WORK OF R.E.

IN THE

EUROPEAN WAR, 1914-19.

GEOLOGICAL WORK

ON THE WESTERN FRONT.

RCF.

THE WORK OF THE ROYAL ENGINEERS IN THE EUROPEAN WAR, 1914–19.

WORK IN THE FIELD UNDER THE ENGINEER-IN-CHIEF, B.E.F.

GEOLOGICAL WORK ON THE WESTERN FRONT.

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INTRODUCTION.

No military geological establishment existed in the British Army at the beginning of the War.

At a very early stage the need for expert geological advice in regard to water supply became apparent, and the Chief Engineer (later Engineer-in-Chief), British Expeditionary Force, applied for the services of a competent geologist. On the nomination of the Director of the Geological Survey of England, Lieut. W. B. R. King, Royal Welsh Fusiliers (now Capt. W. B. R. King, O.B.E.), was appointed in April, 1915, and at first worked at the War Office under the Director of Fortifications and Works. In June he joined the Staff of the Chief Engineer in France, under whom he continued to work throughout the War.

The earliest work in England consisted of studying the available information on Belgium and Northern France, particularly in relation to borings, and was mostly done at the Geological Survey and Museum, 28, Jermyn Street. Assistance was also given by the Director of the Geological Survey, who was engaged upon a report for the War Office on "Geological conditions affecting the available sources of water in Belgium and the North of France."

A geological map of Belgium, scale 1/160,000, was prepared from the 1/40,000 Belgian maps in possession of the Geological Survey, and was printed at Southampton—5 sheets (hand-coloured).

The entire resources of the Geological Survey and Museum were always at the disposal of the military geologists, and the whole-hearted co-operation of the Director proved invaluable.

Much useful information was obtained at this time from Professor Stainier of Ghent.

Valuable advice and assistance were later on given by Dr. Imbeaux, of Nancy, Professor Ch. Barrois and M. P. Pruvost, of the University of Lille, and Professor A. Renier, of Brussels.

In May, 1916, the Australian Mining Corps, organized as a battalion for Gallipoli (but too late for active operations there), arrived on the Western Front. Major T. W. E. David (now Lieut.-Col. Sir T. W. Edgeworth David, K.B.E., C.M.G., D.S.O.), Professor of Geology, University of Sydney, accompanied it, and up till 25th September, 1916, acted as Geological Adviser to the Controllers of Mines of the First, Second and Third Armies. After this, he was transferred to the Inspector of Mines Office, G.H.Q., where he became general Geological Adviser on matters connected with military mining. A considerable amount of testing of the ground was carried out with a special light boring plant presented to the Mining Corps by Sir Samuel Hordern, of

Sydney, the immediate supervision of this work being placed under Lieut. Loftus Hills, Assistant Government Geologist of Tasmania, of the 2nd Australian Mining Corps, from 25th September, 1916 until the end of the War. In the aggregate, some 35,000 feet of test bores, for dug-outs, etc., were made under his direction, largely in front-line positions.

On 17th September, 1918, Lieut. Hills was transferred to the Inspector of Mines Office, G.H.Q., and a few weeks later two more Australian Tunnelling Co. Officers were lent to the Geological Staff at G.H.Q., in order to cope with the number of fresh geological maps required by the rapidly advancing armies. Thus, at the date of the signing of the Armistice, 11th November, 1918, there were five geologists at G.H.Q., whereas from November, 1916, to September, 1918, there were only two at G.H.Q., and one at the H.Q. of the Australian Electrical and Mechanical Mining and Boring Company; while from April, 1915, until May, 1916, there was one geologist only for all the British Forces on the Western Front.

The whole of the information in the following chapters has been supplied by Professor Sir T. W. Edgeworth David and Capt. King.

THE WORK OF THE ROYAL ENGINEERS IN THE EUROPEAN WAR, 1914–1919.

GEOLOGICAL WORK ON THE WESTERN FRONT.—WATER-SUPPLY.

CHAPTER I.

1. GENERAL SUMMARY.

The chief part of the earlier work consisted of compiling water supply maps of those areas of Northern France and Belgium occupied by the enemy. The scheme was to show on maps the pre-war civilian sources of supply, so as to give some indication as to the natural resources of the area. The information was arranged on maps 1/100,000 scale, which were printed at Southampton.

Maps were also drawn on purely theoretical grounds of much of the chalk area of the Scarpe and Somme to give some indication of the depth to water.

During the period just prior to, and all the time since, the first battle of the Somme, boring had become the chief method of obtaining supplies of water in the chalk plateau areas. Personal touch was more or less maintained with the Water Supply Officers of the Armies, but the area was too large to enable each site to be inspected before boring started, and only the general geological lines could be given to the Water Supply Officers.

During the later stages of the War, maps on 1/250,000 scale were prepared for the greater part of Belgium and Northern France, dividing the country up into areas where the water supply conditions were similar, and short notes were compiled with the help of the I.R.E.M. at G.H.Q., giving a general idea of the conditions and type of plant and machinery required in each area.

A card index of all bores made by the British Armies was also kept up to date.

Sites for bores, etc., were also visited in the L. of C. areas, the central group of the Canadian Forestry Corps, and in the Nancy area where the aerodromes of the Independent Air Force, R.A.F., were needing supplies of water. In this latter area much useful information was supplied by the Chief Geologist to the American Expeditionary Forces, and by the Engineer-in-Chief, Ponts et Chaussées, and the Director of Municipal Service at Nancy.

2. PREPARATION OF MAPS.

At the time of the arrival in France of the first military geologist information was being collected regarding the conditions of water supply in the area in front of our line. This was to enable plans to be formulated for dealing with the problem of supply of water to troops in case of an advance. Such information as could be found was being entered on maps of 1/100,000 scale. This work was carried on for the whole of Belgium and invaded territory of Northern France.

It was difficult to obtain up-to-date and accurate statistics on the actual conditions of town supplies. The supplies for villages in agricultural districts are not likely to change much, but in towns where water is supplied by a water company the machinery is constantly being changed to meet larger demands, and the pipe-line system is always growing. It results, therefore, that records ten to fifteen years old are liable to be gravely out of date. The results obtained, however, were such that some idea of the state of the water supply of an area could be arrived at, and this was ot use in making plans for an advance through the country.

The type of information collected and entered on the maps is shown on *Fig.* 18, which is a portion taken from the Namur Water Supply Map. These maps show the actual site of springs and their daily yield, location of pipe-lines and adits for collecting water, pumping stations with daily supply, reservoirs with particulars as to capacity, sites of boreholes with yield and depth, number of wells per Commune with range of depth where possible, and whether the supplies were sufficient for the needs of the civil population in peace time, etc.

All available information was collected together and arranged on maps 1/100,000 scale. The work needed considerable judgment in order to avoid confusion on the maps.

In 1915 a map was prepared of the ground in front of our lines as far as Brussels, to show in a general sort of way where water could be obtained in great abundance, where a medium supply could be expected, and where it would be scarce. The map was coloured in three shades, the deeper shade being the area where most water was to be expected. On this map also an attempt to depict the quality of the water was made by having red for poor quality, purple for medium, and blue for good quality water. Thus there were nine different types of water depicted :—

Good but scarce.
Medium quality but scarce.
Bad and scarce.
Good and medium quantity.
Medium in quantity and quality.
Bad quality but of fair quantity.
Good and abundant.
Abundant but only of medium quality.
Abundant but bad.

This map was printed on the scale of 1/250,000, although the work was done on maps of 1/100,000 scale. As none of the ground could be visited, the lines had to be drawn from the evidence of the contours taken in conjunction with the geological structure of the country, and any notes regarding the abundance or scarcity of the village supplies which were available. The map was required by a certain date, but if more time had been available, a more accurate result could probably have been obtained. It was frequently a question of personal interpretation as to the category to which an area should belong. The final result was more of use as a general indication of the difficulty or ease with which a supply of water could be obtained for troops, in the case of existing supplies having been destroyed by the enemy, than as an accurate detailed statement of conditions.

As an example, it may be said that this map was of use in emphasizing the need for additional water sterilizing plants and lorries in the event of an advance towards Ghent, as this area was shown as having water of bad quality and frequently only in small quantities insufficient for troops during summer months.

A map of this nature, prepared on the site during the dry summer months, would be of great value in drawing up the requirements of an Army which might need to occupy the area at some future period.

During the battle of the Somme, and afterwards, it was frequently of use to have some idea as to the depth in the chalk at which water might be expected when troops arrived at any spot formerly in enemy occupation.

To give this information it was necessary to predict the shape of the water table (*i.e.*, the surface up to which the chalk is saturated with water). This was arrived at by drawing cross-sections of the country, and, from the surface configuration, estimating the level up to which the chalk would be saturated. The sections thus obtained were plotted, and contour lines joining similar heights were drawn. The contour lines were drawn at five-metre intervals and printed on tracing cloth with the grid lines and letters of the 1/40,000 map. This method enabled the tracing to be laid over a contoured 1/40,000 map, and the difference between the surface altitude, as taken from the contours, and the altitude of the "water table," as taken from the tracing, gave a figure in metres which was the thickness of dry strata before water could be reached. There were, however, several factors which made the results extremely general and frequently very inaccurate. Among them was the purely theoretical nature of the method adopted, which, while giving a result probably fairly accurate in general principle, was frequently in error in respect to degree. Secondly, no account was taken of annual variation of the water level, and, thirdly, the surface contours of much of the area were liable to considerable error, which, although not having any great effect on the "water table" contours, introduced grave errors when arriving at the depth to water by subtracting the " water table " levels from those given by the surface contours.

As the area which was occupied by troops was so large, it was impossible to visit the sites for all bore-holes before work started. It was therefore necessary to give such information as was available in a condensed form which could be taken in at a glance. With this aim in view a series of maps was prepared which divided the ground into areas within which the conditions for boring were similar. To take an example :—

The ground near Bethune and Lens divided into areas—

1. Chalk yielding 6,000–10,000 g.p.h. from bore-holes with air lift.
2. Chalk thin and clayey—bore-holes no good—surface springs to be used.
3. Doubtful area—before boring consult a geologist.
4. Artesian chalk-water area—good for boring.
5. " Blue " Clay area—only small supplies from the " Green " sand.

In this way the Army Water Supply Officers and others could see at a glance in most cases whether a locality would be a good one for a bore-hole or not.

The first of these maps dealt with ground within our own lines, but they were gradually extended to take in enemy territory. Maps of this type, with explanatory notes, were found to be one of the most convenient methods of sending information out to the troops, for in this way a general idea of the country ahead is given without the necessity of reading a large amount of printed matter. Similar maps and notes were prepared for Intelligence Reports on Eastern Belgium shortly before the Armistice.

From time to time geological sections, with a short descriptive note of two or three pages, were prepared and sent to Armies to illustrate the structure either of the area occupied by the troops, or to show any points of special interest in the area ahead. An example of one of these sections is given in *Fig.* 19.

3. Selection of Sites for Bore-holes.

(*a*) *In Army Areas.* A very large percentage of the Army areas where boring was the chief method of supply was formed of beds of Upper Chalk (Senonian). These beds usually contained flints, particularly in the lower portions. Below the Upper Chalk came some more beds of chalk with flints, which frequently contained a certain amount of phosphatic material, and various beds of hard nodular chalk. The fossil contents of these beds, locally known as " Tun," have led the French geologists to group them with the Middle or Turonian Chalk. The main thickness of the Middle and Lower Chalk is of a marly character, particularly in the eastern portions of the area. These beds may be grouped together, from a water supply point of view, as Chalk Marls. The chalk marls are practically impervious to water and hold up the water which is circulating in the fissures of the overlying chalk. It results, therefore, that, as the surface of the marls nears the surface of the "water table," the thickness of water-bearing chalk is reduced until the surface of the marls comes to actually coincide with, or reach higher than, the normal "water table." When this condition is reached the water is found only in fissures in the harder beds of the marls, and a bore-hole may easily miss the fissures and so fail to obtain any quantity of water. These conditions were found on the high ground of the Vimy Ridge (*see Fig.* 19), and accounted for the failure of the bore-holes put down near Roclincourt and Gouy Servins.

The majority of the sites for bore-holes were chosen more from military than geological considerations. Amongst the chief qualifications for a good site, from the military point of view, was ability to deliver the water by means of an air-lift pump into a tank formed of canvas placed on the ground, which in turn would gravitate to water-cart filling points, etc. It was found that 6-in. bore-holes placed in or near the bottom of a dry valley would yield 8,000 to 12,000 gallons per hour, according to the depth at which water was found below the surface. When it was important to obtain a good supply in the shortest space of time, bores were sited in the valley bottoms, and when so sited in areas where there was a thickness of 50 ft. or more of good water-bearing chalk, the results were always satisfactory. As the urgency of demand for water became less, new holes were frequently made at points further up the valleys, or even on the plateau top. It was found that, provided the bore was not on the actual summit, in most cases a fairly good yield was obtained, the actual volume depending largely on the depth to water-level. As a rule, however, where bores were placed on the actual summit of the plateau, the yield was small; as examples of this—Gurlu Wood, Fressenneville and Pozières may be quoted.

The bore at Saulty, on the top of the plateau, was also a failure, but this was probably due to the fact that here the chalk marls were near the surface (*see* p. 21).

As a rule the yield of a bore could be fairly accurately predicted and, provided it was not on the actual summit of the plateau and that there was sufficient thickness of saturated water-bearing chalk, the results were satisfactory, *i.e.*, 5,000 gallons per hour, or more, per 6-in. bore.

In order to arrive at some estimate of the thickness of the saturated water-bearing chalk, a map of the surface of the chalk marls was prepared and sent to the Army Water Supply Officers concerned.

Besides these bores in the chalk of Picardy and Artois a certain number were made by the Armies situated in Flanders. In this area the only water-bearing horizon is that of the Landenian or Thanet sands, which is found beneath the Ypresian or London clay at a depth of 200 ft. to 400 ft. below the surface. Curves of the base of the Ypresian clay were drawn, from which the depth to the sands could be estimated. The yield from these bores, however, was always small, and there was constant trouble owing to the fine sand choking the bores. Various methods were tried to overcome this difficulty but seldom with much success (*see* para. 4).

Some attempts were made to obtain water from the chalk which underlies the Landenian in Flanders, but this was against the advice of the geologists, since it was known that here the chalk was thin and of a hard marly nature, being practically impervious to water. The results were what might have been expected, and the bores were abandoned.

(*b*) *L. of C. Area.*—The majority of the L. of C. area was chalk similar to that of the Army areas, and the problem was similar, but several bores were made in the Jurassic rocks of the Boulonnais. In the neighbourhood of Boulogne and Wimereux the strata belong to the Kimmeridgian overlying Corallian and Oxfordian. The water-bearing horizons are :—

(i) A bed of sand and soft sandstone in the middle of the Kimmeridgian (Astartian), and
(ii) In certain limestone beds in the Corallian.

This latter is extremely variable both in thickness and water-bearing qualities. It resulted that the bores which were made into the sands yielded good supplies, but while a bore in the valley of the Liane yielded an excellent supply from the Corallian limestones, a bore near Boulogne proved that the limestone had entirely thinned out, and the bore ended at a depth of 725 ft. still in blue clay, which probably belonged to the Oxfordian. In another bore near Ambleteuse a thickness of 40 ft. of oolitic limestone of Corallian age was passed through, but this yielded no water, while beds of the same age within a mile or so yielded over 5,000 gallons per hour.

(*c*) *Aerodromes of Independent Air Force, R.A.F.*—The aerodromes in Nancy area and the depôt at Courban needed supplies of water for the camps. The majority of the aerodromes were situated on the flat, slightly undulating, ground formed by the Lower Lias limestones. The limestones themselves gave rise to small springs, but the quality of this water was not good, and they were liable to almost dry up during the summer months. Another source of supply was available in most cases from the Infra-Lias or Rhaetic sandstones. They were reached either by borings or by wells in the valleys, and yielded good water, but not always in large volumes. Two aerodromes were situated on the Bunter sandstones of the Trias, and a boring on one of these yielded a good supply.

Much useful information was obtained from Dr. E. Imbeaux, Engineer-in-Chief of Ponts et Chaussées at Nancy, who has made a life-study of the hydrology of this area. Lieut.-Colonel Alfred H. Brooks, Chief Geologist to the American Expeditionary Forces, also gave much help over work in this area.

At Courban the aerodrome was on ground formed of the uppermost beds of the Great Oolite, and it was expected that the limestones would yield a good supply. Two bores were put down about 700 ft. but only yielded supplies of about 2,000 gallons per hour, although from one of the bores the water actually flowed at the surface at the rate of about 200–300 gallons per hour. The limestone proved to be very compact at a depth, and only small water-bearing fissures were struck.

(*d*) *Central Group, Canadian Forestry Corps.*—Several saw mills in the Central Group of the Canadian Forestry Corps were in need of an adequate supply of water during the summer of 1918. The operations were being carried out in the area between Rouen, Eveux and Alençon. Much of this area is underlain by chalk, but conditions are rather different from those in Picardy. Here there is a great covering of "clay with flints," some 100 ft. thick on the plateau, and also the lower beds of the chalk are passing into the sandy facies of the "Sables de Perche." The conditions made boring more difficult, but good results were obtained in the bores which were made by the Australian Electrical and Mechanical Mining and Boring Company.

In the neighbourhood of Alençon old palæozoic grit rocks come to the surface, and in this area it was advised to use surface water, and not to bore.

4. Extraction of Water from Thanet Sands.

Geological Conditions.—The strata under the Flanders Plains are :—

Palæozoic :—Slates and mudstones—Devonian or older.
Cretaceous :—Hard marly chalk with flints.
Tertiary :—(*a*) Landenian clays and sands.
(*b*) Ypresian or London clay.
Recent alluvial and loamy deposits.

Of these, the only strata which yield water, with the exception of certain sands in the Recent deposits, are the sand-beds of the Landenian. These sands are some 50 ft. thick as a general rule and overlie the Louvil clays which are the basal beds of the Tertiary. The sands lie at a depth of 250 to 400 ft. below the surface, immediately beneath the thick impervious mass of Ypresian clay.

Borings made into these sands usually started with 8-in. casing, which was driven firmly into the blue clay to ensure that none of the recent superficial sands worked down into the bore ; 6-in. casing was used to line the bore in the clay until the "green sand" was reached.

The Landenian or Thanet sands are extremely fine and of a grey to grey-green colour, and were usually spoken of as the "green sands." The extremely fine nature of the sands made the problem of obtaining water in quantity from them by means of bore-holes a difficult one; various methods were tried from time to time; these were:—

(*a*) Air-lift without strainer.
(*b*) Tube-well pumps— (i) with gauze strainer;
(ii) with horse-hair strainer.
(*c*) Ashford strainer.

(*a*) *Air-Lift without Strainer.*—This was tried experimentally at Houtkerque. The green sand was struck at 369 ft. below the surface. There was 30 ft. of sand before the underlying Louvil clay was reached. Water rose to within 21 ft. of the surface. A 130 c. ft. per minute compressor was used—starting pressure about 150 lbs. per sq. in. which dropped to 75 lbs. per sq. in. when running. The only result with this method was to bring up large quantities of a mixture of sand and water. A large cavity was formed at the bottom of the bore. The water never pumped clear of sand from this bore. The volume of air was evidently much too great.

Some bores were made near Neuve Eglise and were being tested with various types of pumps when the experiments had to be stopped for military reasons. One bore, however, which was cased only 1 ft. 8 in. into the sand, was tested with a 21 c. ft. per minute Ingersol Rand $4\frac{1}{2}$ in. × 5 in. compressor. This yielded 450 gallons per hour of water, which was only slightly cloudy and sandy, and would probably have cleared after being pumped for a week or two. This small compressor gave much better results than the large one used at Houtkerque.

(*b*) *Tube Well Pumps.*

(i) *Gauze Strainer.*—This was the type of strainer generally used. The gauze was of brass with 60 mesh per linear inch soldered over a perforated 4-in. iron pipe and protected by perforated brass sheeting. Gauze of this type was found to hold back only 15 to 30 per cent of the sand. The result was that as soon as the pump was speeded up to deliver more than about 300 gallons per hour, sand was sucked into the bore, and this not only choked the bore, but also rapidly destroyed the leathers of the pump buckets. When bores fitted with this type of strainer were not pumped at more than 300 gallons per hour, the water came up reasonably clear, but even then the bores became sand-choked from time to time and needed flushing out.

(ii) *With Horse-hair Strainer.*—This form of strainer was experimented with in only one bore, and, although it appeared to give results slightly better than the brass gauze, the test was not sufficient to permit of any definite conclusions.

(*c*) *Ashford Strainer.*—The Ashford strainer used in France consisted of an octagonal column formed of rods kept in place by internal rings with copper-wire spaced to leave 4/1000 to 6/1000 in. between wires ; for each 50 ft. run of strainer this left open spaces equal to an opening of about 400 sq. in. In a test made at Cunewele near Hazebrouck 50 ft. of Ashford strainer was used ; this was embedded in the Thanet sands so as to give maximum percolating surface. Rest water-level was at 62 ft. from the surface : the air compressor used was a 60 c. ft. of air per minute Broom & Wade (Coventry) Simplex set, starting pressure 95 lbs. per sq. in. and running pressure 40 lbs. per sq. in.

At first a 1-in. air pipe inside the 4-in. rising main was used, but this was not satisfactory owing to the quantity of water being too small for the area of the rising main. Later a 2-in. pipe was put inside the 4-in. and air blown down between the 4-in. and 2-in. pipes, the 2-in. pipe thus being used as the rising main. This proved a satisfactory arrangement, and a yield of nearly 1,000 gallons per hour was obtained. The water was practically free from sand.

Conclusions.—The work done in the Landenian or Thanet sands of Flanders would seem to point to the following conclusions :—

(i) That the sands will only yield a certain volume of water per diem without having bad effects on the bore. When, after several hours' rest, the water fails to return to its former level, it would appear to indicate that the sands in the neighbourhood of the bore are being " dried out," due to the slow rate of percolation of the water through the excessively fine sand. In other words, a zone of sand which is not fully saturated with water is being produced round the bore. The daily yield of a bore should be between 6,000–10,000 gallons without lowering the rest level of the water. The gauge of the quantity of water which can be taken from a bore would seem to be the rest level after pumping has ceased for several hours.

(ii) In order to avoid raising sand when pumping, one or two things must be done :—

(*a*) Pump slowly at a rate of about 300 gallons per hour.

(*b*) Have an efficient strainer which will keep back the sand when pumping at a rate of about 1,000 gallons per hour.

The Ashford strainer when wound to about 4/1000 to 6/1000 in. spacing would appear to fulfil the latter conditions.

For a strainer to be efficient in this type of deposit it must hold back a sufficient percentage of the sand to form a natural filter of the larger grains of sand outside the artificial strainer. While forming this natural filter only a small quantity of sand must be drawn into the bore, for, if large volumes are sucked through the strainer, cavitation tends to set in, which breaks down the natural arrangement of the sand, and prevents the natural filter from forming. It would appear advisable, however, in these extremely fine sands to break up the natural arrangement of the sand for a short distance (probably only a few inches) around the bore-hole. When this was done a more efficient natural sand-filter seemed to form.

(iii) A steady flow of water, such as induced by an air lift pump, is preferable to the pulsating flow of a tube well pump. The pulsating is deleterious to the strainer itself and tends to disturb the sand astride the strainer.

(iv) The scheme of artificially introducing a filter of coarse sand outside the Ashford strainer was not tried owing to the fact that larger bores would have been necessary to enable the sand to be fed down between the casing and the filter. It would probably be advantageous to have an artificial sand filter, but, unless this filling was of an appreciable thickness, it would be difficult to prevent a small volume of fine sand from being sucked into the bore-hole during the initial stages of pumping. The removal of this small volume might easily cause a readjustment in the artificial sand filter, resulting in a breaking up of the original arrangement around the strainer, thus exposing portions of the strainer direct to Thanet sands.

(v) Another type of strainer known as the Beeby Thompson strainer was on order, but did not arrive in France in time to be tested.

5. Card Index of Bores.

When it was seen that boring would be extensively used as a method of obtaining water, suitable forms were drawn up for forwarding the records to G.H.Q. These forms were of foolscap size and had spaces for details of the strata and pumping machinery, output, etc. As the forms were received from the Armies the information on them was entered on cards which were kept in a card index arranged alphabetically by place names. A sample of one of these cards is given below, and contained practically all the information on the larger forms received from the Armies :—

BETHENCOURT. 57^EV 9 d. 8.2. Altitude 42 metres.

Depth from Surface.	Thickness.	Nature of Strata.	Remarks.
0	10	*Soil and clay*	*No. C/41.*
10	25	*Chalk and flint* ...	
35	5	*Chalk*	
40	12	*Chalk and flint* ...	
52	158	*White chalk marl* ...	
210	43	*Blue chalk marl* ...	
253			

Details of Pumps and Outfit.

Air Lift.	*Deep Well Pump.*
Compressor, Engine, } *Broom & Wade, mounted on lorry.*	Pump Engine
Starting Pressure 104 *lbs. per sq. inch.*	Depth of Pump
Running ,, 100 ,, ,, ,,	Barrel from surface ft.
130 *cubic ft. Air per minute.*	Diameter of Pump
245 *ft. of* 4-*in. Rising Main.*	Barrel ins.
235 *ft.* of 1-*in. Air Pipe.*	Length of stroke ins.
Yield, 12,000 *gallons per hour.*	Strokes per minute.
Water Level at rest, 32 *ft. from surface.*	
,, ,, after pumping 36 *ft.* ,,	
47 *ft. of* 8-*in. dia. casing.*	

(Signed) *X.Y.Z.* O.C. No. 3 Water Boring Section, R.E.

A map of 1/250,000 scale, with the position of each bore marked by a small circle, and the place name by which the bore was known, was also kept up to date so that the map acted as a cross index to the cards.

During the war a total of over 470 bores for water were made by the British Armies.

6. Curves of Marl Surface.

The chief percentage of the bores were in the chalk country of Artois and Picardy. The bores were as a rule carried down through the water-bearing Upper Chalk into the marls of the Middle and Lower Chalk, in order to give sufficient submersion for the use of air-lift pumps. The method of boring by percussion made it extremely difficult to get accurate records. The character of the strata, moreover, made it difficult for the drillers to tell within a few feet the junction between the chalk and the underlying marls, particularly as broken flints frequently got mixed up with marl and led to the term " marl and flint." When the marls could be studied in sections and mining galleries, flints were absent except for a very occasional layer of tabular flint. When, therefore, the term " marl and flint " was used, it was presumed that the marls of the Middle Chalk had been reached, but that a few flints had been knocked out of the Upper Chalk and had been pounded up with the marls.

It resulted that it was impossible to tell with any accuracy the exact depth at which the marls were reached

During the early part of 1918 sufficient data were available to draw contour lines at 25-metre intervals of the surface of the marls. In order to arrive at the altitude of the surface of the marls above sea level, the altitude of the ground at the site of the bore was estimated from the contours of the 1/40,000 map, and the depth from ground level to the surface of the marls in metres was subtracted. This gave the data from which the curves were drawn. The figures thus arrived at were open to several errors, viz. :—

(*a*) The difficulty in recognizing the surface of the marls when boring ;
(*b*) The errors in the contours of the 1/40,000 map ;
(*c*) The errors in estimating the altitude when the bore was situated between two contours.

Bores were, however, sufficiently numerous to enable some interesting results to be obtained. As new records came in they were entered on the map, and the curves corrected to conform with the additional data. The final result is given on *Plate* II. It should be mentioned that the curves agree in essential points with those published in Lemoine's "Bassin de Paris" from a map by M. G. Dollfus.

On looking at *Plate* II the most striking thing is the general agreement between the direction of folding of the strata and the direction of the rivers. This has always been pointed out by the French geologists. It will be noticed that the syncline of the Somme apparently has its axis somewhat to the south of the river. Immediately south of the Authie there would also appear to be a synclinal trough. This is particularly apparent near the phosphate districts of Beauval, Beauquesne, and Raincheval.

The next marked syncline is the Scarpe-Upper Ternoise Valley. On this line is the low col between the west-flowing Ternoise and the east-flowing Scarpe, which is crossed by the main road and railway from St. Pol to Arras.

The anticlinal ridge between the Somme and the Authie rises to the 100-metre level south of Candas, but appears to be more of the nature of an elongated dome rather than a true anticlinal ridge.

The case of the ridge separating the Authie and Ternoise–Scarpe synclines is different. The marls rise to an altitude of 140 metres, and although they fall to an altitude of 65 m. to 70 m. in the neighbourhood of Bapaume, the axis appears to be in line with that which gradually falls from the east, as shown by the line of the 75 m. curve which reaches to Nurlu. This axis is practically the same as the Cayeux's axis of Artois. (*See Ann. Soc. Géol. du Nord*, Vol. XVII., p. 71 and *Plate*.)

South of this axis one branch of the Somme syncline coincides with the line of the Somme to Peronne, and is continued in a south-easterly direction towards St. Quentin.

A dome of relatively high ground with its centre near Chaulnes separates the Amiens–Peronne–St. Quentin syncline from that of the Avre ; this latter being a direct continuation of the Somme syncline below Amiens. To the north the marls gradually fall to the Basin of Orchies, as illustrated by M. Gosselet's work.

The question of whether the north and south-flowing rivers have any connection with the geological structure is not so obvious. Apart from the upper Escaut the most striking line of north and south-flowing streams is that followed by the new Canal du Nord. From the river Sensée this canal follows the Hirondelle, then by means of a tunnel crosses the ridge into the valley of the Tortille. Near Peronne it joins the Somme where that river takes such a remarkable change of direction from east–west to north–south. Near Nesle the canal leaves the Somme, which gradually swings east and follows the line of the low ground which is drained by the Ignon, and reaches the river Oise at Noyon by the valley of the Verse.

Although the main structure of the country is clearly shown by the N.W.–S.E. trend of the curves, there are several changes along this N.–S. line. For instance, the curves near Cambrai have an E.N.E.–W.S.W. direction, but change to the usual N.W.–S.E. trend on the line of the Hirondelle. More important than this is the marked lowering in the main axis of Artois between the high area west of Bucquoy and the high ground to the east.

The bulging-in of the dome along the line of the Somme south of Peronne would appear to be some indication of secondary folding along this north and south axis.

The question of practical interest is to see if bores situated in the synclinal areas yield better supplies than those on the anticlines.

As far as the evidence of the bores goes there is practically no difference in the yield of bores in the anticlinal areas compared with those in the synclinal, provided both are situated in favourable positions, such as a dry valley. On the plateaux, however, the fact that on the anticline the thickness of water-bearing chalk is greatly reduced has a bad effect on the yield, thus the bores of Saulty, Monchy-au-Bois, Fienvillers, etc., where the thickness of water-bearing chalk was small, only yielded small quantities of water. It does not follow that bores on high ground in a synclinal area necessarily yield good supplies, although in some cases, such as Beaurains, a good yield was obtained from a bore on the top of a hill. It would appear, therefore, that the local topography has much more effect on the water-bearing properties of the chalk than the larger tectonic structures.

Chapter II.

MINING, FIELD POSITIONS, ETC.

7. Mining in Regard to Water Level.

The first geological test bores were put down at Mont Kemmel in May, 1916, and proved the existence of the water-bearing Kemmel sands between the levels of the 70-metre and 60-metre contours at that hill. These sands were subsequently traced over large areas northwards through Wytschaete and Hill 60, near Ypres, to Passchendaele. In most cases it was impossible to obtain dug-outs in these sands, which were usually so charged with water as to be "running" (*see Fig.* 9 and *Plate* V).

The geological boring sets were next transferred to Hill 63, to the north of Ploegsteert, and proved that it was possible to excavate dugouts satisfactorily there in the Paniselian clay immediately above the Ypresian clay. Dug-outs were at once made there. These dug-outs, when completed, accommodated about 3,000 troops.

The geological boring sets were next moved to Givenchy-lez-la-Bassée at the request of the Controller of Mines of the First Army. The enemy a short time previous (June 22nd, 1916) had done some damage to our lines by blowing the "Red Dragon Crater" (*Fig.* 1). It was obvious from this "blow" that his mining system must have been somewhat deeper than our own.

Previous to this blow some of our mining galleries in this sector, east of Bunny Hutch Shaft, had been inundated through the workings having struck the artesian water in the chalk, but there was no accurate record as to the exact depth at which the water horizon had been touched. Accurate determination of the exact depth to which mining could safely be carried in this important sector now became very urgent. The Hordern boring sets were employed successively at North Shaft and Coventry Shaft (*Fig.* 2), and as water under pressure was expected, a boring bit was used with a diameter of only $\frac{3}{4}$ in. In each case, as soon as the Louvil clay was penetrated, and the surface of the chalk reached, artesian water gushed up the bore. Small bags of oats, of haricot beans, rice and wheat were forced down the bore-hole with the boring rods, and the material allowed to swell for about a couple of hours, with the boring rods resting on top of the bags, so as to prevent the artesian water forcing them out of the bore. As soon as the bags had swelled sufficiently to grip the sides of the bore firmly, the boring rods were withdrawn, and the flow of the water having been checked, small bags of Portland cement were forced down the bore where they were able to set. The sealing of the bores by this method was fairly satisfactory, but the operation was somewhat tedious. A hollow rubber stopper, similar to those used for corking bottles containing effervescent liquids, would probably be quicker and more effective in stopping the flow of the water ; or, for larger bores or openings, the method successfully adopted by Captain J. W. Fidoe, R.E., might be followed, which is this :—When, during 1918, a sump at Givenchy was accidentally carried down too close to the chalk surface, and the artesian water started bursting up through the clay, concrete was at once applied and heavily weighted on top, but the artesian water kept forcing its way through the concrete. A short piece of iron pipe with a tap at the top was then placed vertically in the concrete, so that its lower end was open to the rising artesian water. The tap was left full open, so that the water flowed freely for about a week, thus taking the water-pressure off the concrete and allowing it to set. The tap was then closed, and the mining system was saved. The pipe afterwards served the purpose of a standpipe for supply of pure water underground to the tunnellers.

The whole operation of making these two bores and sealing them, and tracing the outcrop of a certain fossil shell bed (containing *cyprina morrisii*) occupied about two days. The evidence of the two bores gave the apparent dip of the strata in one direction, and from that of the outcrop of the shell-bed the apparent dip was found to be in a direction more or less at right angles to the first. From these two directions the true dip was easily calculated, and the exact depth of the artesian water surface was thus determined. From this new datum a new mining system for the Givenchy sector was laid out, and all underground works at Givenchy from then until the final great defence of Givenchy in June–July, 1918, were laid off in reference to this horizon.

The problem, though of course an extremely simple one, was essentially a geological one, and had the geological examination been made earlier, it is probable that the Red Dragon Crater would never have been blown.

8. Determination of Chalk Underground " Water Table."

In August–September, 1916, it became a matter of importance to determine :—

(*a*) The actual depth at that time to the underground " water table " in the chalk (*i.e.*, the depth to the surface in the chalk), and

(*b*) the exact amount of seasonal variation in the level of this zone.

For example, in late autumn the " water table " is usually at its lowest level, whereas after the winter rains its surface rises. It followed, therefore, that if mine galleries were carried down to the level of the top of the chalk " water table " in the autumn, there would be a certainty of their becoming inundated by the rise of the " water table " the following spring. At the time investigations commenced there was much uncertainty in the British Armies engaged in tunnelling in chalk country (First and Third Armies) as to how much to allow for rise of the chalk " water table " and how the approximate date of the rise could be predicted. The amount of seasonal variation was set down at about 6 ft.

The underground " water table " in the chalk must be carefully distinguished from " quarry water." Almost everywhere in the chalk, at 8 ft. or so below the surface, there is enough water stored in the very fine pores of the chalk to make the chalk slightly moist, so that, if drilled with an auger, it works up into a stiff putty-like substance. This water is stored in microscopic (capillary) cavities, and is not free to circulate to any great extent. This water is the " quarry water."

The water below the " water table " on the other hand, is stored in countless small cracks and fissures in the chalk. These are most numerous and carry most water in the " chalk without flints " of the Upper Chalk (*see* (*a*) of *Fig*. 5). In the " chalk with flints " underlying the preceding, the water of the " water table " still circulates fairly freely in numerous minute fissures, and in places in larger fissures.

Underlying the preceding is the marly chalk, the lowest formations, in the chalk regions, in which the mine galleries were driven. The underground water in this formation does not circulate nearly as freely as it does in the two preceding.

The movement of the water in the chalk marls is restricted to the larger fissures which may be some scores of yards apart from each other, so that galleries driven in this formation may be practically dry even when they are below the general " water table " surface of the area, provided they do not strike a fissure.

The variation of water-level in chalk with the seasons depends on :—

(i) Rainfall.
(ii) Evaporation.
(iii) Run-off of rainfall—
   (*a*) Superficial, in brooks and rivers,
   (*b*) Underground, as a more or less continuous sheet creeping seawards, or discharging by springs into low-lying areas like those of the Flot de Wingles, the La Bassée Canal, the Sensée Marshes, etc.

Evaporation is perhaps the most important of these factors ; thus a heavy rainfall at time of maximum evaporation (as, for example, in July or August) produces little, if any, effect on the level of the chalk " water table." On the other hand, a similar rainfall at the end of winter or early spring, when evaporation has practically ceased, produces a rapid rise in the " water table."

As regards its general shape, the underground " water table " rises under the hills, and sinks towards the main river valleys and more important springs. Its upward and downward movement, following the seasons, is greatest when comparatively high hills, like those of the Loos salient, Calonne and Souchez, adjoin low-lying areas like those of the Flot de Wingles, the Souchez River, the La Bassée Canal, etc.

In this case the " water table " has a seasonal movement of the kind shown in *Fig.* 5 (*b*) (the movement hinging on the above mentioned low points of outlet).

The " water table " surface rises under the hills for two reasons, at least :—

Like a river, in flowing from under the hills to lower-lying areas, it develops a definite grade owing to the frictional resistance of the openings in the rock through which it is circulating (increasing porosity lessens the grade ; decrease of porosity steepens the grade).

The rainfall is usually heavier on the hills than on the lower ground, hence a greater amount of water percolates under the hills than under the lower ground.

At Croydon Corporation Waterworks in England, well gaugings show that water levels vary from late autumn to spring by as much as 100 ft.

Information was obtained in regard to this subject, on the Western Front, in two ways :—

(*a*) By boring, to find out exactly at what depth below mine galleries the chalk water level lay at any particular time ;

(*b*) Examining the daily or weekly records kept for many years past by coal-mining companies in this area, and then referring the actual level found for the chalk " water table " at any particular military mine to its proper place, for the time of the year on the mean curve of " water table " variation calculated from the colliery records. Corrections dependent on distribution of rainfall for the particular year in question had also to be applied.

As regards (*a*), the light geological boring sets were used, and at Loos, at Hill 70, The Copse, The Triangle and The Double Crassier, after some trouble in getting through the layers and lumps of flint, the exact level of the surface of the " water table " at each of those mines was successfully determined.

In the case of Hill 70 it was necessary to bore through over 40 ft. of tough chalk and flints, which occupied two days, before the surface of the chalk " water table " was touched. There was no difficulty in telling when the auger had reached the top of the " water table."

As long as it was boring in the chalk above that level, the auger, when withdrawn from the bore, brought up in its spiral chalk of the consistency of putty, there being enough quarry water to enable the fine chalk borings to cohere; but as soon as the "water table" was touched, the auger brought up the pulverized chalk in the form of a thick, white, milky substance which dripped off the auger. This was the crucial test, *viz.*, if the material dripped off the auger when freshly withdrawn from the borehole, it was concluded that water level was reached.

Another test was the sucking sound that the auger made at the beginning of the upward pull after water had been reached.

The depths to the surface of the chalk "water table" in relation to the mining systems in the Loos Salient were determined by the above method in September, 1916. The next step was to compare them with any records which tunnelling companies had preserved of the former level of the table when it stood higher earlier in the year. Only a few of such observations were available.

Next, enquiries were made amongst the engineers of the French collieries as to whether they had any continuous records of chalk "water table" variation extending over a number of years.

M. Malatray, the Chief Engineer of the Compagnie des Mines de Bethune, very generously placed at disposal the whole of his very valuable data on this subject, extending over the years shown on *Fig.* 3. Efforts were made to trace a relation between the curves of variation in chalk "water table" level and those of the local rainfall, but without success at first. It had been the received idea among British geologists that there was a delay action, or lag, of about three to four months between any peak of heavy rainfall and the following peak in chalk "water table" level.

The Commandant of the Meteorological Section of the British Armies solved the problem at once by pointing out that the evaporation factor was an extremely important one, and that the correction for this must first be applied. There were no accurate data on this head for Northern France, but data for such parts of the South-East portions of England as had climatic conditions most nearly approaching to those of Northern France were procured. These corrections are shown by the pink areas on *Fig.* 3. A small correction (shown green on the above figure) was also applied for run-off discharged by brooks and rivers. These two quantities having been deducted from the gross rainfall, the net rainfall which percolates, and which is the only part of the rainfall which is effective in raising underground water level, was calculated approximately. The relation between percolating-rainfall curve and variation of "water table" curve then became very apparent.

It will be seen from *Fig.* 3 that (after the big deduction is made for evaporation during the months of April to October inclusive) it is apparent that there is a lag of only from two weeks to a month in the peak of the rainfall and that of the chalk " water table."

Experience shows that there is a greater lag in rise of water-level in low-lying areas than in high areas. For example, at Hohenzollern the maximum water-level in 1917 was three weeks later there than at the Triangle. The lag at Hohenzollern may thus amount to five or even six weeks. This is probably owing to the time that it takes the crest of the wave of the chalk water to arrive at the lower levels, the rainfall as already stated being heaviest on the highest ground, and so bringing down, as it were, a flood in the " water table " which travels like the flood in a river, from the source towards the outlet.

This conclusion as to a general lag of only about three weeks is obviously very important, as it makes it at once possible to predict exactly when the chalk " water table " will attain a peak after any particular period of heavy rain. The necessary data are :—

Knowledge of level of " water table " before rain began.
Amount of rainfall lost by evaporation.
Amount of rainfall lost by run-off.
Average amount of rise of " water table " per unit of percolated rainfall as observed in previous years.

It was now possible to draw up a table for use by the various Tunnelling Companies, to show them just up to where the " water table " would rise, on the assumption of a maximum rainfall during winter when evaporation is at a minimum.

In all the Loos mines, including Hill 70, the calculations made in September of 1916 worked out fairly closely (within a foot or two) of the maximum (almost a " record " maximum) chalk " water table " level in January, 1917. It was found in September, 1916, as the result of these calculations, that the new mining systems begun at the Copse, the Triangle and the Double Crassier, were already considerably too deep, and so another system was laid out at a level from 12 ft. to 15 ft. higher. When in January, 1917, the water rose to its maximum level, it just reached the floor of the main lateral of this latest system of galleries. At Hulluch and Hohenzollern, however, the " water table " rose about 2 ft. higher than had been estimated, as enough allowance had not been made for the " travelling wave " from the highest point of chalk water towards the hinging point or outlet at the La Bassée Canal and the Flot de Wingles. In other words, the movement of chalk water level is not merely a straight up-and-down hinging motion, as shown at (*b*) on *Fig.* 5, but is a wave movement superimposed on a hinging movement.

As regards the actual amount of variation of chalk water-level in the La Bassée Canal to Souchez River area, this is shown on *Fig.* 4. The maximum variation was found to be 30 ft., at the Triangle near the Double Crassier.

In 1917, in the abnormally rapid rise of chalk water level, between Christmas Eve, 1916, and 8th January, 1917, the water rose 18 ft. in fifteen days, and at the Triangle it rose no less than 30 ft. above its minimum level of November, 1916. At Calonne the rise was fully 26 ft.; at the Copse 22 ft.; at Hill 70, 22 ft.; at Hulluch 12 to 15 ft.; at the Hairpin from 18 ft. at the south end to 11 ft. at the north end. In Hohenzollern the rise was from 11 ft. at the south end to about 9 ft. at the north end. From here the variation steadily lessened to practically zero at the La Bassée Canal near Pont Fixe.

The whole of this work of predicting for the Tunnelling Companies just up to where chalk "water table" level would rise would, of course, have been impossible without the valuable curves supplied by M. Malatray, and there is no question that this information contributed very much to save some of the most important mining systems.

The determination of the variation of the chalk "water table" at Givenchy-lez-la-Bassée and the Loos salient was eventually extended to Calonne, Vimy and Arras. In the course of investigating the geological conditions at Vimy, partly by boring with the modified "Acme" drilling plant, and with the "Wombat" boring machine, and partly by examining the sections in the tunnels and shafts of the 176th Tunnelling Company, R.E., evidence was obtained useful from the military, as well as from the purely scientific point of view.

9. Relation of Military Mining to Geological Structure.

(*a*) *The Vimy Ridge* owes its origin to a very important geological structure, the Marqueffles Fold and Fault. This tectonic feature has a general W.N.W. to E.S.E. trend. Near Souchez this structure is shown on the French geological map of Arras (1/80,000 and numbered 7) as a fold, but there has been some doubt as to how far the displacement of strata in this neighbourhood is due to faulting and how much to folding. The total amount of displacement effected is at least 190 ft. (58 metres). In places, Gosselet estimates the displacement as up to 95 metres. British evidence shows (*vide Fig.* 6) that about 130 ft. of this is due to folding, and 60 ft. to faulting. The geological conditions, as shown by this evidence, inasmuch as they brought down the clayey and sandy beds of the Tertiary strata into a very suitable position for military mining, favoured an attempt to tunnel under the very important stronghold of the enemy which gave him such command and fine observation —"The Pimple." The scheme was to drive a gallery from D.5 shaft (*see Fig.* 6) through the chalk near the bottom of the monocline, so as to reach the Louvil clay at a sufficient distance from the enemy lines for the latest part of the tunnelling in the chalk to be inaudible. Once the Louvil clay and its underlying sand were reached, it should be quite possible to tunnel, without being heard, right along this bed of clay until a point should be reached right under the enemy's strong points. Previous to the starting of this scheme, as accurate a survey as possible was made of the Louvil clay outcrop which there just touched, and in places entered, the British front line of trenches. The geological evidence, chiefly obtained from the French maps and scientific papers, proved correct and was verified by small bores. Had the Vimy offensive of 9th April, 1917, been postponed for about a week, the end of the offensive tunnel would probably have been carried right under the enemy strong point. As it was, it had arrived by 9th April, 1917, within about 70 ft. of the enemy's front line, as shown on *Fig.* 6. This is a special example of the importance of determining geological structure accurately before military mining is commenced.

Another point brought to light by the geological borings here, partly with the "Acme" and partly with the "Wombat" boring machine—was that at a depth of about 150 ft. (46 metres) below the surface of Vimy Ridge a thick layer of marly clay occurred, sufficiently soft to admit of silent tunnelling being carried on in it. A deep mining system in these marly clays would have been developed had time permitted. Meanwhile the great attack (which proved so successful) between Vimy and Arras was launched on 9th April, 1917. It may here be mentioned that a short time previous to this attack five horizontal bore-holes were made from the ends of the subways, along which latter the attacking infantry were brought up under cover to the edge of "No Man's Land." The subways, preparatory to the boring, mostly with about 30 ft. of cover, chiefly chalk, were inclined upwards at their blind ends until the cover was reduced to about 16 ft., and then a chamber about 6 ft. × 6 ft. × 7 ft. was excavated. "Wombat" boring machines were introduced into the chambers of five subways, and 6-in. bores were made to a length of about 200 ft. under "No Man's Land" up to the enemy's trenches. These bores were then charged with ammonal cartridges, $5\frac{1}{2}$ in. in diameter. Out of this total of five bores which had been completed, three were utilized during the attack, chiefly in the area between Neuville St. Vaast and La Folie Farm, and were fired at zero on 9th April. The explosions formed instantaneously, wide trenches, one of the two near Chassery Crater being 195 ft. long, 25 ft. wide at the surface and 14 ft. deep; the other 174 ft. long, 25 ft. wide at the surface and 15 ft. deep. The firing of these bore-holes at once opened up these explosion-trenches from the ends of the subways across "No Man's Land," and the leading troops swarmed to the attack through them, but the enemy made so little resistance that the remainder of the troops had no need to take cover, and went straight over the top. The official report on the result of these bore-explosions at the time was that they afforded excellent cover for troops, and would probably be most valuable on the flank of an attack.

Geological examination had often to be made of the ground where it was proposed to use the "Wombat" borers. If the formation was clayey, a twist auger was used, and if of chalk, with or without flints, a calyx barrel with steel cutter was employed. The boring past the flints needed percussion, and was therefore too noisy to be used in close proximity to the enemy's lines, except in cases to be detailed later.

The photograph, *Fig.* 7, shows one of these explosion-trenches near Chassery Crater. As the photograph was taken over twenty months after the "blow," the trench has been considerably filled up through rainwash.

(*b*) For some time previous to the Vimy attack of 9th April, 1917, much time and thought had been given to the preparation of the immense mining system from Ploegsteert, along the zone Messines, Wytschaete, St. Eloi, to Hill 60, near Ypres. One of the most difficult mines to construct was that of Boyle's Farm, between Wulverghem and Messines, extending to Ontario Farm, the latter being strongly held by the enemy. The difficulty arose chiefly from the great thickness (93 ft.) of water-bearing alluvials, chiefly sands and sandy clays, overlying the blue clay, in which the driving of galleries was possible. Two unsuccessful attempts were made to sink shafts through the running sands. Then, the most favourable spot having been selected, as the result of the evidence of geological test bores, a third atetmpt was made, which eventually proved successful. The mining system shown on *Fig.* 8 was developed by the 171st Tunnelling Company, R.E., steel tubbing being sunk through the running alluvials well down into the Ypresian clay (blue clay). When the gallery had reached the point shown at about 480 ft. distant from the bottom of the Winze Shaft, the clay in the roof softened, and water with sand started to come in. With great promptitude the end of the gallery was sealed off. A careful geological examination was made, with a view to estimate the exact maximum depth of the old alluvial channel, so as to decide how much deeper the tunnel would have to be carried in order to be safe from the running sand and the gravel. The conclusions were based on a series of bores made by the Belgians, details of which were published on their maps, as well as on evidence from workings in the vicinity, and particularly on the character of a few blocks of shingle up to 1 ft. in diameter which had worked their way down into the clay at the end of the tunnel, and gave good evidence by their coarseness that the very bottom of the channel had been touched at the end of the sealed-off gallery. The gallery was dipped another 7 ft. and the bottom of the channel was just cleared, with a sufficiency of clay in the roof to keep back the water.

This tunnel was completed, chambered and charged just in time to be fired at the attack of 7th June, 1917, and the resulting explosion was very satisfactory.

(*c*) *The Messines–Wytschaete--Hill* 60 *Mines.*—Another serious geological difficulty, in mining in this zone, apart from the thickness of the quarternary alluvials of the Petite Douve Valley just mentioned was the presence of the water-bearing Kemmel sands. These sands were first identified at Mont Kemmel, where they outcrop between the 70 metres and 60 metres contour. There they formed quite a useful source of water supply on a small scale, but it was impossible to make dug-outs or tunnels in them, excepting in the case of small isolated knolls, where natural conditions for drainage were exceptionally good. Traced north-eastwards, the Kemmel sands gradually dip, so that, on the eastern slopes of Wytschaete Hill they outcrop between the altitudes of 58 and 48 metres. They are therefore about 10 metres in thickness. The running character of this sand is well seen in *Fig.* 9, in which is shown the railway cutting at Hill 60. The concussion of exploding mines and bursting shells has caused the banks of the cutting to collapse ; and sand and water have flowed inwards from the bases of the slopes of the cutting, partly filling it up. It was these Kemmel sands that made it impossible to obtain satisfactory dug-outs at Verbrandenmolen, Battle Wood, Shrewsbury Forest, Clapham Junction, Dumbarton Wood, Polygon, and many other areas extending through Zonnebeke along the Passchendaele Ridge.

Fig. 10 shows the general geological conditions in the Flandrian area between Ploegsteert and Hill 60, along the zone where these important mines were situated. It will be seen that the only one of them which penetrated the Ypresian clay (blue clay) to any depth was the St. Eloi mine.

With the exception of the mines in the Ploegsteert area all the rest of the mines were in the sandy clays and sands of the Paniselian formation (so-called after Mt. Panisel, near Mons, where it is typically developed).

Fig. 10 shows that mines such as those of Kruisstraart, Spanbroekmolen and Peckham, were driven in the sandy clays just below the base of the water-bearing Kemmel sands. Had geological advice been available at the time these mines were begun, there would certainly have been a recommendation to sink a little deeper before tunnelling, so as to place the galleries well below the level of the Kemmel sands, excavating them in the brown to greenish clay, which there usually forms the base of the Paniselian formation. This was done, for example, in the case of the mine at Maedelstede Farm, at the Caterpillar (Hill 60 B) and at Hill 60 A, in which the galleries were driven along perhaps the best possible geological horizon.

M. Ch. Barrois, the Professor of Geology at the University of Lille, stated that at the time the Messines–Wytschaete mines were fired the whole of the City of Lille experienced what seemed to be a sharp shock of earthquake. He and all his household were wakened by it, and dressed hurriedly in anticipation of possibly a more severe shock following the first. Lille is about $11\frac{1}{2}$ miles distant from the nearest of the mines (that of Ontario). On the morning of the explosion of the mines many German soldiers were to be seen running apparently panic-stricken down the streets of Lille.

It is interesting to notice the effect of different geological formations in controlling the type of crater produced by the explosion. Reference to *Fig.* 10 shows that one of the most disappointing craters was that of St. Eloi. The obvious reason for this is the extreme tenacity of the Ypresian clay (blue clay) and its resistance to disruption. In the Paniselian sands and clays, on the other hand, the disruptive effects of the charges were much greater, as is obvious from a study of the craters at Hill 60, for example, as shown on *Fig.* 11. It is also interesting to note that at Ontario Farm, where there was 93 ft. in depth of soft water-bearing alluvial, scarcely any crater rim at all was formed, the material erupted simply falling back and almost completely filling the crater. On the other hand, in the Paniselian formation, as already stated, the craters were well formed, deep, and with high raised rims. For comparison of these two types, the crater at Ontario Farm (*Fig.* 11) may be compared with the crater at Hill 60 A (*Fig.* 12).

Antecedent and subsequent to the blowing of the Messines–Wytschaete mines, the Australian Electrical and Mechanical Mining and Boring Company were, through their boring section, making large numbers of trial bores in the Flanders area, with a view to testing the suitability or otherwise of the ground for dug-outs, battery positions, observation posts, tunnels, subways, etc. Subways were constructed about this time under the Ypres Canal, near Boesinghe, in preparation foı the third battle of Ypres.

10. Test Bores for Subway at Nieuport.

Just previous to the capture of Vimy, a special geological examination was made of the sand dunes along the coast between La Panne and Nieuport, with a view to ascertaining whether it was possible to extend offensive tunnels into the sands and to construct dug-outs. The geological report was favourable, and the 2nd Australian Tunnelling Company attempted this rather difficult task, using an ingenious method of timbering, which has been specially described in the reports of the Inspector of Mines, G.H.Q. It was officially stated that the galleries and dug-outs made in the dunes by this Company and the 184th, 256th and 257th Companies, R.E., contributed very much to strengthen the position of the British troops when the enemy took the Grande Dune on the northern bank of the Canal, to the north-west of Nieuport, on the 10th July, 1917.

In September of 1917 it was decided to test the depth of the Ypresian clay (blue clay) on either bank of the Yser at Nieuport. This was done with a view to the possibility of constructing a subway under the Yser. It was foreseen, from the geological evidence afforded by the Belgian bores at some few miles away, that a considerable thickness—at least 50 or 60 ft.—of running sand, practically quicksand, would be encountered. The boring would have to be done more or less under shell-fire the whole time, so that only a light hand-boring plant could be employed. For the method adopted, Captain Stanley Hunter, of the Australian E. and M. M. and Bo. Company, was responsible, the work being actually carried out by the 2nd Australian Tunnelling Company. The apparatus and method of boring was ultimately so successful that it may be here described in detail, with a view to guidance in the solution of similar problems. The section and apparatus are shown on *Fig* 13.

11. Special Plant for Thick Beds of Water-Bearing Sand.

(*a*) *Description of Apparatus.*—The principle used in boring in thick beds of water-bearing sand was that of the water-jet.

The boring rods carrying water under pressure consisted of 1¼-in. pipe in 3-ft. lengths, to the bottom length of which was attached a calyx cutter.

The casing used was 3 in. in diameter in 6-ft. lengths.

The water under pressure was supplied by two horizontal double-acting hand pumps connected in series, *i.e.*, the discharge of one connected to the inlet of the other. This water was led through flexible hose to a water-swivel connecting up with the top length of the 1¼-in. rods. A tripod, 10 ft. in height, with a block and tackle, enabled the casing and boring rods to be handled with ease.

A geological test boring set was used to bore through solid clay when that bed was reached.

The complete plant consisted of the following :—

120 ft. 1¼-in. pipe, in 3 ft. lengths.
50 ft. 3-in. casing, in 6 ft. lengths.
1 water-swivel.
1 block and tackle, with about 50 ft. of rope.
2 Trimo wrenches, and 2 chain tongs.
2 horizontal double-acting hand pumps, connected in series.
1 force pump.
30 ft. suction hose } for force pump.
30 ft. delivery hose } for force pump.
20 ft. suction hose, 2-in. diameter } for hand pumps.
30 ft. pressure hose, 1½-in. diameter } for hand pumps.
2 lifting jacks.
1 complete geological test boring plant, with 120 ft. of ½-in. rods.

(*b*) *Method of Boring.*—Boring is started with the $1\frac{1}{2}$-in. rods connected up to the water-swivel, with the calyx cutter and water-jet at the bottom. This is suspended to the tripod by a rope through the pulley block. Pumping is commenced, and a length of 3-in. casing is placed over the hole with the $1\frac{1}{4}$-in. rods inside. A percussion movement is given to the latter by means of the rope through the pulley.

Boring proceeds rapidly, and the casing sinks as the water jet raises the sand to the surface. Lengths of casing and $1\frac{1}{4}$-in. pipe are screwed on as required and as rapidly as possible, as the object is not to allow the sand to pack after it has been once moved, as there is a danger of the rods becoming fixed in it if they are deeper than the casing.

Pumping becomes more difficult as depth is gained, as there is an increasing head of sand and water to overcome. The two pumps connected together in series, as explained above, however, give sufficient pressure for depths of 90 ft. to 100 ft.

The samples are collected at the collar of the bore as boring proceeds.

(*c*) *Rate of Boring and Number of Men Required.*—It is almost impossible to give any exact figure of the rate of boring, in the only case in which this method has been used, in the battle area, many difficulties were met with and there was no chance of arriving at an estimate of the average rate of boring. When a straight run was obtained, an 80-ft. hole was completed in about five hours, but this was only after many previous attempts had been made during two days and subsequently abandoned, owing to shelling or mechanical troubles. That figure of 80 ft. in five hours may be taken, however, as indicative of the rate of boring with the plant equipped as described above and free from sudden interference of the bursting of a shell in the vicinity, which generally results in the temporary cessation of pumping and boring and the seizing of the boring rods by the packing of the sand around them, which cannot be removed by pumping but necessitates the lifting of the boring rods by means of jacks. Excluding such stoppages and delays, the figure may be taken as indicative of the rate of progress.

Six men are required on the plant—three on the pumps and three handling the rods and casing.

(*d*) *Application to Recent Marine Sands at Nieuport.*—The bore on the Nieuport side of the canal was put down from a cellar, while that on the opposite bank of the canal was put down from the surface, near the wall of the "India-rubber House."

At the latter point, the collar of the bore was 2 ft. above high-water mark. The tidal rise at Nieuport was about 16 ft. It was only during the interval between about half-flood and half-ebb tide that boring could be carried out, as the pump had not sufficient lift.

Two iron tanks were, however, sunk in the ground near the bore and the canal water pumped into them, from which the water was pumped by the two horizontal double-acting hand pumps through the water-swivel to the 1¼-in. boring rods. The overflow water from the bore flowed back to these tanks and was used over again several times, and so boring was possible even after the canal level sank below the point at which the pump ceased to act.

The bore site was near the Putney Bridge, which was systematically bombarded by the enemy, and this seriously interfered with boring operations. On one occasion a shell fell on the water's edge and completely destroyed the suction hose.

The marine sand consisted of a greyish sharp sand with shell fragments, and towards the lower portion a considerable amount of lignitized wood. At 22 ft., 30 ft., 40 ft., 44 ft., 50 ft. and 60 ft. layers of clay (Polder) were encountered which were about 3 in. thick, excepting that at 50 ft., which was about 6 in. in thickness. These were passed through by continuing the percussion movement of the boring rods and the clay came to the surface in small fragments. They presented no difficulties in boring.

There was only sufficient 3-in. casing to go to 50 ft., and from that depth the 1¼-in. rod was continued downwards to the blue clay. This could only be done by a continuous downward progress and incessant pumping. After several attempts it was at last forced down to the blue clay. The geological test boring set, with the 1-in. auger, was then used inside the 1¼-in. pipe, and boring was continued for 10 ft. in the blue clay.

The blue clay was struck at 87 ft. and was typical Ypresian blue clay. The complete section of this bore is shown on *Fig.* 13. The 1¼-in. pipe was subsequently removed by using lifting jacks.

These bores showed the blue clay to be far too deep below the surface to permit of the underground passage being constructed, as the shafts would have had to have been about 100 ft. deep.

12. Geological Report on Country N. and E. of Passchendaele Ridge.

In October of 1917 a geological report, accompanied by a geological map on a 1/160,000 scale, and taken chiefly from the map prepared by the Director of the Geological Survey, and reduced from the 1/40,000 maps of the "Carte Géologique de la Belgique," was prepared for the General Staff. This report covered the area from Nieuport to Zeebrugge, and thence through Bruges and Ghent to Lille, Ypres, Dixmude and back to Nieuport. The object of this report was to explain particularly the nature of the surface of the country, and what would result if that surface were broken by shell-fire to depths of 10 to 15 ft. This report dealt specially with the water conditions in the soil, subsoil and underlying geological strata.

For the purpose of this enquiry the country was divided up as follows :—

CLAY COUNTRY.

(1)
Blue Clay (*a*) of Roulers region. (*b*) of Dixmude region.

(2)
Clay, W. of Eccloo, and E. of Bruges.

(3)
Clay of Polders, Nieuport to Ostend.

SAND COUNTRY.

(4)
The Coastal Dunes.

(5)
The Ypresian Sands. (Water-bearing.)

(6)
Dry Sands: (*a*) of top of Passchendaele Ridge, and (*b*) of the forest region from Thielt and Thourout to Bruges.

SANDY CLAY COUNTRY.

(7)
Alluvials of the Lys Valley and of the Bruges and Ghent areas.

(8)
High-level sandy clays of the Passchendaele Ridge and of the region between Thielt, Thourout and Bruges.

(9)
Alternating patches of the sand and clay of the Polders east of Ostend and of the Dutch frontier.

Shell-holes in this country were classed as follows :—

Those from which rain-water would drain away naturally—4 and 6 ; and 5, 7 and 8 in part.

Those in which rain-water would remain until it became evaporated—1 and 2 ; and 5, 7 and 8 in part.

Those in which water would be permanent—3 and 9 ; and 5 in part.

The general conclusion was as follows :—

The country to the north and east of the present (October, 1917) lines of the Allies, from east of Ypres to Nieuport, consists of two long belts of plains :—

(*a*) the Polder Plain, and
(*b*) the Lys–Bruges Plain, separated by the Passchendaele–Hooglede Ridge, which expands into a low, wide platform between Thielt and Thourout.

The Polder Plain, after much shell-fire, would be quite impassable. Fair drinking-water could be obtained from its north-east half between Ostend and Zeebrugge.

The Lys alluvial belt would have its surface affected by shell-fire precisely like the country around Armentières and Ploegsteert.

In moving inwards from the two belts of plain towards the higher ground enclosed by them, one would meet three clay areas, respectively :—

(*a*) around Roulers,
(*b*) east of Dixmude, and
(*c*) west of Eccloo.

In all these areas water would lodge in shell-holes after rain. Shell-holes in (*b*) would be somewhat wetter than those in (*a*) or (*c*).

Above these clay areas come the wet Ypresian sands. Wherever their surface was broken by shell-fire, except where natural drainage is specially good, water would lodge permanently in the shell-holes.

Still higher in altitude is an unreliable formation, in which wet sands alternate with clays. The country from Messines to Hollebeke may be taken as a type of this.

Lastly, crowning the Passchendaele–Hooglede and Staden Ridges, and capping the higher portions of the low platform dipping from Thielt to Bruges, are dry sands. These are a continuation of the sands at the summit of Wytschaete. These areas are mostly small isolated patches, but they should be important as affording firm dry ground.

On the whole, the country on the east side of the Passchendaele–Hooglede Ridge, from the point of view of the effects of shell-fire on it, may be regarded as very similar to that on the west side, but while the Lys Valley alluvials would be passable after the surface had been broken by shell-fire, that of the Polder area, under similar circumstances, would be quite impassable, so that our own barrage would stop our own progress. At the same time, in dry weather, the clay area of the Polder country, provided its surface were not broken by shell-fire, should be passable even for tanks, provided they could clear the ditches.

The general geological structure of the part of the country referred to above is shown on *Plate* I.

13. Geological Maps of Areas for Dug-outs in Flanders and in N. France.

While the work of testing the ground proposed for dug-outs, by means of the light geological boring sets, had been proceeding almost without intermission since May, 1916, it was not until after the third battle of Ypres that these boring operations assumed considerable proportion, as many as 100 bores per week being completed about this time. These were mostly put down by the Tunnelling Companies who borrowed geological boring sets from the depôt at the H.Q. of the Australian E. and M. M. and B. Company. Owing to the demand for these bores it was found necessary to increase the length of boring rods used by adding to the original total of 400 ft. an additional 4,000 ft., a total of about 110 boring sets being provided. This work was extended from Flanders, where conditions for dug-outs were very uncertain, to areas like those of the Bois de Riaumont and Bois de l'Hirondelle near Liévin, and Monchy-le-Preux, south of the Scarpe, and to south-east of Arras, where the presence of water-bearing tertiary sands made conditions for dug-outs uncertain. Early in 1918 test geological bores were made in the St. Quentin to Noyon area, recently taken over by the British from the French. In this area there was a considerable development of clay with lignites (lignite et argile plastique) which was very unsuitable for dugouts, observation posts, etc., and doubtful spots were thus definitely tested.

The method was to enlarge the French geological maps on the 1/80,000 scale up to a 1/40,000 or 1/20,000 scale ; and then distribute copies of these maps to the Chief Engineer and to the Controller of Mines of the Armies concerned. It was in many cases obvious at once from the geological map that a particular spot was suitable or unsuitable, as the case might be, for the purposes of dug-outs. It was only in the doubtful cases that bores to a depth of about 40 ft. each were made.

Twelve geological maps showing the relative suitability or otherwise of the ground for dug-outs, and based mostly on the Belgian geological maps, partly on the results of the geological test bores, were published at the Ordnance Survey at Southampton. These embraced an area from Ploegsteert and Ypres to Staden, and to near Dixmude of about 200 square miles. On these maps two primary colours were used, blue and red. Three shades of blue and three shades of red were employed, and two shades of purple. The redder the formation as indicated on the map, the drier was it for dugout, etc., purposes, and the bluer, the wetter. These maps were widely distributed to the Second and Fifth Armies.

Geological maps, on a scale of 1/40,000, enlarged from the French, and specially adapted to give information in regard to good and bad ground from the dug-out point of view, were published of about 350 square miles of country between Noyon and Lassigny and Peronne, and about 330 square miles on and around the Cambrai plateau.

With the exception of the piece of the line between Festubert and La Cordonnerie and Dixmude to Nieuport, geological maps for dug-out purposes were published for practically the whole of the part of the Western Front occupied by the British. Geological sections of the entire front were published, as shown on *Plates* I., II. and III. *Plates* IV. and V. show typical maps and section for the 1/10,000 scale maps.

In regard to the making of dug-outs and tunnels to the south of Armentières, it will be seen from the geological section (*Plate* I.) that between the Bois Grenier anticline and Neuve-Chapelle the conditions are different, for the following reasons :—firstly, there is a thickness of 8 to 15 ft. of water-bearing alluvials overlying the Ypresian clay (blue clay), and secondly, the blue clays themselves, in which alone in that area dug-outs and tunnels are possible, are in places so thin that there is a risk of the subartesian water in the Thanet sands under the blue clay bursting through the floors of the workings and inundating them. In this area, therefore, a large number of geological test bores were made partly by the 255th and 181st Companies, R.E., and partly by the 2nd and 3rd Australian Tunnelling Companies, and the Australian E. and M. M. and B. Company. Where these test bores showed that there was not more than about 10 ft. of overlying wet alluvial and not less than 35 ft. of good clay below that, conditions were considered possible for dug-outs. That is, the whole thickness of the strata down to the surface of the Thanet sands being about 45 ft., more or less, the work would be carried on in this way: Tubbing in segments, made of mild steel in rings of three sizes, either 6 ft. or 5 ft. 3 in., or 4 ft. 6 in. in diameter, was used. The complete ring in each case was made up of three segments, each 1 ft. 6 in. in depth. The horizontal flanges were made of angle iron riveted on to the steel casing, while the vertical flanges were formed of the turned-in edges of the steel plate of the casing itself. At the joint where the vertical flange met the horizontal there was a good deal of leakage, which was very difficult to stop. In the later types of tubbing it was always specified that the vertical flange was to be welded to the horizontal flange at each joint. This was effective in stopping any serious leakage. The lowest segment of the tubbing was provided with a cutting edge of cast iron, and the tubbing was forced down either by weighting or jacking, or both. It was taken far enough into the clay to make a secure watertight joint and sinking was continued in the clay until a depth of about 35 ft. from the surface of the ground was reached. The space for the dug-outs was now excavated to a height of about 7 ft., so as to leave about 28 ft. of cover. In the case taken, where the Thanet sands surface was at 45 ft. below the surface of the ground, there would thus be a thickness of 10 ft. of blue clay below the floor of the dug-out. Most of these dug-outs required a little pumping in order to keep them dry. The water did not, as a rule, weep in from the floor or from the roof, but leaked at the joint between the bottom of the tubbing and the blue clay or from between the joints of the tubbing. It was allowed to collect in a sump close to the bottom of the shaft, from which it was pumped to the surface. The tubbed shafts were usually provided with a spiral staircase. Thus the men in the dug-outs between Jay's Post, near Fleurbaix (south of Armentières) and Neuve-Chapelle were sandwiched in between the water-bearing sands of the Lys River alluvials above and those of the Thanet sands below.

It was at one time proposed to bore from the floors of the dug-outs down through the 10 ft. or so of blue clay into the Thanet sands below, and then fix a standpipe in the bore with a tap, so that fresh artesian water would be available for drinking and cooking purposes for the men in the dug-out, but the proposal was abandoned, as it was feared that the artesian water might force a passage for itself along the junction line of the outer surface of the standpipe and the blue clay and so inundate the dug-out.

14. Crushing of Dug-out Timbers in Ypresian Clay.

An important feature in connection with these dug-outs made in the Ypresian clay (blue clay) was the question as to why the timber of dug-outs and galleries in blue clay so often became crushed in at depths of only 28 to 30 ft. below the surface. The point chiefly at issue was as to whether the crushing of mine and dug-out timbers was due to :—

(*a*) the swelling of the clays,
(*b*) top pressure—the clay behaving as a more or less rigid body, or
(*c*) both top pressure, side pressure, and, to some extent, bottom pressure—the clay behaving as a viscous fluid.

As regards the crushing of mine timbers, it was often found that 9 in. × 3 in. Baltic on the flat was crushed after a few months or less, both legs and cap pieces giving way. The vertical pressure on 9 in. × 3 in. legs with a cap-piece 9 in. × 3 in. and 3 ft. long would be approximately a little over 3 tons. On the assumption that the whole pressure on the cap-piece is transmitted to the legs, and that the legs remain absolutely vertical, they should be capable of sustaining about 18 tons. But, as a matter of fact, they do not remain absolutely vertical for any long period, even if they were originally placed in an absolutely vertical position. The slightest movement of the clay at the sides of the legs pushes them out of the true vertical, and at once their ability to sustain the load lessens enormously. The legs become more and more bent under the vertical pressure and lateral pressure until they snap. If there are many cleavage planes in the drier part of the clay, the tendency for the timber to yield under the load is increased. The presence of sand in the clay greatly increases its stability. In pure sand no crushing of mine timbers is usually experienced. The Director of the Geological Survey, London, states, in reference to the alleged swelling of clay, that no chemical action of importance can take place, at all events rapidly, in this type of clay when exposed to the air of a mine gallery. He thinks that, under the circumstances, the clay is more likely to become desiccated and so to shrink. On the other hand, some O.C.'s of Tunnelling Companies maintain that the dry clay is hygroscopic, and absorbs moisture from the air and that this hydration causes the clay to swell. Certainly the dry clay of a freshly exposed face at the end of a mine gallery often starts to crumble down. This seems, on the whole, to be due to absorption of moisture. It is possible, therefore, that in the first stages a slight swelling takes place of the clay in the sides of a gallery—just enough to slightly bend the legs. Then top pressure transmitted sideways by the viscous state of the clay, aided perhaps by joints in the clay, does the rest. Top pressure transmitted sideways seems the main factor.

Certain measures can be taken to mitigate the trouble of the crushing in of mine timbers and dug-out timbers by clay pressure, *e.g.*:

(i) In the first case, no more clay should be taken out than is absolutely necessary to make room for the timber sets, so that no hollows are left such as encourage the clay " to get a move on."

(ii) Every caution should be taken to stop or diminish side pressure. Side pressure, if sufficient to bend the legs of the sets, changes the conditions for the legs, so that they no longer act as columns but as beams, and thus they become inadequate to sustain the top pressure, which is the principal pressure.

(iii) Much side pressure may be avoided, not only by taking the above precaution, but also by always spacing parallel excavations, such as dug-out chambers, in such a way that the pillars separating them from one another are never less than 40 ft. wide. If they are less, side pressure is sure to develop.

(iv) Side-pressure may be reduced by spacing the timbers, in the case only of *temporary* galleries and as a measure of economy, when timber is scarce. In this case, the clay works through the openings in the timber and has to be shaved off from time to time as fast as it projects from the walls of the galleries. Side-pressure is reduced by this method, just as " weep-holes " take off the water pressure against the inner surfaces of retaining walls. The great objection to this system of leaving spaces between the timbers is that it allows the clay to move, and, once the movement is started it is very hard to stop it, and obviously it involves a certain amount of constant labour in cutting away and removing the clay as fast as it forces its way between the timbers.

(v) In view of the fact that clay behaves as a very viscous liquid, in the matter of exerting pressure in all directions on hollows, such as dug-outs, the legs of sets should be regarded as beams rather than columns, and should be made strong enough to sustain a pillar of clay equal in height to the depth of the dug-out below the surface—that is, if the top of the dug-out is 30 ft. below the surface, and the dug-out is 6 ft. high, the maximum pressure per square inch on any leg of the sets would be about equal to that of a pillar of clay 33 ft. high, that is, a pressure of about 31 lbs. per square inch. If the whole of this pressure were transmitted as a load distributed uniformly over the 6 ft. × 9 in. × 3 in. legs, regarded as beams, the timber on the flat is only able to sustain a pressure of 1,500 lbs. per foot run (= 14 lbs. per square inch), whereas the load on the 9 in. × 3 in. timber on the flat would be about 3,342 lbs. per foot run (= 31 lbs. per square inch). It is the case that on edge the 9 in. × 3 in. timber sustains about three times the pressure that it would on the flat, that is, a pressure, when on edge, of 42 lb. per square inch. Strong close supports should therefore be put in always, and, certainly in the case of all horizontal excavations, these should be placed in a vertical position.

In regard to what thickness of timber is really sufficient to withstand clay pressure of this amount, it has been the experience at Messines South that galleries under 30 ft. of clay (in this case Paniselian clay) broke Baltic legs and cap-pieces of sets 6 ft. 6 in. × 3 ft. made of 9 in. × 3 in. timber on the flat. In the calculations just given it is shown that 9 in. × 3 in. timber on edge is equal to resist the maximum possible theoretical pressure that a free prism of clay 33 ft. high can exert. Such timbering, although absolutely safe, is very costly.

A Tunnelling Company Commander, who had a wide experience in tunnelling in Ypresian clay, both at London in the London Tube system, and in Flanders, states that at Arbre, near St. Julien, in the Ypres salient, where the clay is very hard and compact and also very dry, 3-in. legs on the flat will not stand for more than two or three days, and 5-in. legs on the flat show signs of pressure within a week. "These have now been replaced by 9 in. × 5 in. timbers on edge close setted, with the result that the caps are now bending under the top-pressure. . . . At Pheasant Trench everything points to top-pressure as being the greatest. In this system side-pressure is brought about by an insufficiently thick pillar (20 ft. thick) between the dug-outs. In this case, where a leg has been strong enough to withstand top-pressure, it has sheared the cleat off the sill and kicked out at the bottom from side-pressure alone. But where the pillar of clay between the dug-outs is some 50 or 60 ft. thick, as is the case with the small dug-outs, the legs only bend, under top weight."

Another Tunnelling Officer suggests that in heavy clay ground, with a cover of about 30 ft. :—

(*a*) Galleries should be close-timbered, with legs of at least 6 in. × 3 in. timber on edge and double-top sills ;

(*b*) Dug-outs in heavy clay ground, as above, should preferably be of the "corridor" type with steel sets close-lagged at 1-ft. to 2-ft. centres.

In each case he is, of course, assuming that the galleries and dug-outs are to be permanent.

The fact may here be emphasized that if dry sand with sufficient cover can be obtained, it is far preferable to clay, for two reasons :—

(i) Shell penetration in sand is less than half what it is in clay ; and
(ii) Sand in the roof of a gallery or dug-out " bridges " far better than clay, particularly if care be taken that the sand does not start running.

Therefore, the timbering of dug-outs and galleries in sand need be only of a comparatively light description, as :—

(*a*) They have less than half the over-burden to carry that clay has (as 12 to 15 ft. of sand is as adequate protection against shell-fire as 30 ft. of clay), and
(*b*) Sand is a far more effective " bridge " across any excavated chamber than clay is, as sand does not flow like clay, but the sand grains grip one another and so, by their bridging action, reduce top-pressure to a minimum.

An interesting case of geological conditions affecting dug-out work occurred at the Scherpenberg, near Mont Kemmel, on 17th May, 1917. The whole situation is illustrated on *Fig.* 14. The tunnels A and B were driven into the hill, with a view to constructing a series of dug-outs between them, as soon as a sufficiency of cover had been reached. The two tunnels were only about 95 ft. apart from one another and started at the same level, and the strata in which they were driven were practically horizontal ; and yet, while tunnel A encountered only dry sand, tunnel B started in clay, and at a distance of 65 ft. from the entrance struck running sand containing so much water that the continuation of this tunnel was impracticable. A geological examination showed at once that there was either a fault with a strong fold, or more probably, as shown on *Fig.* 15, two step faults. The total amount of throw of the two faults was determined at about 40 ft. The trend of the faults was determined, and suggestions made for excavating the dug-outs off tunnel A (after it had been extended into the hill to a considerable distance further) in such a direction as to avoid the faults. This work was satisfactorily completed later.

It is difficult to estimate the total number and length of the geological test bores, for dug-outs alone, put down along the British part of the Western Front, but they were certainly well over 1,000, their total length (the general depth being about 35 ft.) aggregating about 35,000 ft.

15. Souterrains.

In the northern part of France, in the chalk country, there exist very numerous " souterrains," otherwise known as " bores " or " muches." Mostly these are what may be termed " mine quarries."

They have been made, for the most part, for the purpose of obtaining the most durable type of chalk for building purposes: near the surface the chalk is much splintered and softened by weathering and is unsuitable for building purposes, but by sinking to a depth of 50 ft., more or less, a tough unweathered type of chalk can be obtained. This was the primary motive which prompted the French in the middle ages, and indeed down to the present time, to mine their chalk rather than work it in opencast quarries. A secondary motive was the desire to conserve the surface of the ground.

Access to the *souterrain* was given either by adits or by inclines with steps, or spiral stairways, or vertical shafts often bell-mouthed at the bottom. Sometimes access was obtained through a local well.

Frequently the entrance to the *souterrain* was from a spiral staircase descending at the west tower of a church (*see Fig.* 15, Type A, Gapennes). Sometimes it was from the cellar of a château or other large building. In some cases the stone was quarried on a regular plan, like that of the stall and pillar used in coal-mining; but more frequently it was irregular, as in the famous caves of Arras (*Fig.* 15, Type B). In the Middle Ages many of these *souterrains* were used as refuges by the local inhabitants in the turbulent times when the country was overrun by the Spaniards and other enemies. The plan on *Fig.* 15 shows a large number of towns and villages in Northern France possessing *souterrains*. It is interesting to note that the *souterrains* of Arras are excavated out of just the same layers of chalk as those of Montreuil. Large numbers of our troops were accommodated in these *souterrains*, which afforded very secure cover.

There were at least a hundred of these *souterrains* in the area occupied by the British Army, but probably not more than about twenty were occupied at any one time. Several of these were ventilated by means of an ancient type of airhole ("soupirail").

16. Ventilation and Drainage of Dug-outs and Souterrains.

Ventilation.—Where possible, the ventilation of dug-outs was improved by making vertical or oblique 6-in. bores by means of the "Wombat" boring machine. The chief use of this type of boring machine on the Western Front was for the above purpose, and it was only occasionally that they were employed on bores for water, on bores for demolitions, and bores for testing geological conditions.

Geological examinations had, in several cases, to be made before the bore for the ventilating hole was commenced.

Many thousands of such ventilating bores were made.

In case of gas attack they were closed by means of a mop of the "Turk's Head" type, made of rags fastened to the end of a short pole. By this means the ventilating hole could be quickly plugged.

Drainage.—As regards the drainage of dug-outs, trenches, etc., geological advice was occasionally sought. "Wombat" bores were used for draining the trenches at Cuinchy and in part of the Ypres salient. In the case of water being held up at the bottom of trenches or of dug-outs by "clay with flints"—a very widely distributed formation in the chalk area—sink-holes were dug or holes blown by means of small charges of explosive.

These holes opened a passage for the water through which it escaped into the chalk. The clay with flints was usually not more than from 3 to 5 ft. in thickness, but was sometimes over 10 ft. thick. In cases where the thickness was considerable, so that drainage was difficult, it was easier to excavate the dug-out altogether under the clay than to place it above the clay and then construct a number of deep drainage holes through the clay into the chalk. This was done particularly in the case of the dug-outs on the G.H.Q. line to the north of Rubempre, about eight miles S. by W. from Doullens.

17. Tank Maps.

These were prepared by the Tank Department itself, certain points only being referred to the geologists, and "Tanks" being furnished with the maps published by the geologists, showing geological conditions for dug-outs and some details of surface soils and subsoils in areas invaded by the enemy, in advance of the British. Had more geologists been available, detailed work could have been done on these maps. Geological considerations were frequently of considerable importance from the point of view of the possibility of moving tanks over the ground. *Fig.* 16 shows a number of Tanks bogged in the soft sandy clay of the Paniselian formation to the east of Ypres.

18. Foundations.

(i) Bridges.

(*a*) *For Building.*—During the latter part of the rapid advance of the British troops in September, October and November a series of geological reports were prepared by Lieutenant Hills on the possibility, or otherwise, of using piles in the building of new bridges over the Meuse between Givet and Vise, over the Sambre, the Escaut, the Dendre, the Mons-Condé Canal, the Blaton Canal, the Charleroi-Brussels Canal and the Canal du Centre, in the event of the bridges then existing being destroyed by the enemy. These reports weie based on the information deducible from the 1/40,000 geological maps of Belgium lent by the Director of the Geological Survey, London.

(*b*) *For Demolition.*—As a precautionary measure at a time when the enemy was threatening an attack on the Channel ports in 1918, the nature of the foundations of the abutments of the chief bridges in the part of Northern France in British occupation, were tested by means of the light geological boring sets. One hundred and twenty-five bores were made for this purpose, and records kept of the strata penetrated.

(ii) *For Heavy Machinery.*—Bores for this purpose were put down at Beaurainville in the Canche Valley.

(iii) *Dams.*—Geological information was given in a few cases on this subject.

Chapter III.

DESCRIPTION AND USE OF BORING PLANTS FOR GEOLOGICAL TEST BORES.

19. Geological Boring Sets.

(*See Plate* VI.)

(*a*) *Description of Apparatus.*—The original $\frac{1}{2}$-in. (O.D.) solid steel boring-rods brought from Australia were gradually replaced with $\frac{1}{2}$-in. gas-pipe, the latter having greater rigidity and less torque than the former.

The boring-rods consist of $\frac{1}{2}$-in. gas-pipe cut to 3-ft. lengths and threaded at both ends with $\frac{1}{2}$-in. pipe-thread. A $\frac{1}{2}$-in. socket is screwed to one end of each length of $\frac{1}{2}$-in. rod.

The augers used are twist augers of 1-in. and 2-in. diameter. The length of the 1-in. augers is 3 ft. and that of the 2-in. augers 18 in. The pitch of the 2-in. augers is 3 in., and that of the 1-in. auger 2 in. The cutting end of both is finished off in fish-tail shape and is spread to measure $1\frac{1}{8}$ in. and $2\frac{1}{8}$ in. respectively, to ensure adequate clearance for the remainder of the auger. The upper end of the augers is provided with $\frac{1}{2}$-in. pipe-thread on which is screwed a $\frac{1}{2}$-in. socket. This enables the socketed end of each boring-rod to be uppermost, which is of advantage in that it decreases the risk of losing rods down the hole by slipping through the jaws of the Trimo or Stillson wrenches, as explained above.

The handle for turning is in the form of a T piece, the horizontal portion being 2 ft. in length. The vertical portion is about 6 in. in length and is provided at its end with $\frac{1}{2}$-in. pipe-thread which fits into the socket at the upper end of the boring rods.

The casing consists of $1\frac{1}{4}$-in. pipe in 3-ft. lengths, threaded and socketed similarly to the $\frac{1}{2}$-in. pipe. A calyx cutter with four cutting teeth is provided to fit to the bottom length of casing, to act as a cutter in working the casing downwards. For turning the casing a clamp with handles is provided which bolts round the outside of the $1\frac{1}{4}$-in. pipe.

A small sand pump which can pass inside the $1\frac{1}{4}$-in. casing and which is fitted with a ball valve is designed for dealing with running sand.

A recovery tool is provided for recovering the $\frac{1}{2}$-in. rods in case of their being lost down the hole. The tapered male thread is designed to engage into the female thread of the uppermost socket of the lost rods.

A hinged clamp for eliminating the risk of the dropping of the ½-in. pipes down the hole while being disconnected is shown in *Plate* VI.

For handling the pipes in screwing and unscrewing, footprints or Trimo or Stillson wrenches are provided. For the ½-in. pipe 9-in. footprints are satisfactory, but at least 12 in. are required for the 1¼-in. casing. It is preferable, however, to use 14-in. Stillson wrenches, which suffice for both the ½-in. and the 1¼-in. pipe.

Each Geological Test boring set, as used on the Western Front during 1917 and 1918, consisted, therefore, of the following :—

13 lengths of ½-in. rod, each 3 ft. long.
1 length of ½-in. rod, 2 ft. long.
1 length of ½-in. rod, 1 ft. long.
4 lengths of 1¼-in. casing, each 3 ft. long.
1 length of 1¼-in. casing, 2 ft. long.
1 length of 1¼-in. casing, 1 ft. long.
1 1-in. auger, 3 ft. long.
1 2-in. auger, 1 ft. 8 in. long.
1 Calyx cutter for 1¼-in. casing.
1 recovery tool.
1 hinged clamp for ½-in. rods.
1 handle for ½-in. rods.
1 clamp for 1¼-in. casing.
2 14-in. Stillson wrenches.

The total weight is 93 lb.—It can be comfortably carried by two men, and can be used without attracting the attention of the enemy, even in the front trenches.

(*b*) *Method of Boring*. The principal boring tools are the 2-in. and 1-in. twist augers. Boring is started with the 2-in. auger and the ½-in. rods. This is continued until a depth of about 15 ft. is reached or further progress is impossible owing to the hole caving in. In this latter case, the requisite length of 1¼-in. casing is joined up with the Calyx cutter at the bottom end. Immediately the 2-in. auger is withdrawn, the casing is inserted and thrust down to the bottom of the hole.

The 2-in. auger is then changed for the 1-in. auger which fits within the 1¼-in. casing, and boring is continued. If the strata passed through continue to consist of water-bearing sand or sandy clay which persists in closing in as the auger is withdrawn, the clamp is fitted to the casing, and by a combination of revolution and downward pressure, thrust downwards in accordance with the progress boring with the auger. This is continued until material is met with sufficiently solid to admit of its being bored through without the help of casing. Boring is then continued with the 1-in. auger.

If, however, running sand is encountered, the casing, when inserted, is forced down some distance—say 1 or 2 ft., if possible—and the sand thus enclosed within the casing is then removed by means of the sand pump. It is preferable, however, to continue using the augers as long as the sand can be withdrawn thereon.

If boring is being carried out in trenches which are under enemy observation, it is necessary to disconnect the boring rods at every 3 ft. whenever they are withdrawn after an auger-length has been bored. The same thing applies in the case of boring in a dug-out or a mine gallery. Occasionally it has happened that a trial bore has been located at the bottom of a shaft, in which case there is no necessity to disconnect the rods, the whole length of which can be hauled up the shaft. If the bore site is located beyond enemy observation the rods may be disconnected in withdrawing at every 15 ft., that being the maximum length which can be handled without bending the rods.

In boring clay care must be taken that the auger is not forced so far as to anchor itself. This may be guarded against by boring for about 6 in. and then lifting about 1 in. In this way the thread of clay around the auger is broken and thus the auger is kept free in the hole, and when the auger-length has been bored the auger can be removed without any difficulty. This particularly applies to the 1-in. auger, 3 ft. in length. Originally the length of the 1-in. augers was about 15 in., but it was found by experiment that if the auger is kept free, in the manner described above, the 3-ft. length can be used with safety. This saves time, as the greater portion of the time occupied in putting down a bore is taken up with screwing and unscrewing the rods. This particularly applies to boring in the front-line trenches, in dug-outs and in mine galleries.

When disconnecting the $\frac{1}{2}$-in. rods, it is advisable to pass them through the hinged clamp to minimize the risk of their slipping down the hole.

The 2-ft. and 1-ft. lengths of $1\frac{1}{4}$-in. and $\frac{1}{2}$-in. pipe are provided in case of boring in a dug-out or mine gallery where headroom is limited. In a mine gallery 4 ft. in height the shorter lengths admit of the application of downward pressure while boring is in progress. This would be impossible if only 3-ft. lengths of boring rods were available.

At times also, where the casing has to be forced through a clay bed, to deal with an underlying water-bearing bed, it may be necessary to force the casing down by means of "jacks." Ordinary lifting-jacks are used for this, thrusting against the roof of the gallery or dug-out. In removing the casing thus forced down by jacks, it will be necessary to use the jacks again by lifting against the clamp employed for turning the casing.

For lifting the $\frac{1}{2}$-in. pipe with the auger full of clay as depth is gained it is desirable to place two lengths of the $1\frac{1}{4}$-in. lining pipe under the handles of the T piece, as close to its centre as possible.

The lifting is then done by the four men, one at each end of the $1\frac{1}{4}$-in. pipe. This method gives free action to four men and lessens the risk to the handles of the T piece, which otherwise are apt to be bent upwards in the process of lifting.

(*c*). *Rate of Boring and Number of Men Required.*—The rate of boring depends on the geological character of the strata, and on whether it is carried out under conditions which :—

(*i*) Necessitate connecting the rods every 3 ft., or
(*ii*) Which allow of disconnecting at not less than 15 ft.

Under the most advantageous conditions, where the strata consist of sandy clay or clay which does not need casing and where there is complete freedom from enemy observation, a 40-ft. bore can be completed in about three hours. Two 40-ft. bores can be put down without any difficulty in a working day. This work becomes progressively heavier and slower with depth, and whereas a 20-ft. bore can be completed in less than one hour, the second 20-ft. takes about twice that time.

Where casing has to be used, a 40-ft. bore may take up to eight hours in difficult ground, but this is quite exceptional, and it is most often possible to put two such bores down in a working day.

The number of men required to work one plant is four. The work of turning should be done by one man alone, but the four men are required for lifting ; as the hole gets deeper there is always considerable resistance to the withdrawal of the auger and rods, and it is this maximum load which necessitates the presence of the four men, two only of whom are required for the operations other than lifting.

20. Modified " Acme " Boring Set.

(*See Plate* VII.)

Description of Apparatus.—The boring rods consist of 1-in. gas-pipe cut to 3-ft. lengths and screwed at both ends with 1-in. pipe-thread. A 1-in. socket is screwed to one end of each length of 1-in. rod.

The boring-tool is what is known as a Skeleton Bit, which is shown in *Plate* VII. It has a cutting edge of 3 in. in width. For boring ventilation holes a 6-in. cutting edge is desirable. The projecting point beyond the cutting edge is from 1 in. to $1\frac{1}{2}$ in. long, the sides being left square. The cutting edge is taped to a knife edge. The bit is 3 ft. in length and screwed at the top end with 1-in. pipe-thread and provided with a 1-in. socket. The chisel bit, with 3-in. cutting edge, is 4 ft. long, and is similarly screwed and socketed at the other end.

The column is that of the " Acme " Boring Outfit shortened to 4 ft. by cutting a length of 1 ft. off the lower end and refitting the base-piece to the shortened column. The head contains an adjusting screw by which the column can be lengthened by about 6 in., and thus thrust and firmly fixed between the roof and floor of a gallery or dug-out.

The feed-screw is the feed-screw of the "Acme" Boring Outfit, provided at each end by enlargements welded on at both ends of the screwed portion which are turned down in the lathe and threaded with 1-in. gas thread.

The ratchet handle is that of the "Acme" Boring Outfit without any alteration.

The sand pump, shown in *Plate* VII, consists of 2-in. pipe, 3 ft. in length, fitted at the bottom end with a brass ball valve. This is screwed inside the 2-in. pipe. The internal part is tapered towards the top to allow the 1-in. brass ball to exactly cover the orifice around which a seating is ground for the ball. The top end of the sand pump is provided with a handle to which can be attached the rope for raising and lowering it in the borehole.

Each modified "Acme" Boring Set, as supplied during 1918, consisted of the following :—

12 lengths of 1-in. pipe, each 3 ft. long.
2 lengths of 1-in. pipe, each 1 ft. 6 in. long.
1 Skeleton Bit with 3-in. cutting edge, 3 ft. long.
1 Chisel bit, 4 ft. in length.
1 Column.
1 Feed screw.
1 Ratchet handle.
1 Sand pump.
50 ft. $\frac{1}{2}$-in. rope.
2 Stillson wrenches.

The total weight is 150 lbs. It can be carried without any trouble by three men.

Method of Boring.—To set up the apparatus, an excavated space about 4 ft. square is required. In mine workings or a dug-out this is easily available, the length of the column being cut down to 4 ft. for the express purpose of convenience in working in mine galleries. For a vertical downward hole the column is set up horizontally about 3 ft. from the floor and fixed in position by means of the adjusting screw, by thrusting against slabs of timber on the sides of the excavation or gallery. The column is so placed that its centre is vertically above the proposed borehole.

The latter is started for a few inches by hand, using the chisel bit. The skeleton bit is then screwed on to the feed screw and the latter placed in the sliding sleeve of the column. The sliding sleeve is left loose until the skeleton bit is in a vertical position, when it is screwed tight and boring started by attaching the handle to the top end of the feed-screw. If the complete revolution of the handle is impossible, owing to confined space, the ratchet attachment may be used. Water is poured down the hole as boring progresses, sufficient water being used to produce a slurry which can be conveniently handled by the sand pump.

When the length of the feed-screw has been bored it is uncoupled and reversed, and then connected to the skeleton bit again and boring continued. The object of having the feed-screw provided with the 1-in. thread at each end is thus seen, for by being able to simply reverse it, the time which would be taken in turning it back to its original position is thus saved.

Boring is continued until the accumulation of slurry is sufficient to interfere with boring, and the rods are then uncoupled from the feed-screw and the sliding sleeve run along to the end of the column and the rods then withdrawn. The sand pump is then lowered by the rope and the hole completely cleared of slurry. The skeleton bit and rods are then replaced and coupled to the feed-screw, but the sliding sleeve is not screwed up tightly. Boring is started and after a few turns the sliding sleeve will have adjusted itself in relation to the rods, and is then screwed up tightly. In this way the original direction of the hole is retained, as the sliding sleeve automatically resumes its original position.

If flints are encountered, the skeleton bit is replaced by the chisel bit and boring continued by percussion. The fragments of flint mixed with the chalk slurry are removed by means of the sand pump.

If a vertical upward hole is to be bored the column is fixed horizontally about 3 ft. from the roof, in a similar manner as previously described. Boring is done with the skeleton bit, but water is not added because the spoil from boring falls away from the cutting edge, leaving the latter always free.

Horizontal holes are more difficult.

The machine is set up, as before, about 3 ft. from the face to be bored. Water is difficult to feed and the spoil cannot be removed by means of the sand pump, but a scraper at the end of ½-in. solid rods must be employed. In fact, this apparatus is not designed to bore horizontal holes, but only vertical ones. Horizontal holes are best bored by means of the "Wombat" Boring Machine, which was specially designed for that work.

Rate of Boring and Number of Men required.—With the plant as described and used above, a vertical downward hole can be put down for a depth of 70 ft. in fifteen hours, and a 40-ft. hole in eight hours. The number of men required to work the plant is two.

A vertical "upper" hole was put up 30 ft. in three and a half hours.

The machine takes eight minutes to erect ready for boring.

In the experiments on which the design of this plant was based it was found that the augers, as supplied with the "Acme" Coal-boring Machine, were inferior in speed of boring in chalk to the twist augers used with the geological test-boring set described above. Further experiments, however, showed that the skeleton bit was infinitely superior to either of these, and after exhaustive tests, was adopted as the most desirable type of bit for boring in the chalk. The combination of continuous downward pressure with the revolution and the cutting effect of the auger supply the requisites which were found to be necessary when boring in chalk with the hand test-boring plant.

21. The "Wombat" Boring Machine.

The No. 1 Australian Mining Corps brought with it thirty-six geared boring machines operated by hand and capable of boring at any angle from horizontal to vertical. They were specially designed for putting in horizontal bores, $6\frac{1}{2}$ in. in diameter for demolition work in Gallipoli. A description of these boring machines is given elsewhere in mining notes. They were designed entirely by Captain Stanley Hunter, of the Geological Survey of Victoria, Australia. They were used on the Western Front for boring for the following purposes :—

(i) For demolitions.
(ii) For boring ventilating holes for dug-outs. This was their principal use.
(iii) For boring for water.
(iv) For putting down deep geological test-bores.

The following description of the "Wombat" machine and method of working it is taken from mining notes No. 73 :—

The "Wombat" type of hand-operated boring machines, brought over by the Australian Mining Companies, have been tested in chalk and clay with satisfactory results. The plant can drill a hole of $6\frac{1}{2}$ in. diameter over 200 ft. in length, at an average speed of 3 or 4 feet per hour in chalk, or 4 to 6 feet per hour in clay.

The opportunity for using long holes of this size, carrying about 11 lbs. of explosive per foot, has not frequently arisen. But their service is likely to develop with the general increase of offensive operations. They can be used in soil unsuited for push-pipe operations and allow a greater latitude for variations of depth. Like the push-pipe, the "Wombat" is described as a "weapon of opportunity," and it is essentially offensive.

(*a*). *General Features.*—The plant can either be erected on a wooden sledge or bedplate, with the columns, carrying the gearbox and feed-screw, supported by back stays ; or else rigged up in an underground chamber, like a machine drill, jacked to the roof. The chamber required must be 7 ft. long, 6 ft. wide, and 5 ft. to 5 ft. 6 in. high, with gallery space in front and behind for control of rods.

The weight of the machine, including wooden bedplate, is 360 lbs.

When dismantled for transportation to trenches, it is an eight-man load, without pump, hose, cutters, rods, etc. The heaviest part can be handled by two men.

The rotation of the rods is actuated through bevel-gearing by drive handles on each side of the machine, allowing four men to work. The feed-screw, with maximum advance of 14 in. at each fleet, passes through a sleeve feed nut controlled by a rotating wheel. If the wheel is fixed, the feed screw advances at the rate of one turn, or $\frac{1}{4}$ in. for each rotation of the drive handles. This speed can be exceeded or reduced by rotating the sleeve feed nut in the opposite or in the same direction as the feed screw. As with push-pipe operations, there is a tendency for holes to rise.

(*b*). *Drill Rods and Cutters.*—The hollow drill rods, through which water is served by a small hand pump to the cutting edge, are $1\frac{1}{4}$ in. diameter, and in 5 ft. lengths.

In clay or soft to medium chalk a spiral auger, 2 ft. long, with detachable bit, is used, followed by two 5-ft. lengths of twist rods. An advance of up to 10 ft. may be made for each withdrawal.

In hard chalk, 6-in. Calyx Bits (cylindrical) with a 3-ft. or 6-ft. core barrel are used. Under favourable conditions, an advance of 7 ft. may be made for each withdrawal of rods. When flints are met, normal progress becomes impossible. It is necessary to draw back the rods about a foot and then drive them as sharply forward as possible to crack the flints, before revolving the bit. Speed in flinty ground may fall to 1 ft. per hour and the work is, of course, noisy.

The core barrel becomes filled with solid core, chips and slime, according to the character of the chalk.

(*c*). *Organziation for work.*—A boring squad consists of an N.C.O. and seven men. Four men are on the drive handles, and one at the chuck, screwing and unscrewing all rods and bits and generally controlling the operation of the machine. The two other men are on the pump, hose connections, and odd jobs.

Water requirements vary widely with the rock or soil. In a recent test at the First Army Mine School, sixteen gallons per hour were used over a long run.

(*d*). *Speed of work.*—Three holes were recently bored in chalk at the school with the following results :—

(i) Length of hole, 232 ft. ; total working hours, 58 hours ; Average speed, 4 ft. per hour. (17 feet of flints and 5 ft. of mixed flint and chalk were passed through).

(ii) Length of hole, 178 ft. ; total working hours, 59 hours ; Average speed, 3 ft. per hour. (40 ft. of flints and 10 ft. of mixed flint and chalk.)

(iii) Length of hole, 166 ft. ; total working hours, 52 hours ; Average speed, 3·2 ft. per hour. (20 ft. of flint passed through.)

In addition a long hole was bored in July on the front of the 251st Co., R.E., in clay.

(iv) Length of hole, 194 ft. ; Speed of drilling, 4·5 ft. per hour.

The entire operation, including the cutting of the chamber, forward gallery, etc., under difficult conditions, was eleven days. The hole was started at a depth of 12 ft., and may have risen towards the end. A charge of 150 lbs. was fired in three $5\frac{1}{2}$-in. diameter cylinders.

The above bore was made on the Cuinchy part of the Western Front, near the " Brickstacks " to the South of the La Bassée Canal.

The explosion of the torpedo cartridges satisfactorily demolished the enemy outpost, which was the objective.

At the taking of Vimy Ridge on April 9th, 1917, the opening up of deep explosion trenches across " No Man's Land " by means of horizontal bores made with the " Wombat " was quite satisfactory, as already described.

On two special occasions the " Wombat " was used at Hill 70, Loos, for offensive demolition during 1917. Owing to the phenominal rise of chalk water-level one of our mine chambers became inundated as well as the gallery connected with it, and the electric leads became damaged so that the mine could not be fired. An enemy's tunnel was approaching this mine, and it was a matter of urgency to blow the mine. A " Wombat " bore was put in and reached the mine chamber. A 5-in. cartridge containing amonal was then pushed to the end of the borehole and fired, and the mine was detonated satisfactorily. On another occasion it was ascertained that near the same spot the enemy was in the act of charging one of his mines. The No. 3 Australian Tunnelling Company bored rapidly with a " Wombat " 97 ft. through hard chalk with a good deal of flint, at a depth of over 100 ft. below the surface and reached the charge of the enemy's mine. A cartridge was then inserted and the enemy mine blown. These two blows very much relieved the enemy mining pressure on this part of the front.

For purposes of ventilation there was so much demand for these machines that, in addition to the original 36, 50 more were constructed, and were more or less constantly in use at the front for this purpose.

Experiments made at the Third Army Mine School showed that for short bores for ventilating purposes, of 50 to 60 ft., when account was taken of the time needed for installing the respective drills, the modified " Acme " could beat the " Wombat " for speed, provided the chalk was soft, but for hard chalk with flints the " Wombat " with calyx barrel is probably the best type of machine for the work.

" Wombats " were also employed in Flanders to bore for water through the Ypresian sands, but as the depth of the bores was 250 ft. to 300 ft., and the clay was extremely tough, the machines were somewhat overtasked, and for the remainder of the bores in this area more powerful drills, like the " Star " or the " Keystone " or the "Hunter" drill were employed. To a limited extent the "Wombats" were also used for draining trenches, and for making horizontal bores for burying Signal wires, etc. The latter was done in the Nieuport area, between Nieuport and Wulpen, the bore following the bank of the canal at 8 ft. below the surface of the ground. Over 2,000 ft. of boring was made for this purpose. To a limited extent the "Wombat" was used at Vimy Ridge for geological test purposes, where by its means the soft clays were located at 150 ft. below the surface, in which a deep tunnelling system was thereafter projected.

22. Earth Augers.

General Description and Method of Working.—Many types of earth augers were tried, but that which gave most satisfaction was the articulating jaw type of R.E. auger such as is used for boring post-holes. These were used in two sizes, 6-in. and 10-in. diameter. The auger consists of two halves, called "jaws," the bottom ends of each being pointed and turned towards each other to form part of a helical screw, with cutting edges at the bottom. One jaw is fixed, while the other is hinged at its upper end, and can be fastened in position by a clip.

The operation of boring consists in revolving the auger which travels downwards in the soil or clay until the auger is full. It is then withdrawn, and the movable jaw opened by moving the clip fastener, and the contents emptied. Boring is continued, and rods added as depth is gained.

With the first augers issued the rods were very weak at the joints. These were replaced by rods consisting of 3-ft. and 4-ft. lengths of ¾-in. and 1-in. gas-pipe, the auger being provided with a male thread to which these rods could be screwed. A T-shaped handle is provided for turning.

Applications and Limitations.—The application of these earth augers for geological test boring is limited. The maximum depth that can be bored is 15 ft., although occasionally by special efforts 20 ft. may be obtained. An additional drawback is that, there being no casing with this method, progress through running ground is impossible. Not only so, but progress in really stiff clay is also very difficult. At the same time, on the Bois Grenier to La Cordonnerie front, it was found possible to bore horizontally with an 8-in. auger to a distance of about 40 ft. (for the purpose of a camouflet) in Ypresian clay.

In a few cases, however, before the introduction of the geological test boring sets bores were put down to 12 ft. or 15 ft. and gave a certain amount of information as to the character of the ground.

The earth augers are, however, valuable in boring through fine and medium grained gravel deposits which cannot be passed through by the geological test borer. Where such gravel exists, the earth auger should be used until the gravel is passed through, when boring is continued by means of the geological test boring set.

In testing gravel deposits for quality of gravel, the earth auger is certainly the best instrument to use.

The earth augers have also been used in boring short holes for placing explosive charges in torpedoes. This was found advisable up to about 15 ft.; beyond that distance or depth the "Wombat" was a more efficient machine.

23. Bores for Listening Purposes.

In April, 1917, it was anticipated that the enemy might be mining in the direction of the Spoil Bank, near the Ypres-Comines Canal. It was not advisable at the time to withdraw tunnellers from elsewhere in order to sink and tunnel at this locality. As a temporary precautionary measure a number of bores were made near the front line there to depths of 30 ft. The bores commenced in Paniselian clay, and in some cases struck running sand before the Ypresian clay was reached, in which latter case the bores were abandoned. In the case of bores which remained dry until the Ypresian clay was reached, after the boring rods were withdrawn, solid steel rods, ½ in. in diameter screwed and socketed, in 10-ft. lengths, were put down the bore-hole so that the bottom of the rod, when connected together, rested on the surface of the Ypresian clay, and the top projected about a foot above the surface of the bore-hole. Listening was done by connecting a geophone to the top of the rod in the usual way. Similar bores were put down for the same purpose in the front line at Shelley Lane, near St. Eloi, south of the Ypres–Comines Canal, to a depth of 50 ft.; and steel rods were then left in the bore, as above. Only negative results were obtained, at either locality.

Probably better results would have been obtained from wooden rods than from steel ones, as was demonstrated at the Second Army Mine School at Proven. For the successful working of this device it is, of course, necessary that the bores do not fill with water. Had enemy mining been detected, it would then have been necessary to sink and drive in order to get a base for estimating the direction of the mining, as the relative intensity of sound method, as deduced by listening at each rod in succession along the line of rods, would give results too approximate to be of practical value. This method deserves further investigation by means of practical experiments under peace conditions.

Chapter IV.

WINNING OF RAW MATERIALS.

24. Road Metal.

Early in the War a valuable report entitled "Note on Road Metal in Belgium" was made by Colonel P. J. van der Schueren, Chief Engineer of the Belgian Ponts et Chaussées Dept., and by Captain J. Millecam, engineer in the same department, both attached to the Belgian Mission, at G.H.Q.

Important information on available road metal in Northern France was supplied by Colonel Stoclet, D.S.O., Chief Engineer of Ponts et Chaussées for the Dept. du Nord, and also by M. Thur, Chief Engineer for Ponts et Chaussées in the Dept. des Travaux Publics, and the engineers of the Chemin de Fer du Nord.

The chief stone worked for maintenance of the roads in the area occupied by the British in Northern France was as follows :—

(i) Limestone from the great quarries of Marquise, between Calais and Boulogne. These belong to an "inlier" of carboniferous limestone surrounded by Jurassic rocks and chalk.

(ii) Quartzites from Devonian "inliers," surrounded by chalk, like those of Dennebroeucq, Matringhem, Bergin, Rebreuve, Marqueffles, etc.

(iii) Hard greenish porphyrite rocks from Brittany.

(iv) "Pierre de fosse," a red carboniferous shale burnt to consistency of brick through spontaneous combustion of colliery dumps.

(v) Flint gravels (of quarternary age) mostly in Pas-de-Calais country.

(vi) "Sarsens," that is, occasional loose blocks of Tertiary quartzite, found in Thanet sand areas.

The Marquise limestone areas and those of Devonian quartzite and Brittany porphyrites were not specially examined by us, but more attention had to be paid to the flint gravels and sands.

In conjunction with a representative of the Director of Roads an examination was made of the areas being exploited for gravel at Aire, Arques and Engoudsent, chiefly in reference to their unworked portions, and estimates of the probable resources still available.

Near Arques, in the remarkable gravel deposit which extends from Aire past St. Martin to Payelville's gravel pits, near the Arques railway station, a number of trial pits were sunk to depths of 20 to 25 ft. which revealed an immense development of these flint gravels under an overburden of from 10 to 15 ft. of sandy clay (limon). A report was also made on the immense unworked gravel deposits which extend from Wizerne to Wisques on the west side of the Aa river. The available amount of gravel there was estimated at about 3,000,000 tons.

From the point of view of supplying material (flint gravels and sands) for the roads as well as for railway ballast, and for making concrete, these supplies were practically inexhaustible for purposes of this war.

A further report was made on possible sources of road metal near Peronne and Vecquemont, and the use of the "yellow chalk" (a magnesian or dolomitic chalk) of Eclusier as foundation material ("blocage") for the local roads was strongly recommended. This yellow chalk is extraordinarily resistant to the action of frost.

It can be seen that in the local churches it has successfully withstood the action of frosts for hundreds of years. A recommendation was made to test the yellow chalk for this purpose, at the Bois de Célestine quarry on the north bank of the Somme, 12 miles west of Peronne. Also at Etinghem, 2½ miles east of the previous quarry, and particularly at Eclusier, on the south side of the Somme, and six miles west of Peronne.

As far as is known the experiment was never tried, but there is good reason to believe that the yellow chalk, on account of its non-freezing properties, would form a good foundation for local macadam roads.

At Vecquemont, near Querrieux, there were estimated to be 200,000 cubic yards of good sand, and 100,000 cubic yards of good flint gravel. Lists of chief quarries in the basins of the Somme, the Escaut and on the Cambrai Plateau were supplied to the C.E.'s of Armies. In the Oise area tests were made by means of boring with earth augers of the flint gravels and coarse sand north of Noyon at Viry Noreuil and Tergnier.

As the result of the enemy advance towards Amiens, the gravel pits near that city could not be used as a source of gravel for concrete. Sources of gravel were therefore sought further westwards behind the Defence Zone. Gravel beds were thought, on geological grounds, to exist in the valleys of the Authie and Grouches Rivers in the vicinity of Doullens, but the amount of over-burden was not known or the exact extent of the deposits. It was important to know the thickness of over-burden, as more than 8 ft. thereof made the working of the deposit inadvisable.

Accordingly, a series of test bores were made in the valleys of both rivers. These were put down as far as the gravel bed, or, in the absence of the latter, to the underlying chalk. The thickness of the gravel bed itself was determined by working a chisel bit attached to the $\frac{1}{2}$-in. boring rods through the deposit until the soft chalk underneath was encountered. In this way the extent of the deposit and the amount of overburden were determined. It was found, as the result of these tests, that only at one locality, namely at Thièvres, were the conditions anything approaching suitability, the average amount of overburden being in the vicinity of 8 ft. It was ultimately decided not to work these deposits.

The amount of gravel available in each was estimated at about 500,000 tons.

An interesting local source of road metal, and particularly of "pavé," is the "Sarsens" ("Saracen Stones") which are widely scattered over the surface of the chalk in Northern France, wherever the Thanet sands have recently been denuded away. These "Sarsens" are hard, irregular-shaped concretions in the Thanet sands themselves. Being very hard, and therefore durable, they are left as the only relics of the former Thanet sand in areas from which it has been wholly denuded. In places, as at Camblain l'Abbé, the "Sarsens" can be seen in their original position in the Thanet sands at the local sandpits. The photograph (*Fig.* 17) illustrates one of these "Sarsens" at the "Pimple" at the north end of Vimy Ridge.

In September, 1918, when the rapid advances of our Armies were in progress, special geological reports were prepared showing the exact location and approximate amounts of "pierre de fosse" material available on First and Second Army fronts up to as far as Mons. The amount was estimated at, at least, 50,000,000 tons.

At the Trith St. Leger flint gravel and sand beds it was estimated that approximately 1,000,000 tons were available there.

A special map was prepared of the Carboniferous and Devonian areas of the Avesnes–Bavai area, as well as a general map of Belgium, based on the earlier report by Colonel P. J. van der Schueren and Captain Millecam, showing the position of the chief quarries, like those of Quenast, Lessines, Soignies, Maffle, Ecaussines, Tournai, etc., and the principal sandpits. Sand was, of course, needed for packing under pavé on the pavé roads so dominant in Central and Western Belgium.

25. Sand and Aggregate for Concrete.

This was obtained chiefly from the "ballastiéres" of the Chemin de Fer du Nord at Aire and at Arques, and, latterly, chiefly from the Engoudsent ballastiére.

From Engoudsent, as a centre, this material was widely distributed along the front. A small portion was also obtained from the terrace of River Somme gravel at Bourdon, near Flexicourt. The flint shingle deposits of Inchville, Le Bourdel (at the mouth of the river Somme) and the older inland shingle beds of the Conchil-le-Temple and Rue were also examined. Both dune sand (from the coastal dunes at Ghyvelde, between Dunkerque and Furnes, etc.) and Thanet sand from near Arques, etc., were tried for mixing with concrete, but for practical purposes, chiefly on account of the extra labour in mixing, they were not as satisfactory as the coarser flint sand associated with the flint gravel in the ballastiéres. Some of the dune sand was stated to be somewhat saline. The Thanet sand was used for mixing with cement from the Orville pits, west of Authie, and at Blaireville, four miles S.S.W. of Arras.

26. Coal Mines.

(A) *Of Northern France.*—In September, 1918, with a view to assisting the French Authorities in the output of coal from such of the Pas-de-Calais coal mines as were in working condition, an inquiry was instituted at G.H.Q. in which the geologists were assisted by Major H. M. Hudspeth, D.S.O., M.C., R.E., O.C. 171st Tunnelling Company, R.E. (in civil life one of H.M. Inspectors of Collieries). Lieut.-Colonel H. H. Yuill, D.S.O., M.C., R.E., also assisted in this work, and afterwards took over the whole of it. The following suggestions were made in the report :—

(*a*) Closer co-operation as regards counter-battery work, and anti-aircraft protection.
(*b*) Replacement of certain French miners then engaged on railway work, so as to free them for colliery work.
(*c*) Limitation of the numbers of British troops billeted in areas where accommodation for the miners was scarce.
(*d*) Evacuation of non-essential civilians from areas where accommodation was needed for miners.
(*e*) Improvement of canal and railway facilities.
(*f*) Assistance from England as regards plant and material.

Captain Laroque, of 172nd Tunnelling Company, R.E., was appointed as *Liaison* Officer with the French Mission, working under the Controller of Mines, First Army.

Special attention was given by the War Office to (*f*) and, in view of the great shortage of oats in France which caused heavy mortality among the colliery horses, to the provision of the necessary oats to complete the ration for the pit-horses.

An interesting geological point developed in this enquiry was the necessity for extreme caution in working the mines near Bethune and Vendin, in view of the fact that geological faults led to local upthrows of the carboniferous limestone, which is strongly water-bearing. The carboniferous limestone is so highly charged with water under pressure that if, in following a coal seam, a drive suddenly strikes one of these faults which has brought up the carboniferous limestone, the whole tunnel and even the whole mine may become inundated. Part of the Vendin Concession was actually inundated through this cause.

(B) *Borinage Coal Mines, Belgium.*—In view of assisting in the re-starting of the Borinage coal mines, information as to the present situation having been obtained from M. Lemaine (Secretary to the Director in Brussels of the Belgian coal mines) as to the geological and economic conditions of the field, meetings were held at Mons from 18th November onwards between Lieut.-Colonel H. H. Yuill with geologists from G.H.Q. and "L'Association Houillière du Couchant de Mons" with M. Jaquet, Inspector-General of Belgian coal mines. Consequent on the report giving the results of several conferences, it was decided that the Controller of Mines, First Army, with Captain Laroque as his *Liaison* Officer, should function in the same way for the Belgian coal mines as hitherto for the Lens coalfield, reporting to the C.E., First Army. It was also agreed that assistance should be given by the British in the repair of the Borinage colliery railways, damaged by the enemy, and in the repair of railway bridges broken by the enemy, between Mons and Jurbise.

A feature in this enquiry was the obvious great economic importance of the as yet undeveloped Campine coalfield situated in the Limbourg and Antwerp provinces. These coal-measures are buried under a great depth of water-bearing newer deposits (Quarternary and Tertiary) which renders access to the coal-measures difficult. On the eastern side of the field the thickness of this overburden is about 1,500 ft., while it is as much as 890 metres (2,920 ft.) at Vlimmeen in the Province of Antwerp and Helchteren in the Province of Limbourg. Nevertheless, the field was obviously of great value for future coal supplies, especially in the Antwerp area.

27. Report on Aggregate used in German "Pill-boxes" on the Western Front.

A Parliamentary Report was made in January, 1918, in regard to the "Transit Traffic across Holland of Materials Insceptible of Employment as Military Supplies."

In reference to the nature of the aggregate used in the German concrete for military works, particularly at Messines, at localities north of Gheluvelt between Becclaere and Zonnebeke, and between Pilkem and Poelcappelle specimens were collected by Intelligence Officers and collected by the Military Geologists and were taken to England, where they were sliced for microscopic examination and critically examined by a committee of experts, including the two geologists on the E.-in-C.'s Staff. The general conclusion (p. 136 of the Parliamentary Report) was that a good deal of the aggregate was to be traced to a German source. "The Niedermendig" rock and the basalts of Linz and Erpel are represented by angular fragments, such as result from quarrying. The fragments show no indication of having been included as pebbles in a gravel or conglomerate. The Triassic sandstone and silicified oolite occur as pebbles.

It appears that of thirty-nine specimens submitted thirty-two are of the same general type. In many of these pebbles occur which prove that the material was not a Belgian gravel. On the other hand, no pebbles occur which cannot be matched in the Rhine gravels, and there is a notable absence of Belgian rocks. In the material which appears to have been derived from quarries, some has been recognized as coming from a German source.

Chapter V.

GEOLOGICAL ESTABLISHMENTS.

28. Geologists in the German Army.

The Geological Establishment in the German Armies appears to have been approximately as follows :—

ARMY.

Corps.	Landaufnahme.	Corps.
Field Survey Company.	Research Geologists.	Field Survey Company.
(*Military*) :—	(*Civilian*)	(*Military*) :—
Professional Geologist.	Geological Group,	Professional Geologist.
Assistant Geologist.	Under Group Leader	Assistant Geologist.
Draughtsman	Draughtsmen	Draughtsman
Clerk	Clerks, etc.	Clerk
Boring Party,		Boring Party,
(?) 4 or 5 men.		(?) 4 or 5 men.

It would appear that the Commanding Officer of the Field Survey Company would issue general orders while the leader of the Geological Group would arrange details. Normally applications for the services of geologists were made to the Division, which then dealt with the application.

The geologists under the command of the group leader were divided into " Geologen Stellen " which were scattered over the Army zone and placed as far forward as possible. It was stated that it was not necessary to make requisition on the Army Commander or Division Commander for having a geologist detailed for work within the zone. The request could be made directly to the " Geologen Stelle " or even to the individual geologist.

The officer in charge must have a constant personal touch with the Army Staff, especially with the Chief Engineer, the Construction Troops, Sanitation Official, etc. He must be acquainted with the larger plans of the Army, contemplated change of troops, etc. He acts as leader for the entire geological groups of the Army, for which he is responsible, and he himself carries on investigations of the larger problems presented.

The geologists of a " Geologen Stelle " are assigned to certain sectors to certain problems. These officers are preferably located near the Map Section, and their Headquarters are marked by signs so that they can be easily found. It is very necessary that the Geological Officers should be introduced to the different staffs with which they may come in contact. The Geological Assistants, N.C.O.'s and soldiers work either under the direction of a more experienced geologist, or are put on special tasks, such as drilling and boring.

The following is an account of the scope of the work of a Geological Group, translated from a German document :—

Geological Section of the Fifth Army.

CORPS HEADQUARTERS.

1-10-1917.

1. The Geologists of the Fifth Army belong to Field Survey Companies 3 and 15, and form a geological section within these Companies.

Reserve Lieutenant X is in command of this section.

2. For the establishment of Geological Offices the Geologists are distributed throughout the Army area according to the subjoined summary.

3. Application for the services of the Geologists will be made direct, and to avoid unnecessary delay should give the object of the application and the exact location of the area to be investigated.

The Geologists deal direct with the formations of their Army Sector.

4. Applications for the service of Geologists must always be sent to the Geological Offices of the Section which is nearest to the formation which makes the application.

5. For Geological work in forward areas and on Lines of Communication, the formation that demands the work must provide labour and transport and arrange for the rationing and billeting.

6. The duty of the Geologist is immediate assistance to the troops in cases where the structure of the ground and its water-bearing qualities are a consideration. Geological advice is of special importance with reference to the following problems :—

I. *Construction of Positions.*

The assistance of a Geologist at the first reconnaissance of the country, before the lines are finally fixed, has proved of special value. *See Regulations for Trench Warfare, for all Arms of the Service,* Part 1b, Cipher 2, and Part II. Directions for the laying-out of trenches, tunnelled dug-outs, dug-outs, etc.

(*a*) In cases where several points are of the same tactical value by choosing such as require the minimum expenditure of labour, time and material, and are not likely to involve land slides or inflow of water.

(*b*) The prediction, in the case of lines already dug, as to what difficulties are likely to occur arising out of the hardness of the strata, and their water-bearing qualities.

(*c*) Information as to tracts in which dry dug-outs are definitely impossible, or whether there is any prospect of draining them by natural means, as by drainage sumps.

(*d*) Testing the possibility of putting in dry tunnelled dug-outs under the water-bearing strata.

(*e*) Advice on subways and galleries. Information as to which strata are the easiest to work, whether there is risk of landslide or inflow of water, the possibility of tunnelling under water channels.

(*f*) A preliminary investigation with a view to the use of boring machines in mine warfare. Selection of favourable and exclusion of unfavourable strata.

(*g*) Information as to the best dug-outs for listening posts and so forth.

(*h*) Opinion as to the stability of existing "subterraneans" (caves and quarries).

(*i*) Inundations and drainage of areas.

II. *Water Supply.*

(*a*) Improvement of existing wells and selection of sites for new ones.

(*b*) Making good defects in existing springs, and the opening up of new ones.

(*c*) Information as to places specially suited for driving wells. (Wells made by percussion, Abyssinian wells.)

(*d*) The development of deep-seated water basins by deep bores.

(*e*) The ensuring of water supply for the defensive battle.

(*f*) Advice on construction of water conduits, the water supply of towns and camps, and of industrial and commercial establishments.

III. *Winning of Raw Material.*

For immediate use in the field. The providing of gravel, sand, loam, clay, building stone, material for cement and plaster, road metal, railway ballast and peat, as near as possible to the places where they are to be used. The marking out of stone quarries, estimate of quantities, information about the stratification and best way of working.

(*b*) Providing of raw material for supplying the needs of the Army. One of the first considerations is the supply, for example, of pyrites, phosphates, copper and, in the Balkan Peninsula, of coal also, for the Directors of Military Railways.

(*c*) Records of the existence in more distant industrial fields of material available for meeting the requirements of munition and ordnance factories (new occurrences), abandoned mines, and their ancient mine and slag dumps.

Of chief importance are ores, rock-oil, coal, asphalt and other materials useful in the economies of war.

IV. *Hygienic and Technical Problems.*

(*a*) Advice on the location of sumps for drainage, cesspits, drainage in general, disinfecting and delousing establishments and cemeteries from the point of view of risk of contamination of sources of water supply.

(*b*). The defining of drainage areas with a view to the protection of wells and springs, having due regard to the nature of the ground.

(*c*) Electrical problems so far as controlled by the condition of the ground with reference to earthing, erecting masts and burying cables.

(*d*) Advice on the locating of roads, field railways, light railways, cable tram-lines, with a view to avoiding, when making, cutting or embankments.

(*e*) Appreciation of suitable sites for dams.

V. *Other Military Problems.*

(*a*) Careful observation of the structure of the substrata (nature, solidity, water-content) for standing camps.

(*b*) Choice of dry substrata for munition dumps.

(*c*) Choice of suitable natural solid surfaces for heavy guns.

(*d*) Choice of spots naturally fitted for aerodromes.

The function of the Geologist is only advisory. It is not his province to see to the technical development of propositions by elaborating them from plans or actual superintendence of the work.

29. Geologists in the American Army.

Lieut.-Colonel Alfred H. Brooks, Director for many years of the Geological Survey of Alaska, was appointed Geologist to the American Armies in 1917. He worked under the Chief Engineer at American G.H.Q. A little later an assistant Geologist was appointed.

Geological maps were produced of special areas of the American line on the Western Front, with a view to giving reliable data, particularly as to the water-bearing properties of the strata :—

(*a*) at the surface, or

(*b*) at a depth.

The various water-bearing horizons and their depths below the surface were shown in sections at the foot of the map. These maps were on a scale of 1/50,000. They showed contour lines at intervals of 10 metres. The cartographic details were mostly from the "Plan Directeur," and the geological details chiefly from the "Service Géologique de la France."

The geological information was partly supplied on the geological maps themselves and partly given in the form of clearly written engineer field notes such as those on "Underground Water and its Relation to Field Works."

After consultations between the British Geologists and Lieut.-Colonel Alfred H. Brooks it was decided by the American G.H.Q. to raise the number of Geologists with the American Forces to a total of 17, and most of these were actually appointed before the signing of the Armistice. It was tentatively suggested that in the matter of water supply a closer *liaison* between the Geologists and the Water Supply Officers would have been desirable, but otherwise the organization worked satisfactorily.

30. Suggested Geological Establishment for the British Army.

The following proposal was put forward in September, 1918, for a Geological Section, R.E., under the Engineer-in-Chief on a similar status to "Camouflage," etc. :—

At G.H.Q.

Commandant (Geologist) ...	... Major or Lieut.-Col.
Assistant Commandant (Geologist)	... Captain
Clerk-Typist	... 1
Draughtsmen	... 3

(With car.)

At H.Q. of an Army.

Geologist	Captain or Lieut.
Clerk-Typist	1
Draughtsman	1

With box car to transport light boring plant and keep Geologist in touch with work in Army Area.

Total-Personnel for G.H.Q. and 5 Armies.

Geologists	7
Draughtsmen	8
Clerks-Typists	6
Drivers (M.T.)	6
Total	27

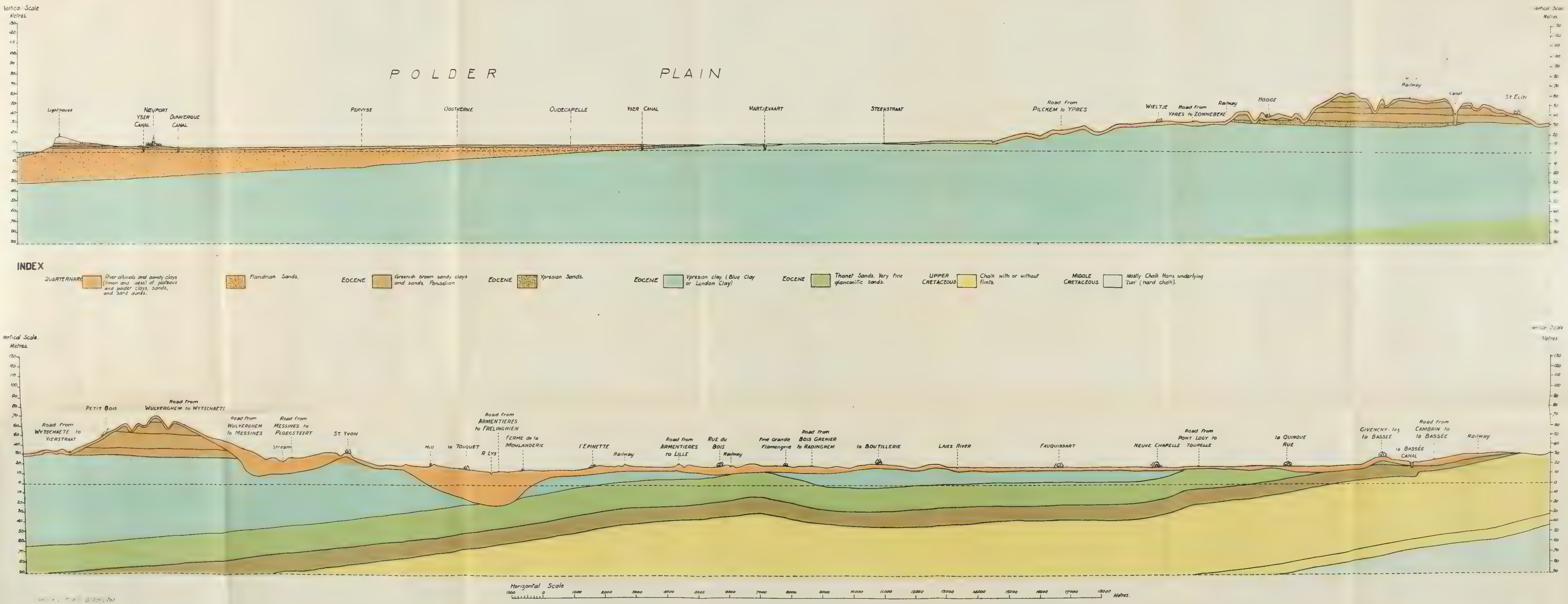
The suitability of such an establishment was generally recognized, though the proposal was put forward at too late a date to materialize. But should the British Empire in the future become involved in another war there can be no question but that the existence of an adequate Geological Staff *from the commencement* would be the means of much saving of expense, labour, and life.

While it is not suggested that Geologists should necessarily belong to the Regular Army in peace time, it is certainly desirable that such touch should be kept with H.M. Geological Survey, and such machinery exist, as will ensure the presence of a geological staff with any future British Army from the outbreak of hostilities.

INDEX.

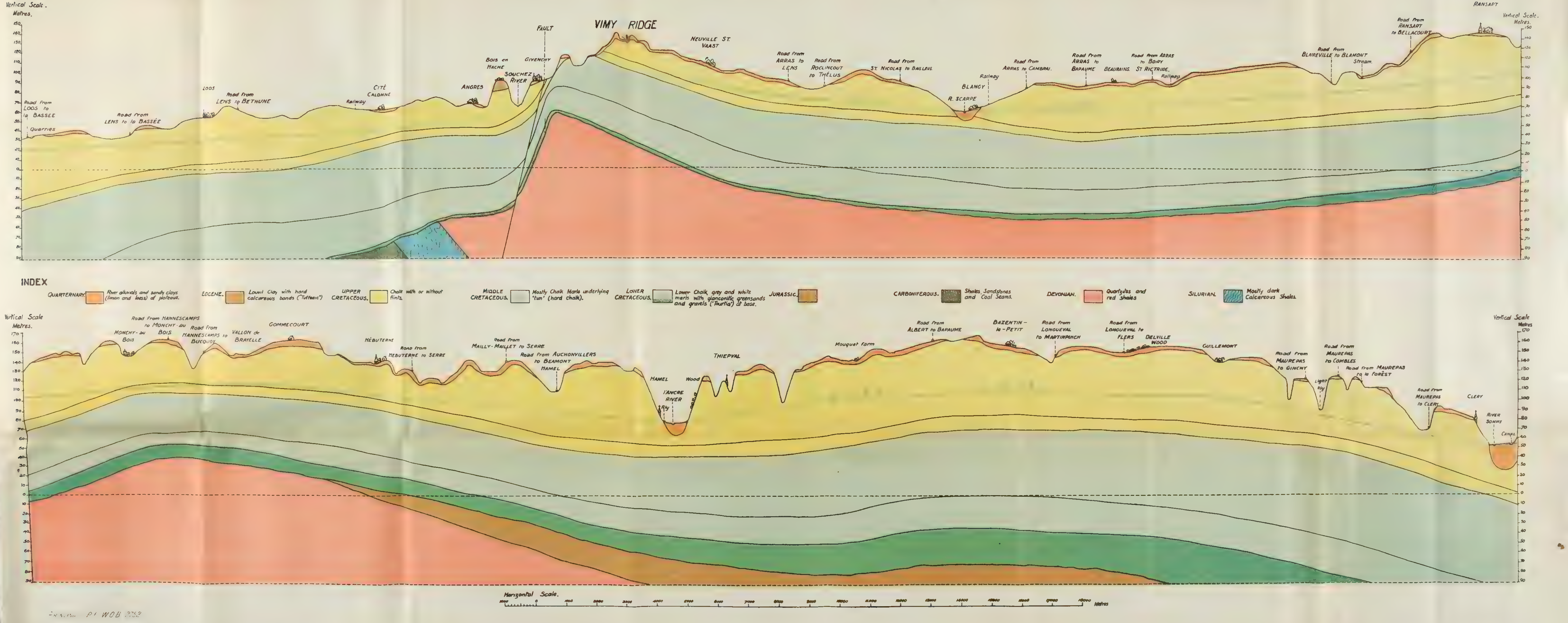
GEOLOGICAL SECTION ALONG FRONT LINE TRENCHES FROM NIEUPORT TO THE SOMME.

PLATE I



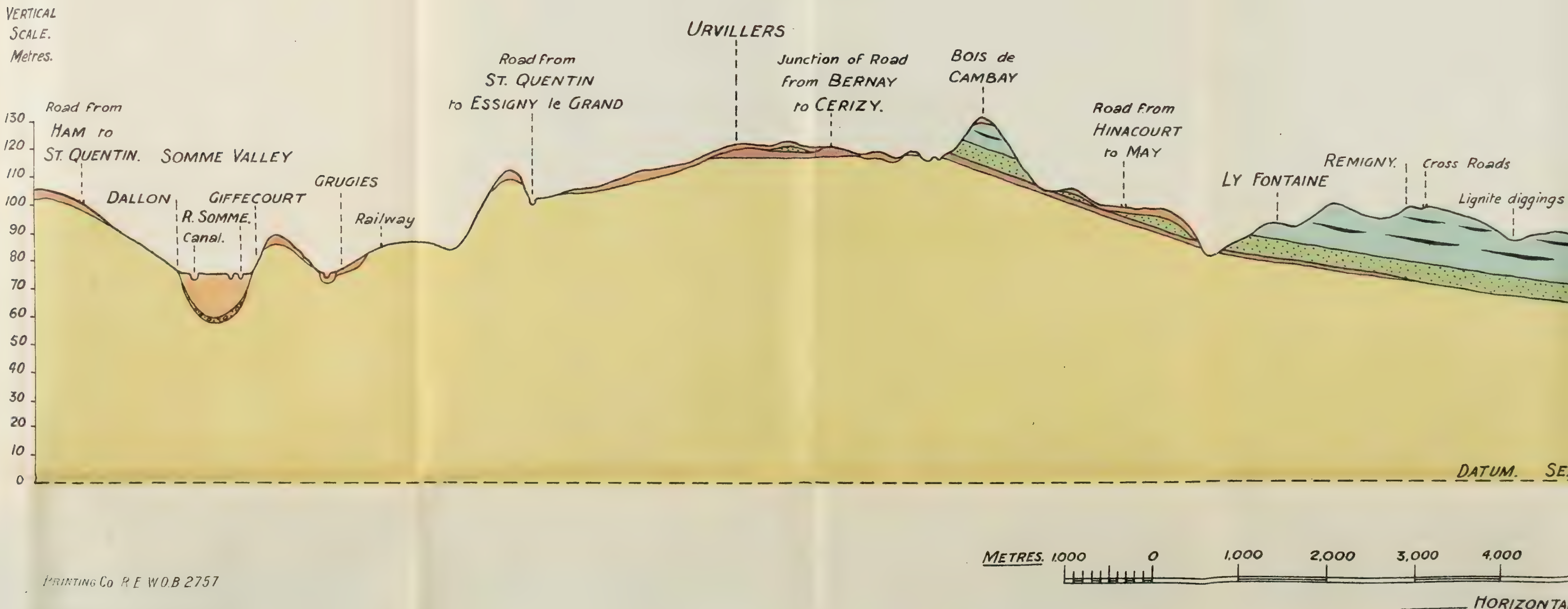
GEOLOGICAL SECTION ALONG FRONT LINE TRENCHES FROM NIEUPORT TO THE SOMME.

PLATE II



GEOLOGICAL SECTION FROM NEAR ST

INDEX: Recent Alluvium. Older Alluvium and Loam. Gravel Terraces. Sable de Beauchamp. (with pebbles) Argile de Saint Gobain. Calcaire fossilifero limestone.



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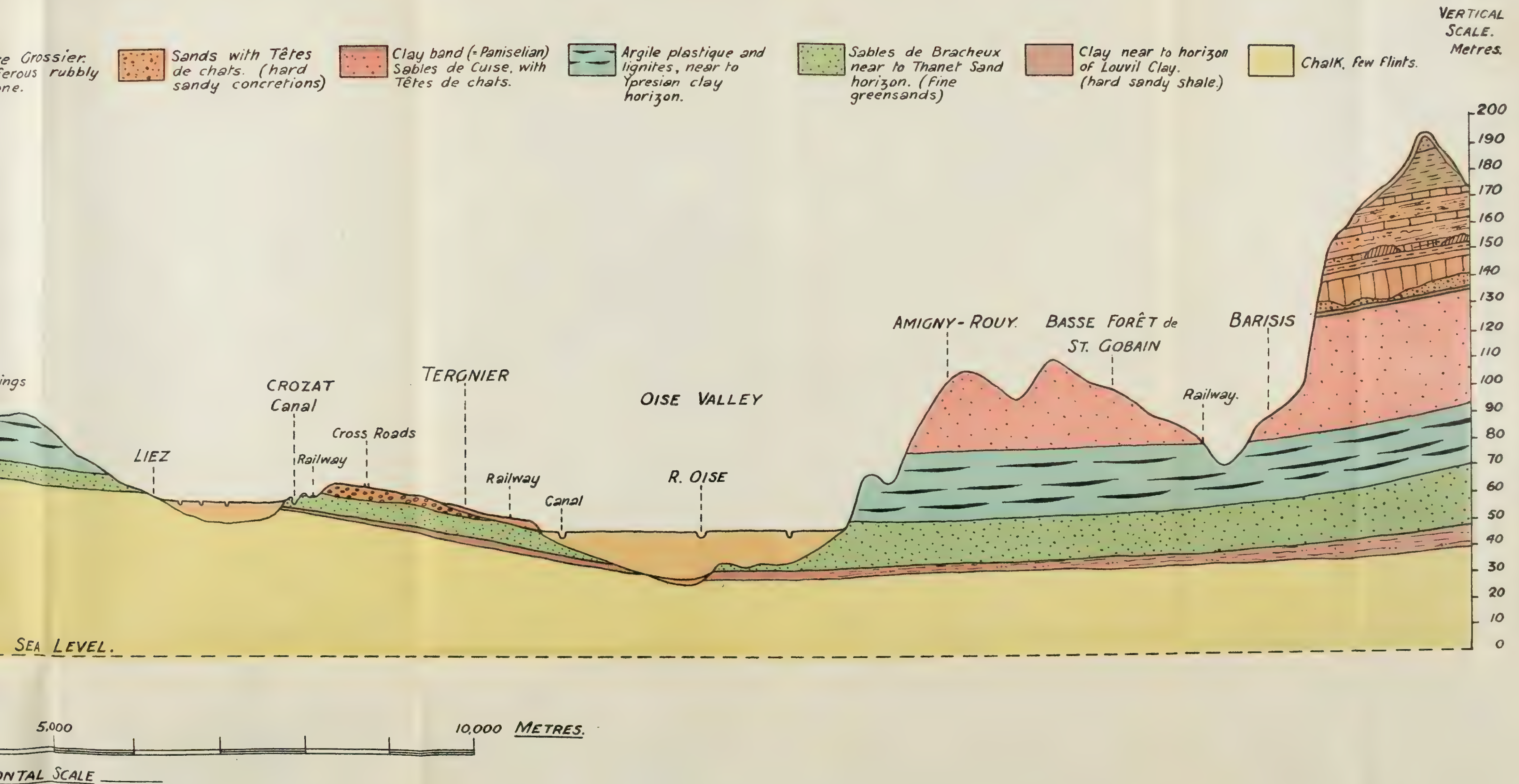
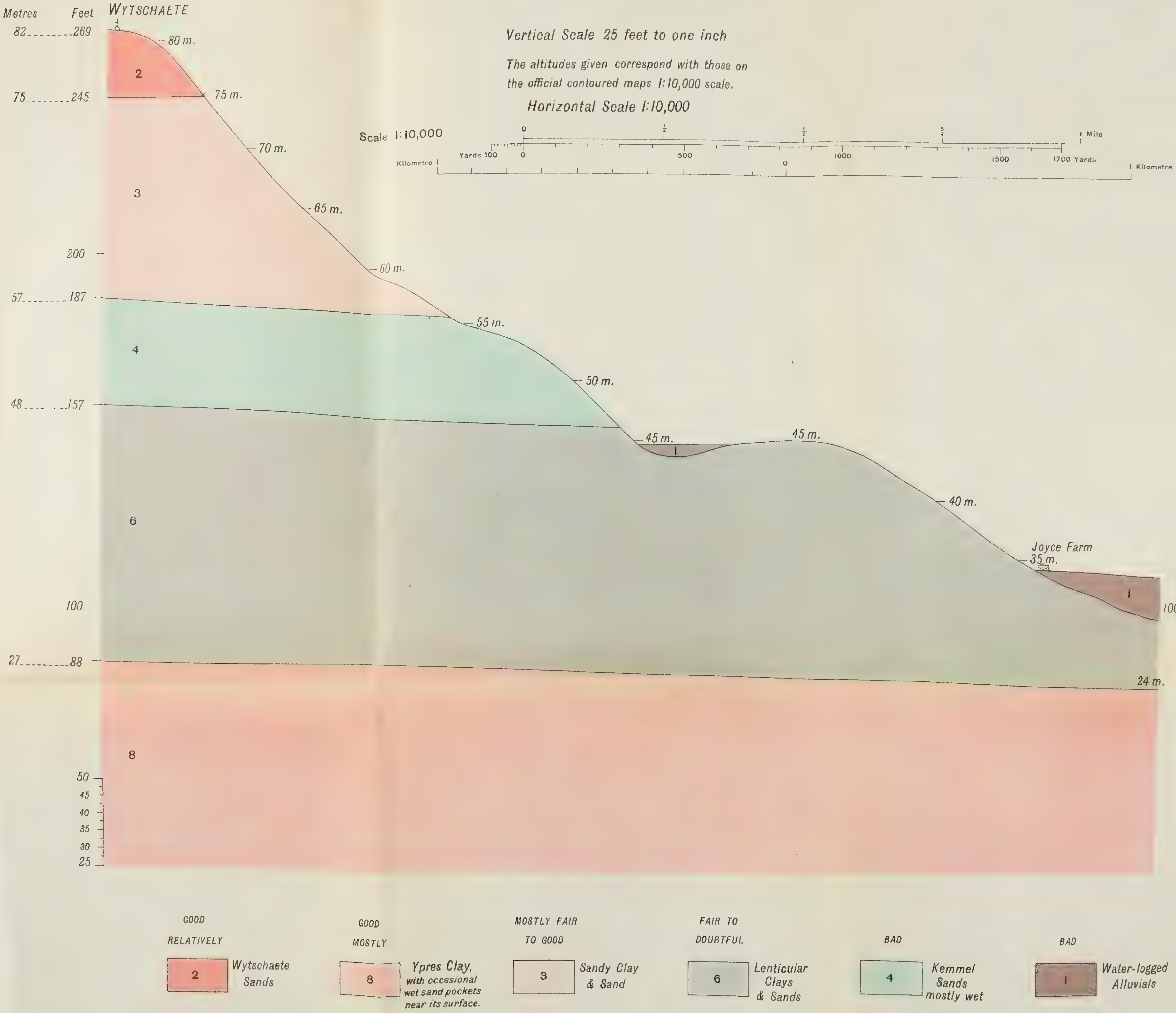


PLATE V.

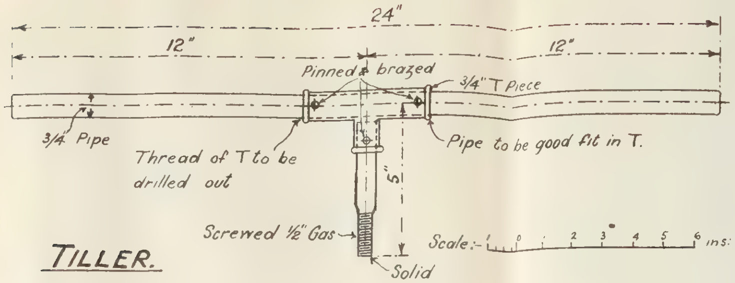
DIAGRAMMATIC SECTION WYTSCHAETE AREA



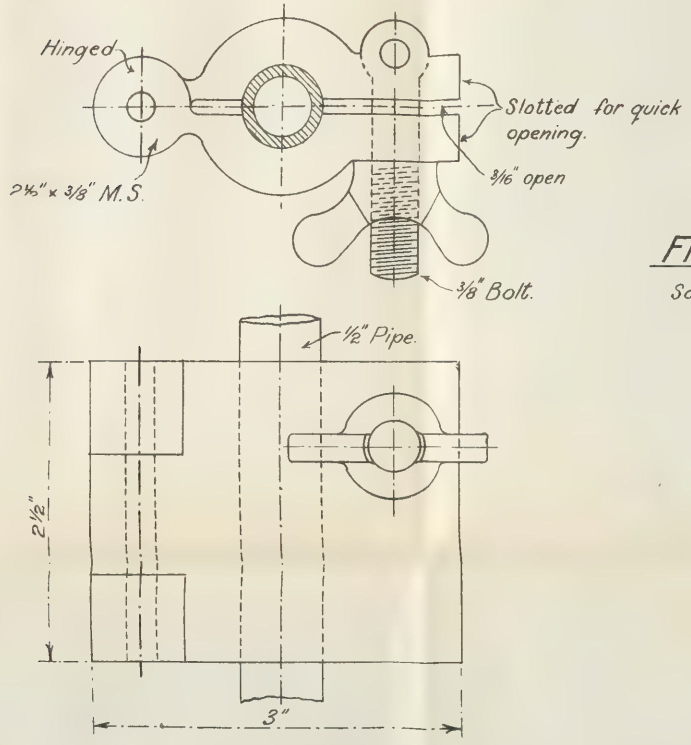
Ordnance Survey, March 1918.

DETAILS FOR GEOLOGICAL TEST BORING SETS.

PLATE VI



TILLER.



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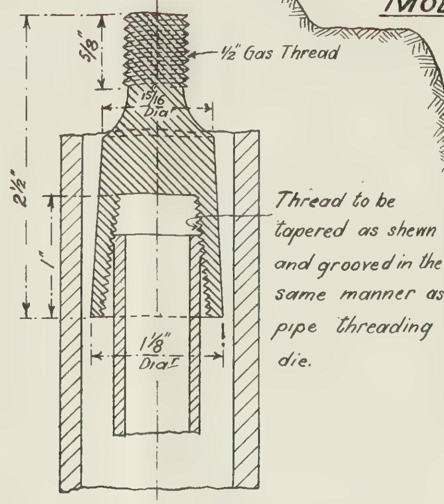

FISHING DIE FOR ½" PIPE.

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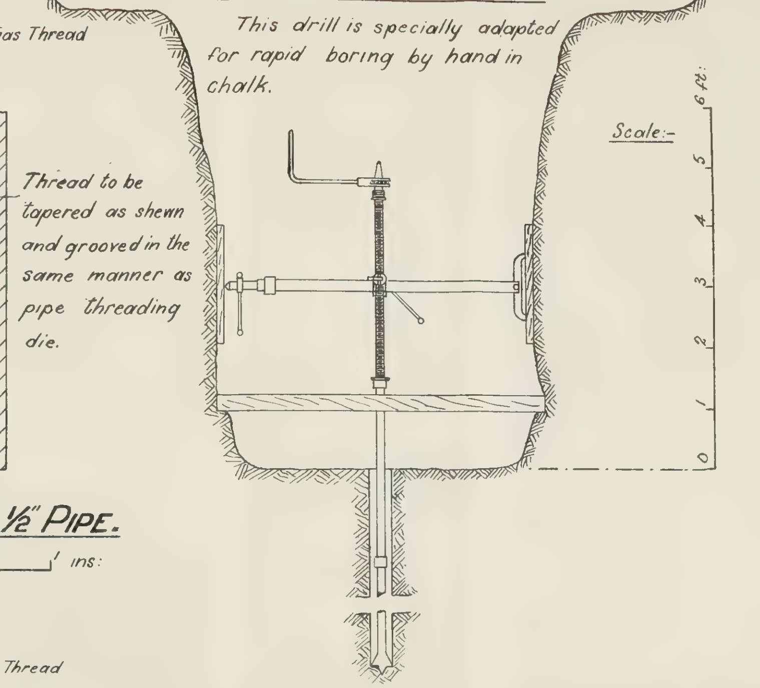
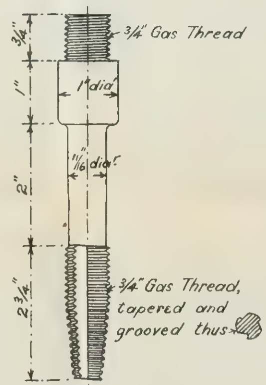
SKETCH SHEWING INSTALLATION OF MODIFIED ACME DRILL.





RECOVERY TOOL FOR ½" PIPE

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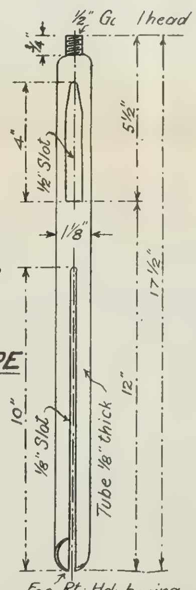
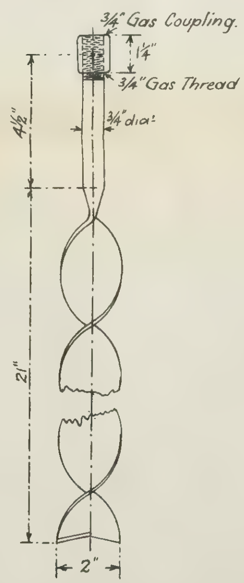
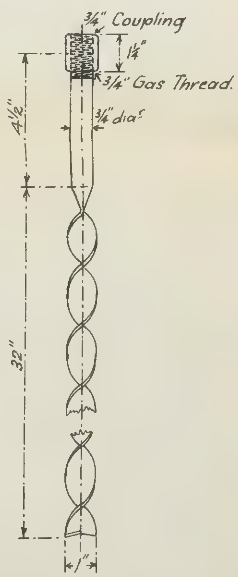


SHELL AUGER.



2" TWIST AUGER.



1" TWIST AUGER.

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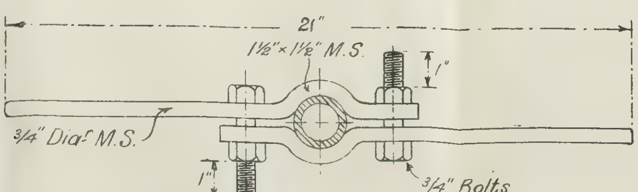

CLAMP FOR 1¼" CASING.

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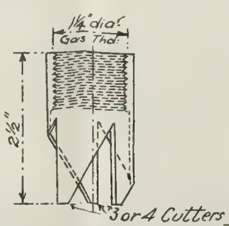

CALYX CUTTER.

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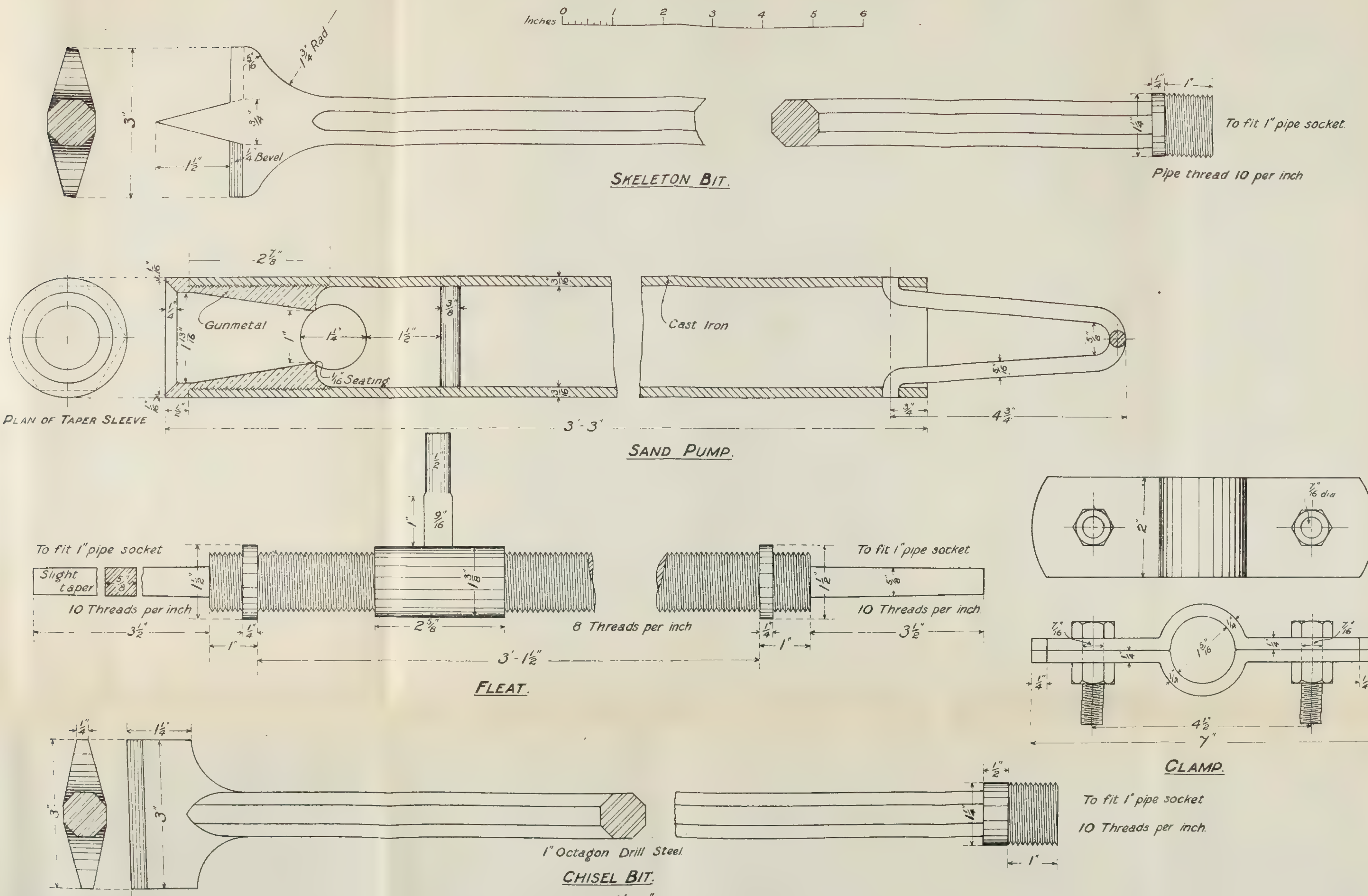
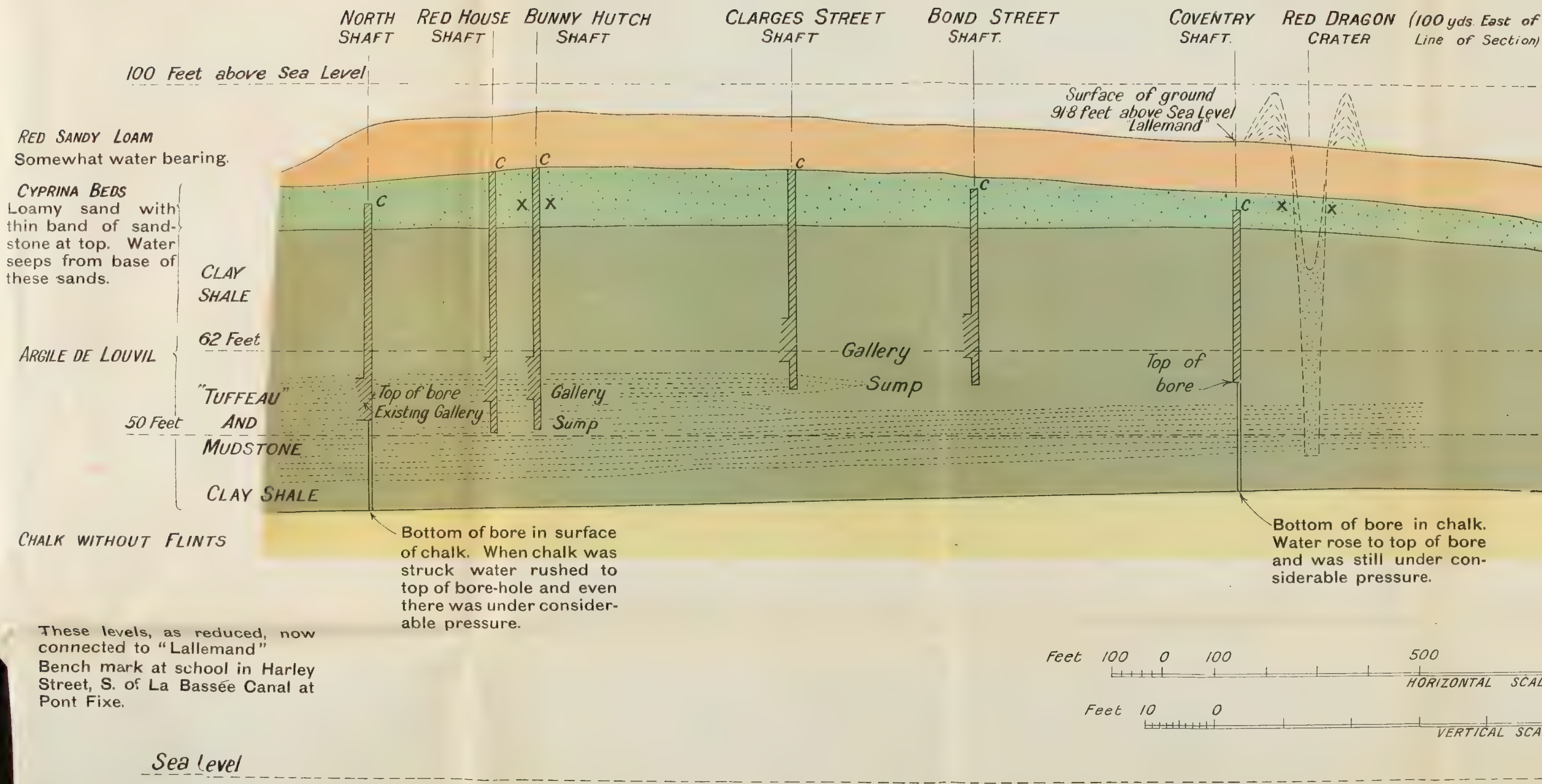
IMPROVEMENTS TO ACME BORING MACHINE FOR BORING IN CHALK.




CONTOURS OF THE SURFACE OF THE CHALK MARLS IN METRES REFERRED TO SEA LEVEL.
The first figure gives the altitude of the surface at the bore taken from the 1:40,000 map. The figure in the circle gives the altitude at which the marls were struck in the bore.
The sign + or – before the circled figure, indicates whether the marl surface is above or below sea level. The sign – after a figure indicates that the marls had not been reached but that the bore was still in chalk at the depth stated.
The area around Douai & Bruay are taken from Études des Gîtes Minéraux, by M J Gosselet.
In the triangle between Montreuil, Auxi-le-Chateau, and Souchez in the north, and also in the S.W. corner south of the R Bresle the marls are seen at the surface in the valleys. The curves are drawn from the figures obtained by studying the altitudes of the base of the "Tun" (C_m^{6c}) as shown on the French Geological Maps.
AMIENS
Printed Cor RE, WOB. 2850.
Scale 1 Inch to 3·95 Miles, or Four Inches to 4 Miles.
1 Centimetre to 2·5 Kilometres

GEOLOGICAL SECTION FROM C

SHOWING MINING C



INDEX.

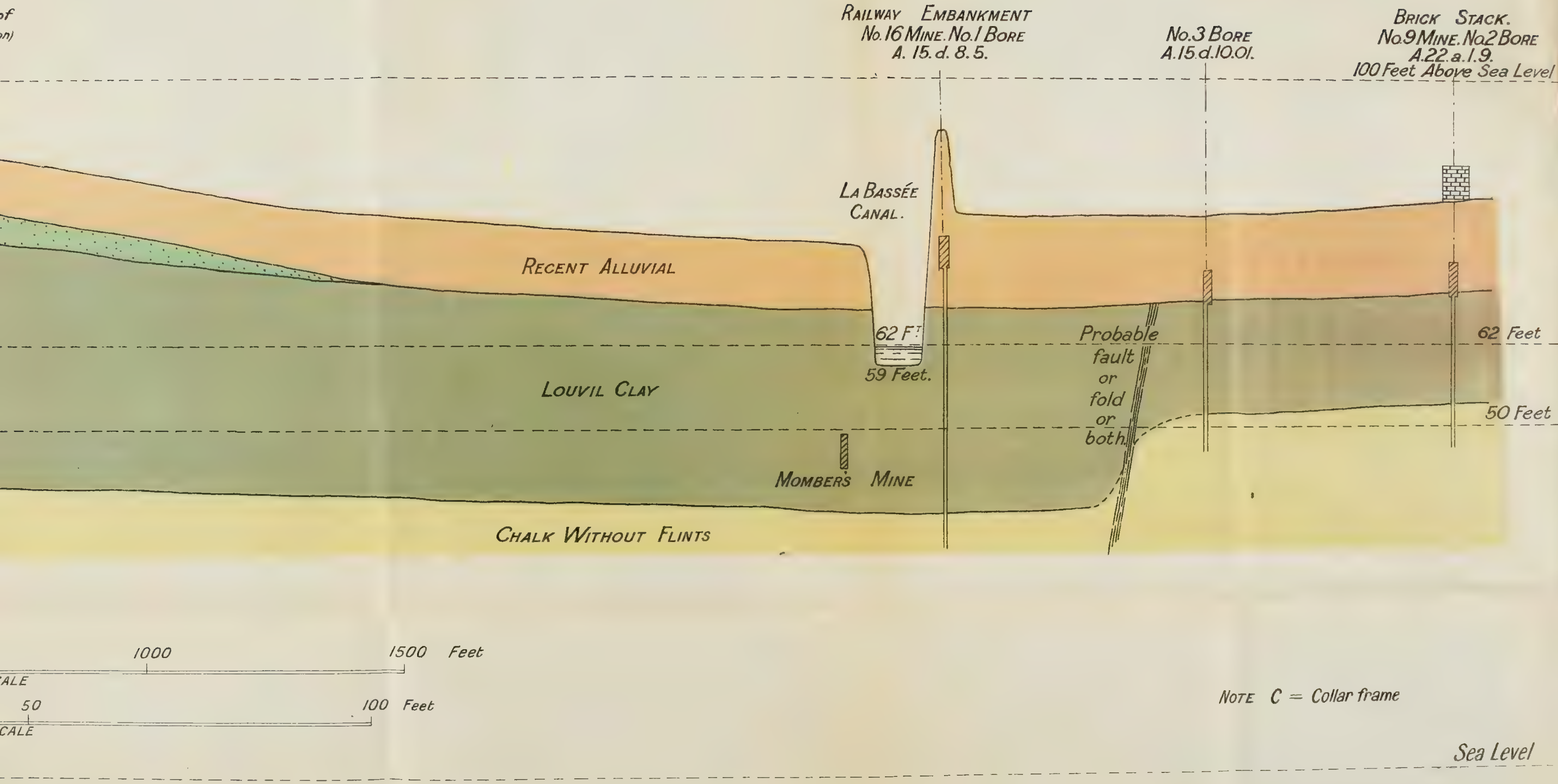
Recent alluvials, chiefly red sandy loams.

Cyprina Sands, with a little clay. These are water-bearing and part of the Thanet Sands. The fossil shells (Cyprina) occur at the point shown at X X

Louvil Clays. Hard greenish black clays and mudstones. These are mostly impervious, even in the case of the mudstones, which are about half sand and half clay; and in spite of the fact that the water in the underlying chalk exerts a considerable pressure against their base, they are quite dry to within less than a foot of the top of the chalk.

GIVENCHY TO CUINCHY.

CONDITIONS.



Upper Chalk, without flints, containing water under pressure equal to a head probably of about 20 to 25 ft., i.e., the water would rise to that level above the top of the chalk, if tapped in any shafts or bores within this area.

NOTE.—The water at the top of the chalk under the Louvil clay is under such pressure that it would at once inundate any galleries in the Louvil clay, if they were to break through into the chalk. The mudstones are fairly impervious, though slightly less so than the clays. It would be desirable to leave not less than 6 feet in thickness of mudstones between the bottoms of the sumps and the top of the chalk.

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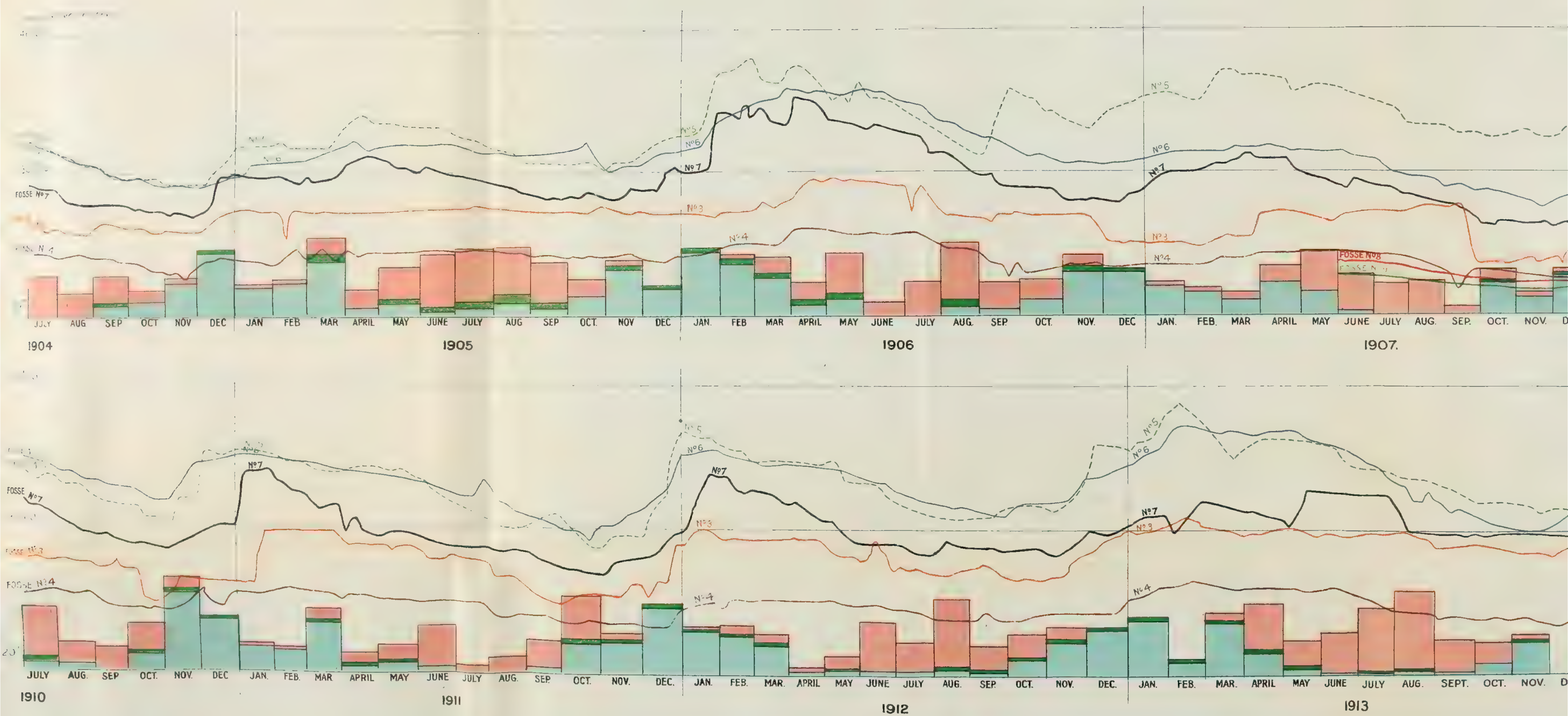
RELATION BETWEEN SEASONAL VARIATION IN LEVEL

AND LOCAL PERCOL

Chalk Water-Level Curves supplied by M. Malat



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VEL OF UNDERGROUND SURFACE OF WATER IN CHALK,

RCOLATED RAINFALL.

Fig. 3.

I. Malatray of Compagnie des Mines de Béthune.

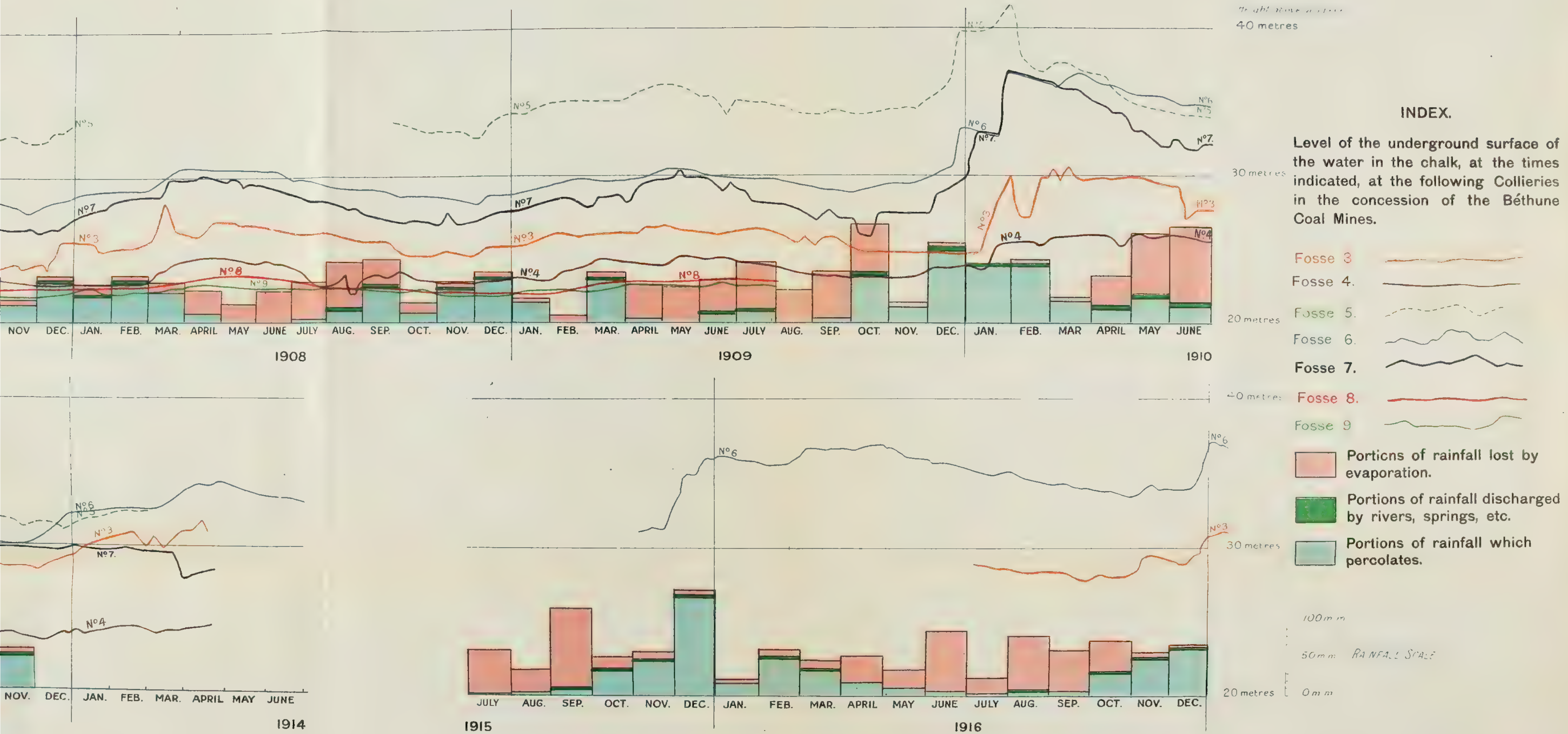

Fig. 1.—Red Dragon

enchy-lez-la-Bassée.

Fig 4.

SECTION FROM GIVENCHY LEZ LA BASSÉE TO VIMY RIDGE
SHOWING
SEASONAL VARIATION OF UNDERGROUND WATER
IN THE CHALK.

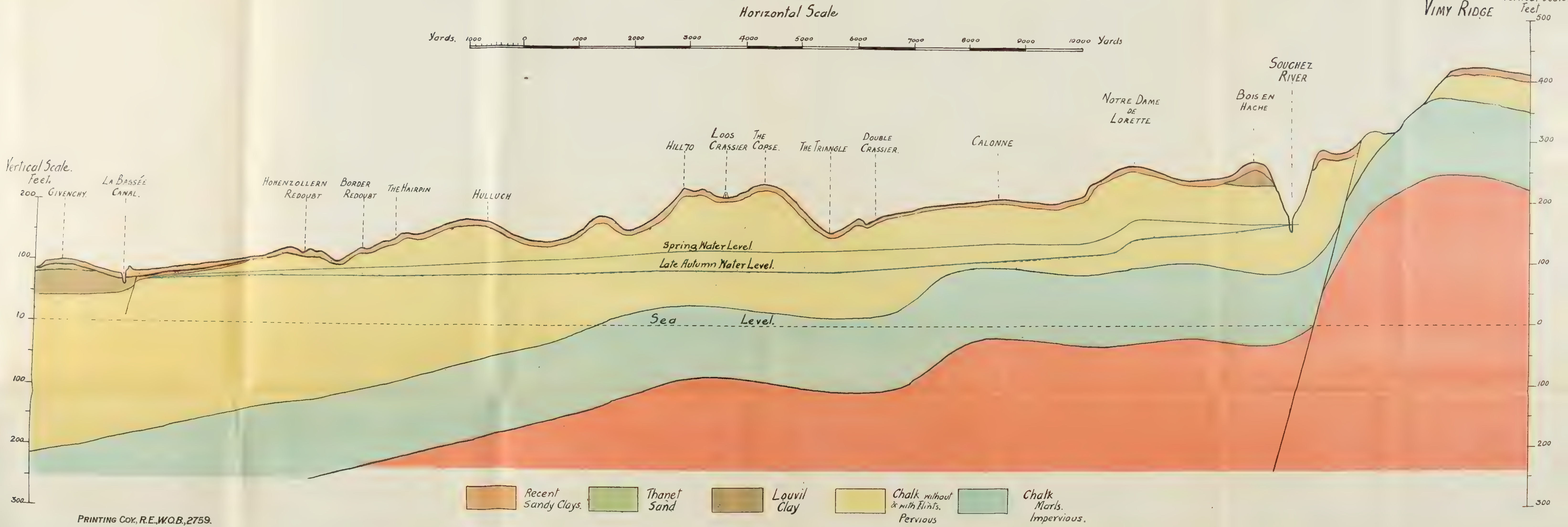

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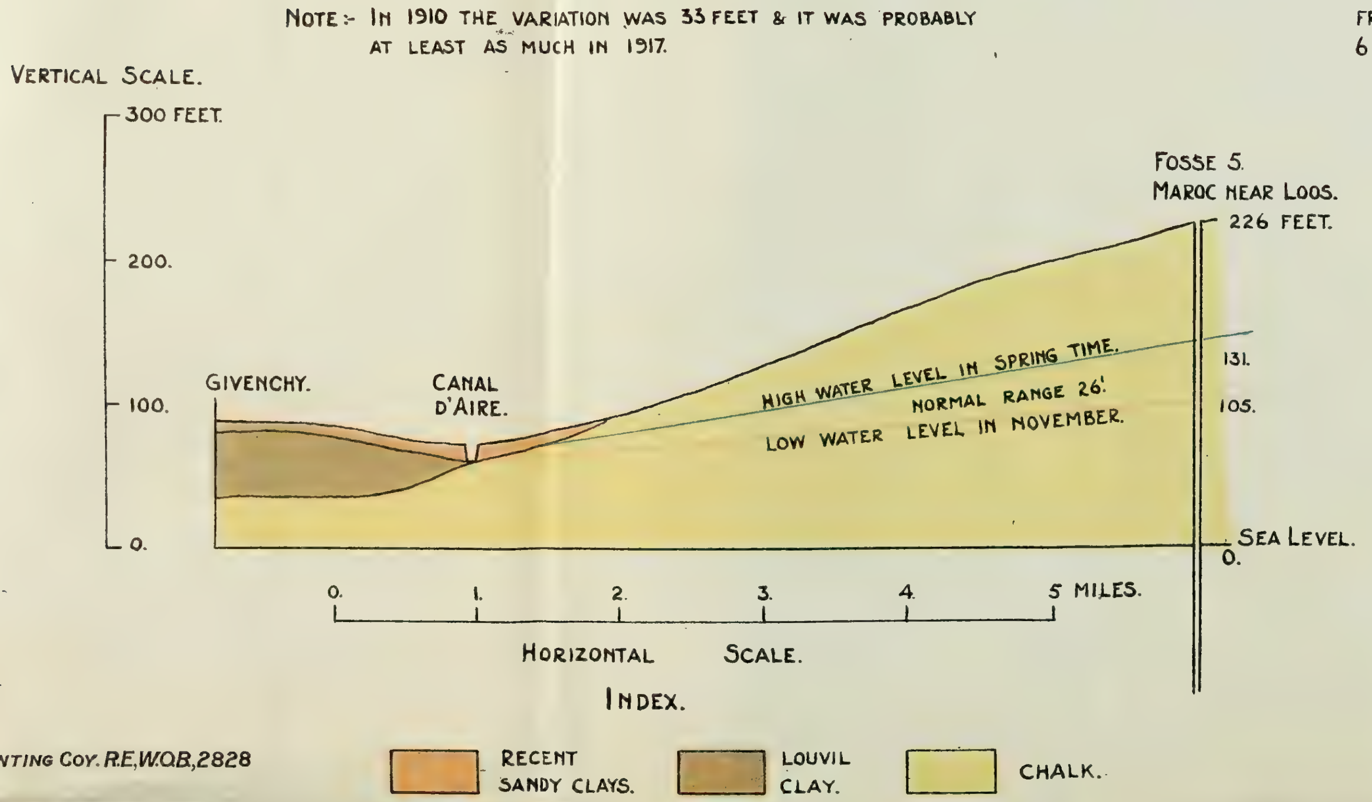
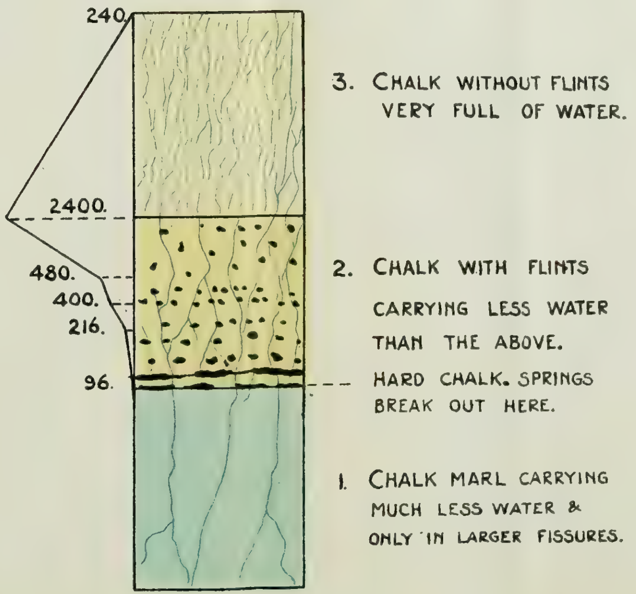
Fig. 5

SKETCH SHEWING VARIATION OF CHALK WATER LEVEL LOOS TO CANAL D'AIRE NEAR GIVENCHY LEZ LA BASSÉE.



SKETCH SHEWING VARIATION IN WATER CAPACITY OF THE THREE CHIEF TYPES OF CHALK ON WESTERN FRONT.

THE FIGURES SHOW YIELD IN CUBIC METRES PER HOUR FROM COLLIERY SHAFT 6 METRES IN DIAMETER.



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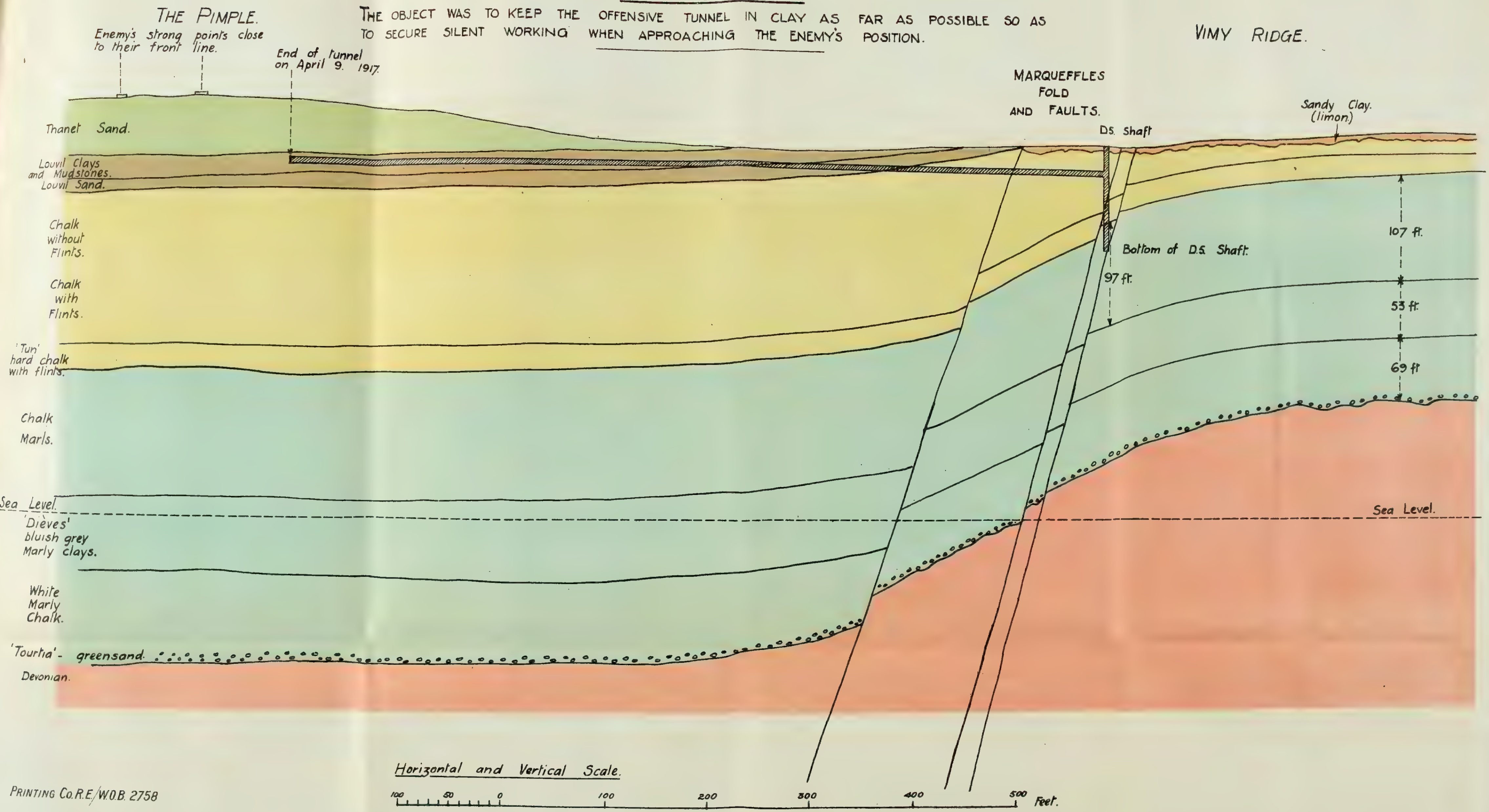
SECTION SHOWING GEOLOGICAL STRUCTURE IN THE MINING OPERATIONS BETWEEN VIMY RIDGE AND "THE PIMPLE"

Fig 6.



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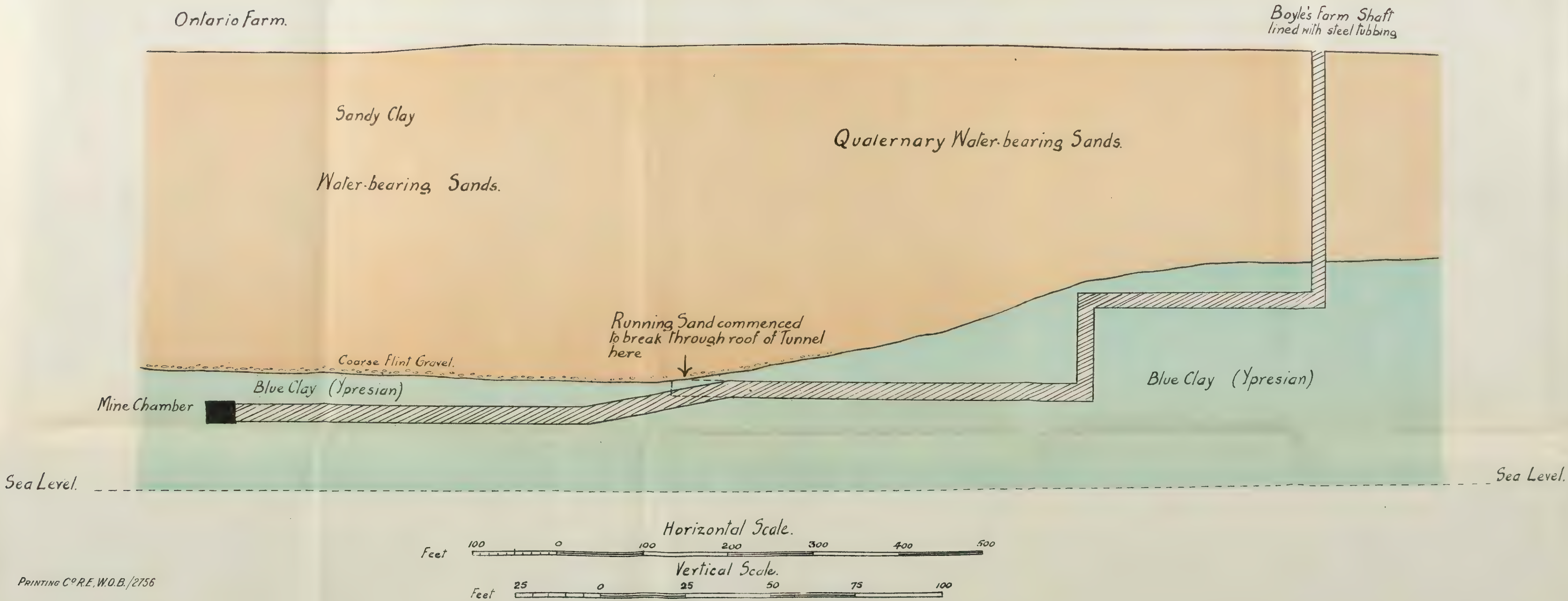
Section Showing Mining Operations Under Old River Channel Between Ontario Farm And Boyle's Farm Near Foot Of Messines Ridge.

Fig. 8.



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SECTION C.
SECOND ARMY OFFENSIVE MINES 7-6-17.
Geological Section through Craters
Hill 60 to Ploegsteert.
LINE OF SECTION SHOWN ON MAP B
INDEX
Wet
Recent
Moist
Hesbayen
Post Tertiary Alluvials
Wet
"Campinien"
Dry
Moist
Wet
Lower Eocene Panisellen formation
Lower Eocene Ypresian formation
Dry
NORTH
HILL 60 "A" CATERPILLAR
ST ELOI
HOLLANDSCHESCHUUR
No3 No1
PETIT BOIS
No2 No1 right
MAEDELSTEDE FARM
PECKHAM
SPANBROEKMOLEN
KRUISSTRAAT
ONTARIO FARM
PETITE DOUVE
SEAFORTH FARM
TRENCH 127
TRENCH 127
SOUTH
Belgian datum level at low tide
INDEX
Recent
Hesbayen
Horizontal Scale

Fig. 7.—"Wombat" Blow. Near Chassery Crater, Vimy Ridge.

SECTION ACROSS YSER CANAL AT NIEUPORT.

Fig. 13

SHEWING METHOD OF BORING THROUGH QUICKSANDS WITH A WATER JET.

REFERENCE.

a. TRIPOD.
b. PIPE i.d.
c. SHEAVE WITH ROPE SUSPENDING PIPE.
c'. COIL OF ROPE.
d. WATER SWIVEL.
e. STRAINER OF INTAKE PIPE.
f. PUMP TO SUPPLY SUMP.
g. SUMP.
h.h. TWO "LOW DOWN" DOUBLE ACTING PUMPS 6" STROKE 5" i.d. BARRELS WITH THE LEVERS COUPLED BY CROSS BAR m.

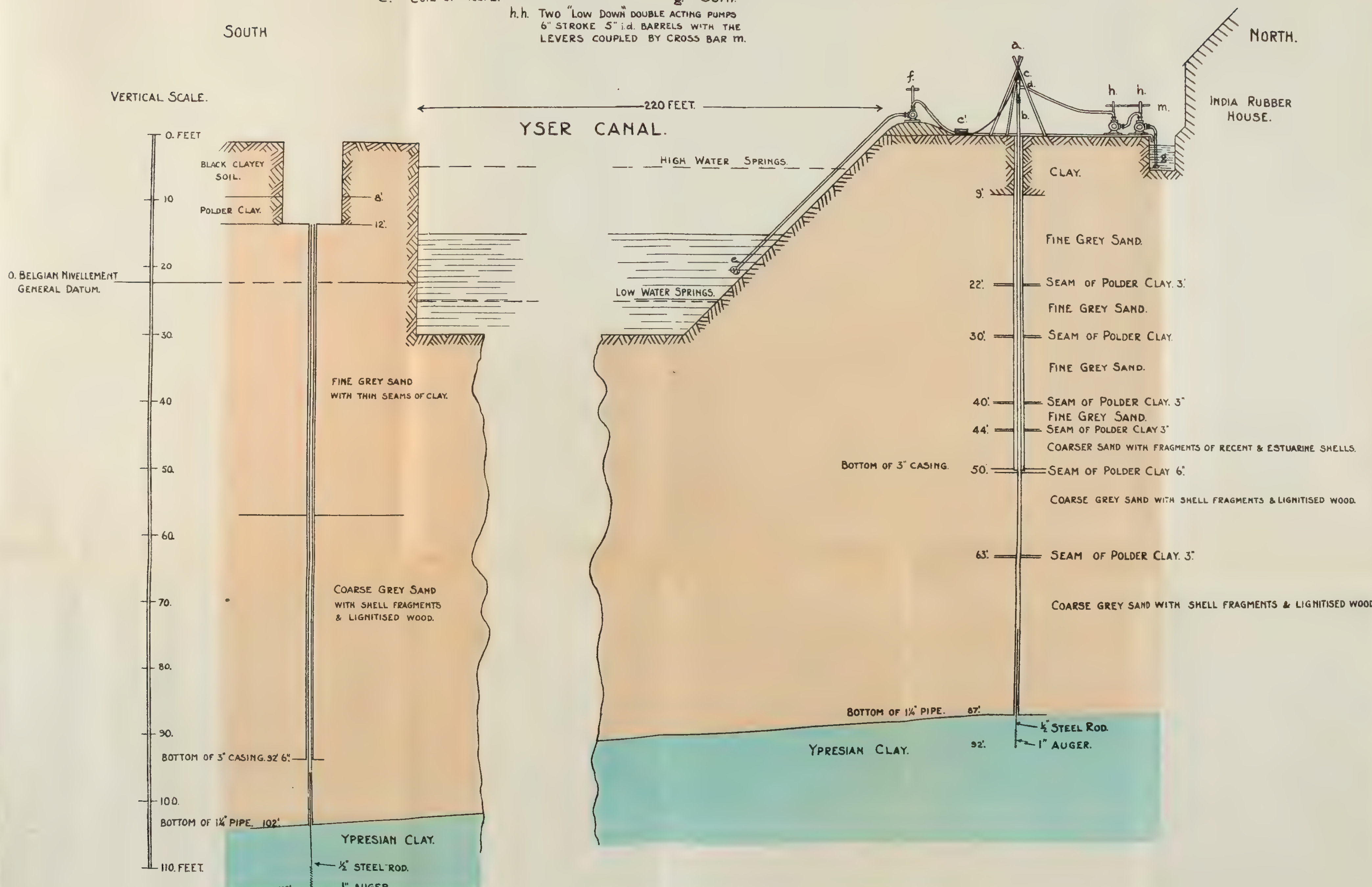


Fig. 9.—Railway Cutting at Hill 60. Ypres Salient.

In Paniselian Sands. Dry above with Shelters; wet below Springs. Looking North-West.
Nov. 27th, 1918.

Fig. 14.

Sections showing Faults at Scherpenberg.

Which led to the loss of Gallery B through inflow of running sands. Gallery A and its system of dugouts remained dry.

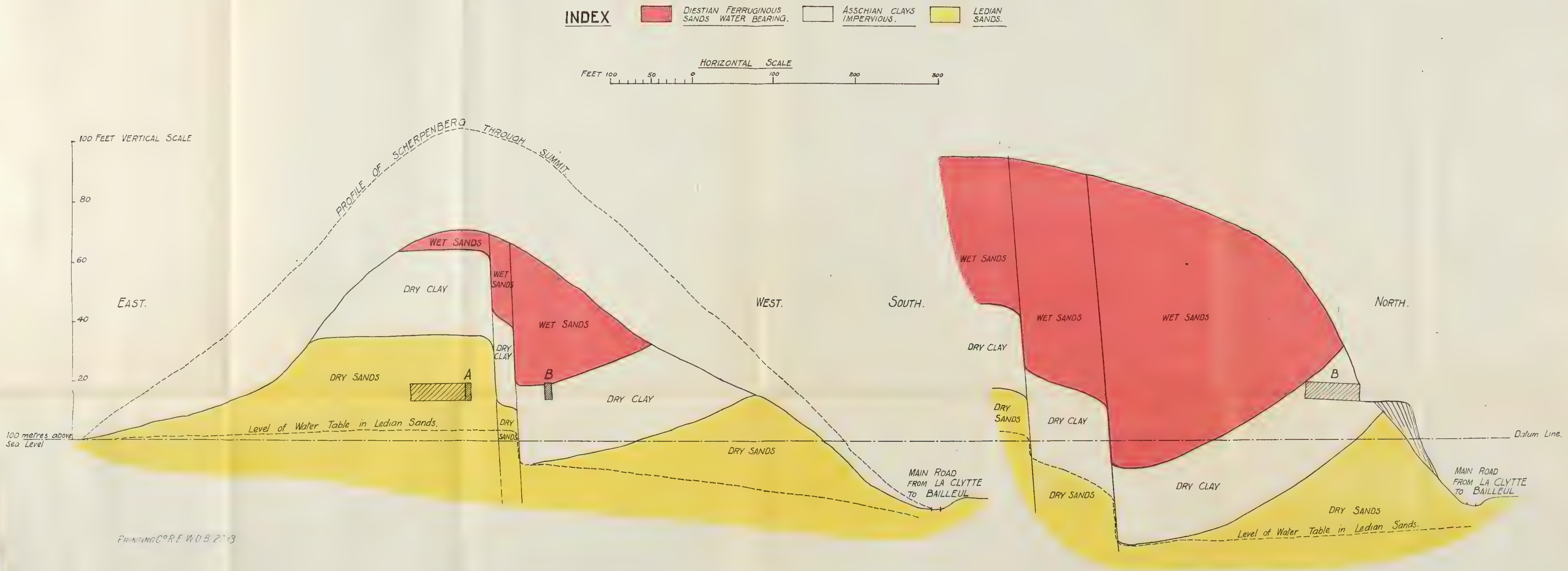


Fig. 11.—Crater at Ontario Farm.

Fig. 12.—Hill 60.

Looki

No

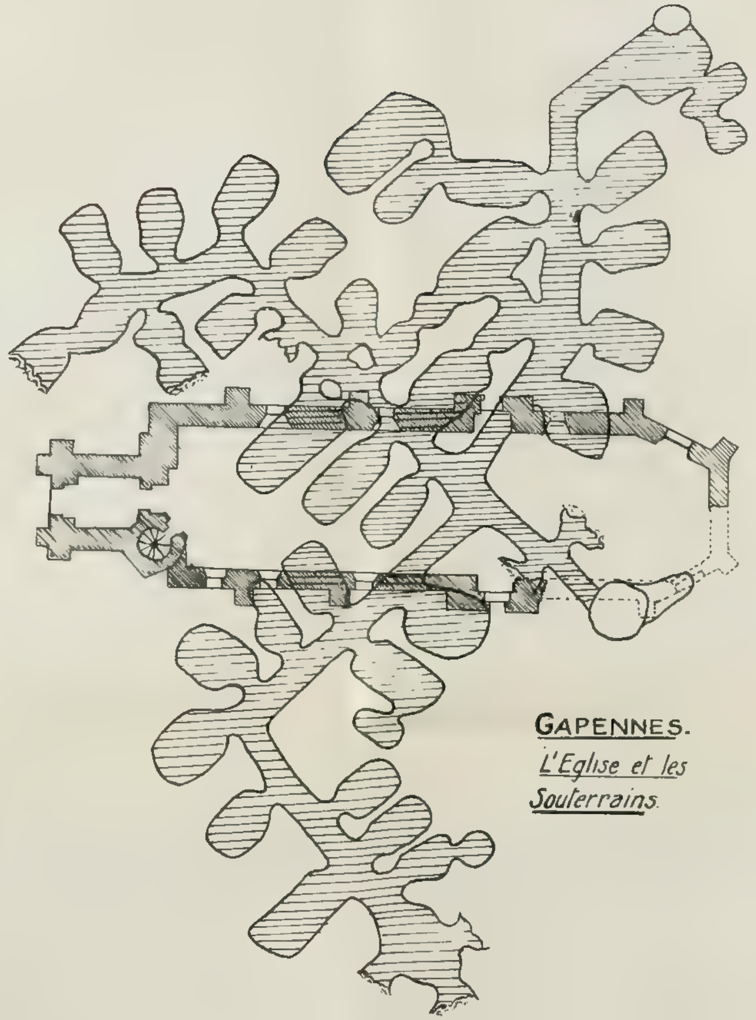
r, Ypres Salient.

st.

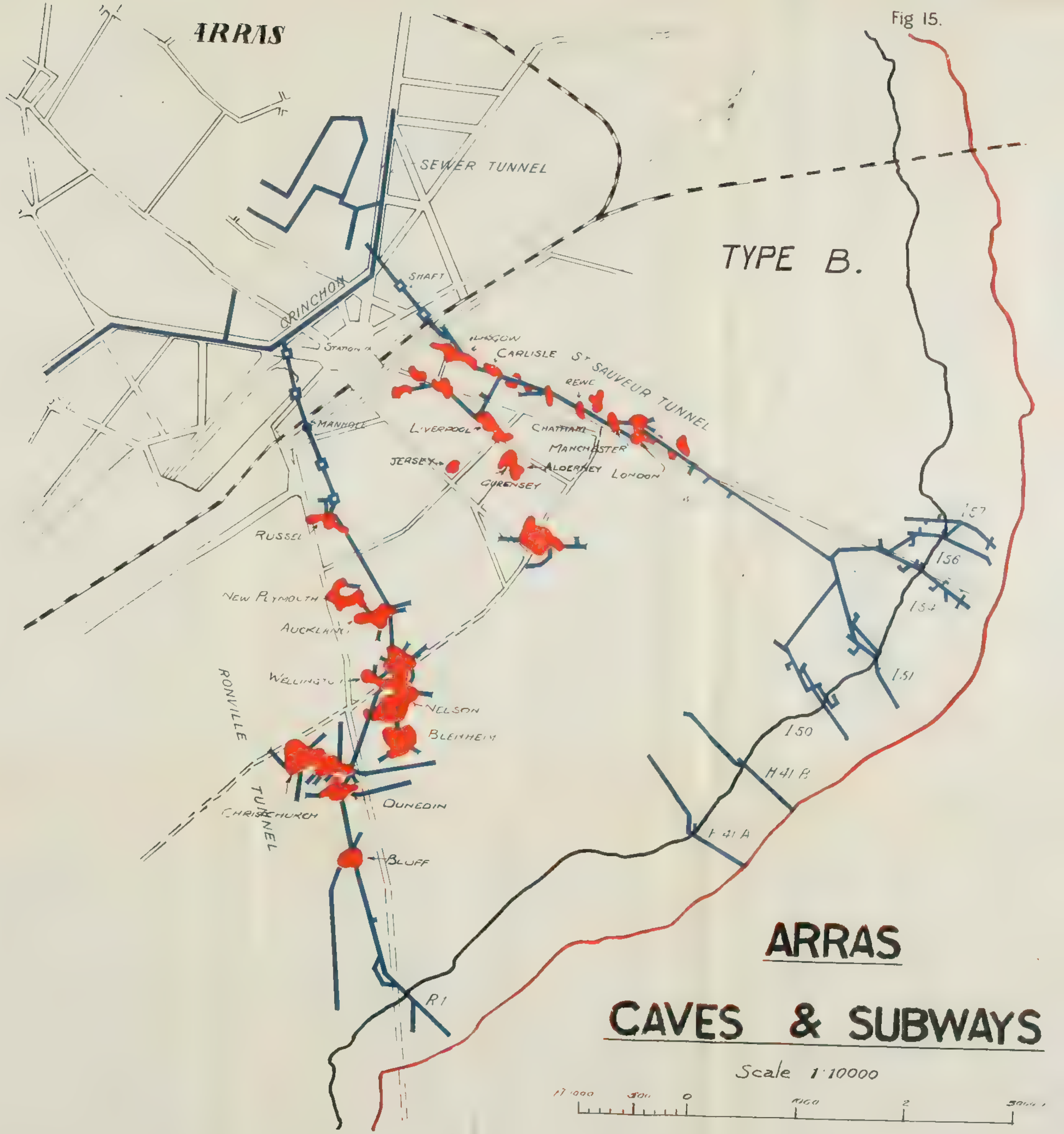
Fig 15.

Map showing Positions of Chief Subterranean Excavations ('Souterrains') in Northern France.

TYPE A.



Gapennes.
L'Eglise et les Souterrains.



ARRAS
CAVES & SUBWAYS

Scale 1:10000

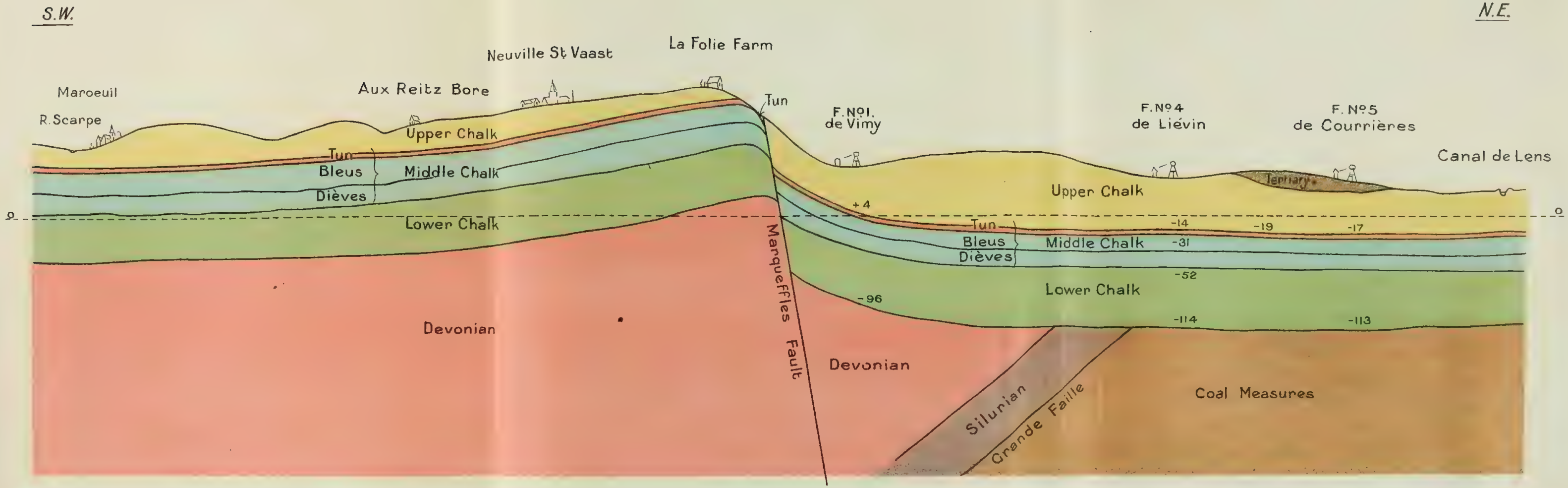
MAP OF WATER SUPPLY.

Fig. 18.

Portion of NAMUR SHEET 1:100,000

For explanatory notes see Text under Water supply maps

Fig. 19.



N.E., S.W., Section across the Vimy Ridge.

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Fig. 16.—Tanks bogged in mud, "Clapham Junction," Ypres Salient.
Looking westwards towards Ypres.

Fig. 17.—Sarsen Stone. (Quartzitic Concretion out of Thanet Sand).
'Pimple,' Vimy Ridge.