the same thing as combining the Group and Section as one unit. The same advantages of pooling personnel and transport when necessary will obtain, and identity of interest will be established.

In peace time, however, the same community of interest will not be so certain if Observation Groups and Sound Ranging Sections are regarded as separate units, which only come together for the purpose of exercise or manœuvres. It would, therefore, be of great advantage, in order to ensure the closest possible touch, to combine them definitely in one unit.

The inclusion in such a unit of other means of location, such as Observation Balloons, would naturally follow if the conclusions arrived at in the final paragraph of this Section are accepted.

4. Co-operation with Other Arms.

In 1916 a good deal of attention was devoted in the Third and Fifth Armies to the question of co-operation between the various sources of location. Following the example of the French (after the experience of the Somme battle), conferences were instituted, and at times were held daily, which were attended by representatives of R.A.F., F.S.C., Corps Artillery Intelligence Officers, and sometimes by Counter Battery Staff Officers and representatives of G.S. Intelligence. In the Third Army direct lines were laid between neighbouring F.S.C. Groups and Sections, and a special motor cycle service was started to all squadrons

R.A.F., Kite Balloon Sections, and Heavy Artillery H.Q., for the transmission of information.

With a view to disseminating knowledge of each other's methods, courses of training and lectures on location were given by various F.S.Cos. to R.A. officers, and lectures to Squadrons R.A.F. and K.B. Sections; officers of Survey units were attached to batteries; and lectures by Survey officers were included as a regular item in the courses at Artillery Schools.

Later, in the First and Second Armies, Report Centres (described below) were established for the purpose of transmitting and combining information.

In the 4th F.S.B., while on the coast, various experiments were carried out, with useful results, in direct co-operation between aeroplanes and kite balloons on the one hand and S.R. Sections on the other.

5. Co-ordination in the Corps.

The Army systems of co-operation and co-ordination mentioned above broke down during movement and hostile attacks, because the Army was too far from the front line for its information to be completely up to date. The natural result was devolution to the Corps.

The original idea in this devolution was that Artillery locations should be analysed at the Corps H.Q. by Artillery Intelligence officers trained in survey methods, and that the conferences which had been so successful in the Army should be reproduced in the Corps. The actual outcome, however, was that the analysis was done by the Corps Counter-Battery Staff officer.

It is beyond the province of this history to discuss the merits of the two methods; but it may be mentioned as a matter of actual fact that the Counter-Battery Staff officer was usually by his position out of direct touch with certain sources of information, and that he had at first, and for some time, little or no knowledge of the work and methods of the Survey units, though these methods were responsible for most of the exact location of enemy batteries. He was not, therefore, at any rate until late in the war, in a position to understand the comparative value of the results obtained.

The outcome of this devolution was, therefore, some degree of retrogression. There was still no general control of means of location, while there was to some extent less co-operation than had been the case when Army conferences were held.

6. Report or Information Centres.

Report Centres were established in the First and Second Armies in the autumn of 1917, with the common object of securing co-operation, but differing in details. In the First Army a Report Centre was established at each Group H.Q.; in the Second a single Centre was formed for the whole Army front.

In order to avoid confusion with certain other Report Centres it was decided to call these "Information Centres," and they will be called by that name hereafter.

An Information Centre in the First Army consisted mainly of a telephone exchange, connected to the nearest Observation Groups and Sound Ranging Sections, Kite Balloons, Artillery H.Q. and Corps H.Q. It was located at an Observation Group H.Q. as being the most convenient centre. It was provided with a wireless receiving set. Its object was to transmit rapidly to all location units concerned information of any kind affecting location. Thus, if an Observation Group obtained a single ray observation, or a 2-ray intersection, adjoining Groups and Sections, if the probable position came within their range of observation, were immediately informed, and so were able to concentrate upon it. Similarly "NF" calls from aeroplanes and reports from Kite Balloons were transmitted. By this means the number of locations obtained was materially increased, and many that would have remained doubtful were converted into certainties.

The Second Army Information Centre differed only in dealing with a larger area.

These Information Centres undoubtedly did most valuable work and increased the efficiency of the organisation for locating enemy batteries and other targets. Other Armies were apathetic, in some cases because they already had a good system of interchanging information, and the question hung fire for some time, being, moreover, complicated by difficulties of obtaining personnel. Finally, the German offensive in the spring of 1918 and subsequent operations put Information Centres out of the question, and they never became general

7. General Control Required.

The foregoing paragraphs deal with the question of location of enemy targets from the Field Survey Battalion point of view, and with the various methods that were adopted or attempted in order to secure co-operation with other means of location. But it is impossible for those who were concerned in the location of targets during the war not to feel that the whole question requires consideration from a broader point of view.

The Conferences, Information Centres, and various schemes for interchange of information were so many attempts to co-ordinate all methods of location, but co-ordination without control, though it can do much, falls far short of effecting all that is required. Co-ordination of results was initiated, and for a long time carried out by the Field Survey Battalions, though latterly it passed to a great extent to the Counter-Battery Staff Officers. This, as will be shown later, was a step in the right direction, but failed to secure the best results through lack of technical knowledge. In neither case was any control of all sources of location exercised.

The need was, however, felt throughout the war of a sound *control,* both technical and tactical, of all means of location by one branch, which would combine and co-ordinate all methods. This control should be exercised over sound ranging, cross-observation, balloons and aeroplanes so far as the last-named are used for location. In order to be efficient, the staff which exercises this control must be trained in the proper methods of exact location, and hence be able to place the right value on results obtained from various sources and in different conditions and co-ordinate them correctly. Lastly, as the object in view is almost entirely the fixing of Artillery targets, the branch which exercises this control should be the Artillery.

Lest there should be any misunderstanding as to the meaning of the expression "tactical control," it should be stated that what is meant is that the responsibility for fixing targets should be given to one branch, and that for that purpose this branch should have all possible means of fixing targets placed under their command, so that Sound Ranging and Flash-Spotting Units, Observation Balloons, Aeroplanes and any other means that exist or may be devised for fixing targets, may be concentrated on the task, in the manner and to the extent best suited to their respective capacities.

The training is a most important point. Without it control and co-ordination will lose half their value. In order to obtain the best value from all results, an intimate knowledge of the various technical methods employed, and of the possibilities and limitations of each, is essential.

To sum up, the experience of the Survey Organisation, both from the lessons derived from their own work and from their contact with and observation of other methods of location, is that—

(1) All means of location of enemy targets should be under the command of one branch.

(2) That branch should be the Artillery.

(3) The Artillery should for this purpose have a staff thoroughly trained in technical methods.

APPENDICES.

APPENDIX I.

THE GEODETIC PROBLEM.

SECTION I.—INTRODUCTORY.

1. Subject Matter.

The subject of this appendix is Geodesy, that is the science which deals with the shape of the earth. At first sight it will not be apparent why, for military purposes, it is necessary to enter at all into this, the highest branch of survey. It will therefore first be explained, in this Section, why a knowledge of geodesy and why survey of the highest class is required as a foundation to the production of the class of map found necessary for war. Next in successive Sections, the geodetic problem as it actually existed in Belgium, France and Germany will be discussed. In Section V. a short account will be given of our own attempts to deal with the problem, the difficulties that were encountered, and the various mistakes that were made; and in a final paragraph lessons for the future will be drawn from our experience.

This discussion of the geodetic problem and the difficulties encountered in dealing with it in the field will show how essential the work of the geodesist is to the surveyor in the field, and how impossible it is for the latter to conduct operations which are independent, and yet which must mutually agree, without his assistance. It will be shown that if it be conceded that the surveyor must always be in a position to give the accurate range and bearing from any gun to any target, the geodetic data must be co-ordinated, and should be studied in advance for all likely theatres of war.

2. Maps in Future Warfare.

The recent war was stationary for the greater part of its duration, but it will be as wrong to assume that the next great war will be precisely the same as that it will be extremely different. In the present state of knowledge it seems likely that there will be stationary phases and mobile phases, and that the change from one to the other may take place quickly; and a clear lesson from recent experience is that the surveyor must be prepared to produce accurate large scale maps wherever required.

Without large scale maps the accurate reproducing of points, the interchange of information between aircraft and artillery, and the measurement of reliable initial elements of fire are not possible.

Without good large scale maps also, accurate map shooting, which is so essential to secrecy of operations and surprise attacks, is not possible.

Even in a war of movement it must not be assumed that large scale maps will not be required. They will have to be provided whenever and wherever possible, because the reasons which necessitate their use in stationary warfare apply frequently with equal force to a war of movement.

It may be taken as proved then that future warfare, stationary or mobile, will necessitate large-scale maps, except of course in case of small campaigns against primitive races. Let us, therefore, consider the accuracy necessary to produce maps of the nature we are considering.

3. Accuracy of Maps Dependent on Class of Survey.

The ideal in the map is an accuracy which a scale of 1/20,000 will not conclusively show. 20 metres on the ground is 1 millimetre on this scale; and 1 millimetre is a dimension so small as to be dangerously near the possible error of contraction and expansion of the paper. Let us, however, suppose as a working hypothesis that the position of every topographical feature is known to an assured absolute accuracy of 20 metres, and let us examine fully what this implies.

In the first place we can never be assured of absolute accuracy on any point, no matter how well fixed. But we can speak of accuracy being nearly absolute with reference to some point fixed in the centre of the country—such a point as the Pantheon at Paris, for example.

Now in any general survey there must necessarily be a classification of points into various orders, say, 1st, 2nd, 3rd, 4th and 5th. Suppose the absolute accuracy, as above defined of the 1st order point is 1/1; then that of the second order may be regarded as 1/2; of the third order, 1/4; of the fourth order, 1/8; and of the fifth order, 1/16. Now, though this scale is arbitrary, a geometrical progression such as that given does in practice fairly well indicate the manner in which the accuracy falls off as the order increases. If we regard a 5th order point as any ordinary topographic feature whatsoever, it is a fair assumption that if the absolute error of that point is not to exceed 16 metres, the absolute error of the 1st order point must not exceed 1 metre.

All points in a given area could of course be fixed approximately to the same order of accuracy, even the highest. But in any other than an extremely limited area the highest order could not be maintained without rejecting the elementary principles of economy. Even in countries with the highest development the economical factor necessitates the introduction of the fifth-order point, notwithstanding that in subsequent warfare this fifth-order point may assume a grave importance. If, however, the assured "absolute" error of this point is to be less than, say, 20 metres, a primary survey of the very highest class is unavoidable.

4. Requisite Precision of Survey.

Modern primary surveys have shown that a precision to one metre in the "absolute" position of a first-order point distant 200 kilometres from the central datum is attainable. On a 1/20,000 map such a point would have an error less than the width of a pencil point. But an accuracy of this order in the countries we are considering could only be expected from the new arcs of meridian and parallel in France or from the better-class primary surveys in Germany. So far as France is concerned, this new triangulation covers a small area only of the country. In the old triangulation the third-order points are only comparable with the fifth-order of which we have spoken above—in other words, their "absolute" positions are certainly not known to an assured accuracy of 20 metres. Even the relative positions of points not very far apart are not known with an assurance of 10 metres, though the average relative displacement may be taken as not greater than 5 metres. Now a relative displacement of 10 metres between two stations even so far apart as 5 kilometres—or, say, three miles—may cause an error on the bearing of the line between them of seven minutes of arc—an amount quite inadmissible in laying out line for artillery.

If third-order points are to be of full trigonometrical value to artillery their "absolute" errors should not exceed four or five metres; one can then feel assured that their relative errors will be less. If, on the other hand, one is to shoot off the map, "absolute" errors of 20 metres, implying relative errors of perhaps one-third of this amount, are permissible in the general topography (fifth-order points), since one can generally obtain points sufficiently far apart to nullify the resultant error of "line"—that is, bearing or direction—and a number of such points will give a good value in the mean.

5. Actual Conditions on Western Front.

Let us now, however, descend from the ideal to the actual. Suppose that the country has been surveyed at two different dates, that the greater part of the survey is old, that the old landmarks have in many cases disappeared or have been destroyed by war, and that some of them have been reconstructed in different positions. Suppose, in addition, that the two surveys have been conducted on different scales, with different origins and different azimuths, and that they have been referred to different spheroids and plotted on different projections. Here we have the conditions which obtain in France to-day. Suppose, further, that we cross the frontier into Belgium or Germany. Here again we meet new scales and origins, fresh azimuths, different spheroids, special systems of projection.

The problem before the Allied Armies was to co-ordinate all this diverse material.

6. Necessity for Geodetic Study and Control.

Such a problem cannot be treated piecemeal. It is not a problem for individual Armies, but for the whole battle area, actual and possible. The partial treatment of the problem was the radical mistake of the early stages of the war. In other words, surveys, even if they are perfectly correct in themselves within the limits of an Army front, are not sufficient; such work inevitably involves a break between Armies, since the fundamental positions, azimuths and bases are never the same. These breaks involve discontinuities in fixing position which become the source of no end of trouble in the subsequent conduct of the war.

Moreover it is so extremely difficult to effect changes during the progress of operations that mistakes once made cannot be rectified without upsetting past arrangements, leading to the greatest confusion. The inertia of a past mistake is almost insuperable.

Again, the discrepancies due to a break between Armies are magnified by any general movement forward or backward of the line and the consequent pushing forward or back of the local surveys. These surveys then become more and more out of touch with the national trig. systems—in other words, with the maps of the country on which subsequent fighting takes place.

Another kind of break has already been mentioned—that which occurs at frontiers, such as between France and Belgium. Breaks of this kind should be studied *before* the war. This implies a collection of essential documents and a thorough understanding of the differences in initial latitudes, longitudes and azimuths, the discrepancies between bases and the spheroidal constants—in short, the general geodetic problem.

To sum up, then, it is necessary to deal with this kind of problem from the broadest point of view and to aim at absolute accuracy (not the accuracy of a single stretch of front), to keep the whole work as far as possible in sympathy with the latest national triangulation in the country as a whole, or, more correctly, to carry out the survey in such a way that it may be brought by very simple means into harmony with the national surveys of all the countries involved.

If, as in the case of the century-old survey of France, the accuracy of the national work is of an inferior order, the problem becomes immensely complicated. It would, however, have been vastly simplified had we begun in 1914 a triangulation based on the new meridian of France, whose accuracy is unquestionable, and which had been already connected with both Belgium and Germany. But there is no use in attempting such work unless it is generally controlled by one whom past experience has trained in the same general field; divided and untrained effort will lead to divergencies as great as those of the surveys which it is proposed to improve.

A thorough understanding of such a question is only possible to the trained geodesist and mathematician who has spent his life in dealing with these complicated problems, and who can devote all his time to the subject. Such problems are always liable to arise, and it is for this reason that a knowledge of geodesy is so important, and that it is essential to have a geodesist on the Survey Staff, both in peace time, and with the headquarters of the Army in the field.

7. Division of Subject.

For the general surveys of Belgium, France and Germany, the groundwork, as we have seen, necessarily consisted of the fundamental points of the national triangulations. These surveys will be dealt with in the order named. We shall have to include in general in the discussion :—

(a) Description and quality of the survey.
(b) Measured bases.
(c) Nature of beacons and signals.
(d) Origin of the geographical system. (Initial latitude, longitude and azimuth.)
(e) Spheroid of Reference.
(f) Nature of Projection and origin of rectangular co-ordinates.
(g) Connection with neighbouring national surveys.
(h) Systems of levelling.
(i) Generally, those relations which were of importance as contributors, direct or indirect, towards the observational efficiency of our Armies.

Although the ideal was so far unattainable, the preliminary remarks in this introduction will enable us to bear in mind the conditions towards which we should have striven to secure as great a co-ordination as possible of the very diverse, sometimes very good, often very bad, material at our disposal.

SECTION II.—BELGIUM.

1. Bases and Triangulation of Belgium.

The primary triangulation of Belgium was executed between 1851 and 1873. Being later in the surveying field than France and Great Britain, Belgium gained by more modern improvements in instruments and methods and the growing necessity for greater precision

Directed by Nerenburger, Houzeau, Simons, Le Maire, Diedenhoven, Ferrier, Hennequin, the triangulation was dependent on two well-measured bases—Lommel and Ostend, with Beverloo as a base of verification. There are eighty-four primary stations, forming a net of 219 triangles; the mean square error of an observed angle is $\pm$ 0.89″, which indicates that the triangulation is on a par with good recent work.

The measurement of the secondary and tertiary net was completed in 1888, and the results of the whole work are set out in three published volumes.

2. Connection between Belgium and France.

The primary survey of Belgium is connected with the new triangulation of France at the four points, Kemmel, Hondschoote, Cassel, and Dunkirk. It was also tied to the principal triangulation of Great Britain by the cross-channel measures made by Anglo-French and Belgian co-operation in 1861-2. The results of these measures proved that there was an excellent concordance between the English and Belgian bases; and that both are in very good agreement with the base of the new French triangulation, if fifty-eight be added to the seventh place of logarithms of distance so as to bring the English and Belgian standards into harmony with the International Metre. The connection with France, except along this limited portion of frontier in Flanders, was weak, consisting only of points common to the old triangulation of France, which, as we shall see, was very far from being up to the standard of modern demand. Moreover, such points as were common occurred in groups with long intervals between them. It may be added here that the French Admiralty had tied their coastal triangulation with Belgium as far as Bruges. Between Kemmel and the sea, then, there was an intimate and strong *liaison* between the surveys of Belgium and France; along the rest of the frontier the weak linkage on the French side was at any rate defensible as evidence of pacific design.

3. Spheroid, Projection and Origin of Co-ordinates.

The spheroid of reference for latitudes, longitudes and azimuths was the old spheroid which Delambre had originally derived from the meridians of Paris and Peru, and which, modified by a Royal Commission in 1820, became known as the spheroid of the Carte de France.* The Belgians were logical in using the same spheroid for their system of rectangular co-ordinates. They adopted the Bonne projection, using as initial meridian the longitude of the old Observatory of Brussels, about $2^{\circ}\ 01'\ 58.75'' = 2^{g}\ 2588.74''$ east of Paris $= 4^{\circ}\ 22'\ 12.7''$ east of Greenwich. The initial parallel was that of $56^{g} = 50^{\circ}\ 24'$ of north latitude. The meridian actually adopted by us as initial for the computation of points in France was $2^{g}\ 2588.7''$ E. of Paris.

The Belgian rectangular co-ordinates were at first computed from the geographical by an approximate conversion in the field, and later by means of tables and formulæ for double interpolation. The results were sufficiently exact for mapping, but a curvilinear system cannot thus be transformed to a rectilinear without loss of precision; and, in fact, errors of one or two metres resulted. Subsequently the rigorous formulæ for direct conversion were employed.

4. Quality of Survey.

Though the Belgian survey was of very general excellence, the third-order points were of much lower accuracy than the primary. There were some actual errors and naturally the survey is in certain places considerably out of date. Nevertheless, had the war been confined to Belgium, the problems confronting the surveyor would have been greatly simplified. The Service Topographique de l'Armée Belge during the course of the operations corrected some of the positions of points on the Belgian front and amended other errors of transcription in the *Répertoire des Points Géodésiques* (published by the French Service Géographique), from which the British service derived its positions during the later middle period of the war. We shall have occasion to refer again to these valuable Répertoires. Towards the end of the war, the co-ordinates, geographical and rectangular, were supplied to us directly by the Commandant of the S.T.A.

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* See note 3.

SECTION III.—FRANCE.

1. Old and New Bases and New Meridian of Paris.

France provided problems of much greater complexity. The new triangulation of France (see Diagram 1), covered a small portion only of the country. Commenced in 1870 as a re-measurement of the old arc of Delambre, known as the meridian of Dunkirk, and extending from the Spanish frontier through Paris to the Straits of Dover, it was not completed until 1892. It was supported on three bases, of which that of Perpignan was the only one which could be identified with the old. The new measure of its 11.7 kms. showed that the old length was too short by 29 cms. only, i.e., one in 40,000. The old main base at Melun was not recoverable, but comparisons of the base net recomputed from the new base between Villejuif and Juvisy, 10 miles south of Paris, showed that the old base of Melun, 11.84 kms. in approximate length, was too short by barely 12 cms., i.e., one in 100,000.* The third new base was measured at Wormhout, north of Cassel.

The new meridian of Paris comprises 119 triangles, whose maximum error of closure is 8.8‶, *i.e.*, less than three seconds sexagesimal; the mean square error of an observed angle is 0.56″. These facts prove that the primary work was of the highest class.

2. New Triangulation of France.

From 1899 onwards other chains were measured, the new work being at first known as the Cadastral Triangulation. In 1907 the survey was re-organised, the chief end in view being the production of a new map in colours on the scale of 1 :50,000; wherefore the new work became known as the "Triangulation of the 50,000." The stations of the first order formed chains of meridian and parallel, which in 1914 included the following arcs: (a) the new Parallel of Paris (1899-1902), containing 23 triangles (m.s.e. of observed angle = 0.65″); (b) the Parallel of Amiens, western part; (c) the Meridian of Lyons, replacing the old Meridian of Sedan, the northern portion of which had not been completed at the outbreak of war; and (d) the Mean Parallel, eastern part.

Between these chains there is a net of triangulation, known as the First Order Complementary, which, together with points of the 2nd and 3rd order, is eventually to fill the rectangular spaces between the chains. The triangulation was at first carried out by Departments of France, but from 1907 the work was done by sheets of the 1 :50,000 map—a method which, essentially vicious as the older survey proved, after 1914 doubtless became unavoidable owing to the exigencies of war. The total area covered by this new triangulation embraced the Departments of the Somme, of the Seine and Marne, and of the Vosges, together with portions of the Pas de Calais, the Seine, the Haute Marne, the Haute Saone and the Doubs. When the front line became stabilised, in the British Army area there were available the triangulations of the Somme and the Pas de Calais, while the French Army was interested in addition in the triangulation of the Vosges.

3. Area covered by New Triangulation.

In 1914 the new triangulation accordingly covered a small part only of France, and, with the exception of the Somme surveys, was, broadly speaking, of comparatively little use to the Allied forces. It is true that the meridian arc of Paris followed for a good way the front line, and the stations were all more or less utilized at some period or other, except perhaps one or two which had been destroyed comparatively early in the war; but in general they were too far apart and too far back to be of immediate value with the means at our disposal. It was not until the summer of 1918, when the Third and Fifth Armies had been driven back and found themselves in the midst of this new triangulation, that it was possible to make practical use of it, and to make arrangements for "breaking down" the primary chain.

For surveys in the back areas the triangulation of the Pas de Calais was finally utilised to the fullest extent.

4. Description of New Stations.

The primary stations of the new triangulation in our area are either church spires or ground beacons. The latter are usually tall circular chimneys, which, though excellent as beacons, are, like the church spires, in general inaccessible as observing stations. The second

* See note 1.

and third order points are spires, chimneys or small brick pillars; already commonly the latter have been wantonly destroyed by the farmers on whose land they were placed, but fortunately our surveyors were in most cases able to discover at least the concrete foundations.

We shall have more to say of the new triangulation; meantime it is necessary to make a passing reference to the triangulation of the French Admiralty.

5. Triangulation of the French Admiralty.

The work of the Admiralty was naturally coastal and comprised a composite triangulation of varying value. On the North Sea littoral it made use of the Belgian triangulation for the fixation of Bruges, Hooglede, Kemmel and Nieuport; then of the 1861-2 Anglo-French triangulation to connect with Mont Lambert and Harlettes, stations of the Pas de Calais; then of the new triangulation of France as far south as Huppy and Hornoy; then of the old parallel of Amiens along the coast to Dieppe. For the last section it employed the old measures of the angles, bringing the lines into sympathy with the azimuth and scale of the new triangulation.

The projection used was peculiar. The position of La Canche and the azimuths thereat were taken from the Pas de Calais triangulation, and this point was chosen as the origin of the projection. North and south from La Canche a single chain of triangles was chosen and the angles of these were reduced by one-third of the excess of their respective triangles. The whole was then treated as a system *in plano* and the rectangular co-ordinates computed accordingly. To transform to the Bonne or the Lambert system it became therefore necessary to compute the sides of the triangles, to work up the geographical co-ordinates starting from La Canche and then convert the geographical to the Bonne and Lambert co-ordinates. To determine the latter correctly it will be seen that it was essential to know the particular chain of triangles which had been originally adopted, the general list of co-ordinates itself giving no clue to this chain. The Admiralty triangulation was obviously of value for back-area surveys, for which purpose full use was made of the measures.

6. Old Meridian of Dunkirk and Comparison with Other Surveys.

Outside the Department of the Somme, the Allied forces, in the Department of the Nord, the Pas de Calais and the Aisne, were chiefly dependent for forward positions on the old triangulation of France. The old survey dates from the commencement of measures of the Meridian of Dunkirk in 1792. This famous arc was carried by Mechain southwards from Rodez to the neighbourhood of Barcelona, and in 1806 was extended by Biot and Arago, using powerful lights, to Formentera in the Balearic Isles. Delambre worked northwards from Rodez to Dunkirk, whence a trigonometrical connection had been established with England in 1787 by Roy, using the new Ramsden theodolites on the British side, and by Cassini IV., Legendre and Mechain, using Borda repeating circles on the French side. The arc was subsequently carried by the Ordnance Survey to Saxaford in the Shetlands, the Anglo-French connection being greatly improved in 1861-2.

Some of our officers will appreciate one of the difficulties Delambre had to face in northern France; in certain places he found local hostility so great that he had to give popular lectures on the objects of his work before he was permitted to establish stations on the Churches, even in revolutionary France. He was actually arrested at Lagni and Saint Denis.

The French section of the arc was published in 1806-10 under the title *Base du Système Métrique*. The arc comprised 93 triangles, 11 per cent. of which had closing errors of over 3″. The mean square error of a measured angle was ± 1.08″; the quality of the measurement was therefore superior to that of many national surveys executed half a century later. Perhaps the most doubtful element in the meridional triangulation was the azimuth. Observations were made at Watten, Paris, Bourges, Carcassone and Montjouy, an extraordinary number of measures being taken for referring a selected station to the morning and evening sun. At Paris there were 396 observations, and we have seen that the old azimuth here differs from the new by two seconds sexagesimal only. But at Bourges, 120 miles south of Paris, where 180 observations were made, the discrepancy between the observed and computed azimuth amounted to 39.4″.* As regards the latitudes, the discrepancy between Mechain's values at Montjouy and Barcelona was the subject of considerable criticism; on the other hand, that of Dunkirk, reobserved by Mudge at Delambre's suggestion, was confirmed.

* See note 2.

These discrepancies were somewhat disheartening to Delambre, who had put into the work all his great fund of knowledge, skill and effort. Modern observation has, however, amply supported Delambre so far at least as the northern portion of the arc between Paris and Dunkirk is concerned. Between Paris and Bourges, however, the extraordinary political difficulties he encountered appeared to have reflected themselves in his results. It is necessary to consider only the final northern line to prove how comparatively small were the errors of the northern portion of the old meridian arc. We append here the results of the five measures which have been made of this line at various dates.

CASSEL CHURCH TO DUNKIRK PAVILION.
COMPARISON OF MEASURES.

Triangulation.	Distance. Log. metres.		Azimuth. °	′	″
Old French	4.438	6784	163	18	40.74
Belgian		6819*			38.0
English, 1861		6824*			50.90
French, 1862		6791*			—
New French	4.438	6862	163	18	50.45

* These logarithms have been increased by 58 to bring the Belgian and English bases into harmony with the International Metre.

These results indicate that the scale of the old French survey in this region is less than the new French by 1/60,000—a change in the same sense and of much the same order as found at Paris and in the south. Incidentally they also indicate a very fair agreement between the Belgian, the British and the new French bases. As regards the azimuth, we find a close agreement between the old French and the Belgian triangulations, and, the new azimuth being assumed correct throughout, since at Paris it is less than the old by 2 seconds, we see that the azimuthal error of Delambre's arc had accumulated to some 12 seconds sexagesimal between Paris and Dunkirk—an amount which cannot be considered condemnatory, even from a modern point of view. The agreement between the British and new French azimuths is very satisfactory.

Though we have given here the results of one line only, all the conclusions are abundantly supported by other lines in northern France.

7. Old Triangulation of France.

The other French chains of meridian and parallel did not maintain this high standard. They comprised 460 triangles, 28% of which had closing errors of over 3″; the *m.s.e.* of a measured angle, moreover, was $\pm$ 1.66″. These measures were executed between 1811 and 1831 by Ingénieurs-géographes, under Brousseaud, Bonne, and others. Between these chains the country was covered with a triangulation, known as that of the First Order Complementary, completed in 1845. Finally, the 2nd and 3rd order points, surveyed according to sheets of the 1/80,000 map, were all fixed by 1855. These latter points, as our Armies have good reason to know, were not always positioned with sufficient accuracy even for a map on this comparatively small scale.

8. Old and New Origins and Spheroids and Methods of Reducing New to Old.

Before attempting a comparison of the old and new triangulations, it is necessary to make some preliminary remarks. The differences in the bases have already been stated; we must now consider the origin of both the old and new nets.

The origin of both the old and the new triangulations was the Panthéon, in Paris. The new and old values of the geographical co-ordinates here, with their differences, are as follows, longitude being reckoned positive westwards from Paris Observatory :—

	Latitude.	Longitude.	Azimuth of St. Martin du Tertre.
New ...	54^g 2736.18″	-0^g 0106.93″	119^g 8721.86″
Old ...	2742.55	0106.81	8728.3
New-Old ...	−6.37	−0.12	−6.44

It was necessary in the first place to consider whether the old should be reduced to the new or the new to the old. Having to face the fact that so little of the country was covered by the new triangulation, to save labour the French decided to reduce the new triangulation to the same origin and spheroid as the old. Hence, to convert the new latitudes and longitudes to the old, the differences above, with opposite signs, must be added to the new latitudes and longitudes to allow for the change of origin. But again: the new triangulation was referred to the Clarke (1880) spheroid, while the old was on the spheroid of the Carte de France. To refer the latitudes and longitudes of the new triangulation to the old spheroid, Andrae's Danish formulæ were employed for the conversion. A table constructed therefrom gave the corrections, including therein the change of origin given above. There remain the questions of the corrections due to change of scale, consequent on the differences between the old and new bases, and to the change of azimuth at the origin. The effect of these last two changes could also have been computed by differential formulæ, and tables constructed to correspond; but, rather than work in this way, it would have been really simpler to have recomputed the new triangulation on the old spheroid from the old origin, and from the changes at the various points of the triangulation interpolate for a single general table containing the resultant effect of all the changes. What the French actually did was to reject the effect of the change of scale and change of azimuth.

It follows from these considerations that no strict individual comparison of a point common to the old and new triangulations is possible. On the other hand, if a sufficient number of common primary points occurred in each area, it would have been possible to arrive at regional corrections showing, in addition to the relative errors of the two triangulations, the effect of neglecting the change of scale and the change of azimuth. It was the intention of the French that this should be done; but, actually, the proposal was generally unworkable. For while regional corrections could have been obtained in the Somme area, in other regions the common primary stations of the old and the new triangulations were far too few to render any effective comparison possible; the old 2nd and 3rd order points were so unreliable that their inclusion would almost certainly have nullified the value of the comparison.

In practice, therefore, we were unwillingly compelled to forego the changes of scale and azimuth and the relative errors of the two triangulations, correct for the changes of origin and spheroid only, and reject the possibility of finding a regional correction. This scheme worked better than perhaps one would have expected; we have seen that the change of scale, as judged by the Melun base, was only 1 : 100,000 and the change of azimuth at the origin, being only 2 sexagesimal seconds, would not have made any important difference in the areas chiefly concerned; even at the German frontier near Metz the effect of the change of azimuth on the latitude would have amounted to $0''.08$ only, and it is curious that at the same frontier the change of scale, as indicated by the Melun base, would have affected the longitude to very nearly the same absolute extent, namely, 8 feet.

9. Comparison of Old and New Positions.

An examination of a few common points will illustrate some of the matters discussed and some other facts not previously mentioned.

Station and Order of Point.	Sheet.	Triangulation.	Geographical Co-ordinates.		Lambert Co-ordinates.	
			Latitude.	Longitude.	W—E	S—N
					metres.	metres.
BONNIÈRES Church spire (1st Order Old, 1st Order Compy. New).	*French*	New	55^{g},8298.″9	+0^{g},0880.″2	109806.5	397212.0
	Arras, S.W.	New revd.	8.95	0.20	6.5	2.0
	Lambert	Old	55,8298.6	+0,0879.7	109809.7	397210.8
	7f, N.E.	New-Old	+0.35	+0.50	−3.2	+1.2
SAULTY Church spire (1st Order).	*French*	New	55,7970.6	−0,2195.7	129261.8	392538.0
	Arras, S.E.	do. revd.	0.65	5.68	1.6	7.9
	Lambert	Old	55,7970.2	−0,2196.2	129264.6	392533.8
	7g, N.W.	New-Old	+0.45	+0.52	−3.0	+4.1
TALMAS Church (3rd Order).	*French*	New	55,5888.7	+0,0132.25	112861.7	372815.2
	Amiens, S.W.	do. revd.	8.707	2.25	61.5	4.9
	Lambert	Old	55,5888.7	+0,0127.5	112893.4	372812.9
	8f, N.E.	New-Old	+0.01	+4.75	−31.9	+2.0
LONGPRÉ LES AMIENS Church (3rd Order).	*French*	New	55,4714.9	+0,0823.6	107566.2	361425.4
	Amiens, S.W.	do. revd.	4.90	3.606	5.9	24.9
	Lambert	Old	55,4715.9	+0,0826.1	107550.7	361486.6
	8f, S.E.	New Old	−1.00	−2.49	+5.2	−61.7
AMIENS Cathedral spire (3rd Order).	*French*	New	55,4329.9	+0,0382.3	110176.3	358006.9
	Amiens, S.W.	do. revd.	2.94	2.33	5.9	6.5
	Lambert	Old	55,4392.8	+0,0382.2	110177.0	358005.8
	9f, N.E.	New-Old	+0.14	+0.13	−1.1	+0.7
SOURDON Church (1st Order).	*French*	New	55,2342.4	−0,0699.0	115693.7	337047.8
	Montdidier, N.E.	do. revd.	2.41	9.03	3.8	6.9
	Lambert	Old	55,2342.1	−0,0699.0	115693.4	337044.5
	10f, N.E.	New-Old	+0.31	+0.0 3	+0.4	+2.4

These may be considered as very fair examples of the discrepancies between the old and the new triangulations. The latitudes and longitudes following the description "New" were, with the corresponding Lambert co-ordinates, those given in the French lists. It will be seen that the former were given in general to the first decimal only of the centesimal second, so that an error in the co-ordinates of half-a-metre was possible, and sometimes occurred. The whole of the latitudes and longitudes were, therefore, recomputed anew by our Depot Battalion, and these appear in the rows indicated as "New revised." It is with the latter, therefore, that we compare the values given for the old triangulation.

It will be noticed that there are many inconsistencies in the figures. These in certain cases are not very serious; they are due to a certain extent to error in the original method of computation, and to a small extent arise from the fact that the old latitudes and longitudes are not carried beyond the first decimal. In the case of Saulty any irregularity could be explained by the fact that the spire is now bent, and very possibly was straight in Delambre's period. But the discrepancies in the case of the third-order points, Talmas and Longpré les Amiens are much too great to be explained in other than four ways. It may be that they are due to (a) errors in the old triangulation; (b) mistakes in transcription; (c) errors in calculation; (d) reconstruction of the churches. With the new triangulation to test them, there is no doubt as to the seriousness of the discrepancies; and it is obvious that any new work based on either or both of these points would have been disastrously incorrect. Consider now the difficulty of detecting such errors in those wide regions of France not covered by the new triangulation and the danger of working from such points, more particularly in those areas where the correct fixation of observation posts, microphone bases and battery positions was all-important. As such errors were all too common, the outsider will appreciate to a certain extent the difficulties of Allied surveyors in discovering these bad points and avoiding them. It will not then surprise the reader that observers were warned not to depend on any single point of the old triangulation or even on two such points. It was their duty to observe as many as reasonably possible and reject the assuredly doubtful results. This is not so simple as one might imagine, for many points were on the rather broad borderland between the sufficiently correct and the excessively incorrect, and it was not by any means always easy to differentiate between them. The unquestionably incorrect point gave much less trouble, and once found could be rejected with equanimity.

10. The French Bonne Projection.

The system of co-ordinates at first in use was, in France as in Belgium, based on the projection of Bonne, known also as the *projection du Depôt de la Guerre*, the original projection of the Carte de France. The origin in France was the crossing of the 45th Parallel (50^g of north latitude) and the meridian of Paris. They were calculated by interpolation from tables drawn up by Du Plessis. Now, in the first place, Du Plessis altered the ellipsoid of the Carte de France. He took the meridian quadrant at 10,000,000 metres instead of the 10,000,724 metres of the Carte de France, thereby changing the scale by 1 in 14,000, *i.e.*, 50 to 60 metres in the whole length of France. Puissant gave correctional formulæ, but they were never applied.* In the second place, it is not possible to transform by formulæ for double interpolation from a geographical (spherical) system, that is, say, from latitudes and longitudes, to a plane rectangular system, without introducing quite appreciable errors, unless the fundamental tables are drawn up with arguments having smaller intervals than one-tenth of a grade. The national disinclination to drudgery nowhere showed itself more than here; and it is open to question if much labour was really saved. The same doubtful procedure was later followed by the Belgians.

11. Conversion to the Belgian Bonne Projection.

Since the British maps were extensions of the Belgium 1/40,000 sheets, it became necessary to refer the French points to the origin of the Belgian Bonne (*vide ante*). These calculations were at first carried out in the field, and later by the Ordnance Survey, using a table similar to that of Du Plessis, which, of course, was quite sufficiently accurate for mapping purposes. When, in the course of time, the British Field Survey Battalions were properly organised, the calculation of Bonne co-ordinates was conducted rigorously; but it must be understood that this eventual progress took two years to develop, and the early workers in the British field found themselves everywhere faced with grievous difficulties.

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* See Note 3.

12. Military Projections. The Lambert Projection.

The French were not satisfied with their old Bonne projection, because an equivalent projection is not suitable for artillery purposes. From the point of view of plottable error there is not, it is true, enough difference between one projection and other (provided that one is not too far from the origin) to introduce any serious practical difficulty; but an orthomorphic projection is desirable for the following reasons: Firstly, it preserves shape, and, consequently, *bearing;* and, secondly, the co-ordinates of an orthomorphic system adapt themselves better to working in the field, since the bearing computed from orthomorphic co-ordinates, treated as a plane system, is almost precisely that of the map grid; in other words, it is simply the azimuth (*i.e.*, the true bearing from true north), $\pm$ the mean local convergence of the meridians. It is true that an orthomorphic projection in preserving bearing increases the exaggeration of distance; but by the adoption of two standard parallels the amount of the lineal error can be reduced by about one half. The balance lies, therefore, with some form of orthomorphic projection, be it latitudinal, longitudinal or circumferential.

In an orthomorphic system bearings are true round a *point*. This postulates that the lines carrying the bearings are very short; if the bearing of a line A—B of some considerable length is computed from the co-ordinates, considered plane, of its extremities A and B, the bearing so found is not in general precisely the same as the azimuth at either extremity less the convergence of meridians at that extremity. But it is so nearly so that the discrepancy is negligible from an artillery commander's point of view; and it is vastly more nearly so than in an equivalent projection like the Bonne.

Of the numerous orthomorphic systems, the French, looking towards Germany, naturally chose the Conical Orthomorphic, identified more particularly with J. H. Lambert (1728-77), an Alsatian refugee who found his life-work in Berlin and whose *Contributions to the Practice of Mathematics* were published in 1772. The central parallel of the new system is that of $55^g = 49°30'$ of latitude, and the initial meridian is taken 6^g east of Paris Observatory. There was no advantage in taking the origin so far east beyond the fact that it reduced the convergence of meridians to zero somewhere near the meridian of Strasburg, which in certain eventualities might have become the central scene of conflict. In order to reduce the lineal scale errors, the scale of the whole map was reduced in the ratio 1:2037, thereby rendering the scale true on the parallels of 53^g and 57^g approximately. Finally, to avoid negative co-ordinates 500 kilometres were added to the eastings and 300 kms. to the northings. The inconsistency was once more maintained of computing the co-ordinates on the Du Plessis Spheroid while the geographical co-ordinates remained on the Carte de France spheroid. Tables similar to those of Du Plessis were computed for the Lambert projection; they were never used by our Armies, the co-ordinates being rigorously calculated throughout.

The adoption of the Conical Orthomorphic projection, with two standard parallels, marked a distinct advance, though unfortunately it came too late to be of general use among the Allies during the period of the war.

13. British Surveys in France. Co-ordination of French and Belgian Triangulations.

Towards the end of the war, surveys were in progress on the British front having for their object the extension of the new triangulation so as to render it available along our whole front. Had the war continued stationary any longer, these surveys would have greatly strengthened our knowledge of position.

Towards the end of the war also, when the prospect of an advance along the Belgian frontier became more obvious, it became of correspondingly greater importance to re-examine the nature of the increasing discrepancy between the longtitudes of Belgium and those of the old survey of France as we moved eastwards. There appeared to be no hope of carrying new surveys forward with sufficient rapidity to maintain effective contact with our advancing forces. The only possible means of improving the positions of the old triangulation was to make use of the new parallel of Paris for the recomputation of the old meridian of Sedan. To explain the method some preliminary remarks are necessary.

14. Discrepancies between France and Belgium.

The French had prepared useful "Répertoires" of the trigonometrical stations in France and Belgium, arranged according to sheets of the French 1 : 80,000 and the Belgian 1 : 40,000 map. It may here be remarked that an alphabetical arrangement would have been in general simpler and better adapted to general requirements. The Répertoire for Belgian points gave "corrections" to reduce Belgian longitudes to French; we speak of longitudes only, for the change of latitude was nearly constant at about 1.7". The longitudinal corrections were given according to sheets of the Belgian map. In Diagram 2 these corrections are shown as a stepped line, marked "Belgian Répertoire." An examination by us of all the points common to Belgium and France showed that the curve marked "Common Points," of which not by any means all are shown on the diagram, more truly represented the change of longitude from point to point—a change which at Bouillon amounted to about 20 metres. Beyond Bouillon there was no means of comparison except through the roundabout method of employing the German triangulation as a connecting link, which we shall consider later.

It is obvious that the use of the stepped line of the Belgian Répertoire would have led to serious inconveniences. Thus between Peruwelz and Bouillon the change of sheet would have produced an abrupt jump of about 8 metres in easting from one Belgian map to another. To convert the Belgian points to the Lambert system it therefore appeared that the Belgian longitudes should be changed according to the values of the longitudinal difference indicated by the curve marked "Common Points," provided that the object was, as in our work, to bring the Belgian points into sympathy with the older French values.

The change, however, between Kemmel and Bouillon amounted to about 20 metres, and the discrepancy was more likely to be due to error in the old French rather than in the later Belgian triangulation; we have seen that the mean square error of a measured angle in the primary triangulation in Belgium was $\pm$ 0.89″, whereas in the main body of the old French primary triangulation it was $\pm$ 1.66″. It therefore appeared advisable if possible to correct the old French triangulation before attempting to force the Belgian triangulation into false sympathy with its doubtful values.

15. Method of Reduction of Discrepancies.

The only possible means of carrying out this design lay in bringing the old meridian of Sedan, containing Bouillon as a terminal point, into sympathy with the new triangulation of France along the Parallel of Paris, in exactly the same way as the French Admiralty had dealt with the old Amiens parallel as far as Dieppe; that is. by computing new positions for the old points by utilizing the new length and azimuth of a junction line and the new positions of its extremities, referred to the Carte de France ellipsoid, and then recomputing the triangles, using the old angles. The only flaw in this method might have arisen from the fact that the French, in changing the new positions into the old, had neglected the change of scale and the change of azimuth at the common origin on the Panthéon. As far as the scale was concerned, recomputation *northwards* from the new Parallel of Paris to Bouillon would have made very little change in the *longitude* of the latter; and in regard to the azimuth, the fact that the latitudes of the two surveys had an almost constant difference along the frontier indicated that the azimuths were in fair agreement.

If longitudes are reckoned positively westwards, in order to convert Belgian longitudes to old French, Diagram 2 shows that at Cassel we must deduct $2,^{g}2588.6$" and at Bouillon $2,2^{g}585.6$". This proves that between Cassel and Bouillon the longitudinal width of the old French triangulation is 3 centesimal seconds less than that of the Belgian. The difference of longitude between the two points being $2,^{g}75$, the difference could be accounted for on the supposition that the French longitudinal scale was too small by about the order of 1/10,000; which so far as it goes is an indication in the same sense as the difference between the old and new French bases.

All the conditions, except perhaps the nearly constant latitudinal difference, seem to point to a scale error in the same sense. Thus, on the former Franco-German frontier near Donon and Bressoir, 4°50′ or about $5^{g}4$ east of Paris, the new French longitude, reduced by table, indicated that Paris was 20°00′ 10.17″ east of the German origin in the island of Ferro, while the old triangulation gave 20°00′ 10.80″ for the same longitude. The difference, 0.63″ = 2", represents a difference in scale of 1/27,000, the old French arc being again too small. As a rough assumption we are therefore justified in supposing that between one-third and two-fifths of the discrepancy at Bouillon—that is, from seven to eight metres—is due to the defect of scale of the old triangulation. Is this supported by the recomputation of the old meridian of Sedan of which we have previously spoken?

16. Result on French Longitude of Recomputation of old Meridian of Sedan.

In Diagram 3 there is shown this meridinal arc of Sedan together with the Parallel of Amiens. Bassu and Longeville form the line between the Parallel of Paris and the Meridian of Sedan. Now, unfortunately, as had so frequently happened in other cases, the old and new stations at Bassu, though not greatly different, were apparently not the same. To determine a new value for the *old* position of Bassu, there was therefore no way of avoiding a recomputation of the positions of common stations further south. Here again the old difficulty presented itself; Chassericourt was found to have changed its position. Fortunately Montiers, St. Antoine and Sempuis were found sound. Thus the old positions of Chassericourt and Bassu were computed in the new terms, and thence the old arc was recomputed step by step northwards to Bouillon. The result was to increase the French longitude of Bouillon by about eight metres, almost the same as the result of the rough scale compensation reached above.

17. Adjustment of Parallel of Amiens.

The old parallel of Amiens was now treated in the same way, the new positions of the former points at Villers Bretonneux, Lihons and Noirtrou being worked up before further progress was possible. The points of this parallel were then adjusted to the new position of Bouillon and became standard points for correcting the co-ordinates of the lower order points in their vicinity. The corrections to these latter were found by weighting inversely to their distances from the standard points the corrections to at least two and commonly four of the standard points around them.

These computations were in progress at the end of the war, but owing to the rapidity of the German collapse were not put into general use.

The new position of Bouillon gave a new curve marked on Diagram 2 as the "Curve finally adopted," for transforming the Belgian points to bring them into harmony with the French longitudes.

18. Surveys of Eastern France and Belgium Connected Through Germany.

The link through Germany between the Belgian and the French triangulations was much too long to permit of any real conclusions to be drawn from it. Nevertheless in itself it is interesting as showing that, though roundabout, it at least exhibits no startling discrepancies. At Ubagsberg (on the Belgian-Dutch Frontier) and Jalhay we find that German longitudes may be reduced to Belgian by deducting $22^{\circ}02' \, 09.23''$. At the former Franco-German Frontier, about a degree further east than the Belgo-German, we saw that German longitude might be reduced to old French by deducting $20^{\circ}00' \, 10.80''$. The difference between these two is $2^{\circ}02' \, 58.43'' = 2^{g}2,587.8^{\backprime\backprime}$, so that it would appear as if in the extreme east of Belgium the longitudinal difference between the Belgian and old French triangulations were reduced to about six metres, since we have seen that the normal geodetic difference of longitude Paris-Brussels has been taken at $2^{g}2,588.7^{\backprime\backprime}$. But very little weight can be attached to such a result,, though it is interesting to record that apparently the French Service Géographique de l'Armée had arrived by some means unknown at much the same conclusion.

19. German Surveys in France.

Before leaving France some references must be made to the German Surveys there. The German Survey Sections worked according to the areas occupied by their Armies, so that the survey of one Army area was at first independent of others. Each Army had thus an origin of its own; there were origins south of Paris, in Paris itself, at Rheims, Laon and Lille, together with others on the French portion of the front. No information was given on the maps as to the origins nor the nature of the projection, but it was possible to form a strong presumption with regard to these. Thus in 1916 it was known that the projection was almost certainly Cassini, and that the Lille origin was in a position not five feet distant from the truth. The question of the projection was confirmed by captured documents containing pages from Jordan and other German writers. Similarly it was believed early that the Germans were using the Carte de France figure, since it was known that they were very puzzled over the discrepancies between their positions and the French due to the French errors in scale. This was shown by a captured map (1/10,000 Epehy) which had on it French and German positions relative to Paris, with various remarks in the margin. The capture of a paper showing the cutting lines of the Paris and Lille grids confirmed the question of the spheroid.

20. Quality of German Surveys in France.

One of the most interesting of the German maps was that showing the area in which the Paris, Lille and Rheims grids met. The difficulty in working in such an area was to a certain extent faced by the preparation of a special map showing a considerable overlapping of the grids, but nevertheless the German artillerist can scarcely have admired the crazv patchwork.

Apart from the confusion caused by having this variety of trigonometrical grids, the Germans must have found grave disadvantage in not having one uniform system of *map reference*, as a point in an overlapping area could evidently be described in several different ways according to the reference grid used. There is reason to believe that towards the end of the war they had adopted (or were adopting) the Paris grid for purposes of reference over the whole of their front, but the evidence on this point is not conclusive. If this was the case they would have had one reference grid for the front-line system (Paris origin), while at the same time they would have had a number of trigonometrical grids for purposes of calculation. Of these trig. grids one only (Paris) would have agreed with the reference grid, while in all other cases the computers would have had the inconvenience of having a reference grid which was quite independent of the trigonometrical grid.

It is believed that the position at the close of the war was as follows in the northern area :—

Two Reference Grids.

Front-line system, with origin in Paris.

L. of C. system, with origin near Antwerp.

Four Trig. Grids.

1. Origin near Antwerp.
2. Origin near Lille.
3. Origin near Paris.
4. Origin near Rheims.

The Laon grid at one time in use had been discarded.

Some documents showing the methods of conversion of co-ordinates from one grid system to another were informative, but more interesting were lists of the co-ordinates themselves, showing the values of the different Armies on their respective grids. These values were usually contradictory *inter se*, the discrepancies being of the order of 5 to 15 metres, though quite a few exceeded the latter figure. In many cases they were obviously the old French positions worked into the German systems. These lists, then, so far from lending much assistance to us for determining position within the German lines, in many areas merely added to the confusion; at the same time it must be confessed that, had they been captured earlier in the war, their value would have been enormously enhanced. No doubt on several occasions they had escaped notice amidst the general rubbish of the battlefield. These lists at any rate proved conclusively that the Germans on the front line had no better knowledge of position than the Allies, and that for surveys in their back areas they were much less informed—conclusions fairly obvious previous to the capture of the confirmatory documents. In brief, they had failed even more than ourselves to appreciate the supreme value of high-class surveys in modern warfare.

21. Superiority of German Beacons.

In one respect German methods were superior to ours; being free to make full use of the timber of the country, they had almost everywhere constructed proper beacons. Had the positions of these, relative to points in our lines, been known with sufficient accuracy their value to the enemy's artillery and Survey Sections would have been vastly greater than it actually was. Nevertheless they were of very considerable value to the Germans, and it was not until our surveyors and battery commanders had actually seen them that they fully realised their advantages. In some few localities they were replaced by the tall timber-braced towers which have been used in various countries for national surveys, particularly on prairies and great plains. The Germans probably used these as much for determining bearing as for more purely surveying purposes. Had the German retreat been slower their beacons would have been of much more value to their forces.

SECTION IV.—GERMANY.

1. Triangulation in Prussia and the Rhine Provinces.

The prospect of an advance into Germany, which became clearer in the autumn of 1918, led to the corresponding necessity for becoming fully acquainted with the condition of the triangulation of Germany in general and of the Rhine Provinces in particular. Regarding this, abundant descriptive material was available; description and actual figures are not, however, one and the same.

The primary triangulation of Prussia, including the Rhenish Provinces, was available in London, as were the complete results of this triangulation, with the exception of four volumes. That all this material was, unknown to the War Office, to be found in the British Museum and not in the War Office itself, at any rate went to indicate that war with Germany was not reckoned as an immediate probability. The British Museum possessed all the eleven volumes of the *Hauptdreiecke*, which included the primary stations of Prussia, and in addition about an equal number of *Zwischenpunkte*, with data for some points of lower orders. It also possessed twenty of the twenty-four volumes of the *Abrisse*, *Koordinaten und Höhen* of the Prussian Landesaufnahme. We were subsequently able to obtain Vol. XXI. The remainder were not generally published. The twenty-four volumes of the *Abrisse* contain the whole of the information necessary for a practical trigonometrical knowledge of Prussia and the Rhine Provinces.

For the Rhine Provinces there was, in addition, the triangulation of the Geodetic Institute of Prussia. This triangulation, which included a few secondary points, extends from Brocken, near Magdeburg, westwards to the Dutch Frontier at Roermond and Ubagsberg and southwards to Röthfluh and Lagern in Switzerland.

Besides these triangulations there were to be found a few references to other work and to points of the triangulations themselves. Volume XXI. of the *Abrisse* gave all the points in an area east of Coblentz. The Army of the Rhine has since been in a position to supplement greatly the knowledge previously obtainable.

2. Quality of Primary Surveys in Germany.

Some facts may be added to indicate the quality of these triangulations, with which it will be convenient to group some others not hitherto mentioned. The following table shows that, with the exception of the old surveys in Bavaria, Baden and Hesse, the primary triangulation of the area considered, involving the greater part of Germany, is of a high order of accuracy. With the triangulations in Baden, Wurtemburg and Bavaria the British Army was not directly concerned, and no great efforts were made to determine how much material was available.

State and Triangulation or Geodesist.	Date.	Number of Triangles.	Mean Square Error of Angle.
Prussia, East, Bessel's Arc	1832–34	29	± 0·69
„ North, Baeyer's Coast Trig.	1837–46	148	·56
„ Landesaufnahme, Period I.	1839–75	367	·54
„ „ „ II.	1875–99	205	·37
„ Geodetic Institute	1860–82	137	·77
Nassau, Oderheimer	1853–63	15	·78
Hesse, Schleiermacher & Eckhardt	1808–40	15	1·22
Baden, Tulla, Klose & Rheiner ...	1816–50	86	1·59
Wurtemburg, Bohnenberger	1818–30	6	·87
„ Baur, Schoder and Hammer	1872–91	6	·47
Bavaria, Soldner, v. Orff and v. Bauernfeind	1804–54	339	1·78
„ Schwerd ...	1820–21	4	·74
	1804–99	1,357	± 1·09

3. Projections in Germany.

The Allied Forces were barely interested in the projection systems of Germany, except for a few points for which we had rectangular co-ordinates only. The system of the Landesaufnahme is a double projection, the idea of which is due to Gauss. Gauss showed how points on the spheroid might be projected orthomorphically on the sphere; from the sphere they are then projected on a plane by the now well-known formulæ of the Cylindrical Orthomorphic, known also as the Gauss Conformal projection. The double projection is not worth the trouble—certainly barely worth all the mathematics that Schreiber spent on its elucidation. In the change from the spheroid to the sphere the error is very slight even at fairly long distances from the origin; practically all the error occurs, as one would expect, in the change from the sphere to the plane. The projection is meridional, and therefore most unsuited to Prussia, including the Rhine. At Metz, for example, the lineal error is 1 :280, almost sufficient to show itself on a map. The projection is therefore so unsuitable for the country in general that it has had to be supplanted by local systems referred to local origins, and here, no doubt, we see the explanation of the numerous German origins in France. These local systems are in general Cassini, but we have the Gauss Conformal in Hannover and the Conical Orthomorphic in Mecklenburg, while Anhalt boasts of a Transverse Cylindrical Orthomorphic projection.

4. Co-ordination of French and German Triangulations.

The geographical co-ordinates, when obtainable, were used in all cases for the purpose of transforming from the German to the Lambert Conical Orthomorphic projection of the new French map. The Germans had adjusted the connections of their triangulation both with France and Belgium; consequently it was easy to compare common points. There were four points in common with the new Parallel of Paris. When these French points were reduced to the old origin and the old spheroid in the manner previously described the following differences were obtained :—

Latitude : German-French = + 1.43″
Longitude : ,, ,, = + 20° 00′ 10.17″

The large longitudinal difference arises from the fact that the Germans reckon their longitudes from some position in or near the island of Ferro in the Canaries, which is conventionally considered by them to be 31° west of Rauenburg, the origin of the Prussian system. The French formerly had taken Ferro 20° west of Paris; the origin is now, of course, of mere historic interest, having been adopted mediævally to divide the eastern and western hemispheres.

Since the old French survey included the Meridian of Strasburg in Alsace-Lorraine, there are many points in common between the survey of Germany and the old survey of France. As a result of the comparison of 9 of these points, we found that at the (1871) Franco-German frontier (near Donon and Bressoir) the differences were :—

Latitude : German-French + 1.25″
Longitude : ,, ,, + 20° 00′ 10.80″

As the conversion of the new triangulation of France to an obsolete spheroid could be considered as only a temporary measure, necessitated by the exigencies of war, and as the German points in Alsace-Lorraine will some day be included in the new triangulation, it seemed, on the whole, desirable to employ the comparison between the German triangulation and the old parallel of Paris, more especially as the discrepancy between the old and the new converted French values is not very serious. As a result there is no change on the French map as one crosses the frontier. The French themselves suggested "about 20° 00′ 11″," and were quite willing to adopt our values. The Americans, following an older French note, adopted an even 20°.

The German geographical co-ordinates are projected on the Bessel spheroid; had we neglected the change of scale and azimuth, it would not have been difficult to have drawn up a table for conversion from the Bessel spheroid to that of the Carte de France, just as the French had changed to the Carte de France from the Clarke (1880) spheroid. But on bearing in mind the fact that French geographicals are on the Carte de France, while the Lambert rectangulars are on the Du Plessis spheroid, and that the whole adjustment is so provisional, it was considered that works of supererogation were hardly consistent with warfare; accordingly, Bessel geographicals were accepted as they stood and converted to the French system by means of the figures given in the second place above.

5. Co-ordination of Belgian and German Triangulations.

The comparison between German and Belgian geographicals gave the following results :

Latitude : German-Belgian + 1.71″
Longitude : ,, ,, + 22° 02′ 09.23″

It has already been shown that the longitudinal difference is in very fair agreement with the geodetic difference to be expected at the Belgo-German frontier between Paris Observatory and the old Brussels origin. As for the latitude we find :—

$$\text{Latitude: French-Belgian} = +\ 0.46'' = +\ 1.4''$$

Since on the Franco-Belgian frontier we saw that old French latitudes were constantly greater than Belgian by + 1.7″, we have here another excellent agreement. Indeed, these figures not only lend weight to the old French latitudes, but to the Belgian and German triangulations in addition. Had the latter been reduced to the Carte de France spheroid, it would have been possible to make comparisons of much more value. But even as it is, the other agreements are so good that the longitudinal difference between old France and Belgium in the neighbourhood of Bouillon seems the more surprising.

SECTION V.—WORK IN THE FIELD.

1. The First Surveys.

The first surveys in the field were carried out by the Ranging and Survey Section. As already explained in Part I., the work was confined to France, and to the area not covered by Plans Directeurs, the Belgian maps and French Plans Directeurs being at that time accepted as sufficiently accurate. The area dealt with lay between Wormhoudt and Bethune. It was not foreseen at that date how greatly the area to be surveyed would increase, nor was it possible to anticipate the many complications that would arise owing to artillery needs and the discordances both within the French surveys and in their junction with others. Much of the knowledge that should have been in our possession from the outset was only gained by encountering these difficulties.

Information on which to base the first survey was demanded from the Service Géographique and from the War Office. The former supplied geographical co-ordinates, which included various errors of position or transcription. The latter gave information as to the figure employed on the Belgian Survey (of which ours was to be an extension), the origin, etc., but this proved later to be erroneous.

In spite of these initial difficulties the R. & S. Section covered the area in question with a system of spheroidal co-ordinates which was sufficiently good for the purpose and which introduced no plottable errors.

2. Subsequent Divergencies of Method.

On the formation of Armies, survey was carried on in each Army area under an independent control. It was then that divergencies of method began, the effect of which, though not immediately apparent, caused great difficulties and much waste of time and efforts at a later date.

In the first place the Army Topographical Sections discarded the spheroidal system and started plane systems.

In the second place the Survey officers of each Army, being dissatisfied with results as they found them, recomputed all points in their areas, with differences of method according to their several ideas.

The result of these divergent and independent methods was that there were discordances at the junction and between all the Armies (as, for example, 7 metres between First and Second); that whenever an Army changed its area all values had to be recomputed; and that there was endless unnecessary work in trying to make a plane rectangular system fit either a sphere or a Bonne projection.

Though it gradually became apparent that many difficulties were arising as survey work extended, there was no one on the staff at G.H.Q. who had either the time or the expert knowledge to deal with these questions as a whole, and exercise a control on the mathematical side. It was not until the last year of the war that a trained geodesist was added to the staff through the medium of the Depot Battalion. Had he been available earlier many of the troubles that arose would have been avoided.

3. Lessons of Experience.

The lessons to be drawn from the above experience are evidently that the study of the geodetic problems of a country form a necessary part of the preparation for war. Such a study should be carried on in peace time for all theatres where modern warfare is likely or possible, so that all data and necessary information should be ready to hand when required. The Geographical Section of the General Staff should be ready with accurate geodetic information on the outbreak of war, and in addition to this, the Survey staff in the field should include a competent geodesist with a small staff to deal with all geodetic questions as affected by local conditions and needs, and to advise on and control mathematical questions, and to initiate such survey work as is required by the general situation as apart from the local and special needs of Armies.

As an example of the need for this provision, the experience of 1915, when survey in the field was begun, may be quoted. It was necessary for the preliminary calculations to know the position of the Belgian origin, its longitude from Paris, and the Belgian and French figure of the earth. Accurate information on these points was not forthcoming, simply because it had never been realised that such essentially geodetic information could have any possible military value. Had the information been available at once, it would have saved a large amount of labour and time in the field.

Again, with regard to the utilisation of the new triangulation of France (see II.3) a competent geodesist on the staff at G.H.Q. would have realised the necessity for pushing up a first class survey from behind from the earliest possible moment. It should be mentioned that it was suggested by Colonel C. F. Close, Director General of the Ordnance Survey, that a primary chain of triangulation should be observed along the front. The suggestion was considered, but though it was thought desirable it was not held to be essential, and as it would have involved the employment of additional personnel it was decided (erroneously as later experience proved) not to carry it out. There is little reason to doubt that had a geodesist been on the staff at the time, able to devote all his time to the consideration of the complicated questions involved, the matter would have been viewed in a different light.

Note 1.—The Old Bases in France.

It was considered by Delambre that the base of Melun reproduced itself through the triangulation on the base of Perpignan to an accuracy of about one-third of a metre. When, however, the meridian of Fontainbleau was subsequently measured, it was seen that the connection between Paris and Bourges was not so good as had been expected from the old arc. The connection *via* Fontainbleau considerably reduced the discordance between the Melun and Bordeaux bases, but on the other hand that between Melun and Perpignan was greatly increased; in fact, the length of Perpignan computed from Melun through the meridian of Fontainbleau was found to be 1.8 metres greater than its length as measured on the ground. Discordances of this nature, if not this amount, are of common occurrence in the general surveys of countries.

Note 2.—The Old Azimuths in France.

After recomputations the discordances between the astronomically observed and geodetically computed azimuths of the old meridian of France were found to be as follows :—

Station.	Point observed.	Az. observed. °	′	″	Az. computed. ″	O = C ″
Dunkirk	Watten	25	19	42.1	36.3	+ 5.8
Pantheon	Belle-Assise	274	47	54.0	54.0	—
Bourges	Dun-le-Roi	329	10	41.3	73.6	−32.3
Carcassonne	Nore	201	18	58.0	97.8	−39.8

The reality of a rapid growth of discordance between Paris and Bourges is supported by the facts adduced by Coraboeuf and Puissant, which have been condensed in Note 1. The northern portion of the arc seems undoubtedly to have been the best.

Note 3.—Spheroids of Reference.

The old standard of length in France before the Revolution was the *Toise of Peru*, which according to convention contained 864 "Paris lines." The Metre, declared by the Decree of 1791 to be the 10-millionth part of the meridian quadrant, was provisionally assumed to have a length of 443.44 Paris lines. The meridian of Dunkirk was measured primarily with a view to determine the correct length of the metre. By combining the arcs of Dunkirk and Equador, the then Commission of Weights and Measures arrived at a value for the metre of 443.296 Paris lines. An *étalon* constructed in platinum as nearly as possible equal to this length, which was described as the "true and definitive" measure of the metre, became known as the ***Metre of the Archives***. It was supposed to have a length at 0° Centrigrade, which bore to the length of the Toise of Peru at 13° Reaumur (= 16¼° C.) the ratio 443,296 : 864. In terms of the Metre of the Archives accordingly the meridian quadrant was 10,000,000 metres in length. The Commission in deciding on this measure had assumed the ellipticity to be 1 :334.

Delambre himself subsequently discovered some small errors, both in his own calculations and in those of Bouguer and Lacondamine on the Peruvian Arc. The revision resulted in a length for the metre at 0° C. of 443,328 Paris lines. The *étalon* having already been constructed, Delambre had to say that the meridian quadrant contained 10,000,724 metres of the archives.

A Royal Commission in 1820 decided that an ellipticity of 1 : 308.64, derived again from the measures in France and Peru, should be adopted for the spheroid on which the new map of France was to be plotted. Among other resolutions this Commission adopted the decimal division of the quadrant.

Du Plessis went back to the old values of 1 : 334 for the ellipticity and 10-million metres for the quadrant; but Puissant, rightly clinging to an ellipticity of 1 : 308.64, modified the Du Plessis spheroid accordingly. With this emendation, the spheroid became known as the Du Plessis Spheroid Reconstituted.

While the spheroid of the Carte de France was used for all purposes in Belgium, in France it was used for the geographical co-ordinates only; the rectangular co-ordinates are plotted in France on the Du Plessis Reconstituted Spheroid.

The principal dimensions of the various spheroids in use on the Western Front are as follows :—

Spheroid of Reference.	Major Semi-axis metres.	Reciprocal of Ellipticity.	$\frac{b^2}{a^2}$ or $(1-e^2)$	Meridian Quadrant metres.
Carte de France .	6,376,985	308·64	0·9935 3045	10,000,724
Logarithms . .	6·8046 15395	7·5105 4779	9·9971 81185	
Du Plessis Reconstituted .	6,376,523·3	308·64	0·9935 3045	10,000,000
Logarithms . .	6·8045 83951	7·5105 4779	9·9971 81185	
Bessel .	6,377,397·15	299·153	0·9933 2563	10,000,856
Logarithms . .	6·8046 43464	7·5241 0691	9·9970 9164	
Clarke (1880) . .	6,378,249·2	293·465	0·9931 9650	10,001,869
Logarithms . .	6·8047 01484	7·5324 4369	9·9970 3518	

Generators of Tangent Cone.

Bonne Projection — Lat. 56ᵍ .... R_o = 5,285,661·44 metres.

Lambert „ — Lat. 55ᵍ .... „ = 5,453,601·7 „

APPENDIX II.

LEVELS.

1. Importance of Subject.

The question of accurate heights and contours became of increasing importance as the war progressed, and accurate methods came more into vogue. Large scale maps for Artillery use lost half their value if the contours did not show heights and ground forms accurately; and with the development of observation for ranging, and especially of ranging on air-bursts, this point was accentuated. The question was also of great importance to the Engineers, whose work included accurate levelling for drainage and inundation purposes, and had frequently to be based on, or checked by, the local bench marks.

The basis of the heights and contours on the maps being the levelling systems of the country, this led to an investigation of these systems, and it was found that there were several existing, which differed from each other and all of which were not equally reliable.

The available information was collected and embodied in a form convenient for reference in "Notes on Levels in Northern France and Belgium," which may be referred to for details. It will be sufficient here to recapitulate shortly the different level systems in the area of operations.

2. Levelling Systems in France and Belgium.

France.

Nivellement Général (*Système Lallemand*). A modern system of the first order, extending all over France.

Nivellement Général (*Système Bourdaloue*). An older system, with errors which vary according to the locality, and which in Northern France gives heights nearly a metre too great. It also extends all over France.

Belgium.

Nivellement Général de Précision. A first order system, but consisting only of a few main lines of levels.

Nivellement Général du Royaume de la Belgique (also called "Depôt de la Guerre" or "État Major" system). A system which extends all over the country, and on which the topographical maps are based. It is believed to be good, but as it has no bench marks it cannot be classed as a precise system.

Ponts et Chaussées. Said to be accurate and to have bench marks, but covers a small area only in the neighbourhood of the coast and Bruges.

3. Necessity for Study.

All the above systems, apart from any errors which they may contain, are based on different datum points, which must be studied before the levels can be utilised and compared. Besides these systems there are various supplementary bench marks and systems; while tide rise is referred to a different datum for apparently every French port.

It is evident then that before levelling systems and records of the country could be used for accurate work an intimate study was required, to enable comparisons to be made, errors estimated, the relation between sea and land heights established, etc. This study had to be extended to the maps of the country to determine the value of the levels and contours shown thereon.

The method by which maps of forward areas, which could not be surveyed on the ground, were contoured has been described in Part I., Chapter 1. As mentioned there, the lines of levels of the French systems, though valuable as a control, afforded little help in determining ground forms, as they are confined almost entirely to roads, canals and railways.

APPENDIX III.

MAP REFERENCES.

1. Early History.

The need for some means of describing the positions of points simply and accurately first arose during the battle of the Aisne, and the maps then in use (1/80,000 and reproductions of the new 1/50,000) were in a few cases overprinted for this purpose with small squares covering a portion of the sheet. The production of 1/20,000 maps (enlarged from 1/80,000) was being taken up at that time, and it was decided to print on them a regular system of squares. The method of describing positions within a square by co-ordinates measured in tenth parts of a side was suggested by Brig.-Gen. Fanshawe, R.A.; it was adopted and came into universal use. The system of designation of squares was that with which we are now generally familiar, namely, to describe a large square or rectangle of 5,000 to 6,000 yard side by a letter; a 1,000 yard square by a number; and the four quarters of the 1,000 yard square by the small letters a, b, c, d.

The size of the squares was the subject of some discussion with the Artillery. All the officers consulted were insistent on the need for squares measured in *yards*. It was not sufficiently realised that the square is a means of location, not of measurement, and that its size is therefore immaterial. The 1,000 yard square was adopted, however, with the result that the grid did not fit the sheets, whose dimensions were in metres.

2. Relation between Map Reference and Survey Co-ordinates.

The use of rectangular co-ordinates began at the same time that the practice was adopted of identifying points by "map reference," that is, by some method of measurement, instead of by topographical description. The two are not necessarily the same.

Rectangular co-ordinates are used for the absolutely precise definition of position of points, such as trigonometrical stations or artillery positions or targets. It is necessary to be able to calculate distance and bearing between such points, and they are therefore fixed by their rectangular co-ordinates measured east and north* from a common origin.

Map reference is some system whereby the position of a point may be described simply and quickly with sufficient accuracy for the purpose of a report, of communication between aeroplane and battery, or of similar requirements. It does not necessarily provide the information whereby distance and bearing may be calculated either exactly or approximately, and it is not necessary that it should do so, though it is convenient. Further it is not necessary that the reference system should be on the same basis as the co-ordinate system. It is most desirable that it should be, and it will be shown that many disadvantages result if it is not; but it is not essential. The British reference system for example was quite independent of the survey co-ordinate system, and it is believed that the same was the case with some of the German Armies (see Appendix I).

The reason why it is desirable that the system of map reference should be based on the system of survey co-ordinates, and not independent of it, is that the conversion from one form of description to another has constantly to be done. For example, a target is reported from the trenches to a Battery Commander by its "map position"; the Battery Commander may wish to compute his range, etc., and to do so he must convert the map position to survey co-ordinates. Again, the position of a bearing picket is given by a F.S.B. by its co-ordinates; the Battery Commander wishes to mention it in a report, or give an N.C.O. instructions about it, and he must convert the co-ordinates to map position.

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* Co-ordinates may, of course, be measured in any direction, but it is usual in military systems to place the origin well to the south-west, to avoid any possibility of having negative co-ordinates, *i.e.*, co-ordinates measured west or south.

If the reference system is quite independent of the survey co-ordinates, this conversion is a comparatively laborious matter; the position must be put down on the map, and the description on the other system measured. This involves time, worry, and increased chance of error. This is what had always to be done with the British system, and many officers must have had ample experience of the resulting disadvantages. On the other hand if the reference system is based directly on the survey system, so that the map reference is a modification or abbreviation of the description by survey co-ordinates, the conversion from one to the other is easy and rapid, and the chance of mistakes is reduced.

3. British System.

The essential features of the British reference system (by which is meant the system used by us on the Western Front) are:—

(a) That it is based on the *sheet*.
(b) That the location depends on *subdivision* of squares (or rectangles).
(c) That a grid based on yards is applied to metric sheets.

(a) Sheet Basis.

(a) Taking the sheet as the basis of the reference system is not necessarily a disadvantage. It has some conveniences. The sheet conveys a definite idea of locality, and the knowledge that a point is situated in Sheet 28A gives you a clear idea at once of its approximate position.

On the other hand it is better not to be too much bound by the idea of the sheet. A regular series of sheets is a convenience, but only a convenience. Operations take place in areas which have no definite relation to sheets. For this reason it is often necessary to make up special sheets, to suit the area concerned. In such a special sheet the arrangement of the squares is upset and it becomes evident that it is better to connect squares in one's mind with areas only, and have them independent of sheets.

This point is referred to again in para. 5 (d).

(b) Location by Sub-Division.

(b) The method of locating by sub-division of squares is of considerable importance. By this expression is meant the location of a point first within a large square, then within a smaller square in that large square, and finally in a sub-division of that small square. Thus we speak of a point as being in A.25b, narrowing the location with each successive letter or figure denoting a square.

Now this method is based on a principle which is totally different from that of co-ordinates measured from a common origin, and this means that our method of map reference could never be made to agree with the survey co-ordinate system. There is no sort of relation between the two, and conversion must always be done by plotting the position on one system, and measuring again on the other.

It should be noted that this has nothing whatever to do with the size of square adopted. Had we used kilometre squares, and adhered to the same method of locating by sub-division, precisely the same difficulty would have occurred.

The final location of a point is of course effected in the British system by measuring co-ordinates within the smallest square; but that does not affect the principle described above.

(c) Misfit of Grid.

(c) The adoption of 1,000 yd. squares meant that the British grid could not fit the size of sheet we had adopted, which was that of the Belgian series. If a grid of 1,000 yd. squares be drawn symmetrically on a 1/40,000 sheet (measuring 32 x 20 km.), *i.e.*, with its central point coinciding with the central point of the sheet, it will be found to project almost exactly 500 yds. on the east and west edges, and about 61 yds. on the north and south. By dropping one row of 500 yds. squares on east and west, we can make the grid coincide on these edges; and this is what was done. It will be seen on examination of a 1/40,000 sheet that only one-half of the 1,000 yd. squares on the western and eastern edges appears, consisting in the former case of the quarters b and d, and in the latter of a and c. On the northern and southern edges however the grid projects over the sheet edge by some 61 yds.

This misfit or projection of the grid is a serious disadvantage. It is always puzzling to the uninitiated; it leads to mistakes in giving references; and it raises various difficulties, such for example as in the preparation of Artillery boards, mentioned in Pt. II.

This disadvantage it will be noted is due to the size of square adopted, together with the fact that the grid is based on the sheet; and has nothing to do with the principle of reference described in (b).

4. French System.

The essential features of the French reference system are that :—

(a) It is based on a grid which extends continuously over the whole area of operations, and

(b) The reference is an abbreviated form of the survey co-ordinates.

It is thus independent of sheets, and the transition from trig. co-ordinates to map reference, or *vice versâ*, is simple and easy.

The French used figures (abbreviated co-ordinates) for their map references. Thus a point was denoted always by four figures, as 3287. This involved an assumption as to the area in question (which could only be denoted by giving the full co-ordinates). The assumption was practically always obvious, as the only mistake likely to occur was confusion with a point at least ten kilometres away. It is believed that this never happened. But when the French system was adopted by the Allies for use throughout the Western Front it was agreed to denote 10-kilometre squares by a letter, so that the French four-figure reference became A 3287. This small addition was a precaution against errors which the practical experience of the French had possibly shown to be unnecessary. However, it was generally agreed to be sound, and the French themselves raised no objection. With this letter added, the only confusion that could arise would be with a point of similar co-ordinates at least 50 kilometres away—a most unlikely contingency.

The system, with this change, is described in the following paragraph.

5. Allied System.

In the following description of the system of map reference adopted by the Allies on the Western Front metric units of measurement are used throughout, because these were actually used, and the decimal division is necessary. But it should be understood that it is not in any way essential that kilometre squares should be used in this system. One thousand yard squares would do just as well, and if co-ordinates are measured in yards the squares must be in yards. The point of the system is that whatever units—metres, yards or feet—are used for the rectangular co-ordinates, the dimensions of the grid squares (for map reference) must be some multiple of 10 of the same unit. Actually 1,000 is the most convenient size.

Description.

(a) Grid.

(a) The area of operations is covered with a continuous network of lines forming squares of one kilometre (1,000 metres) side. This network is called the "grid." The lines are drawn parallel to "grid" north and east, and the most westerly and southerly are drawn through the origin of the rectangular co-ordinates, so that each line is a certain number of kilometres east or north of that origin.

(b) Designation.

(b) Starting from the origin, every tenth grid line is emphasized. These tenth lines form squares of 10-kilometre side, and each of these is given a letter. In a square of 50-kilometre side there are 25 10-kilometre squares denoted by 25 letters, A-Z, omitting I.

Each kilometre square is given a two-figure number, which represents the co-ordinates of its S.W. corner in kilometres, measured from the S.W. corner of the large-lettered square.

Thus squares are known as follows :—

Large (10-kilometre) squares by a letter—A.

Small (1-kilometre) squares by a number—19.

These letters and numbers are printed on the map. Along the margin of the map are printed also numbers which represent the distance in kilometres of each grid line east or north of the origin. Every tenth line has this number in full, while the intervening lines are numbered one to nine (see Figs. 1 and 2).

Fig. 1.

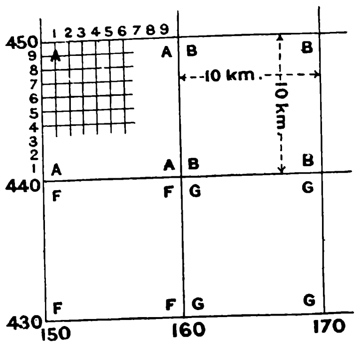
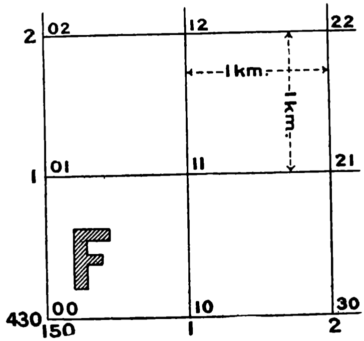


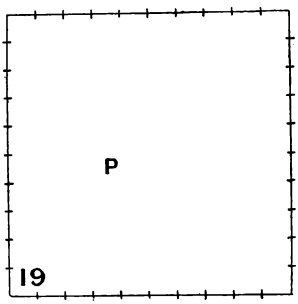
Fig. 2.



(c) **Description of a Point.**

(c) The position of a point is described by its co-ordinates *in the large lettered square.*

Fig. 3.



Suppose the co-ordinates of a point P in square 19 to be 3, 4, measured in the usual way by taking so many tenths of the side east and north. Since a tenth of a kilometre side is 100 metres, this means that P is 300 metres east and 400 metres north of the S.W. corner of square 19. Now the number 19 means that the S.W. corner of this square is 1 kilometre east and 9 kilometres north of the S.W. corner of the big square. Therefore the co-ordinates of P in the big square are (in metres) 1,300 east and 9,400 north, and the map reference of point P is A 1,3 — 9,4.

If we want to describe P more accurately we take hundredths of the square side instead of tenths, and use six-figure co-ordinates.

Thus, supposing P to be 320 metres east and 430 metres north, its "pin-point" co-ordinate are A 1,32 — 9,43.

Four-figure co-ordinates describe a point to the nearest 100 metres and six-figure to the nearest 10 metres.

Note.—The difference between this system and the British should be noted. In the British you first describe the small square (by letter or number) and then give the co-ordinates in the small square. In the French system the co-ordinates are given in the *large* (10-kilometre) square. The number of the small square is not mentioned, but it may be noted that it is always evident, as it is formed by the first figures in the east and north co-ordinates. Thus the point 1,3—9,4 must be in square 19.

(d) Use of Square Letters.

(d) The letter denoting a 10-kilometre square is adopted as a convenient abbreviation to show the position of the square and to save writing the full co-ordinates. Thus it will be seen from Fig. 1 that the square A illustrated lies between 150 and 160 east and 440 and 450 north. Further, it means (and this is important for conversions) that every point in square A has co-ordinates which begin with 15 . . . and 44. . . .

Square letters are repeated at every 50 kilometres. Thus the next square A, lying to the north, lies between co-ordinates 490 and 500 north (with the same easterly co-ordinates), and all points lying within this square have co-ordinates beginning with 15 . . . and 49. . . .

The letter should always be given if there is any risk of confusion with an adjoining square, and if there is any risk of doubt as to which lettered square is meant, the 1/40,000 sheet should be given.

Square numbers within a 10-kilometre square are all different, and no mistake can be made between them.

It will be seen that in this system the square letters are not repeated on every sheet, as was the case with the much smaller squares on the British system. A 1/40,000 sheet measuring 30 by 20 kilometres (the normal size) would include, say, squares A, B, C, F, G, H, the sheets adjoining it in the south would include squares L, M, N, Q, R, S, while that on the east would have squares D, E, A, J, K, F. The square letter thus simply conveys the idea of a certain area, quite irrespective of the sheet on which it falls (see remarks on this subject in 3 (a)).

(e) Map References.

(e) The map reference of a *point* must always be given by not less than four figures. Thus while a square is known as 47, the *point* at the S.W. corner of the square is 4,0—7,0.

It was decided by the Inter-Allied agreement that in reports a stop or comma should always be put after the figure denoting *kilometres*, and a line or dash between the east and north co-ordinates, so that references would be written in any of the following forms :—

1,3—9,4; 4.57—6.83; 3.21/5.42.

This arrangement is logical, as the co-ordinates are actually kilometric co-ordinates—that is to say, co-ordinates expressed in kilometres and decimals of a kilometre. The precaution is, however, perhaps rather over-cautious when it is remembered that the first figure, and the first figure only, can represent kilometres. In other words, it is impossible when describing a point by co-ordinates within a 10-kilometre square for the kilometres to reach double figures. The method of writing is, however, very clear and might be adhered to.

It was agreed that map references printed or written on maps should always be four-figure, and written without comma or dash thus—3428.

6. System Based on Survey Co-ordinates.

The above description shows how *map references* are given. When exact co-ordinates are required for calculations the full figures must be given. Thus for the same point P the co-ordinates to the nearest metre might be :—

151,325 East; 449,432 North.

It will be seen that this system of map reference is based directly on the survey co-ordinates of the point in question. The same figures (with certain exceptions mentioned below) appear throughout, and the map reference is obtained by omitting figures that are unnecessary.

This can be seen by the following example, which shows the way in which figures are gradually dropped as the description becomes less and less precise :—

	East.		North.
Trig. Co-ordinates ...	151,325	......	449,432
Map References :—			
6-figure (pin-point)	A 1,32		9,43
4-figure	A 1,3		9,4
Kilometre square	A 1,		9,

In certain cases the same figures do not appear throughout. For example, if a co-ordinate is 449,999 the *nearest* figure to this for the abbreviation is 450,000. Cases will occur also where the square quoted in the six-figure reference is different from that in the four-figure.

Examples of changes in figures and letters are given below :—

Rect. Co-ordinates.		Map Reference. 6-Figure.		4-Figure.
164,379	438,228	G 4,38—8,23	......	G 4,4—8,2
167,998	442,991	B 8,00—2,99	......	B 8,0—3,0
169,990	441,002	B 9,99—1,00	......	C 0,0—1,0
159,998	439,982	G 0,00—9,98	......	B 0,0—0,0

Note the third and fourth examples. In the third the point lies so near to the eastern edge of square B that the four-figure reference (which gives the position to the nearest 100 metres) must be given in the adjoining square C. Similarly, in the fourth case, the point lies in the extreme north-east of square F. The six-figure reference must be given as if it lay on the western edge of square G, and the four-figure as if it were the extreme S.W. point of square B.

7. Map Reference in the Future.

The circumstances which led to the adoption of the French system and the advantages which it has over ours have been treated in some detail, as it is necessary for future guidance to understand the reasons for the change.

In any operations precise location may at some time or another become necessary. Whenever it is possible, therefore, the Allied system of reference should be adopted from the outset. There will then be no subsequent changes and confusion. This, of course, presupposes that there is a trigonometrical system in the area of operations and a scheme of rectangular co-ordinates. It should be the first business of the Survey Staff to see that such a system, if it does not already exist, is initiated on sound lines.

8. Improvised Methods.

There will, however, be many cases in which such a system is not possible or is unnecessary. Small operations carried out on small scale maps do not require methods of great precision. In these cases it is always possible to devise a simple method of map reference by squares or rectangles and "tenth" co-ordinates—that is, so many tenths east and so many north measured from the S.W. corner. Such a method of reference is always simpler, quicker, and less liable to error than a topographical description.

All that is necessary is that the map should be covered with a system of squares or rectangles which can be identified by letters or numbers, and the reference for a point is then given by quoting the square letter or number and the "tenth" co-ordinates in the square. Squares may already exist on the map. On most maps if there is not a system of squares there is a "grid" formed by meridians and parallels, and these are often near enough to the rectangular to serve the purpose. A case in point is the 1/100,000 map of France and Belgium.

If there is no existing grid, one should be overprinted or drawn.

If squares are denoted by marginal letters and numbers, as is often the case, it is best to make the rule that the number should be written first, thus : 9B. Then, if co-ordinates are added to describe a point in the square, the figures of the co-ordinates are divided from the square number by the square letter, and there is less chance of confusion. Thus, to denote a point, 9B.43.28 is better than B9.43.28.

APPENDIX IV.

COURSES OF INSTRUCTION.

SECTION I.—SURVEY.

1. General Survey.

Object.—Instruction of additional officers and o.r. for survey work with Field Survey Battalions in the field.

Duration.—6 weeks.

SYLLABUS.

Use and adjustment of instruments.
Solution of a triangle; plane rectangular co-ordinates.
Re-section, by trigonometrical, graphical and differential methods.
Geographical co-ordinates; conversion into rectangular spheroidal and *vice versâ.*
Bonne Projection.
Astronomical observations for time, latitude and azimuth.
Simple adjustment of figures.
Railway Survey.
Survey of a Sound Ranging Base.
Survey of a Battery position.

Practical Work.

The trig. survey of an area (rect. co-ords.).
The survey of a battery position.
,, ,, a S.R. base.
,, ,, a railway curve.

2. Sound Ranging Survey.

Object.—To train at least one officer in each S.R. Section to survey microphone bases.

Duration.—One month.

SYLLABUS.

First Ten Days.

Use and adjustment of theodolite.
Rectangular co-ords. and solution of a triangle.
Theodolite traverse.
Reduction to centre.
Computation of a simple triangulation.
Trigonometrical re-section.

Remainder of Course.

Officers were divided into groups, and each group laid out at least 3 full-size S.R. bases. During this period lectures were given on differential and graphic re-section, azimuths, battery fixing, and also on other subjects connected with Survey work in general.

The "Deflection angle" method was usually adopted for computing co-ords. of microphones.

Data. Deflection angle.
Length and approx. bearing of long chord.
Distance between micros.
Approximate co-ords of 1 micro.

The microphones were then fixed approximately by triangulation and re-section, and finally by short traverses. The usual checks were applied. Officers were also taught a rapid differential method of fixing.

SECTION II.—SOUND RANGING.

1. Officers' Course.

Duration.—17 days.

SYLLABUS.

1st Day.

MORNING.

Lecture.—Aim of sound ranging, its history and the results achieved.
Outline of method of working and statement of the fundamental proposition.
Methods of plotting.
Deduction of formula for asymptote method.
Practical.—Plotting easy films for all.

AFTERNOON.

Description and simple explanation of the instrument.
Arrangement of base. A microphone emplacement is shown.

2nd Day.

MORNING.

Lecture.—Necessity for correction. Standard sound velocity and effect on it of meteorological conditions. Deduction of formulæ for wind and temperature correction.
Practical.—Plotting film with wind and temperature correction.

AFTERNOON.

Practical.—Construction of correction tables from the formulæ.

3rd Day.

MORNING.

Lecture.—Times of flight, plotting bursts by method of circles. Asymptote corrections.
Practical.—Film illustrating the above.

AFTERNOON.

Lecture.—Order of accuracy. Effect of wind and temperature correction.

4th Day.

MORNING.

Lecture.—General description of phenomenon of shell wave. Simple diagram illustrating the order of hearing the shell wave and gun wave. Geometrical construction for shell wave.
Practical.—Construction of shell wave diagram for a special case and the determination of the type of film given by the example taken.

AFTERNOON.

Plotting examples of guns.

5th Day.

MORNING.

Lecture.—Shell wave—gun wave intervals. Dependence on position of observer, range, etc. Bertrand's graphs, their construction and use.
Practical.—Plotting examples of guns.

AFTERNOON.

Plotting.

6th Day.

MORNING.

Lecture.—Detailed description of instrument and microphone and diagram of wiring.
Practical.—One group. Erecting and adjusting instrument. One group. Making experiments with microphone, measuring resistance, etc. One group. Reading film.

AFTERNOON.

Practical.—As above but with groups interchanged.

7th Day.

MORNING.

Lecture.—German artillery and shells.

Practical.—Erection of instrument, experiments with microphone and reading film.

AFTERNOON.

Practical.—As above.

8th Day.

MORNING.

Lecture.—Ranging. Explanation of differential principle. Discussion of ellipse method and proof of formula. Organisation of a shoot. M.P.I. method and its advantages.

Practical.—Examples of ranging film.

AFTERNOON.

Practical.—As above.

9th Day.

MORNING.

Lecture.—Maps and drawing the plotting board. Brief description of 1/40,000 sheet and system of grids and overlap. Plotting points on a board from their co-ordinates. Calculation of a point on the right bisector. Tangent method and sine plotter method. Gridding a standard board.

Practical.—Drawing a Plotting Board.

AFTERNOON.

Practical.—Drawing a Plotting Board.

10th Day.

MORNING.

Lecture.—Corrections by a Wind Section. Explanation of need of a wind section. Method of working and deduction of effective wind and temperature from the records.

Practical.—Working out Wind Section films.

AFTERNOON.

Practical.—Drawing a Plotting Board (continued).

11th Day.

MORNING.

Lecture.—Types of break. Theoretical form, influence of container. Damping. Wind screening. Effect of meteorological conditions.

Practical.—All film reading. Finish up class films and start day's films if ready.

AFTERNOON.

Practical.—As above.

12th Day.

MORNING.

Lecture.—Organisation of Section. Personnel, choice of headquarters and base. Upkeep of lines. Keeping of records and preparation of reports. Hostile battery maps.

Practical.—Explain method of tackling the day's films. Speed essential. Three groups start on the day's films. The remainder work on test and balancing board.

AFTERNOON.

Practical.—Continuation of above.

13th Day.

MORNING.

Practical.—Day's films. Test and balancing board.

AFTERNOON.

Practical.—As above.

14th Day.

ALL DAY.

Practical.—First groups should finish day's films. Work on lines, location and repairing of faults.

15th Day.

General work on instrument, balancing board and line testing.

16th Day.

General revision.

17th Day.

Examination.

2. Computers' Course.

Duration.—14 days.

Syllabus similar to Officers' course, but more elementary, see Part II., Chap. 3, II., 15.

3. Mobile Course.

Object.—To afford practice in the speedy and efficient installation of a Section on a new base.

Duration.—8 days.

General Scheme.

The scheme was to drill the Section in :—

(1) Selecting microphone positions and O.P.
(2) Wiring up these points to Headquarters.
(3) Installation of apparatus at Headquarters.
(4) Surveying microphone positions.
(5) Preparation of the board.
(6) Coming out of action and packing up.

After the preliminary training (see below) was finished, the Sound-Ranging Section took over a complete set of stores.

The O.C. Section was given the approximate position of the 4½ x 35 second base which was to be laid out. He went over the ground the day before, selected the microphone positions and marked them on the map (not on the ground). A position for Headquarters was given.

On the day of getting into action all the work was carried out by squads working under their N.C.O.'s. When all the microphones and the O.P.'s were through, and the instrument working and the board ready, the section was reported ready for action.

The O.C. School went over the whole installation with the O.C. Section and made his report, criticising the way in which the work had been carried out.

On the next day, the cable was reeled up, and the apparatus and all stores were packed and handed over to the O.C. School.

The personnel usually available during the war was as follows :—

4 Officers (1 O.C., 1 A.P.O., 1 Computing, 1 Instrument).

1 Q.M.S.	3 Photographers.
10 F.O.'s.	2 Sound Ranging Operators.
8 Linemen.	1 Carpenter.
6 Computers.	1 Cook.
	3 Batmen.
	4 A.S.C.

Transport.—1 Box-Car, 3 Cycles.

SYLLABUS.

The course was divided into four parts :—

(1) Preliminary training of personnel.
(2) Preparation for getting into action
(3) Getting into action.
(4) Coming out of action.

(1) Preliminary Training.

The preliminary training of personnel included courses of instruction for :—

(a) Linemen and Forward Observers, etc. (5 days).
(b) Computers (6 days).
(c) Sound Ranging Operators (Instrument Repairers), and Photographers (5 days).

(a) Linemen, Forward Observers, spare Computers and Photographers (5 days).

The Section was divided into four squads each with an N.C.O. in charge :—

One N.C.O. and three men.	O.P. Party.
One N.C.O. and seven men.	1st Line Party.
One N.C.O. and seven men.	2nd Line Party.
One N.C.O. and seven men.	3rd Line Party.

First Day.

MORNING.—Practice in joints, pole-crossings, bury crossings. The men of the squad worked under their N.C.O., with supervision by an Officer.

AFTERNOON.—Lecture to whole section on map-reading.

Second Day.

MORNING.—Squads laid one mile of cable each, with pole crossings, buries, labels, etc. The time taken was checked. The work of each squad was criticised with regard to neatness and general efficiency of methods.

AFTERNOON.—Map reading in the field by the N.C.O.'s. Instruction in setting a map, identifying objects, finding one's position on the map, and placing a picket at a special point.

Overhaul of cable by men.

Third Day.

Map reading for whole section. Selection of routes. The men were given instruction in map reading in the field. They were given maps with certain points marked on them, and told to find their way to these points and place pickets there. In going to these positions the men were told to pick the best routes for cable, to make a note of the number of crossings, buries, etc., and an estimate of the amount of cable required.

The pickets were recovered by other parties who also noted the best routes as above and reported on position of the pickets. This afforded a good check on the work.

Fourth Day.

Each squad laid a mile of cable across country between two specified points. The N.C.O. chose the route he would follow. The work was criticised by an officer.

Fifth Day.

As above.

Construction of microphone emplacements.

(b) Computers (6 days).

The two best computers were given a course of training in the calculation of the co-ordinates of the microphones, given a map with their approximate positions marked, and in the drawing of the approximate grids on a standard board.

They were also instructed in the rapid construction of wind-tables and were given all numerical data necessary which could be worked out without knowing the position of the base.

This was extended over 6 days.

(c) Sound Ranging Operators (5 days).

The Sound Ranging Operators and photographer were given the following training :—

Revision of Connections of Instruments.

The connections behind the board were traced out and any necessary diagrams were made.

The connections for the test and balancing board were studied as fully as possible, and all terminals and leads were properly labelled.

Adjustment of Instrument.

The Sound-Ranging Operators and photographers were trained to adjust the lens system and the prisms quickly and systematically. The Sound-Ranging Operators were taught how to test whether the harp strings were properly sensitive and to alter the sensitivity if they were not.

Drill with Apparatus.

The apparatus was taken down and set up several times until everything worked smoothly and everyone knew exactly what was required of him. In taking the apparatus down it was packed away properly in its box each time as if it were about to be moved. Emphasis was placed on the importance of this part of the work. The aim was not only to pack up the main parts of the instrument but also the various leads and wires, in such a way that, if the section moved off to a new position, the erection of the instrument could at once be recommenced.

Testing of Lines.

The Sound-Ranging Operators and photographers were taught how to give tests for the linemen engaged in laying the line and how to test whether any line were through.

So far as time allowed the instrument repairers were instructed in the faults which the instrument was most likely to develop, and how to overcome them. The likely places for bad contacts to occur were also enumerated, and also the most usual causes for jambing in the automatic developer.

(2) Preparation for Coming into Action (6th Day).

General Programme.

Overhaul of stores for getting into action.

Test all cable.

Test microphone grid, telephones, O.P. Key and Cells.

See to provision of spunyarn, stays, labels, stakes, pickets for microphone positions, emplacements, camouflage.

Inspection of stores by O.C. Section.

Details of Work.

LABELLING OF TERMINALS.

When the connections had all been properly traced out, the terminals were labelled carefully in such a way that it was at once obvious which had to be connected together by wires. In the case of the Cambridge type of apparatus, the terminals are already labelled.

PREPARATION OF WIRES AND TERMINALS.

(a) *For the Recording Instrument and Microphone Current Leads.*

Wires of the right lengths for the various connections were cut. J.5 wire was used for the main recording instrument leads, and stout connecting tags were soldered on to the end of each wire. Each lead was plainly labelled at each end, in order to indicate clearly the terminal to which it had to be connected.

(b) *From the Bridge Board.*

Six lengths of twisted flexible wire were prepared for the leads from the six bridges to the six pairs of galvanometer terminals. To each were soldered an appropriate connecting tag, and each of the four ends of any one lead was labelled in the same way. The six leads properly prepared and labelled could then be bound together in a rope. This avoided the confusion produced by six separate lengths of wire, and it was the work of a very few minutes to make the connections from the bridge board to the galvanometer.

(c) *From the Microphone Lines to the Bridge Board.*

It was found in practice that confusion was produced if each microphone line was brought in separately by the linemen concerned and connected to the bridge board. The course was therefore adopted of making a rope of 12 strands of S.11 wire, the four ends of the two leads belonging to any one microphone being carefully and distinctly labelled as above. The rope can be connected by one of the Sound Ranging Operators to the test board and can be led outside the instrument room, where the linemen can make the necessary connections to the outside lines.

BENCH FOR INSTRUMENT.

The carpenter prepared a bench for the instrument during the first six days of the course. This was made collapsible and was capable of being erected rapidly, but was also as rigid as possible. On the bench the instrument was erected, the two parts placed properly in alignment and the prisms adjusted. The carpenter then screwed down wooden stops along each side of the base board of the camera board and galvanometer board in such a way that if the table were erected and the instrument boards were taken from their boxes and placed between the wooden stops on the table, the two parts would be in relatively correct positions.

CHECKING SPARES, ETC.

Before packing the instrument finally, the Sound Ranging Operators checked all necessary spares, and any small articles likely to be forgotten, such as :—

(1) Mercury.
(2) Prism Key, "tommies," and so on.
(3) Spare contact springs or tuning fork.
(4) Spare harps.
(5) Spare lamps.
(6) Platinum or Tungsten wire for harp repairing.
(7) Spare microphone grids.

(3) Getting into Action (7th day).

1. The section went to the position chosen for Headquarters with all stores.

2. The O.C. gave to each N.C.O. in charge of a line-party a map showing the microphone positions which he had to wire up.

The A.P. officer and N.C. officers arranged "departure points" at which wire was to be dumped. The parties commenced laying the wires.

3. The O.C. then proceeded to various microphone positions which he had roughly fixed the day before and fixed them as accurately as possible by detail from the map.

4. The N.C.O. in charge was given a map showing the area in which the O.P. had to be. He chose a suitable position and his party wired it up.

5. The apparatus was erected by the instrument repairers.

6. From the data given them by the O.C. Section, the computers calculated the microphone positions and drew the plotting board.

The lines were cut at odd moments during the day to represent the effects of shell fire, and were repaired as on service.

(4) Coming Out of Action (8th Day).

All cable was reeled in and stores properly packed and returned.

Note.—Courses for S.R. Operators and Forward Observers were adapted to individual requirements. See Pt. II., Chap. 3, Section II., 15.

SECTION III.—CROSS OBSERVATION.

1. Preliminary Course.

Object.—Training in Cross Observation, especially of gun flashes.
Duration.—Three weeks.

SYLLABUS.

Theoretical.	*Practical.*
(1) FIELD SURVEY COMPANY.	
Outlines of organisation.	Examine :— Maps. Battery Boards. Battery Lists. Summaries.

(2) OBSERVATION SECTION.

Its work and importance of keenness, vigilance and honesty of observation.

(3) OBSERVATION.

(a) Angle.	Practise stop-watch intervals, etc.
(b) The circle.	Compass.
(c) Its graduation.	Director.
(d) Zero point (hence R.O. and zero line, etc.).	Micrometer.
(e) Bearing.	Large diagrams of scales and micrometer.
(f) How to pick up new country.	Estimation of angles and clock code.

(4) INSTRUMENTS IN USE.

(a) General principles.	Director drill and work in School survey posts and flash range.
(b) Details of construction.	
(c) Care and manipulation.	
(d) Graticules.	
(e) Lighting Set.	

(5) MAPS.

(a) Conventional signs.	Examine maps.
(b) A base.	Plot rays and intersections.
(d) Fixing new points by intersection.	
(e) North points.	
(f) The grid system.	
(g) Contours and dead ground.	

(6) TIMES.

(a) Watches and synchronization.	Synchronize watches.
(b) Timing of flashes.	Practice stop-watch intervals, etc.
(c) Recording of times.	
(d) Stop-watch intervals.	

(7) GERMAN GUNS AND SHELLS.

(a) Gun, howitzer and mortar.	Examine Shell and Fuze books and actual shells and fuzes.
(b) Different calibres and velocities.	
(c) Types of shell and fuzes	

(8) FLASHES AND PUFFS.

(a) Classification of flashes.	Practice on flashes and puffs in School Group.
(b) Smoke puffs.	
(c) Dummy flashes and puffs.	

(9) FIXING BATTERIES AND CONCENTRATION.

(a) Synchronization of times.	Flash range and School Survey Posts.
(b) Synchronization of observations.	
(c) Bearing and time interval.	
(d) Velocity of sound.	

2. Advanced Course.

Object.—Further training of N.C.O. and men who had gained experience at the front, to fit them for advancement.

Duration.—Three weeks.

SYLLABUS.

(1) MAPS.

Theoretical.	*Practical.*
(a) The framework of trigonometrical points and how they are fixed.	Interpolation with box sextant or director and graphic solution (voluntary extra instruction in trigonometrical solution).
(b) Co-ordinates and grids.	Conversion of co-ordinates to map square references.
(c) Compilation and reproduction of maps and the errors to be expected.	Construction of panoramas, sections and dead ground charts.
(d) Conventional signs and scales.	
(e) Contours and bench marks, fixed heights, angle of sight.	

(2) Observation.

(a) Instruments in use by us and the French.
(b) The box sextant.
(c) Importance of accuracy of observation.
(d) Relation of angular to linear distance.
(e) Classification of intersections.
(f) Single rays and time intervals.

Care of instruments and how to get the best results with them.
Methods of overcoming defects in the instruments.

(3) Other Units Engaged in Battery Location.

(a) Sound Ranging.
(b) Aeroplanes.
(c) Balloons.
(d) Information centres.

Co-operation with these Units and verification of their results.

(4) Ranging Our Own Guns.

(a) Construction and use of graphs.
(b) Ranging on shrapnel bursts.
(c) Form of report.

Prepare graphs and give corrections.

(5) The Survey Post.

(a) Responsibilities, discipline, smartness, etc.
(b) Instruction of post, personnel and maintenance of interest.
(c) Honesty of observation.
(d) Construction, camouflage, and concealment of post.
(e) Reports from Post to Group (telephonic, and, if called for, written).
(f) Description of landscape to a newcomer.

Take charge of construction and running of Post.
Arrangement and orderly maintenance of Post.
Reports of visibility.

(6) The Group.

(a) Synchronisation of observations, history of its development and alternative methods.
(b) The Group board, hostile battery charts and registers.
(c) Traces of intersections.
(d) Telephones, switchboards and keys "Flash and Buzzing"; construction and connections.
(e) Telephones, construction and connections.

Practice working Group H.Q., Plot and index active hostile batteries and make tracings of intersections.

3. Computers' Course.

Object.—To provide in the H.Q. of each Observation Group a computer who will be able to deal with the computations necessary to rapid surveys and ranging. The idea was to train one of the Survey Post Observers, and so save officers' time; not to inaugurate a new post, as it was not anticipated that the computing work would occupy a man's whole time.

Duration.—Two weeks.

Syllabus.

(1) Bearings and measurements of angles.
(2) Trigonometrical ratios and their relationship to one another.
(3) Solution of triangles.
(4) Logarithms.
(5) Co-ordinates and grid system, including French grids.

(6) Computations of bearings and distances.
(7) Cutting lines.
(8) Preparation of map boards, plotting trig. points and drawing arcs.
(9) Computation of intersections.
(10) Interpolation.
(11) Preparation and use of grid for artillery shoot.
(12) Heights and distances, corrections and curvature and refraction.
(13) Bearing traverses.

4. Signalling Course.

Object.—To teach officers the proper methods of repairs, maintenance, making connections, etc. (Note.—The references in the syllabus to sound-ranging apparatus are with the object of enabling Observation Group Officers to assist in the installation of a S.R. Section.)

Duration.—Four weeks.

SYLLABUS.

Theory.	*Practice.*
(1) D.III. and Trench telephones. (2) General principles of external connections, metallic and earth circuits. (3) Ladder lines. (4) Morse Code. (5) Patrolling lines. (6) Breaks and repairs, tests of lines for conductivity and insulation. (7) Switchboard and keys, flash and buzzing. (8) The Exchange.	Practice sending messages on model group. Practice with tapping key, flag and signalling lamp. Practice jointing common and special sound-ranging wires. Testing lines for conductivity and insulation. Construction and maintenance of air lines and buried cables for low resistance lines. Manipulation of exchanges. Connecting up and working of special switchboard "Flash and Buzzing" and keys, "Flash and Buzzing." Fitting of "Tucker" microphone.

Men's Course.—A similar but more elementary course was held for N.C.O.'s and men.

APPENDIX V.

MAGNETIC BEARINGS.

1. The Compass.

The magnetic compass has always been a useful military instrument and was largely used in the war. It can be a valuable instrument in proper hands, while it can be very dangerous when used by those who are ignorant of its limitations. All officers are trained to use the compass, but perhaps sufficient emphasis is not laid by instructors on the precautions to be taken. Certainly, as far as the experience of the Field Survey Battalions went, there appeared to be great ignorance of the subject as much among the regular as among the temporary officers. An example, perhaps an extreme one, is that of the artillery officer who was found laying out his line from a compass placed inside the bore of his gun. The steel helmet also proved a great trap to the unwary.

The Field Survey Battalions came into contact with the compass mainly through the artillery, with whom a great part of their work lay. For the artillery accurate methods of using the compass are essential, and instruction on this subject was given. Many compasses were, however, examined also for the infantry.

2. Compass Testing.

When the line became stationary after the opening phases of the war large scale maps appeared on which accurate work could be done, and the errors of individual compasses began to be noticed.

In December, 1914, and January, 1915, many compasses were tested by the First Ranging Section, R.E. These compasses belonged for the most part to Battery Commanders.

In February, 1915, a printed circular from Maps, G.H.Q., drew attention to the possibility of having compasses tested and many more were examined both at Headquarters of the 8th Divisional Artillery (where the First Ranging Section had its office) and later at Marie Cappelle, the Headquarters of the First Ranging and Survey Section.

In many cases it was found that the point of suspension had been damaged, and a considerable number were quite valueless.

On the formation of the Topographical Sections the practice of examining compasses dropped out for a time, because of the great press of work and the smallness of the staff. When both Corps Topographical Sections and the Observation Groups were formed, however, the practice was reverted to, and in some cases special compass testing stations were formed where large numbers of compasses were examined.

3. Bearings from Grid North.

Apart from compass errors, an additional source of uncertainty was introduced by the adherence to the old principle of reporting bearings from true north. In France it became an established practice to report bearings from Grid North from about 1917, but apparently some schools of training in England continued to lay down the principle of reporting bearings from true north until a late date.

To adopt this principle on a rectangular series of maps is equivalent to inserting an additional plotting, either in estimating the bearing or in plotting it afterwards.

In early map editions the three north points—true, grid and magnetic—were all shown in the margin of the large scale maps. It was decided later, however, to show only the two which matter—the grid and the magnetic.

4. Magnetic Survey.

Very little accurate knowledge existed before the war as to the magnetic variation in N.E. France. Perhaps the best source of information was contained in the chart illustrating the "Reseau Magnetique de la France" (Monsieur Moureaux). Moreover the rate of secular change was under-estimated. The result was that the value for the magnetic variation on our maps was too high by some 30 minutes, and the shape of the curves was not good. Lieut.-Col. Keeling, of the 3rd Field Survey Battalion was the first to point this out, basing his argument upon the results obtained by testing a large number of compasses in the VI. Corps in May, 1918. His estimate of the error of our figures was borne out to some extent by the curves shown in the French Manual for their "Officiers Orienteurs."

At Lieut.-Col. Keeling's suggestion a magnetometer was borrowed from Kew, and the magnetic survey of the 3rd Army area fully endorsed his statements. A magnetic survey of the whole of our area was therefore carried out in July and August.

Observations were made at eighty-eight stations with Kew magnetometer No. 140. The usual methods were followed, the magnetometer being set up, with the aid of a theodolite, on a line of known bearing, usually between two trigonometrical points. The stations were selected as far away as possible from railways and other disturbing influences. The correction for tortion was always less than one minute, and was neglected. The convergence for each station was determined and the variation from true north thus obtained.

The corrections for diurnal inequalities and the reduction of the readings to 1st January, 1918, were made at Kew Observatory in the usual way.

Maps available in the War Office (The Magnetic Survey of 1918, Printing Co., R.E., W.O.B./2769) show the observation stations, the magnetic variation (from true north) on 1/1/18 at each station, and the lines of equal magnetic variation for the area on that date.

The variation from grid north was published to the troops, but as a permanent record the variation from true north is, as above stated, shown on the map.

(NOTE.—In the above the word "variation" is used in accordance with military practice to express the difference between magnetic and true or grid north.)

APPENDIX VI.

SCREEN CALIBRATION.

1. Early Experiments in England.

Early in 1917 Lt.-Col. Marton, of the Overseas Artillery School (Salisbury Plain) suggested that the Bull recording apparatus used by the Experimental Sound-Ranging Section might be employed for measuring muzzle velocity; the usual method of firing through wire screens being adopted, but with the Bull apparatus in place of the Boulanger chronograph.

Lieut. Tucker, then O.C. Experimental Section, carried out the idea, and modified the apparatus for the purpose. The modification consisted chiefly in embodying a train of gear wheels in order to run the film at a much higher speed, and so measure the very small time intervals necessary for the object in view. It was found that intervals as small as 1/25,000 second could be measured without great difficulty, but at first 1/10,000 second was considered sufficient. The Bull apparatus lent itself well for the purpose, as a large number of strings can be used in the galvanometer, and the method of transmitting the time signal from the screen to the record is simple and extremely accurate.

2. Initiation of Work in France.

The results of these experiments appeared to offer distinct possibilities for calibration in the field, and they were communicated to the M.G.R.A., G.H.Q., France. The Ordnance Committee, who had been consulted, expressed the opinion that no value could be expected from the determination of muzzle velocity in the field, because the M.V. of a worn gun was no exact criterion of the performance of the shell, owing mainly to unsteadiness of flight. In other words, they considered that so many other factors influenced the range that the measurement of M.V. would serve no useful purpose.

The M.G.R.A. however disagreed with this opinion, and Armies were notified that, while no special sections were to be formed, screens might be erected and sound ranging apparatus used for the purpose, if considered desirable locally.

Brig.-General Kirwan, who had previously been Commandant of the Artillery School, Salisbury Plain, was a believer in the system, and took the matter up on his return to France as G.O.C.R.A. XV. Corps. As a consequence D Sound Ranging Section, under the command of Capt. Chapman, R.E., was placed at his disposal in June, 1917, and was installed near the coast at Coxyde Bains. Lieut. Tucker came out from England and explained his methods. In July D Section was taken over by the 4th F.S.C., on the arrival of that unit with the Fourth Army H.Q.

Calibration by measurement of M.V. had in the meantime been commenced tentatively in other areas, as for example by S Section near Gouzeaucourt Wood; but without satisfactory results, owing to ignorance of certain factors which were later determined by Capt. Chapman.

3. Calibration Section on Belgian Coast.

Up to the date on which D Section was taken over by the 4th F.S.B., calibration had been carried out by firing through screens only, the guns so calibrated being sent back to the line. The Battery Commanders were presumably asked to give their opinions on the utility of the work after a suitable interval. This procedure, though it would doubtless have ultimately collected a body of opinion either for or against the method, could hardly be expected to furnish any precise data as to its value; it was therefore suggested by the O.C. 4th F.S.B. that by installing three observation posts along the coast and observing the fall of the shot in the sea, it would be possible to make an exact comparison between the M.V. determined by the screen method, and that deduced from observation of the range in the usual way.

These posts were consequently established (after some difficulties with regard to labour, which were solved by the help of Lt.-Col B. A. B. Butler, R.F.A.), and the complete installation was working satisfactorily by the beginning of August. The fall of each shot was observed from the three posts and plotted on a 1/5,000 board at the firing point. The M.V. worked out from the observed range was tabulated for comparison with the M.V. measured by firing through the screens.

At about this date, D Section being required for its legitimate work of location, the necessary personnel for calibration was provided by the formation in the Army of No. 22 Observation Group, which continued the work under Capt. Chapman with the unofficial title of the "Calibration Section."

4. Research by Capt. Chapman.

A detachment from Meteor 4th Army was attached to the Calibration Section in order to give a continuous and accurate record of wind, barometer, air temperature and sea level throughout the day. The methods adopted by this detachment enabled the mean wind and air temperature to be accurately determined for any trajectory. Using the existing range tables, the M.V. which would theoretically produce the range actually found by observation was determined, and this figure compared with the M.V. actually developed by the piece as ascertained by the screens.

It was then found that considerable discrepancies existed between the actual M.V. and the M.V. so deduced from observation, and these discrepancies were subsequently traced to a variation in the difference between the actual angle of projection and the quadrant elevation as given by a clinometer, for different individual pieces.

The range table for any given gun or howitzer is based on a certain definite jump, and individual pieces were found to give jumps varying very considerably from this figure. The procedure was therefore adopted of measuring for each gun calibrated the droop plus jump, this being the actual angle between the line of the clinometer plane before firing and the line of departure of the shell. Due allowance having been made for the difference between this angle and the jump given in the range table, excellent agreement was found between the M.V. deduced from observation as already explained and M.V. obtained by means of the screens.

A constant difference was however sometimes obtained. For example the 18-pr. gun gave a constant difference of 12 F/S between screen and observed results, the screen result being the greater; while the 4.5-in. howitzer gave a difference of about 14 F/S with 5th charge, in this case the result from observation being the greater.

Such differences could be due to:—

(i) A constant difference in the M.V. registered by the Boulanger chronograph and the Bull apparatus.

(ii) Any difference in the projectile used in the practice on which the range table was based, and that used in the experiments at Coxyde.

(iii) Any error in the determination of the meteorological conditions during the above practice.

As, however, it remained a constant difference, it was allowed for in the result given to the Battery Commander, and in no way affected the accuracy of subsequent firing based on the figures given and using the existing range table.

During the time these experiments were being carried out calibration results were given to batteries from observation alone, so that the section was performing useful routine work at the same time as it was obtaining the necessary information for working with screens alone.

The experiments proved that the opinion of the Ordnance Committee was incorrect, and that the unsteadiness factor was, at medium and short ranges, negligible, even with guns worn to the condemning limit. It was found, however, that the unsteadiness of the shell with worn guns made the method unreliable at extreme ranges. The smoothness (or newness) of shell and fuse was shown to have a considerable effect, and variations in the behaviour of different lots of shell and charge were observed.

It was considered that in all probability the variation in the ballistic co-efficient at long and extreme ranges could be expressed as a function of the loss of M.V. or wear, or both, but, unfortunately, just as this stage (December, 1917) was reached the range on the coast had to be closed down owing to the area being taken over by the French.

An exhaustive report on the above work, in the stage which it had then reached, was submitted by Capt. Chapman in October, 1917. Dealing with so large a number of results, it proved conclusively the value of screen calibration. Capt. Chapman's careful and thorough arrangements, and his masterly analysis of results, were thus responsible for a rapid advance both in method and in the confidence of the Artillery during the summer of 1917.

5. Calibration Section at Tilques.

On the move of the Fourth Army to the Ypres front the Calibration Section was established at Tilques, near St. Omer. Here it no longer had the advantage of observation in the fall of the rounds, and its work thereafter consisted of calibration by measurement of M.V. with corrections based on previous experience, and various practical improvements and investigations.

The progress from this stage may be considered under the following heads:—

(a) Increasing the capacity of a section so as to enable the calibration of guns to be undertaken on a large scale.

(b) Investigation of other factors which could affect the accuracy of results.

(c) Improvement of the apparatus and investigation of its limits of accuracy.

Considering these points in detail:—

(a) As soon as the range was moved to Tilques three guns were fired simultaneously through three sets of screens, and on this proving a practical method, guns were fired in salvoes of six in the same way, enabling a battery of guns to be calibrated at one time, thus enormously increasing the capacity of the range. This method was adopted in the calibration ranges subsequently formed.

(b) The most important factor which can affect the results of screen calibration is the existing variation between different charge lots, and in order to overcome this difficulty as much as possible in a practical way, a series of 12 rounds was fired for each gun of the battery with cartridges of 12 distinct lot numbers. The same 12 lots were fired for each gun. This ensured (1) an exact relative calibration of each gun in the battery, and (2) that the M.V. recorded as the mean of a series represented the mean performance of the gun.

This procedure also led to valuable information being obtained showing the relation between different charges and propellants, previous figures being unreliable in this respect owing to the uncertainty of the value of the ammunition used. All the calibration sections accumulated a great deal of valuable data on this point.

The next question was possible variation in jump. Experiments at Coxyde and Tilques showed that the effects of varying elevation, platform and propellant on jump are negligible, and are in no way sufficient to detract from the value of results given to batteries. This conclusion has been quite recently confirmed, as regards the effect of varying elevation on jump, by extensive trials carried out at Chapperton Down Artillery School with 18-pounder guns, which have also shown that the projectile used has no appreciable effect.

(c) While the above investigations were in progress in France experiments were carried out at the Experimental Sound Ranging and Calibration Section on Salisbury Plain, which led to a considerable increase in the accuracy and reliability of the instrument, and at the same time showed conclusively its value for the work which it was called upon to perform.

6. Formation of Other Sections.

By the end of 1917 there was little doubt as to the practical value of calibration by the screen method, but the shortage of men made it very difficult to obtain personnel to form sections in other Armies. Enough was, however, borrowed to start sections in the First and Third Armies. The latter had not got properly into action when the German offensive resulted in the loss of the proposed range. It was installed soon after on a new site, and both this and the First Army Section got to work with much success. Large numbers of batteries were sent to these Sections to be calibrated, and Battery Commanders frequently testified to the great value of the results obtained.

7. Further Experiment.

Screen calibration had hitherto been confined to 60-pr. guns, 6-in. and 4.5-in. howitzers, and 18-pr. guns, and had proved of practical utility only up to medium ranges. Investigation was still required of the unsteadiness factor, with a view to calibrating for long ranges, and of the application of the method to heavy guns and howitzers. The former was the more important problem, and to deal with it Capt. Chapman was sent to the Experimental S.R. and Calibration Section on Salisbury Plain. Owing, however, to various delays and difficulties, practically no progress was made in this direction before hostilities ceased, after which experimental work stopped.

Some interesting experiments on Salisbury Plain in which the National Physical Laboratory took part (August, 1918) showed that screens were not really necessary, but that microphones might be used instead. The shell passing over these not only allowed of a measurement of time taken between microphones, but of the jump of the gun. As a practical drawback, however, this method will allow of the calibration of only one gun at a time, whereas with screens the guns of a battery can be calibrated all together, firing in salvoes, each gun through its own screen. It was also shown that the measurement of muzzle velocity alone could be carried out successfully by firing through coils.

In connection with the question of calibration of heavy guns, the "Joly" apparatus produced by the French for this purpose may be mentioned. The apparatus is light and portable, and the system easy and accurate to work. It has, however, two great drawbacks, in that it depends upon the shell wave and cannot therefore be applied to any shell whose velocity is less than that of sound in air, and that it does not enable one to measure the jump. These drawbacks are important, and the Joly apparatus does not seem to be worth taking up seriously.

8. Present Position.

The position of Screen Calibration at the close of hostilities was thus as follows:—

Provided that wind, temperature, etc., are known, it has been proved that the range a gun will attain at medium or short ranges with a certain lot of ammunition is a direct function of the M.V. obtained by calibration with that ammunition. It has been shown that the unsteadiness factor does not complicate the issue at such medium or short ranges.

The perfect registering instrument has not been evolved, but it is clear that a string galvanometer is an excellent, if not the best, solution for ranges where guns can be calibrated in bulk.

A really good apparatus for calibrating heavy guns and howitzers in the field has not yet been evolved.

Calibration in the line by observation of the fall of the rounds must play an important role for heavy and siege batteries, because there is at present no other method of doing it. It may under careful management be valuable and moderately accurate, but the following information is most important and is seldom obtained as correctly as it might be.

1. True range, obtained by survey of gun position and of fall of rounds.
2. True angle of sight, obtained by survey of height of gun and of burst, and not from contours.
3. Accurate meteorological corrections.

On the other hand, when screen calibration is employed, a knowledge of range, angle of sight and meteorological corrections is unnecessary, as the muzzle velocity is measured directly and not deduced from the fall of the rounds.

In the case of calibration by the fall of the rounds, the probable error deduced from results obtained in the line may be taken as about 9 feet per second, *if all the necessary data are carefully and accurately measured.* If these data are not accurately known the error may be much greater.

The probable error of a muzzle velocity obtained by screen calibration on the other hand is about 3 feet per second.

Screen calibration is therefore far more accurate and reliable than the best calibration in the line by observation of fire can be, not only because of the accuracy of measurement, but because it automatically eliminates errors of survey and of meteorological data.

In order to be of value, calibration both by observation and by the screen method must be done with mixed charge lots. It has been found in the case of a field gun that outside variations from the mean M.V. determined with mixed charge lots may amount to as much as 35 feet per second either way. Rounds fired with one charge lot only may therefore give a M.V. widely different from the true mean.

APPENDIX VII.

PANORAMAS AND STEREOSCOPIC PHOTOGRAPHS.

1. Classes of panorama.

Panoramas are made for different purposes, and differ in their treatment accordingly. Broadly speaking, panoramas may be divided into the following categories, though this classification is not necessarily exhaustive.

(a) Rapid sketches for use in mobile warfare, for first reports on positions, etc.

(b) Panoramas to give a clear general idea of the landscape and nature of the country and tactical features, for the information of commanders.

(c) Panoramas for the exact identification of position of targets or points of military importance.

The "rapid sketch" panorama hardly came within the province of the Survey units, whose work lay more in the direction of exact representation and measurement. Cases did occur when the photograph, quickly developed in the field, might answer for this purpose; but, generally speaking, such a panorama would be done by hand, and this pre-supposes artistic skill and considerable practise to ensure its value. Further reference will not be made here to this type of panorama.

Panoramas under the headings (b) and (c) form the main subject of this appendix. Most panoramas made during the war (and the bulk were produced by, or under the auspices of the Field Survey Battalions) fell under head (c) and were prepared accordingly. These panoramas were consequently as a rule used for the purpose of head (b), but they contained certain additions (such as measurement of angles, etc.), which were not, strictly speaking, necessary for (b).

Further, the question whether a panorama should be photographic or hand drawn depended to a great extent on whether it was intended for (b) or (c). This point will be dealt with in discussing the relative values of photographic and drawn panoramas. In the meantime it may be stated that as a general rule the same panoramas did duty for both classes (b) and (c).

2. Relative value of photographic and hand-drawn Panorama.

To be of military value, panoramas should possess the following characteristics.

(a) They should eliminate all "artistic" and "atmospheric" effect, accuracy and freedom from ambiguity being the chief requirements.

(b) They should be clearer than the original landscape, and should *as a rule* accentuate features of military importance.

(c) They should omit unnecessary and adventitious detail, especially in the foreground.

(d) They should represent the facts, not the author's interpretation of them.

With these points in mind it is possible to consider the relative value of the photographic and the hand-drawn panorama.

In the first place it is evident that the photographic panorama cannot fulfil all these conditions. The photograph produces, with certain limitations, an accurate representation of the landscape under the conditions existing at the moment. It cannot, however, exercise any selection, it cannot accentuate important features, nor can it omit unnecessary detail. In certain cases the photographic panorama is entirely satisfactory, as, for example, in country with artificial detail, or in areas with clearly marked topographical features. It fails, however, in areas that are covered by woods and hedges, and it does not bring up topographical features in broken country; and it also fails to convey adequately the correct sense of distance.

The great advantage of the hand-drawn panorama is the power of selection which it allows. Important points can be emphasized and unimportant subdued or ignored. Features of tactical importance which are inconspicuous in the general view or when seen from one point only can be brought out. The relative distance of various points can be correctly represented.

There is, however, one respect in which this very advantage of the hand-drawn panorama is for certain purposes a disadvantage. A hand-drawn panorama represents the landscape as seen through the eyes of another man, and however carefully and accurately it may be drawn, this fact cannot be forgotten. Further, although the power of selection is for many purposes a great advantage, it is also an advantage to have a representation that shows faithfully, as far as optical limitations allow, every detail, whether important or not, in the landscape. Details that at one time seem unimportant may at another, owing to new information or other reasons, prove to be important.

For these reasons a commander who has a panorama before him for the purpose of study or consultation will, as a rule, prefer a photograph, or will at any rate like to have a photograph at hand to supplement the hand-drawn picture.

Other points affecting the question of relative values are that the photographic panorama is quicker to produce in the first instance, and requires no artistic skill; but its reproduction in quantity is difficult, and it provides a bad surface for writing notes. The reproduction in quantity of the hand-drawn picture, on the other hand, is easy, and the paper used is suitable for drawing or writing.

To recapitulate, the advantages of the photographic panorama are :—

The first production is quicker.
No artistic skill is required.
It omits no details.

Those of the hand-drawn panorama are :—

Selection is possible.
In certain circumstances a truer representation of the landscape can be given.
Reproduction is easy.
Surface is good for writing.

It is thus evident that it is impossible to say that the photographic panorama is better than the drawn, or *vice versa*. Each is better suited to certain purposes, and should when possible be employed accordingly.

Actually it is inevitable that the photographic panorama should to a great extent replace the drawing, as was the case in the war, if only for the reason that photographers are always available, while skilled panoramic draughtsmen are not. There is also, however, the reason that those who have to use them will always prefer panoramas produced by a mechanical method as being less liable to false representation.

It should, however, not be forgotten that the drawn panorama continues to have a real value and is sometimes the only kind possible.

3. Photographic Panoramas.

Photographic panoramas were taken during the war with 5 in. by 4 in. "Panros" cameras, mounted on special stands with graduated arcs and pointers. Experiments in the subject had been carried out before the war, and one of these cameras was taken into the field with the Headquarters of the Printing Company. Later each Topographical Section was supplied with one.

In order to take the distant detail with sufficient clearness the panoramic camera was fitted with a telephoto lens giving three focal lengths, 30 in., 18 in. and 12 in., the length being varied according to the subject and the quality of the light. As in all telephoto work, it was necessary to use a colour screen and panchromatic plates.

The final prints were 10 in. by 8 in., being enlargements from the original 5 in. by 4 in. plates.

The following criticisms may be made on the apparatus used :—

(a) The camera body was not sufficiently rigid. The front should not be held in position by metal stays, but by wooden flaps. A design for such an arrangement was got out by Cpl. Rawbone, of the 3rd F.S.B., in 1917, and sent to England. This type of body would also lend itself better to camouflage than the other.

(b) The focal-plane shutter was too complicated, and frequently got out of order. A simpler form of shutter would be more suitable.

(c) The method of mounting on the stand was too complicated and not easy to manipulate in an awkward trench. The stand itself was satisfactory.

(d) The camera used was an ordinary hand camera with certain adaptations. It is probable that a more suitable type of camera could be found or designed for the special purpose of taking panoramas.

In spite of these criticisms, however, the excellent results obtained in panoramic photography during the war show that there cannot have been any serious defects either in the instruments or in the methods employed.

A special periscopic type of camera (designed by Major Wilbraham) was made, and proved very useful in exposed positions.

It was found that panoramas were more convenient to use if mounted and folded concertina fashion and not rolled. The following additions add greatly to their value, and are essential if the panorama is to be of real use in identifying points in the landscape :—

(1) A note stating the exact point (co-ordinates or map reference) from which it was taken, the direction and extent of the field of view, length on the photograph corresponding to an angle of one degree in the horizontal plane, and the date on which it was taken.

(2) A portion of the map showing graphically the point and angle of view.

(3) The name and map reference of all important points should be written with arrows indicating the exact position.

(4) A horizontal scale of degrees should be drawn along the bottom of the panorama showing *grid bearings*. Failing this, which time does not always permit, the grid bearing of one, or, better, two or three, prominent points should be given. This, with the length of the degree mentioned in (1), will enable the bearings of other points to be measured.

A convenient addition also is the German method of showing a distance scale. A foreshortened sketch of the map is reproduced above the panorama, marked with equally-spaced horizontal lines representing kilometres of distance from the observer. The salient points in the panorama and main features, such as woods, are sketched in, and their distance and depth can thus be seen at a glance. The scale of distance is varied to suit different depths of view, and is quite conventional and without perspective.

4. Hand-Drawn Panoramas.

Hand-drawn panoramas were found useful in the following cases :—

(1) To represent country which, for the reasons given in paragraph 2, could not be satisfactorily shown by a photograph.

(2) In cases where it was important to emphasize certain details.

(3) To supplement photographic panoramas, as it was found impossible to take photographs from every suitable point along the front.

(4) For a rapid sketch of a situation.

The educative value of a hand-drawn panorama should be remembered in this connection. There is no better way of learning the country than by drawing it.

It may also be mentioned that a photograph can be used as a very convenient basis for drawing a panorama. It is possible to ink in outlines and emphasize important details and subsequently to bleach the photograph away.

A useful method of drawing a panorama is given in the "Manual of Map Reading," but in France the plan was adopted of preparing a special "grid" for the purpose. The grid consisted of vertical lines representing bearings and horizontal lines representing degrees of elevation and depression. Such grids could be prepared by hand, but they were also printed by the A.P. and S.S.) was published, giving hints on methods and drawing, and exaggerate the vertical scale to one and a quarter or one and a-half times the horizontal, and not to represent it correctly as recommended in the Manual.

A useful note on hand-drawn panoramas (Notes on Panoramas, Ic/12614, July, 1918, printed by the A.P. and S.S.) was published, giving hints on methods and drawing, and examples.

5. Panoramas from Observation Posts.

Panoramas made by the Field Survey Battalions were generally either (1) from their own Survey Posts, or (2) from the O.P.'s of Heavy Artillery. In case (1) they fulfilled the following purposes.

(a) They ensured that the man who made them had the best knowledge possible of the country he observed. By no othe means could such intimate knowledge of an area of country be obtained as by sketching.

(b) They formed a record which served as a guide to any new observers who might occupy the post.

(c) They provided a picture of the datum points which should be fixed, and of the areas in which calibration could be carried out.

(d) They formed a valuable adjunct to the map in the preparation of any tactical scheme.

(e) They formed a permanent record on which new hostile works could be noted from time to time.

(f) They were useful to complete the reconnaissance of back line posts which might be wanted later.

In case (2), (b), (c) and (e) applied equally well, the question of forming a record as a guide to new observers applying with particular force.

A special box should be provided, in every O.P. from which a panorama has been taken, with a copy of that panorama in it, and the Observer on duty should be responsible that it is not removed.

6. Panoramas from Balloons.

The taking of panoramas from balloons was developed in the German Army with considerable success. There are certain obvious difficulties which must have taken some ingenuity to overcome, and it is not clear exactly what the German methods were. A good deal of mapping information might be obtained in this way, and annotated panoramas would be very useful for balloon observers.

7. Use of Panoramas.

The value of a good panorama properly annotated is undoubted, and was fully realised in the war by those who appreciated them. It cannot be denied, however, that they were not used properly by all to whom they were issued. They were not sufficiently used for studying the country with a map. They were not sufficiently used as records for targets, or for instructing new observers when taking over an Observation Post. They were too often collected as souvenirs.

The value of a panorama photo for mapping purposes is not very great. They have been used with considerable success in some cases for contouring—angles of depression and elevation being marked on them for the purpose. A certain amount of information was obtained from them by the identification of objects visible in air photos, but such questions were, as a rule, much more satisfactorily settled by a visit to the O.P. with a theodolite.

8. Reproduction and Distribution.

The reproduction of photographic panoramas offered certain difficulties. Producing the ordinary photographic print in quantity is a slow process, and formed a heavy strain on the resources of the Field Survey Battalions. The Army Printing and Stationery Service were better equipped for this purpose, and when reproduction was handed over to that Department it was carried out in a thoroughly satisfactory manner; but it remained of necessity a slow business in comparison with lithographic or similar methods. Reproduction by the half-tone process, which would seem the obvious method, was found unsatisfactory, as the finer detail, often of great importance, was usually lost.

The reproduction of the hand-drawn panorama was an easy and rapid process, as it was done by ordinary lithographic methods. Any quantity required could be printed in a short time, with colour, if necessary.

The problem of distribution is similar to that of maps. Steps should be taken to ensure that the actual units in the lines receive their proper issue.

Every battery should be provided with copies of the panoramas from its own O.P.'s, or from commanding points near by, from which the country over which it has to shoot is visible.

9. Stereoscopic Photographs.

The question of taking stereoscopic views from the trenches was taken up in the early days of the war with some assiduity, mainly by Major Wilbraham, while O.C. Printing Company. He used two cameras, mounted on a baseboard, about 3 feet apart. A number of photographs were taken in this way, with excellent stereoscopic effect, but the difficulties were considerable, and, generally speaking, the danger and the labour involved were out of proportion to the results gained. To be of any use it was necessary to take the photo from a certain elevation. This meant the use of a mast, either telescopic or raised by a counter weight. A good deal of preparation was required, which in narrow, overcrowded and muddy trenches was not a simple matter; the camera had to be raised and lowered rapidly, and invariably drew fire; while the view taken was limited, and it was not always possible to ensure that it was exactly in the direction desired.

The occasions when such photographs could produce results of military value, and such as to justify the labour and risk, were necessarily few; and the taking of stereoscopic photographs was dropped after the early attempts.

APPENDIX VIII.

FOREIGN SURVEY ORGANISATION AND METHODS.

In this Appendix a brief account is given of the Survey Organisation of the American, Belgian, French, and German Armies in the war, for the purpose of comparison with our own, with special notes on methods, where these call for remark.

The account is arranged in each case (except that of the Belgian Army) under the following heads :—

General Organisation.
Reproduction and Map Supply.
Survey and Mapping.
Flash and Sound Observation.
Notes.

More detailed information is available if required in the Geographical Section, War Office, in the form of reports by our own or foreign officers, and foreign pamphlets, circulars, orders, etc.

SECTION I.—AMERICAN ARMY.

1. General Organisation.

G.H.Q.—The organisation corresponding to our "Maps, G.H.Q." was similar to ours, being a branch of the General Staff, Intelligence. Relations with the Chief Engineer were closer than in the British Army; reinforcements and most stores came through him, and the chain of executive authority led completely up to him, though in practice the G.2.C. officers acted for him.

The Staff was as follows :—

General Staff.

G.2.C. (Colonel).
Lt.-Colonel. Technical Assistant (Flash and Sound).
Lt.-Colonel. Cartography.
Major. Administration.
Captain. Supply.

Attached from the Base Survey and Printing Battalion.

4 Lieutenants. 1 Drawing.
2 Printing.
1 Map Supply.

Army.—It should be mentioned that the numbers quoted below are in all cases those of the establishments, and not the actual numbers available. Many units never arrived, and the actual numbers were always much below those given.

The organisation consisted of a Staff-Officer (G.2.C.), a Survey and Printing Battalion, and a Sound and Flash Ranging Battalion.

The Staff Officer had no assistants on the General Staff. His duty was general supervision of technical work and liaison with the various branches of the Staff.

Survey and Printing Battalion.

H.Q.—O.C. and 3 officers (Adjutant, Supply, Transport), 3 Companies, each of 6 officers and 250 other ranks.

Nominal total—22 officers, 750 other ranks.

S. and F. Ranging Battalion.

H.Q.—O.C. and 3 officers (Adjutant, Supply, Transport), 5 Companies, each of 18 officers and 250 other ranks.

This was the maximum strength, and was based on one Company per Corps in a full-sized Army.

Corps.—1 Captain or Lieutenant and 23 other ranks were carried in Corps H.Q., under G.2.C. for map purposes.

Division.—4 Draughtsmen, in G.2. for map purposes.

Base.—At the Advanced Base (Langres, about 40 km. from G.H.Q.) a Survey and Printing Battalion was located, and this provided the personnel for the Base Printing Plant, and also for the Computing, Drawing, and Relief Map Departments. There was also a Stores Depot here.

The Staff was a Lt.-Colonel Director, with ten assistants of varying rank, in charge of the following Departments: Cartography, Relief Maps, Surveys, Instruction, Litho, Photo, Engraving, Drawing, Computing, and Map Supply.

2. Reproduction and Map Supply.

(a) Reproduction.

The Base Printing Plant corresponded to a combination of our Overseas Branch of the Ordnance Survey and the Base Establishment of the Army Printing and Stationery Services; that is to say, it was the office in which bulk printing and reproduction, both letterpress and lithographic, was carried on for the whole Army. The reproduction arrangements were most complete.

For letterpress printing there were several linotype and monotype composing machines and machine presses.

For lithographic work (or zincographic, for stones were hardly, if at all, used), there was a large installation of machines, all of direct printing rotary type. These included two large stationary and ten smaller portable machines, of American make, and four large and one small Mann machine. The larger machines (British and American) were quad-demy, or approximately that size; the smaller about double-demy, the exact printing surface of the American portable machines being 34 ins. x 22½ ins. As these rotary machines could turn out about 2,500 runs an hour, it will be seen that the printing capacity was very large.

The reproduction arrangements included a Penrose Camera, big enough for their largest size of plate; a complete outfit for wet and dry plate work, and for the Vandyke process. The last-named process has been slightly modified by the Americans, and they claim to have improved it. An electric photostat copier was also installed. Electrical power was used throughout, and was derived from a battery of eight petrol-electric units, each capable of producing 25 kilowatts, and about half of which were enough for normal requirements. There was thus a reserve of about 100 per cent of power.

G.H.Q.—A small reproduction plant was kept at G.H.Q., consisting of hand letterpress and litho machines and a Dorel outfit.

Army.—The reproduction outfit for an Army consisted of a treadle press printing machine, a Dorel apparatus, a large stationary rotary machine, a portable machine used dismounted, and a mobile lithographic plant, which included a Vandyke outfit. No provision was made for Helio work with an Army.

The mobile printing plant consisted of five lorries; one containing a portable machine, one an electric generator, with arc lamps and printing frame, one a Vandyke apparatus, one a proving press, etc., and one stores.

The portable machine was a direct printing rotary of special design, made by the Hall Printing Company, New Jersey. Its chief feature was that the number of inking rollers had been reduced and a lot of the top hamper removed, so that the machine was very compact and possible to work in a confined space. The machine could be driven either by belt drive from the lorry engine or by motor, the power in the latter case being obtained from the power lorry. These machines could be used either in the lorries or dismounted as stationary machines. This mobile printing plant was very well designed and most ingenious and practical.

Corps and Divisions.—A variety of duplicators were used of the ordinary kinds (clay, wax stencil, etc.).

(b) Map Supply.

(b) The Survey Staff Officer of the Army (G.2.C.), and not the Survey Battalions, was responsible for map supply to troops. His responsibility was nominally limited to delivery to Corps; but actually it was found that distributions had to be made direct to Divisions to ensure that troops received their due. The Americans found, as we did, that there was a distinct tendency for all staffs through whom maps passed to retain a number for their own use, or as a reserve.

3. Survey and Mapping.

Little mention is required of survey methods in general, as these were on accepted and well-known lines.

The mathematical side, as might be expected, was in most competent hands. Both French and British methods were thoroughly investigated, and adapted to their own requirements. A full description, with some tables, of the Lambert Projection was prepared by the "Coast and Geodetic Survey," and copies are available at the G.S.G.S.

American topographical methods are remarkable chiefly for their system of plane-tabling, which differs from ours. It is based on careful stadia traversing, interpolation being the exception rather than the rule as with us. A plane-table "party" consists of four men (a superintendent, a booker, and two rodmen). Progress is rapid, and considerable accuracy in heights is claimed. The system is described and discussed in Part I. in the Section dealing with Survey. A school for instruction in compilation and drawing from air photos was established, being based on British and French methods.

4. Sound and Flash Observation.

(a) Organisation.

Sound and Flash Observation were organised together in the American Army, and will be so described.

Each Company of a Sound and Flash-Ranging Battalion consisted of 18 officers and 250 men, and this was intended to serve a Corps.

Each Company was to provide,
on a quiet front,

Two S.R. Sections of about 6 officers and 55 other ranks;
Two F.R. Sections of about 3 officers and 70 other ranks;

on an active front,

Two S.R. Sections of about 7 officers and 80 other ranks;
One F.R. Section of about 4 officers and 90 other ranks.

The above organisation pre-supposes a considerable amount of common training and interchangeability.

(b) Equipment.

The Sound-Ranging equipment was practically the same as the British, most if not all of the apparatus used in the war having been obtained from us.

The Flash Observation optical instruments were French (the Longue-vue monoculaire and the Binoculaire à Prisme). The French equivalent to a Flash and Buzzer board was used in most cases, though a British board was tried, and an American pattern was in course of production.

No information is available as to the transport provided, but a report states that the amount originally allowed was insufficient, and never more than half of that was available.

(c) Stores.

At Langres there was a Stores Depot with one officer and some eighteen other ranks. From this all technical stores were issued, and testing of apparatus and small repairs were carried out. The intention was to develop a research laboratory and a machine shop.

At the H.Q. of the S. and F. Ranging Battalion a reserve of technical equipment was kept, and of transport if possible.

At the Company H.Q. there was a small reserve of material, and of spare men if available.

(d) Training.

The School near Langres was in charge of a captain, with three subaltern assistants (one in Flash and two in Sound Observation) and seventeen other ranks as instructors and assistants. Forty men were allowed for miscellaneous duties such as fatigues, cooking, etc.

Instruction was carried out mainly by units for the purpose of training in Flash and Sound Observation. Courses lasted about a month, the first portion being individual instruction and the last week being devoted to training as a Section. Courses overlapped to some extent to give men an intelligent understanding of duties of other Sections.

An average of about 130 men a month were passed through, but numbers varied from 40 to 280.

In addition to the above a large number of officers, mainly Artillery, were given short courses of instruction and lectures.

It is worth mention that a branch of the School was formed to train cooks, to provide for the great subdivision of Sound and Flash units. Men found unsuitable for technical work were taken for this.

5. Notes.

The American organisation, having started so long after our own, was able to take advantage of both British and French experience, and was to a great extent modelled on both. The organisation was, however, in force for such a short time that it hardly stood the test of practical experience, and it is not therefore to be expected that many lessons can be learnt from it. At the same time there are several points of interest to note.

Like ourselves, the Americans found that inclusion of the direction of Survey work in the Intelligence Branch of the General Staff had certain disadvantages. A close knowledge of the projected movements of our own troops and timely warning of our own plans is most important if map preparation and map supply are to be carried out efficiently. This knowledge is not directly the concern of the Intelligence Branch, and despite all arrangements they found, as we did, that the necessary information is only to be obtained by repeated personal enquiry and effort.

The reproduction arrangements call for no remark. They were in advance of our own.

Their topographical methods differ from ours and are not necessarily better, though their system of plane-tabling should certainly be studied. The subject has been fully discussed and the relative merits of the British and American systems compared in Part I., and need not, therefore, be further dealt with here.

The organisation for Sound and Flash Ranging, whereby either Sound or Flash Sections could be formed from the same unit, and to some extent from the same men, is stated in Lieut.-Col. Trowbridge's report to have proved not wholly satisfactory. This is somewhat contrary to our experience, the tendency of which is to combine the two services in one unit. At the same time it is not considered that the American organisation was sound, as the administration was too much centralised.

In the policy laid down for the American location units it was ordered that "while administered and located by officers of the Engineer Corps," they "are under the immediate orders of the Artillery Information Officer . . . in all that pertains to the tactical use and employment of such Sections." In practise the administration, technical supervision, etc., was carried out entirely by the Chief of the Topographical Section at G.H.Q.—G.2.C. This was only to be expected.

(Note.—For further details see reports by American officers and by Lieut.-Col. Winterbotham.)

SECTION II.—BELGIAN ARMY.

The Belgian organisation was on a small scale; their methods followed generally on the lines of the French, and there are no points of special technical interest to note.

Survey was controlled by the Section Topographique de l'Armée, situated near the Army H.Q. The whole Army front being in Belgium, the maps of their own national survey were available, and little survey was done in the field.

There were three Sections de repérage aux lueurs (S.R.L.) or "Flash Observation Sections," and three Sections de repérage par le son (S.R.S.), and these were grouped into one "Service de repérage d'artillerie" (S.R.A.), whose duty was laid down as being the location, by observation of flash and sound, of hostile batteries, and of the points of ascent of enemy balloons.

Divisional observation posts, if not actually part of the same service, worked in close liaison with it.

All locations and information connected therewith were reported to and co-ordinated by the Information Officer (Officier de renseignements) at the Corps Artillery H.Q. There was apparently no central control higher than the Corps (called in the Belgian Army "Division d'Armée"), as no mention is made of any such authority in the Belgian circular laying down instructions for the S.R.A.

Ranging was carried out by both S.R.L. and S.R.S., but Corps and Divisions also had their own ranging groups and carried out ranging on shrapnel.

(NOTE.—It will be observed that the Belgian S.R.A. had not the same meaning as the French S.R.A.)

SECTION III.—FRENCH ARMY.

1. General Organisation.

THE SERVICE GEOGRAPHIQUE.—The Survey organisation in the French Army was largely influenced by the proximity of Paris and the Service Géographique. There was at French G.Q G., no organisation corresponding to our Maps G.H.Q., and all the work done for the British Army by the latter was carried out for the French by the Service Géographique de l'Armée in Paris. There was, however, a representative of the Service Géographique at G.Q.G.

The Service Géographique corresponds to our Geographical Section of the General Staff at the War Office. It is, however, a much larger establishment, and with its reproduction, printing and computing branches, did work that was done for the British Army by the Ordnance Survey and War Office.

The Service Géographique therefore combined the functions of our War Office, Ordnance Survey, and Maps G.H.Q.

The Director-General of the Service Géographique exercised technical control over all the Survey units of the Army, and over the Sound Ranging Sections and Observation Groups. He carried out all promotions and transfers; decided technical equipment and was responsible for its supply; detailed Groups and Section complete; inspected their work; and inspected and approved of sites, Sound Ranging bases, etc.

ARMY.—With each Army H.Q. was a Groupe de Canevas de Tir (G.C.T.A.). It was attached to the General Staff, and placed directly under the orders of the Chef d'Etat-Major. It corresponded to our Field Survey Battalion (H.Q. Section).

The strength of a G.C.T.A. was about 9 officers and 70 technical other ranks, with clerks, storemen, drivers, orderlies, etc., in addition. There seemed to be no fixed establishment; the above figures are those actually with the 2nd French Army in 1916.

The G.C.T.A. was responsible for duties similar to those of our Field Survey Battalions, namely, survey work generally, both for map and artillery purposes, map construction, printing (to a limited extent) and supply, technical direction of Corps and Divisional Topo-Sections, and instruction in technical methods.

The G.C.T.A. did not, however, fix the French battery positions, this work being done by the Officiers Orienteurs. These were selected Artillery Officers, who were trained either by the G.C.T. or at the special school for the purpose. There was one Officier Orienteur with each "Group" of Artillery.

The G.C.T.A. supplied artillery boards with grid only; the rest of the work was done under the direction of the Officiers Orienteurs.

At each Army H.Q. there was also a Service de Renseignements d'Artillerie de l'Armée (S.R.A.A.), which dealt with the results of the Obs. Groups and S.R. Sections. This will be referred to under the head of Flash and Sound Organisation. The S.R.A. fixed approximate positions for enemy batteries; the G.C.T. fixed the exact positions.

Mention should be made of the Section Topographique, though this was not part of the Survey Organisation. This Section existed at Army H.Q. for the purpose of issuing pre-war maps (Cartes d'Etat-Major) and of doing map colouring, mounting, and drawing for the General Staff. It was an indoor office only.

CORPS.—At the Corps H.Q. was a Section Topographique de Corps d'Armee (S.T.C.A.). It consisted nominally of one officer and four other ranks, but this number was always exceeded in practice.

The chief duty of the S.T.C.A. was the production of correction copies (Rectificatifs) of portions of Plans Directeurs showing the approximate position and nature of new works, to enable officers to keep their maps up to date. Information for this purpose was obtained from the Divisional Topo. Sections (S.T.D.I.) and the Divisional Intelligence Officers.

The exact location of trenches was done by the G.C.T.A., but it was for the S.T.C.A.

to report when a new trench was dug and to send a rough plan showing it approximately, and to notify "Aviation" and ask for it to be photographed.

These rectificatifs were usually done on the "paté" (composition) duplicator, and aimed at speed rather than accuracy. About 60 copies were as a rule printed, showing in different colours allied and hostile trenches and new work, and they were issued down to Company Commanders concerned.

The S.T.C.A. kept a small reserve (100-200 copies) of Plans Directeurs.

They also took panorama photographs, prepared and printed plans and maps for Corps Staff, and kept a file of all maps, drawings, photos, etc., which concerned the Corps.

DIVISION.—With an Infantry Division was a Topographical Section (S.T.D.I.), consisting nominally of one officer and four other ranks (topographers and draughtsmen). Their chief duties were the survey, by air-photos and work on the ground, of French trenches, and the provision of information for the Rectificatifs.

2. Reproduction and Map Supply.

(a) Reproduction.

(a) It is unnecessary to describe the reproduction plant at the Service Geographique, as it requires no special comment. The installation is, as already stated, larger than that at our War Office, but much smaller than that at the Ordnance Survey.

It is not known if the reproduction plant at all Army H.Q. was the same, but it is probable that it was not. That at the G.C.T.A. 2e. Armée was probably fairly representative. It consisted of two large lithographic presses, two sets of "Dorel" apparatus, and two treadle letterpress printing machines. An outfit for Vandyke, or a similar process, was carried, but no helio work was done at Army H.Q.

A Corps Topo. Section in the same Army carried a hand lithographic press, demy-size, and another very light one about brief size, a cyclostyle duplicator and a composition duplicator. For panorama work a small periscopic camera, arranged to take vertical or horizontal panoramas, was kept.

The Divisional Topo. Sections had a variety of equipment. Some had hand lithographic presses, others duplicators of various patterns.

A point of particular interest is, however, the French Printing Trains, of which it is believed that four in all were constructed. These were trains of about sixteen wagons of ordinary type and one special wagon. The latter contained a large flat-bed litho. machine. The remaining wagons were fitted as offices for drawing, process work, proving, electric power and living rooms. The whole formed a completely self-contained drawing and reproduction office which could start work immediately on arrival at its destination. The advantages of this system have already been discussed in Part I., Chapter 2, Section IV.

(b) Map Supply.

(b) The chief points to note about the French map supply are the issue of 1/5,000 maps, the smaller scale of issue, and the mode of supply by the Service des Couriers.

In position warfare the French issued a 1/5,000 map. On account of the small area covered by maps of this large scale a much larger number are required. Hence the French actually issued as a rule more maps than we did, though, the scale of issue being smaller, fewer people got maps.

Thus, taking a front covered by one of our 1/20,000 and two of our 1/10,000, a British Division would get 723 of the former and 300 each of the latter (total 1,323), a French Division would receive 100 of 1/20,000, 200 of 1/10,000, and 2,000 of 1/5,000 (total 2,300).

French Plans Directeurs were much larger than ours, and units usually received one map of each scale only. Hence they required much smaller editions. It was unusual for editions of more than 3,000 copies of any map to be printed. This may be compared with our normal order of 20,000 for each 1/20,000 sheet and 6-8,000 for 1/10,000 sheets. The British figures included Reinforcement Reserve, not always used.

These small editions could be obtained very quickly from Paris.

With regard to actual supply to troops, the G.C.T.A. were in the happy position of being relieved of all responsibility for transport. All maps were delivered to units by the "Service des Couriers." Vehicles plied between Army and Corps, and Corps and Divisions, at fixed hours in the same way as our D.R.L.S., and all maps were sent by them. Specially urgent orders were sent by special D.R., or by car ordered by the General Staff.

3. Survey and Mapping.

There are no special points to note about French Survey methods, which followed generally recognised lines.

4. Sound and Flash Observation.

(a) Organisation.

(a) The Sound and Flash units were Sections de Renseignements par le Son (S.R.S.) and Sections de R. par Observation Terrestre (S.R.O.T.).

The establishment of the S.R.S. varied a good deal during the war, but towards the end there were two types of Section with the following approximate numbers :—

Section Mobile.—2 officers, 1 W.O., 47 other ranks, including drivers, 1 touring car, 1 box-car, 2 lorries and a trailer, and bicycles.

Section Fixée.—2 officers, 1 W.O., 41 other ranks; no transport except bicycles.

There were about twice as many stationary Sections as mobile. The former were obviously useless during any movement without outside help.

The S.R.O.T. were of three types. The numbers given are those found in practice, not necessarily those of the establishment.

S.R.O.T. Territoriale.—3 officers (including the Adjutant), 75 other ranks, a light car and a box car, and 4 bicycles. Intended for use on a stable front, and to provide 4 observation and 3 ranging posts.

S.R.O.T. Territoriale Telemetrique.—4 officers, 92 other ranks, and the same transport. Intended for same work as the "Territoriale," but provided for "Telemetrique" posts.

S.R.O.T. Mobile.—3 officers, 85 other ranks; a light car, box-car, 3 lorries, 2 trailers, 10 bicycles. Intended for active fronts, and for observation only (not ranging).

The above organisation was admitted to be defective. It was impossible to redistribute Sections for battles, and Territorial Sections had to be used on active fronts. Limitations of transport, however, and an unsuitable class of men (they were nearly all B.2) prevented the Territorial Sections being used with effect on active fronts, unless helped with transport supplied by the Army Artillery.

The Mobile Sections were seldom up to establishment, especially in transport.

The Telemetrique posts mentioned above were for ranging long-range H.V. guns. Only two posts were used and no check was obtained. They used very accurate and somewhat impracticable instruments. Good results were obtained on quiet fronts, but not, as a rule, elsewhere.

The Sound and Flash units were under a dual control. The G.C.T.A., representing the Service Géographique, was their superior in matters of technical methods, supply of technical equipment, and interior economy, while the Service de Renseignements d'Artillerie (S.R.A.) collected and analysed their results, and ordered their movements.

The S.R.A. consisted, both at Army and Corps H.Q., of 2 officers and 2 or 3 clerks; it performed the functions of our Compilation Section, but was a purely Artillery organisation.

The S.R.A.C. (Corps) compiled all results from Sound and Flash Units, from Aviation and Balloons, and from Divisional Artillery. This branch gave approximate co-ordinates to batteries considered active, and supplied to the 2e. Bureau (Intelligence) of the Corps a list of the day's fixings and identifications. These results were reported to the S.R.A.A. (Army) who compiled them, and examined for Battery positions beyond Corps Areas; besides receiving information from 2e. Bureau (prisoners, agents, etc.). The G.C.T.A. fixed exact co-ordinates of batteries. Finally, the Active Hostile Battery List was prepared by the S.R.A.A.

It will be seen that the procedure corresponded to ours, in that the active batteries were determined by the Artillery, and the positions of all batteries and emplacements was determined by the Survey Organisation.

A somewhat noticeable point was that all positions of S.R.O.T. and S.R.S. had finally to be approved by the Service Geographique, a special officer being sent for this purpose. The S.R.A.A. selected the approximate positions, subject to the above approval. The survey of the positions was done by the G.C.T.A.

(b) Equipment.

(b) The S.R.O.T. were equipped with the optical instruments already mentioned in Part II., namely, the longue-vue monoculaire and the binoculaire à prisme. The former, it will be remembered, was adopted by us. It was a good optical instrument, but had an inferior mounting.

A popular instrument in wide use was a pivoted arm (with arc) carrying an ordinary pair of field glasses and a luminous alidade. Bearings could be read to 30 minutes. It was simple and rapid in use, but did not pretend to be accurate.

The work of the Section was co-ordinated by means of a small exchange showing lights, as with us, but no buzzers were used.

The standard equipment adopted by the French Army for Sound-Ranging was the T.M., which has been referred to in the Technical history of Sound-Ranging, in Pt. II. Briefly, the relative merits of the British and French standard systems are that the former gives a finer and better record, while the latter is more economical. The French, however, never reached an absolute standardisation, and to the end of the war there were a small number of Sections at work using, respectively, the Bull, the Cotton-Weiss, and the Dufour systems. The latter was considered by our experts to be nearly as good as the Bull-Tucker apparatus.

(c) Stores.

(c) All technical stores were supplied by the Service Géographique through the G.C.T.A.

(d) Training.

(d) There was a Sound-Ranging school a St. Cloud. For Flash Observation there was a school at Mont Valerian, near Paris; another for ranging and topography on the Artillery Range near Chalons, and a school at G.H.Q.

Methods were, on the whole, similar to our own.

5. Notes.

In commenting on the differences between the British and French survey organisation and methods the fact should be recorded that in many cases the French were ahead of us in ideas, which we adopted from them and adapted to our own requirements. Instances of such cases are Artillery Boards, the "Flash" exchange for Observation Groups (but without buzzer), and the science of Sound Ranging.

In one particular and remarkable case we appear to have been ahead of the French, and that was in the use of their own cadastral maps and bench marks.

In questions of survey, reproduction, and map supply there is not much which requires special comment. It is certainly matter for remark that the French could conduct successful military operations with a much smaller scale of issue of maps than we had, and that those maps were on paper, and never backed with linen; but it is unlikely that this fact would induce greater economy in our methods. The French system of supply by a special transport service is also noteworthy. It is far more economical than our system; but it is doubtful if any regular service of transport would be established in our service of sufficient capacity to cope with our map supply in times of stress. This is undoubtedly the chief disadvantage of supply by a regular outside service; the supply must be made to fit the capacity of the service rather than the needs of the troops.

In our service there was good reason for the fact that the R.E. did all the survey work, including much that should properly have been done by the R.A., the reason being that the R.E. had had previous training in survey methods and the Artillery had none. But it is curious to find that the French had an almost similar division of duties between the G.C.T.A. and the Artillery, because survey in the French Army is much more closely connected with the Artillery than it has been in our service. Most of the officers of the Service Géographique, for example, are Artillery officers. It is then curious to find that the G.C.T.A. did all survey work for S.R.O.T. and S.R.S., and that these Sections were not self-contained in this respect.

On the other hand, the French have developed an excellent system within their Artillery for fixing their own batteries, giving line, etc., by means of their Officiers Orienteurs, who were Artillery officers trained in survey methods. This made their Artillery self-contained as far as their own battery positions, etc., were concerned.

For battery survey the French used traverses much more than we did, running them as a rule along the battery positions. It was claimed that the legs of the traverse were an easy method of defining bearings for the artillery. It is considered, however, that our interpolated "bearing picket" was generally more useful, more accurate, and less costly in time.

In observation of enemy guns the French had a much more clearly defined system of Artillery Intelligence than ourselves. We started Artillery Intelligence officers, but so far as Battery fixing—the prime object of Artillery Intelligence—was concerned, our Counter Battery service (mainly an executive branch) took over their work. The S.R.A., on the other hand, was purely an Artillery Intelligence service.

As far as results from Sound Ranging and Flash Spotting went, it is considered that our organisation and methods were superior, and that we obtained a greater number of accurate locations. It is believed that our service paid a good deal more attention to the question of mobility, and in the final phase of the war obtained more results.

Ranging of the fire of their own batteries was practised by the S.R.O.T. Percussion ranging methods were similar to our own. Air-burst ranging was done almost entirely by the Trajectory method and (because this method entails command of the Battery from the S.R.O.T.) was less popular with the Artillery than with the S.R.O.T. Very little calibration was done.

NOTE.—For further information see—

Reports by Lt.-Col. Winterbotham, Lt.-Col. MacLeod, Lt.-Col. Twiss, Major Bragg, Major Hemming, and Lt. Davidson, on visits to the French Armies.

Instruction sur l'organisation et le fonctionnement des G.C.T.A., etc. (Service Géographique).

SECTION IV.—GERMAN ARMY.

1. General Organisation.

The German Survey organisation consisted of Survey units and Artillery Survey units, which were quite independent, though they worked in close liaison for certain purposes.

The Director of Military Survey at G.H.Q. was the official head of the Survey units, and was responsible for their technical work, personnel, and equipment. It is not known if he also exercised technical supervision of the Artillery Survey units.

ARMY.—At the H.Q. of each Army was a Survey Staff Officer, and usually one, but occasionally two, Survey Detachments (Vermessungs Abteilungen).

The Vermessungs Abteilung corresponded to the H.Q. Section of our Field Survey Battalion. It had a map-printing section attached, and was responsible for trigonometrical and topographical work, the preparation of artillery maps and boards, and the supply and issue of maps. A number of "printing trains" were also in existence, and each V. Abteilung is stated to have had one.

The strength of a Vermessungs Abteilung was about 19 officers and 90 other ranks; total, about 110.

CORPS AND DIVISION.—At the H.Q. of ach was a Topographical Section (Kartenstelle), consisting of an officer or survey official and a staff of qualified draughtsmen. These sections were branches of the Army Vermessungs-Abteilung. There was a G.S.O. for maps at each Corps H.Q.

The Vermessungs Abteilung put at the disposal of each G.O.C. Foot Artillery, 1 trig. and 2 topographical officers, to fix battery positions. Artillery Boards were, as a rule, prepared by the Verm. Abteilung, but occasionally by the Mess Trupp. (See sub-section 4.)

The German Geological Service was apparently included under the head of Survey, and each Verm. Abteilung included a Geological Detachment.

At the Army H.Q. there was also a Cartographical Section, which formed no part of the Survey Organisation, but corresponded to the French Section Topographique, and existed simply to issue General Staff maps and to do unskilled cartographic work for the Staff of the Army.

2. Reproduction and Map Supply.

(a) Reproduction.

(a) The Karten Felddruckerei, or Map Printing Section, attached to the Verm. Abteilung, had a power-printing plant, but not of standardised type. In addition, certain Armies, and possibly all. had printing trains. The personnel of this consisted of an officer and about 45 men. The press carried printed apparently up to 80 x 80 cm., using zinc plates only. Maps were drawn on tracing paper and apparently transferred to the zinc by a process analogous to the Dorel.

Corps Topo. Sections were provided, wherever possible, with a lithographic power press.

(b) Map Supply.

(b) The basic German map was the 1/25,000 (corresponding to our 1/20,000). The larger scales used (usually enlargements of the 1/25,000) were 1/10,000, 1/5,000, issued largely to Infantry, and 1/2,000, for Trench Mortars. Smaller scales were the 1/50,000 and the General Staff maps, 1/80,000 and 1/100,000. Editions of 20,000 to 24,000 were printed of the 1/25,000 and 1/5,000 scales.

Corrections to existing editions were issued largely in the form of correction slips, to be gummed on.

A very large proportion of captured German maps were either enlargements of the French 1/80,000 or reproductions of British or French maps. On the whole their maps, both in quality and style, were poor.

3. Survey and Mapping.

The only point of particular interest that was discovered in connection with German Survey methods was the use of the vertical light ray for fixing positions rapidly. A rocket was discharged vertically from a special apparatus, at the point to be fixed, and was intersected from posts to the rear. The method offers possibilities, and experiments have been made with it by our service.

The surveying of posts of L.M.T. and S.M.T. is included in the duties of the Verm. Abt., but instructions for this work are given in the Manual for Artillerie Mess Trupps, and there is no doubt that some, at any rate, of this duty was undertaken by the L.M.T. and S.M.T. themselves.

4. Sound and Flash Observation.

(a) Organisation.

(a) The location of hostile batteries was carried out by Artillery units. Originally these were concerned with Flash Observation only, and were called Artillerie Messtrupps, which units were a development of the original Mess Plan Abteilungen, or Artillery Board Detachments. When sound ranging developed, the Schall-Messtrupps (Sound Ranging Sections) were directed to work with the Artillerie-Messtrupps, and finally the title Artillerie-Messtrupps appears to have been applied to the directing staff of a Licht-Messtrupp (L.M.T. or Flash Observation Group) and a Schall-Messtrupp (S.M.T.) working together, and probably also to the whole combination. The whole was not apparently combined as a single unit, because a proposal that they should be so combined, under the title of "Art. Beobachtungsabteilung" (or Art. Observation Detachment), is found in the report on the experiences of 1918 dated 8/6/18.

The location units belonged to the Artillery, and were allotted by Armies as required to Corps and Divisions. They were detailed to a sector, and did not move when the formation for which they were working was relieved. One L.M.T. and one S.M.T. was usually allotted to each Divisional sector.

A L.M.T. consisted of four or five officers and about 100 men, and though originally intended to man four or five flash-spotting posts, by the latest instruction it was ordered to maintain on an active front eight or ten, to allow of casualties and lack of synchronisation. It included a ranging staff or "Schiessplan."

A S.M.T. was of about the same strength, and manned from four to six posts.

The information obtained by these units was compiled by the H.Q. (Mess Zentrale) of the Artillerie-Messtrupp, and passed to the Artillery. Results were also sent to the Vermessungs Abteilung for accurate plotting on the map.

It may be noted that although there appears to be no specific mention (in captured documents) that observation balloons were included in, or under the technical control of, the Artillerie-Messtrupp, yet there is a section in the Manual for Artillerie-Messtrupps (December 17th) laying down methods of battery location by balloons, and there is a report by the Artillery Survey School, Wahn, on experiments in taking rays from balloons. It is evident that balloons were used in collaboration with L.M.T. as extra observation posts.

(b) Equipment.

(b) The posts of a Licht-Messtrupp were equipped with a director, or similar instrument, a stereo-telescope, stop-watch, chronometer, telephone outfit, panorama, maps, etc. Of the above the stereo-telescope is the most interesting instrument to us. This telescope was a great favourite with the Germans. It is a binocular with the object glasses set at the ends of pivoted arms. When these are in the horizontal position the telescope can be used with stereoscopic effect; when in the vertical it can be used as a periscope. For use in the Licht-Messtrupp it was provided with illumination and graticules.

At the H.Q. of a L.M.T. there was a telephone exchange and a plotting board, neither being of special design, and an elaborate plotting equipment, including a pantagraph, 3-ft. diagonal and other scales, slide rule, etc.

German Sound Ranging was done almost entirely by the "human observer" method (described in Part II.). The equipment was therefore simple. At each observing post it consisted of a stop-watch (1/50 sec.), a buzzer telephone apparatus, a map board with hostile artillery positions, and at some posts an anemometer and thermometer. At the Section H.Q. the computing was done from the time intervals reported by the observers. Orthophones were also used, and although admitted to be a rough instrument, were apparently valued more than by ourselves or the French, no doubt on account of the general inferiority of their sound ranging. The new automatic system introduced at the end of the war is mentioned in paragraph 5.

Balloons used a form of sextant, and at the moment of observation the exact position of the balloon was fixed by theodolite measurement by a ground observer.

(c) Stores.

(c) Optical and mathematical instruments were not issued by the Verm. Abteilung, but by the Section I.D. of the General Staff, who probably received them from the Ordnance.

(d) Training.

(d) There was a large school of instruction for both Flash and Sound Observation at Wahn, near Cologne. A point was made of practice for mobile warfare. Lecturers from the school visited all theatres of war.

5. Notes.

The chief criticism that may be made on German Survey during the war is that, although they appear to have foreseen the application of survey to military operations rather more than ourselves, they were certainly not in advance of us or of the French in their methods, and in many respects were behind.

Their cartography was distinctly poor, and it is astonishing to see to what a late date they were content to use photographic enlargements of small scale maps, a method which we decided in 1914 to be useless. Their method of map reference was not good, and what is far more important, it varied from one Army to another, and as a rule was independent of the trig. reference.

There is evidence that at first the German Army was in survey matters no more enlightened than our own, and that much propaganda work was necessary to induce the German Field Artillery to take up modern scientific methods. This attitude on the part of the Artillery changed entirely before the end of the war. By the beginning of 1918 the German High Command seems to have appreciated fully the great importance of survey work to military operations, and the necessity for making special provision for technical staffs. Orders over the signature of Ludendorff, for example, show an intimate acquaintance with the special needs of survey units; they lay emphasis on the provision of good quarters, the necessity for having active fit men in the Artillery Survey units, the importance of making use of the local knowledge of these units, and the absolute necessity for providing them with sufficient transport.

In Artillery Survey questions we had practically nothing to learn from them, except, perhaps, in the observation of fire. Their method of flash observation was analagous to our own, being carried out by leading observer and telephone buzzer, and was probably good. A good deal of attention was devoted to ranging; in the case of air-bursts they seem to have employed the trajectory method only.

There is little evidence as to the results obtained by German Sound-Ranging, but there cannot be much doubt that they were inferior to ours. The "human observer" system could not compete with the refined automatic methods employed by the British and the French.

At the end of the war the Germans had devised a new system of the automatic type, some sixteen sets of which were stated to be in use at the time of the Armistice. No specimens were found either of the microphone or of the recorder, but drawings of the latter were obtained at Wahn, and specimens of the records. The recorder comprised an oscillograph and a clockwork arrangement for driving a sensitised strip on which the records were taken. The records found were much inferior to those of the Bull apparatus. If the designs found at Wahn represent truly the type of the new automatic apparatus in use, it would appear to be a clumsy and inaccurate recorder. Its cost was said to be 28,000 marks, and it must have been expensive in current. The apparatus in use may, however, have been greatly improved, or even of a different type.

The earth tremor apparatus on the other hand is interesting and deserves further study.

Great stress was laid on the importance of training in mobility for both L.M.T. and S.M.T.

An interesting point is the method of fixing the positions of observation posts of both L.M.T. and S.M.T. This was usually done by survey of the vertical light ray, and it is stated that this was never interfered with by the enemy.

In their Manual a method is described of surveying Sound-Ranging posts by sound, but this does not seem to have been used much.

Note.—For further information consult :—

Report by Lt.-Col. Winterbotham on captured German documents, with Appendices, II. Battery Survey, III. Artillery Boards, IV. Obs. Groups, V. Sound-Ranging, VI. Visit to Art. Survey School, Wahn (Sound-Ranging). VII. German Seismic methods of location.

Handbook of German Army in war.

Various German documents and translations, particularly the following :—

Duties, etc., of German Survey Section (Vermessungs-Abteilung).
Manual for Artillery Survey Sections (Artillerie-Messtrupps).

DIAGRAMS AND MAPS
on following pages.

Diagram of area surveyed or partially surveyed during the war.

Illustrations to Appendix I.

Diagram 1. Systems of triangulation in Northern France and Belgium.
2. Adjustments in longitude.
3. Common and adjusted points.

SPECIMENS OF MAPS.

The seven specimens which follow are exact reproductions of maps produced during the war, and illustrate changes in style and in methods of drawing and reproduction from the earliest to the latest dates.

The first six specimens show the same portion of 1/20,000 sheet 57c.N.W. in the neighbourhood of Bapaume, in six different editions, drawn in the style current during the war. The seventh specimen shows a portion of sheet 5e.S.W., drawn with the Allied signs and the new grid. The following descriptive notes give the chief points calling for attention.

No. 1. Edition 1 (B Series), 1915.

This edition was produced by enlarging the 1/80,000 map, and re-drawing. The detail is coarse and bears little relation, except in the rough general outline, to the true facts. The contours are especially vague.

No. 2. Edition 2, May, 1916.

This edition was produced by compilation of cadastral plans corrected by air photos. Note the great refinement of detail as compared with the First Edition and the improvement in the contours. Note also the blank spaces due to lack of photos, *e.g.*, south-west of Bapaume.

(Edition 3 shows practically no change.)

No. 3. Edition 4, October, 1916.

Note the numerous additions to detail (such as trees and road cuttings) due to a plentiful supply of better photographs. In this edition a large amount of tactical information is written on the map for the first time. The contours remain unchanged.

No. 4. Edition 5, December, 1916.

The most noticeable feature of this edition is the greater fineness of the detail, which is due to photographic reduction from an original drawing on the 1/10,000 scale. The typing of names has, however, been done after reduction, and they are consequently legible, though perhaps a little coarse. Note the additions to the detail, the omission of much of the written information, and the remarkable improvement in the contours, which show much greater detail in the ground forms. This is due mainly to close study of the air photos.

No. 5. Edition 6, February, 1917.

This edition is instructive from the point of view of reproduction. The detail is the same as that on Edition 5, with few, if any, alterations. The names have, however, been typed on the original drawing, with the result that they have been reduced in size with the outline. The consequence is that in many cases they are much too small, and are inclined to be illegible. This map, though presenting a fine appearance is, as regards legibility and usefulness, to some extent a set back from the previous edition, and shows the unsuitability of reduction to half scale, unless special provision be made in the typing of names.

On the other hand there is a noticeable improvement in the contours, partly due to their being printed in brown, and partly to the insertion of intermediate contours at 5 metre intervals. Otherwise their shape remains as in Edition 5.

(Editions 7 and 8 show no change.)

No. 6. Edition 9, July, 1918.

This map is from a new drawing on 1/10,000 scale. As in Edition 5, the outline has been reduced from the original, but the names have been typed after reduction, so that they are now legible, though finer than in Edition 5. Note numerous alterations in detail, some due to actual changes and others to better information. Note also the changes in the contours, due to survey on the ground in the previous year, when Bapaume and the adjoining country were in our possession.

The contours on this edition are for the first time due to survey on the ground, and the difference between them and those of the last edition, which were the best that could be produced without visiting the ground, should be noticed.

No. 7. New Series on Lambert Projection.

The last specimen shows a portion of 5e.S.W. (Lambert Series) drawn with the Allied conventional signs and the French grid. In comparing this with the previous specimens it should be noted that the original drawing for this map was done on the same scale, and that the detail cannot therefore appear so fine as in a reduction from a drawing on twice the scale.

The chief points to notice are the signs for woods, brushwood and fir trees, the tree-lined roads, and the light effect of the hedge and tree symbols when in or close to villages. The railway symbol is heavier than the British sign (it is drawn a little too thickly on this specimen), and it is open to question whether it is an improvement. Lastly, the general effect of the grid should be noticed. The absence of the small 500-yard squares used in the British system relieves the map of a great many lines, and gives it a more open appearance.

It should be remembered that this map is of accessible ground, whereas the Bapaume area was for most of the war inaccessible. Sheet 5e.S.W. was produced by a combination of ground survey, cadastral compilation, and air photos.

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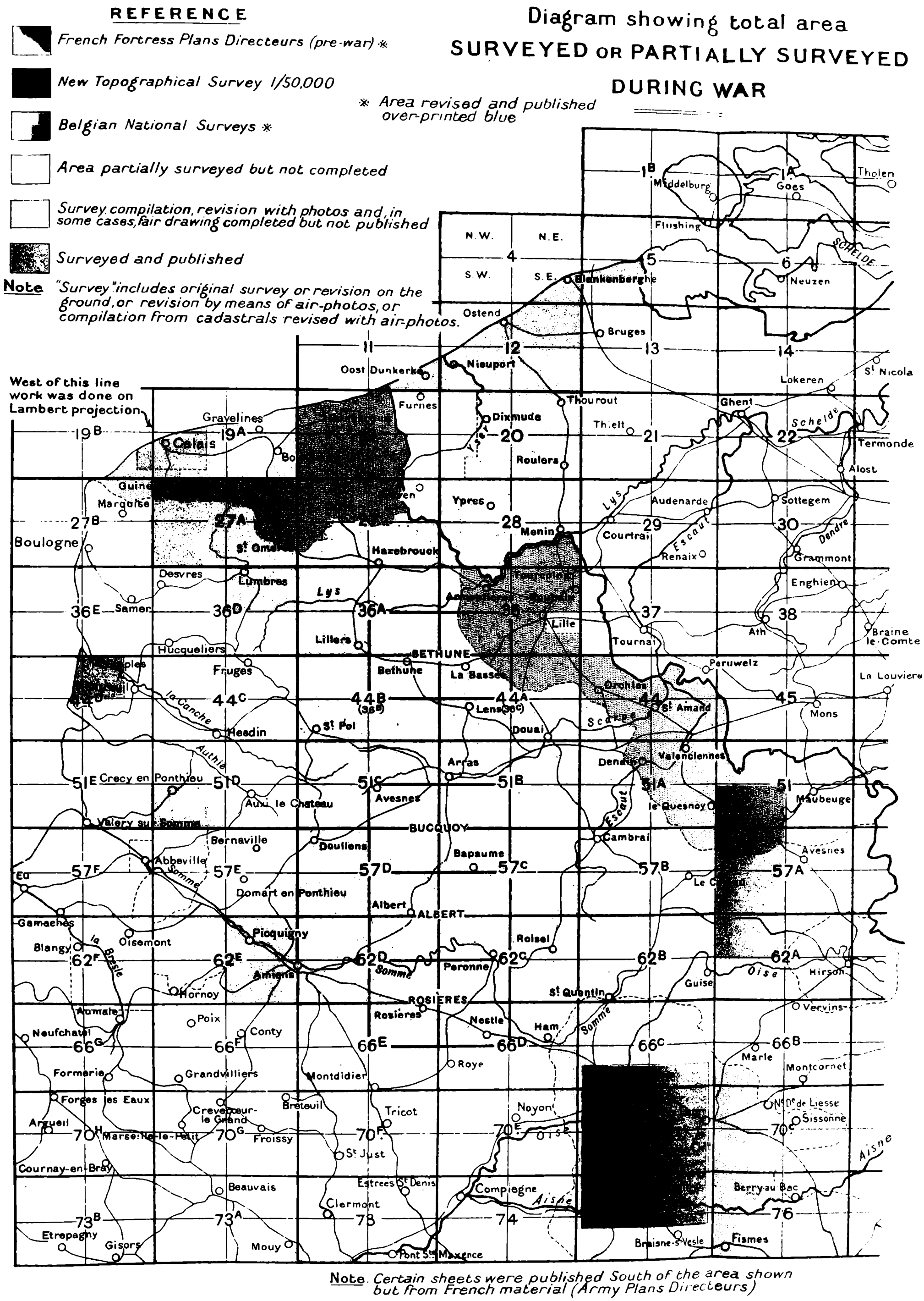

REFERENCE
French Fortress Plans Directeurs (pre-war) ※
New Topographical Survey 1/50,000
Belgian National Surveys ※
Area partially surveyed but not completed
Survey compilation, revision with photos and, in some cases, fair drawing completed but not published
Surveyed and published
Note "Survey" includes original survey or revision on the ground, or revision by means of air-photos, or compilation from cadastrals revised with air-photos.
※ Area revised and published over-printed blue
Diagram showing total area SURVEYED OR PARTIALLY SURVEYED DURING WAR
West of this line work was done on Lambert projection
Middelburg
Goes
Tholen
Flushing
Neuzen
Schelde
N.W.
N.E.
S.W.
S.E.
Blankenberghe
Ostend
Bruges
Oost Dunkerke
Nieuport
Lokeren
St Nicola
Furnes
Thourout
Ghent
Dixmude
Thielt
Termonde
Gravelines
Calais
Roulers
Alost
Ypres
Audenarde
Sottegem
Marquise
Boulogne
Menin
Courtrai
Renaix
Grammont
Dendre
Escaut
Lys
St Omer
Hazebrouck
Desvres
Lumbres
Enghien
Samer
Lille
Ath
Braine le Comte
Lillers
BETHUNE
Bethune
La Basse
Tournai
Peruwelz
Hucqueliers
Fruges
Orchies
La Louviere
la Canche
Lens (36C)
St Amand
Mons
Hesdin
St Pol
Douai
Scarpe
Authie
Arras
Denain
Valenciennes
Crecy en Ponthieu
Auxi le Chateau
Avesnes
Maubeuge
Valery sur Somme
le Quesnoy
BUCQUOY
Bernaville
Doullens
Cambrai
Abbeville
Bapaume
Eu
Somme
Domart en Ponthieu
Le Cateau
Albert
ALBERT
Gamaches
Picquigny
Oisemont
Roisel
Blangy
la Bresle
Amiens
Peronne
Guise
Oise
Hirson
Hornoy
St Quentin
ROSIERES
Rosieres
Aumale
Poix
Conty
Nestle
Ham
Vervins
Neufchatel
Marle
Roye
Formerie
Grandvilliers
Montdidier
Montcornet
Forges les Eaux
Breteuil
Crevecoeur-le Grand
Tricot
Noyon
Nd De de Liesse
Sissonne
Argueil
Marseille-le-Petit
Froissy
St Just
Aisne
Cournay-en-Bray
Beauvais
Estrees St Denis
Compiegne
Berry au Bac
Clermont
Etrepagny
Gisors
Mouy
Pont Ste Maxence
Braisne-s-Vesle
Fismes
Note. Certain sheets were published South of the area shown but from French material (Army Plans Directeurs)

Appendix I
DIAGRAM 1

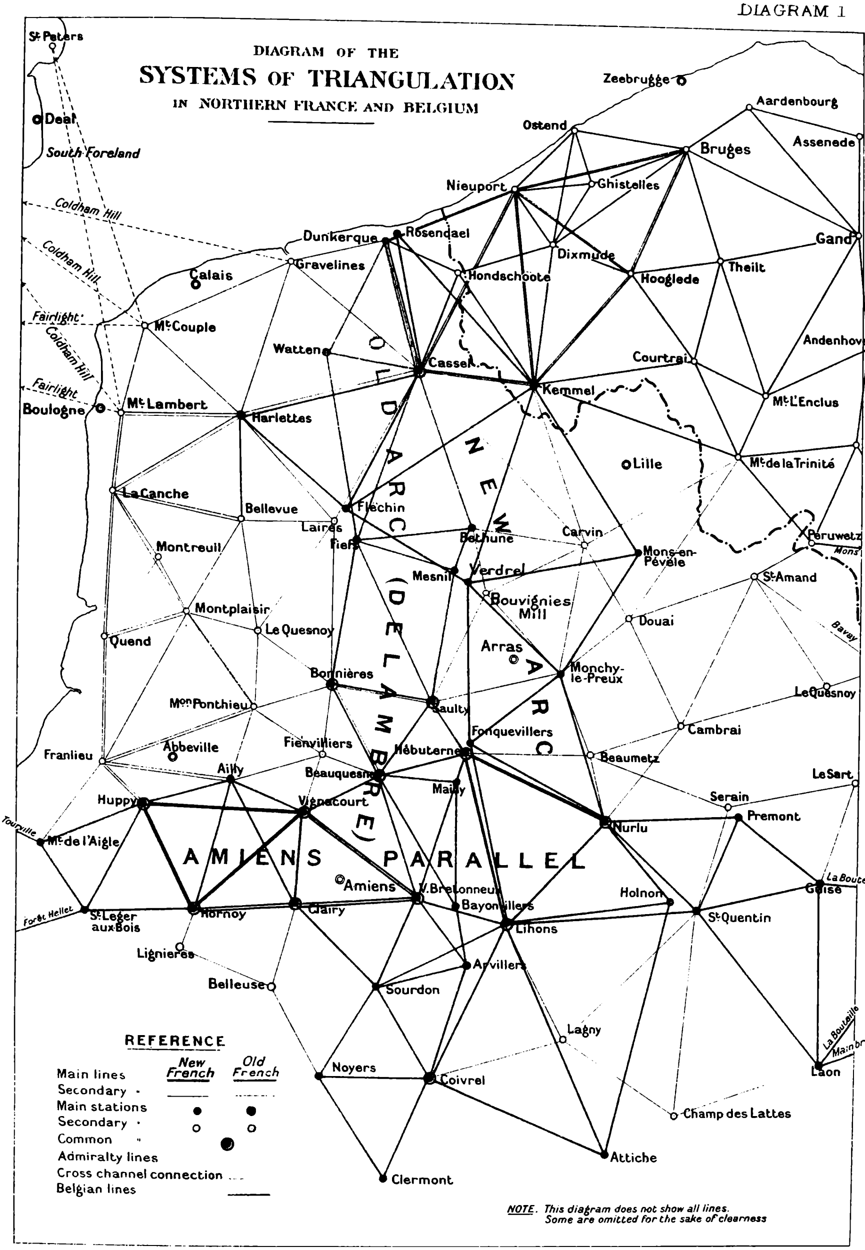
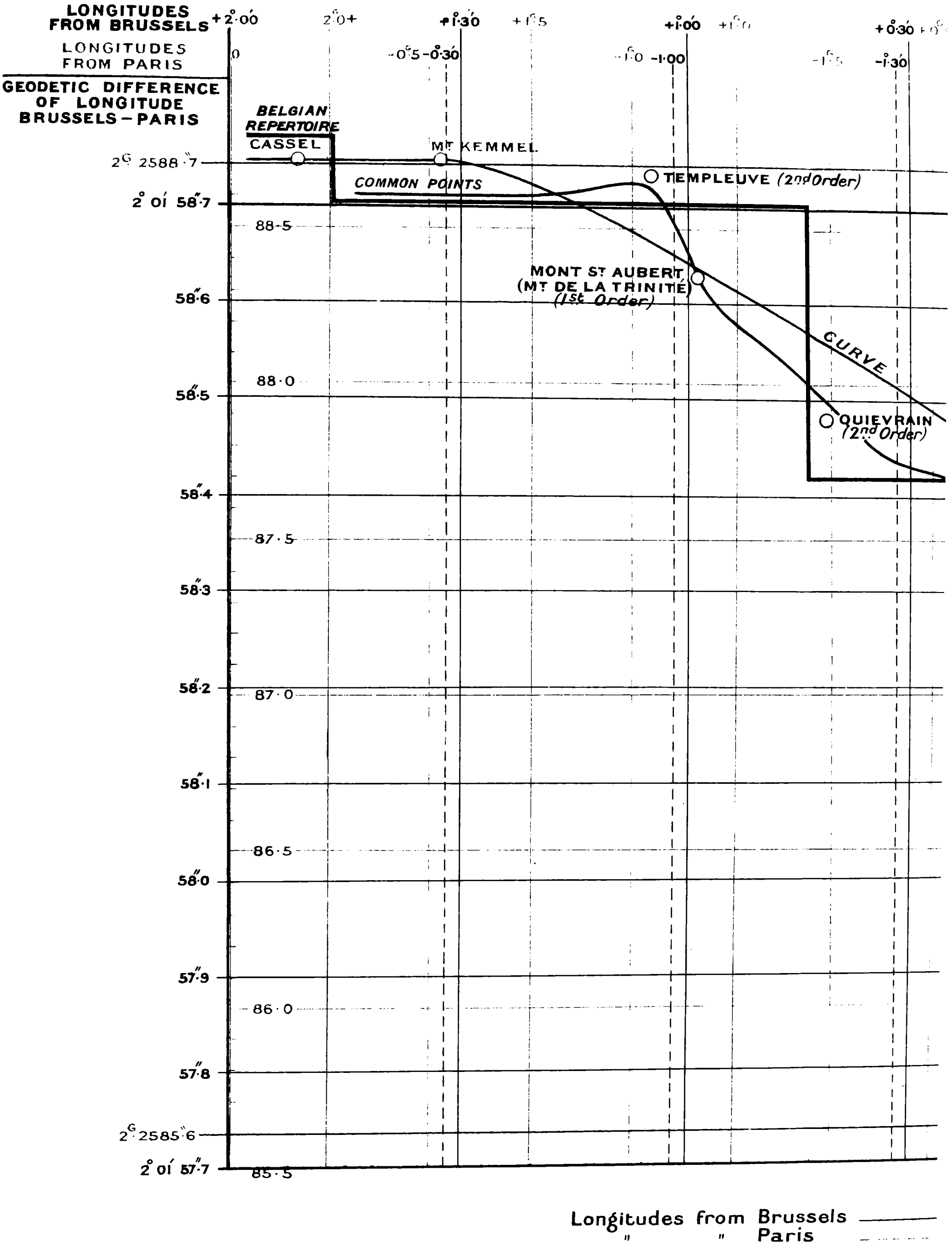
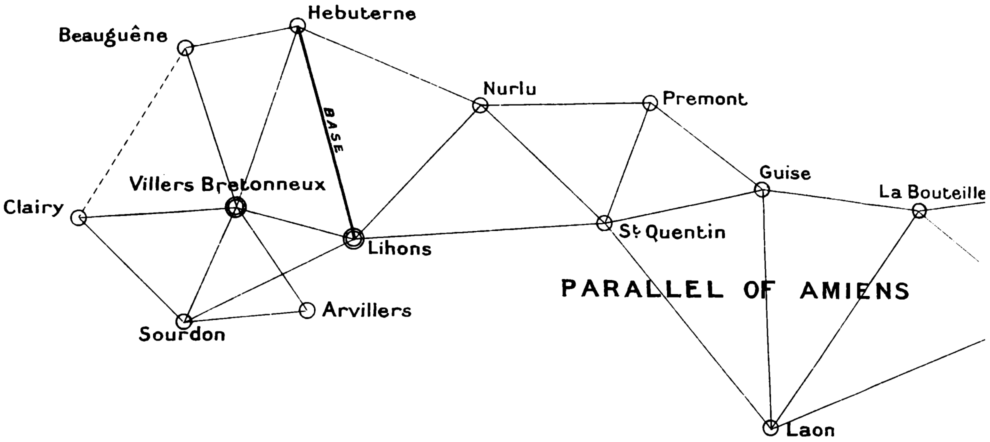


DIAGRAM OF ADJ



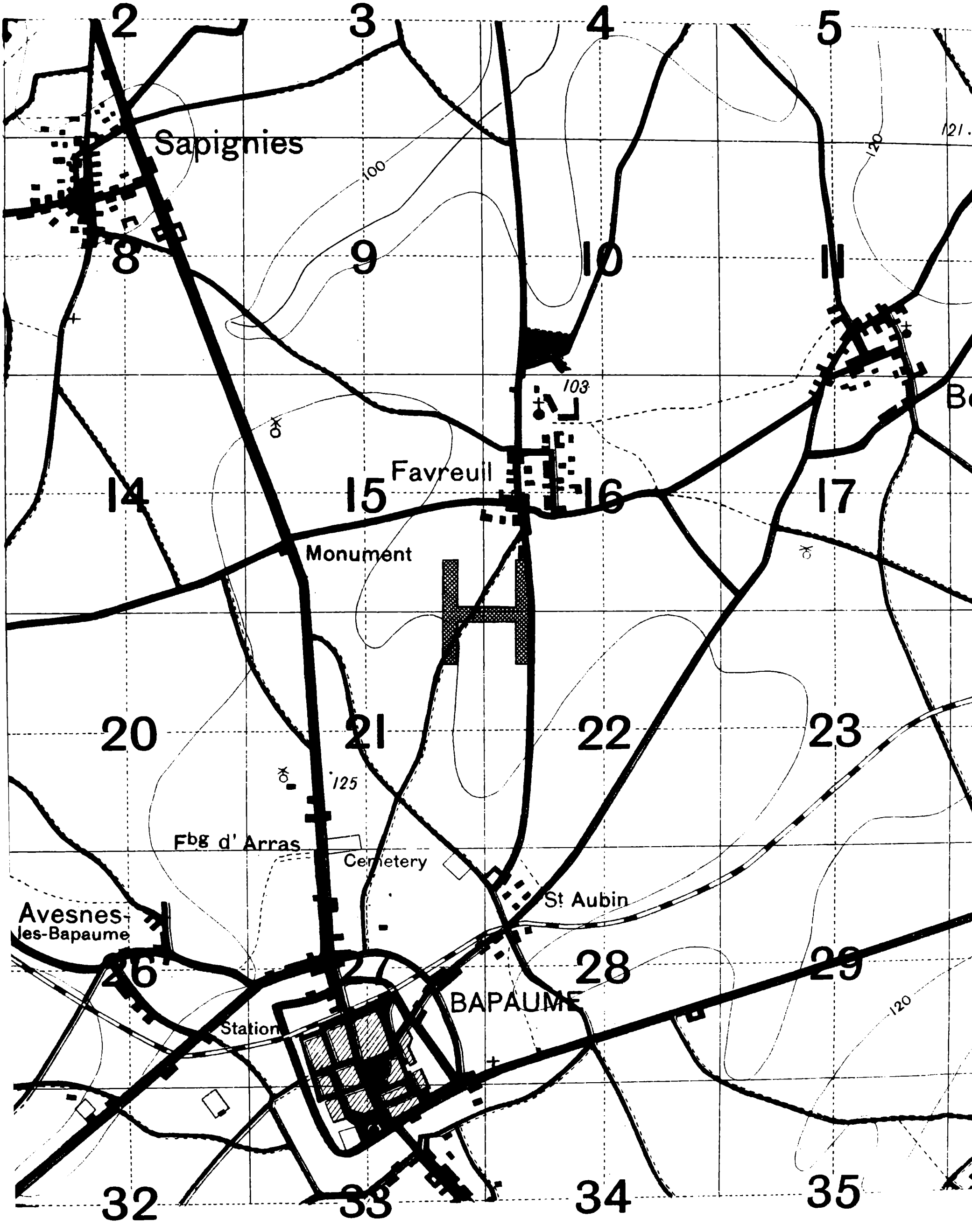


Adjusted points

Common "

DIAGRAM OF COMMON AND ADJUSTED POINTS

Scale about 1:792,500


2
3
4
5
Sapignies
100
120
121
8
9
10
11
103
Be
Favreuil
14
15
16
17
Monument
20
21
22
23
125
Fbg d' Arras
Cemetery
St Aubin
Avesnes-
les-Bapaume
26
27
28
29
BAPAUME
Station
120
32
33
34
35

His Majesty's Stationery Office

Report on Survey on the Western Front