Feature

Geology and the war on the Western Front, 1914–1918

Peter Doyle

Department of Earth Sciences

University College London

Gower Street WC1E 6BT UK

geologytoday@btinternet.com

The First World War started a hundred years ago this year. On 4 August 2014 the United Kingdom marks the anniversary of involvement in this war with a remembrance event at Mons, and over the next four years there will be new museums and exhibitions, services and events, conferences and colloquia worldwide. The aim of this collective recognition of a major event in world history is to pick over the impact and effects, innovations and consequences of a war that claimed the lives of at least 16 million people and left the world with geopolitical consequences that still reverberate today. One of these is the use of geology in warfare. As is well known, compared with the open war fought against the Russians on the eastern front, the war in the west very quickly became positional, with opposing trench lines locked into position that would dictate the war's approach. And with trench warfare,

came the need to understand the geology of the land over which the men were fighting.

The First World War was fought principally on two fronts in Europe – described as the Western and Eastern fronts respectively – from July 1914 to November 1918. Not confined to Europe, the war spread worldwide, with lesser known land campaigns in the Middle East, Asia and Africa, and with a naval war that saw action from South America to the North Sea.

In Europe, the ‘Triple Entente’ (France, Britain and Russia), faced the Central Powers (principally Germany and Austria-Hungary), but other countries took their place in the developing battlefields, with Serbia and Belgium embroiled from the outset. The origins and early development of the war are too complex to enter into here, but with Germany committed to the war, the Schlieffen Plan of 1904 was enacted, a plan which dictated an assault on France through neutral Belgium, in order to knock its enemies of 1870–71 out of the war – before taking on the might of Russia. The plan predicted the advance of a great arc of German armies through northern France and Belgium. Its aim was to engulf and surround Paris, thereby knocking its principal enemy out of the war. The invasion of neutral Belgium brought Britain into the war, and the British Expeditionary Force took its position in the line at the town of Mons in late August 1914.

The weight of the German invasion was such that the French and British troops fell back to take up a position along the line of the River Marne before Paris, and in the battle that ensued from 5–12 September, the German advance was stopped in its tracks. With the Schlieffen plan in disarray, from

13 September to 19 October the Allied and German armies attempted to outflank each other in what has become known as the ‘Race to the Sea’. By November 1914, both armies in the west had ground to a halt in parallel lines that stretched from the North Sea to the Swiss Frontier – a situation that was to remain in place until the lines were broken in 1918, leading to the resumption of open warfare (Fig. 1).

Throughout history, the most effective military commanders have been those who have understood topography and the nature of terrain, with records at least back to some 512 BC recorded in the Chinese text attributed to Sun tzu, in the *Art of War*. Of its 13 chapters, at least seven of them refer explicitly to the use of terrain in battle and manoeuvre, the need to understand terrain types, and of the pitfalls and advantages of defensive positions: ‘How to make the best of both strong and weak – that is a question involving the proper use of ground.’ Tellingly, first English translation of this classic of military literature appeared in 1910. The First World War provided ample opportunities to test this. In this article, I examine aspects of the ‘proper use of ground’ by the British and German armies facing each other in Belgium and northern France.

Geology of Flanders and northern France

For the most part, on the Western Front, the British fought in Flanders and Artois-Picardy. In the north the frontline encompassed the Belgian city of Ypres (Ieper), before passing southwards through French Flanders (close to the cities of Armentieres and Lens) and on to Arras and Albert in Artois-Picardy.

The geology of this region is not complex, consisting primarily of Upper Cretaceous chalks overlain by Palaeogene clays and sands, capped by various Quaternary deposits of varying thickness. Even so, it presented many challenges for the men who fought there.

North of Ypres, is the coastal plain of Flanders, 'the Polders' – littoral and estuarine sediments associated with the Quaternary transgressive phase. The coastal plain is effectively at sea level, and drainage has been achieved by canalizing rivers, and the creation of a complex of drainage ditches and canals. In 1914, as a defensive measure, the lock gates controlling this system were opened and the land inundated to help impede the German advance. Held mostly by Belgian troops, the coastal plain is bordered seawards by a coastal dune belt, a 2-km-wide strip of coastal dunes that fringe the North Sea coast.

From Ypres southwards, Flanders comprises an extensive, flat plain composed of thick Palaeogene sediments of Eocene age. The topography of the clay plain is uncomplicated, its flatness relieved only by a series of low hills with elevations of no greater than 50 metres (Fig. 2). The plain itself is mostly composed of Early Eocene (Ypresian) clays once called the 'Ypres Clay', but which are now attributed to the Kortijk Formation. These heavy clays are of variable depth, up to 130 m thick but reducing to around 50 m, and are broadly equivalent to the London Clay Formation of southern England.

Overlying the clay plain is a complex of sandier units traditionally grouped into the 'Paniselian Formation', but which are now known as the Gent Formation and lower levels of the Tielt Formation. Across Flanders the

‘Paniselian’ sand complex has helped form mature fluvial surfaces that are evident as low lying ‘ridges’. These sand units are eroded remnants of a former, more extensive coverage in the region. Notable is the Passendale (Passchendaele) Ridge complex, which comprises heterogeneous sand, clay and silt sedimentary units of Ypresian age that overly the clay plain.

At depth are Cretaceous chalk deposits; farther south into French Flanders, the Carboniferous Coal Measures are found closer to the surface, close to the Marqueffles fault system, which is seen at the fault scarp of the Vimy Ridge, a feature that divides Flanders from Artois and Picardy. The Artois region exposes the Chalk in a broad anticline, which is an extension of the Weald anticline in southern England. It forms a dissected chalk plain with some remnants of Palaeogene sediments, and is covered by Quaternary sediments.

The Picardy region (the Somme) is representative of a dissected chalk upland (Fig. 3). The chalk of the Somme is equivalent in lithology to that of southern England, and like it, comprises three broad divisions. The Chalk is mostly frost shattered in its upper part, and is typically overlain by at least four geological units of Quaternary age: clay with flints, loess, loam and alluvium, although not all will be present at any given location. Loess caps the clay-with-flints and is in turn covered by a clay-rich sand or loam. The loess and loam are often classified together on French maps as *Limons de Plateaux* which constitutes a fine covering on the upland areas, but sometimes reach a thickness of up to 10 metres.

Several rivers cut the plain and many dry valleys, some of them deeply incised, are also found within the area. Where clay with flints caps the Chalk, water is retained leaving a heavy soil that is often uncultivated, except for forestry. Many of the wooded areas of the Somme battlefield lie in soils developed in clay with flints, with the chalk forming most of the valleys in the region, with the loess and loam capping the hills and forming the intermediate slopes.

Terrain and warfare

The development of the largely static conflict on the Western Front was arguably a direct result of the increased efficiency and accuracy of artillery and machine gun fire, which reduced the effectiveness of offensive action by infantry, especially where deployed in direct frontal assault, and increased the importance of defensive positions. As the early nineteenth century Prussian military theorist, Carl von Clausewitz put it in the classic book *On War* (1832) ‘The object of a strong position is to make the force there stationed in point of fact unattackable, and by that means, either really to cover a certain space directly, or only the troops which occupy that space in order then, through them, in another way to effect the covering of the country indirectly.’ This was certainly true of the First World War.

As a consequence, the nature of the ground fought over was extremely significant to the outcome of the war, as it was this that ultimately controlled the efficacy of defensive positions. It is generally held that the war in the west was simply a struggle for topographic position. The disposition of high ground, the relative incision of valleys, and the presence of wooded areas was of paramount importance to both attacker and defender; while the nature of the ground conditions controlled the effectiveness with which defensive trench positions could be constructed. This meant that geology, which not only ultimately controls topography, but also the nature of ground conditions, was therefore one of the most important factors in the outcome of the siege warfare waged on the Western Front.

Trench warfare: military engineering geology

Trench warfare was in many ways a function of the offensive capability of modern weapons, and the desire to stop the war of movement by ‘digging in’. The creation of the trench lines in late 1914 did just that, and produced what was, in effect, two parallel fortresses that were exceptionally difficult to destroy, and which required extensive siege weapons.

It is important to understand that the situation of Allied trench systems was often greatly influenced by the General Staff's offensive policy and unwillingness to yield ground. The Allies (France, Britain and its Empire, Belgium, and later, Portugal and the USA) were fighting on French and Belgian soil and were on the tactical defensive, a situation that could only be reversed by a sustained tactical offensive. The Germans, on the other hand, had gained ground early in the war and were able to retain their position through maintenance of an overall defensive attitude.

In practical terms, this equated with an unwillingness, in the early parts of the war at least, of the Allies to construct permanent and sophisticated positions providing safe accommodation for the troops, and of an inability to actively select in advance the best tactical position for the trench lines. Therefore, deep shelters designed to protect troops from direct shellfire were mostly a feature of German defensive positions, while Allied positions had mostly small excavations in trench walls, or, later, cut and cover shelters using corrugated iron and sandbags. This meant in many cases that Allied lines were poorly situated with respect to topography and ground conditions, while German policy allowed for strategic withdrawal to carefully prepared and suitably located positions.

Three important factors may be identified: (1) the location of trench systems with respect to the topographic relief, which directly influenced their safety through exposure of troops direct observation and therefore to effective artillery or small arms fire; (2) the location of defensive positions with respect to the solid and drift geology, and the maintenance of the health, safety and well-being of the troops contained within them, and; (3) the nature of ground conditions in influencing the movement of troops, equipment, and later, tanks. In all three factors, accurate knowledge of topography and ground conditions was essential. This led to a series of detailed suitability surveys in the British area of operations, and to the production of a large body of trench, geological, hydrological and ground suitability maps which were produced during the war.

The recognition of the need for the establishment of a geological staff in the British armies was made in April 1915, and by May 1916, the British had two geologists who were attached to the Royal Engineers: Lieutenant (later Captain) W.B.R King working to the Chief Engineer, and Major (later Lieutenant Colonel) T.W. Edgeworth David, working under the Inspector of Mines. The responsibilities of this small establishment lay predominantly in the areas of water supply (King) and military mining and dugout construction (David). In turn, the Germans are known to have had a large geological establishment which, for example, had the benefit of the local geological information contained within the occupied city of Lille. These men all contributed to the development of warfare on the western Front.

For the most part, similar trench systems were employed by the main protagonists on the Western Front (Fig. 4). Trenches were constructed in roughly parallel rows, each trench approximately two metres deep, and 0.6 metres wide at the bottom, usually widening to two metres at its top. Raised earth works provided protection at the front (the 'parapet') and rear (the 'parados') of the trench lip. Trenches were constructed in right-angled ‘zigzag’ patterns of straight 'bays' designed to prevent enfilade fire (i.e. fire along the length of the trench), and to limit the effect of shellfire and bomb explosions. The forward, or front line, fire trench was equipped with a raised 'firestep' in forward projecting bays, so that troops could stand to see over the top of the trench for offensive action or night sentry duty. Daytime observation was carried out using periscopes.

The front line trenches of the opposing armies were separated by a belt of contested ground known as 'No Man's Land', usually extensively pitted by shell holes and mine craters. No Man's Land was bordered by belts of barbed wire entanglements which were renewed by wiring parties working under the cover of darkness. The second line or 'support' fire trenches were 10 to 30 metres behind the front line trenches, and these were in turn replaced by the final line of reserve trenches. These were intended as second and third lines of defence, but also enabled troops to concentrate before offensive action. The whole system could be encapsulated within a zone of 50 to 150 metres width, and access from the rear areas to each of the trenches in turn was through communication trenches, which traversed the ground between the lines of fire trenches. In some cases, particularly where the enemy controlled the high ground, tunnels were constructed to allow safe passage of troops to the front from the rear areas.

On the British front, the Royal Engineers were responsible for site investigations of ground suitable for dugout construction and concrete emplacements. Though initial site investigations of British trench positions was usually impossible, such investigations for dugouts were more extensive, particularly in the reserve areas, where they contained headquarters and medical staff. The results of these site investigations were published in a series of specially annotated geological maps for the Flanders battlefront that were primarily summaries of suitability of ground for the construction of defensive positions, particularly dugouts. Formations were mapped in the usual manner, but were denoted on the map in shades of blue or red, depending on whether they were suitable or unsuitable (i.e. water-bearing or permeable) for dugout construction.

Trench construction was usually carried out by labour battalions and fatigue parties, who had mostly to dig their trenches rapidly under the cover of darkness, generally with men spaced between two to three paces apart. Speed of digging was directly influenced by ground conditions, prevailing weather, and the nature of the troops. Little reference to the nature of the local geological structure was made, but it is clear that the success and ease of trench construction was directly influenced by three geological factors: (1) the position relative to slope; (2) the nature of the underlying geological material, and; (3) the relative position of the water table.

Position relative to slope was an important factor to be considered in the construction of trenches (Fig. 5). Basic principles for entrenchment were laid down that emphasized theoretical aspects of position in relation to forward and reverse slopes, valleys and spurs, and topographical height. These aspects were considered important in order to allow effective observation of opposing trench positions, to prevent enemy observation of forward and reserve trenches, and to provide necessary supportive arcs of fire for small arms. Ideally, the trench lines were to be designed to contour hills and valleys, particularly important in providing 'mutual enfilade' fire in valleys, the assaulting troops being attacked from both sides of the valley, and on the slopes of spurs by the defenders.

In all cases, the positioning relative to slope was to maximise observation of the enemy to direct artillery and machine gun fire. In the Ypres area, the British trench lines were positioned either at the foot of or on the reverse slopes of the sand ridges overlying the Kortrijk Formation. This made artillery observation difficult, and provided ample opportunity for accurate offensive fire from the German artillery. In the rolling Chalk upland of the Somme, British positions were more variably positioned, and more able to follow the guidelines laid down by the official regulations.

The nature of the underlying material and the position of the water table controlled both the ease of digging and the capability of the trench sides to remain intact without slumping (Fig. 6). In the Ypres area, trenches were cut in clays or poorly consolidated Palaeogene sands, and were therefore likely to slump or flow, and considerable revetment with wattle, sandbags or corrugated sheet iron was necessary (Fig. 7). Trench drainage was difficult, especially where cut into the impermeable Ypresian clay of the Kortrijk Formation. Pumping was usually necessary, and was a demanding and difficult task. Where trenches did not penetrate either the clay, or the overlying clays of the Paniselian Formation, some drainage was possible, but trenches cut through water-saturated sands, such as the Kemmel Sands of the Paniselian, usually lead to trench failure and slumping. On the Somme, trenches usually penetrated either the thick loess, loam and clay with flints, or were cut into the frost-shattered surface units of the Chalk. As with the trenches dug in the Ypres area, these were largely incapable of retaining trench side definition, and needed revetment, except in those rare cases where trench sides penetrated sound chalk. Drainage was problematic only where trenches were floored by impermeable clay with flints, or where trenches were deep enough to penetrate the zone of water saturated chalk.

Dugouts are underground shelters intended for a variety of uses, and their usefulness was largely controlled by local geology (Fig. 8). They may also be classified according to the depth to which they penetrate. Initially, shallow recesses were mostly cut into trench sides, and were constrained by the same factors as influenced trench construction. Those cut into sand units commonly gave limited protection, needing considerable revetment to stop movement. Cut and cover dugouts were essentially covered over trenches, with the same attendant problems. Deep shelters, the most desirable type, were intended to withstand direct shellfire, and therefore needed an adequate cover of undisturbed geology as a roof, usually between a minimum of two metres for light artillery fire and 16 metres to withstand heavy fire (Fig. 9).

Concrete shelters constructed at surface level were an alternative to the construction of deep dugouts.

In the Ypres area, satisfactory deep shelters could be constructed at depth in the impermeable clays. On the slopes of the Passchendaele and Messines ridges, water-bearing sands of the Gent and Tielt formations were apt to flow and were incapable of retaining the integrity of the dugout walls, although the overlying sandy clay units were more suitable. On the Somme, deep dugout construction was limited by the depth to water table, which varied according to season and maximum rainfall. The depth to saturated chalk was estimated through a programme of borings intended for the task. Shallow dugouts could be constructed in the overlying Quaternary deposits, as long as they did not cross boundaries between water bearing and impermeable units, leading to springs.

Offensive mining

Geological advice to the British army on military mining was the responsibility of Major Edgworth David. Military mines may be defined as any underground system intended for offensive action through explosion, or defensive action to counter enemy mining. Tunnels are intended for shelter and troop movements underground (Fig. 10). Mining and tunnelling was carried out by specialist mining units on both sides.

In Flanders, mining was inhibited by the nature of the subcrop of clays and sands. Surrounding Ypres, successful mining was mostly restricted to the Kortrijk Formation, or to the overlying clays of the Tielt Formation. The clay was worked by hand by miners known as 'clay kickers' to avoid noise and subsequent countermining by the Germans. Mechanical extraction was attempted, but was abandoned, and at least one boring machine remains underground today. Above these clay units, the sands and sandy clays of the Gent and Tielt formations, and of the Quaternary were mostly found to be too water saturated to work, the water perched on the clay below. Some sands, known as *Schwimsande* in German, had high pore water pressure leading to significant fluidity, and these prevented successful shallow mining operations in this sector, with average mine depths being between 20-30 metres.

On the Somme, successful mining operations were largely restricted by the height of the water table within the Chalk. This varied according to topography, and according to season.

Military resources: water supply and aggregates

Sufficient potable water for troops, horses and pack animals was of great importance to the armies engaged in all theatres of the war, and providing an adequate supply of potable water was a significant problem on the Western Front. In the majority of cases, it was hard to maintain water supply to the front line troops, most of which had to be brought forward from rear areas in containers. Such transport of water supplies from rear areas was costly in time and effort and therefore a major task was the investigation of local water supplies through bores.

In the Ypres area, peace-time water supply was largely derived from surface water in lakes, together with shallow wells tapping water perched on the Kortrijk Formation and other clays in the sands, surface loams and alluvium. Water supply for the troops was similarly to be obtained through purification of surface water supplies, and through borings.

In the Somme region, where surface water is relatively rare in the Chalk uplands, maintenance of a sufficient water supply was dependant on boring to the saturated chalk below the water table, and on pipelines. However, the position and shape of this water table was known to be variable, rising under the hills, and sinking towards the main river valleys, and constrained by underlying marls. The height of the water table was found to be in direct relationship with the amount of rainfall and evaporation, particularly in the winter, when rainfall was at its maximum, and evaporation at its minimum.

The survey and exploitation of locally-derived aggregates was of also great importance, as the static condition of the lines meant that enough resources had to be available for the construction of new roads and for concrete emplacements. Aggregates for road construction were mostly obtained from northern France and Brittany, outside the immediate area of operations on the Western Front. However, Quaternary river gravels in the valleys were examined for road stone extraction, and it was estimated that they had a yield of approximately 500 000 tons.

Aggregates for concrete emplacements for both sides of the British sector of the Western Front were also mostly derived from outside the immediate area of operations, quite simply because there were few suitable materials. The Germans made extensive use of concrete emplacements in the Ypres region, and aggregate resourcing for this was a considerable problem (Fig. 11). The British were able to demonstrate during the war that aggregates used by the Germans in concrete emplacements on the Passchendaele Ridge, which were captured in 1917, had been transported considerable distances through Holland from the Rhine, an infringement of Dutch neutrality.

Conclusions

Geology had a significant impact on the outcome of the Great War on the Western Front. In fact, many of the failed offensives, and human suffering of the Western Front can be traced to an insufficient understanding of the nature of the underlying geology. This is particularly the case in the Passchendaele Offensive which followed the Battle of Messines in Autumn 1917. Here, an intense bombardment led to the creation of an extensively cratered landscape in the Tertiary clays which was incapable of draining surface waters, and which was to be the graveyard of both men and machines; it is well known that tanks quickly became ineffective, hopelessly bogged down in this quagmire.

However, the British Army, through its small establishment of geologists attached to the Royal Engineers, did have a good understanding of the importance of geology to the waging of this static war, particularly where it came to the adequate provision of potable water, and in the construction of defensive positions. More often than not, the siting of these positions was more usually dictated by strategic policy rather than the best use of ground.

The experience of warfare on the Western Front was to directly influence post-war considerations of the applications of geology in war, particularly in the fields of: (1) military resourcing (water supply and aggregates/minerals); (2) military engineering geology (construction of defences, and military mining), and; (3) strategy and tactics with respect to ground. These principles remain important on the battlefield today, and any re-examination of past experience can only help in our level of understanding of these aspects.

Suggestions for further reading

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Figure Captions

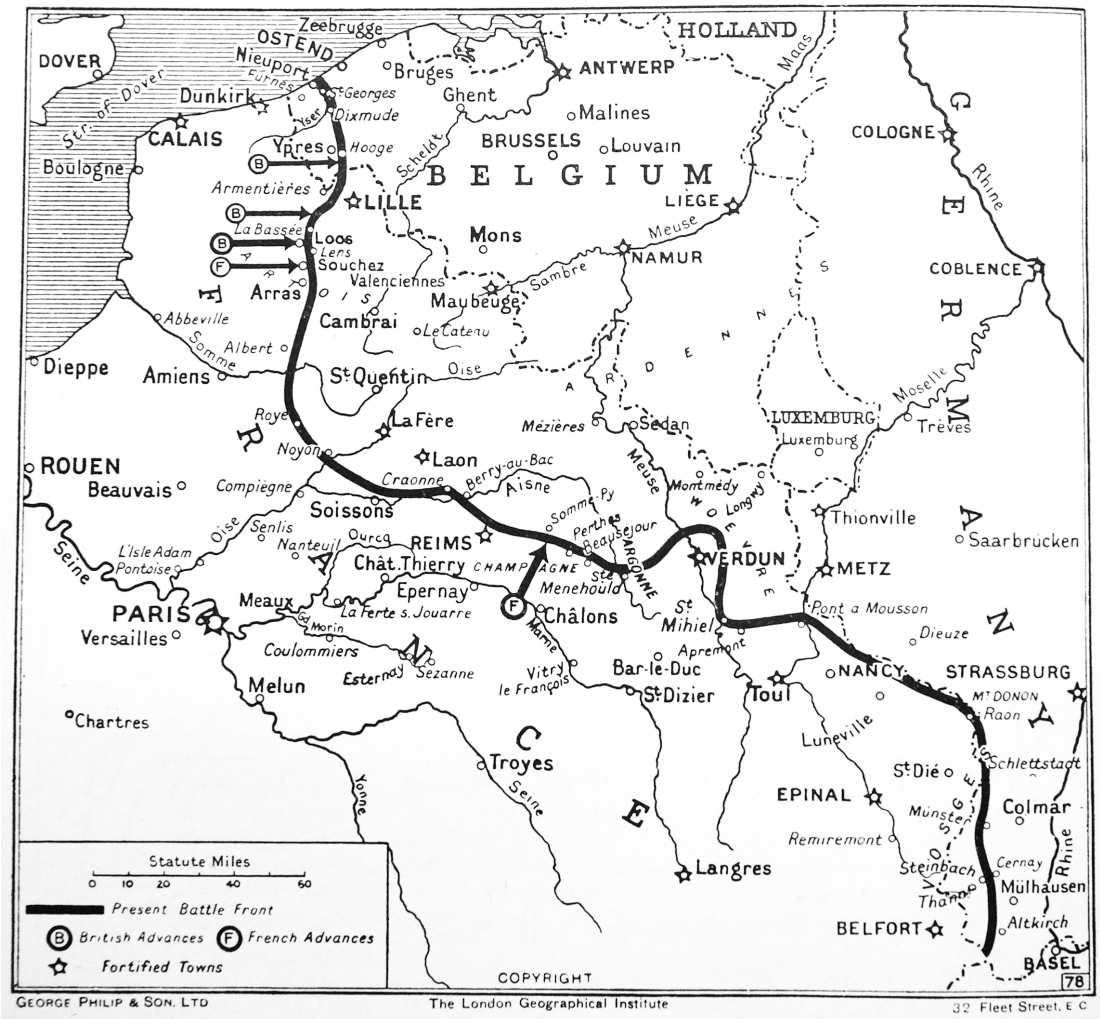

Fig. 1. The Western Front in 1915, stretching from the North Sea to the Swiss Frontier. Static from late 1914, the Allied offensives marked were intended to drive in the front line and cut off the great ‘knee’ at Noyon. They failed.

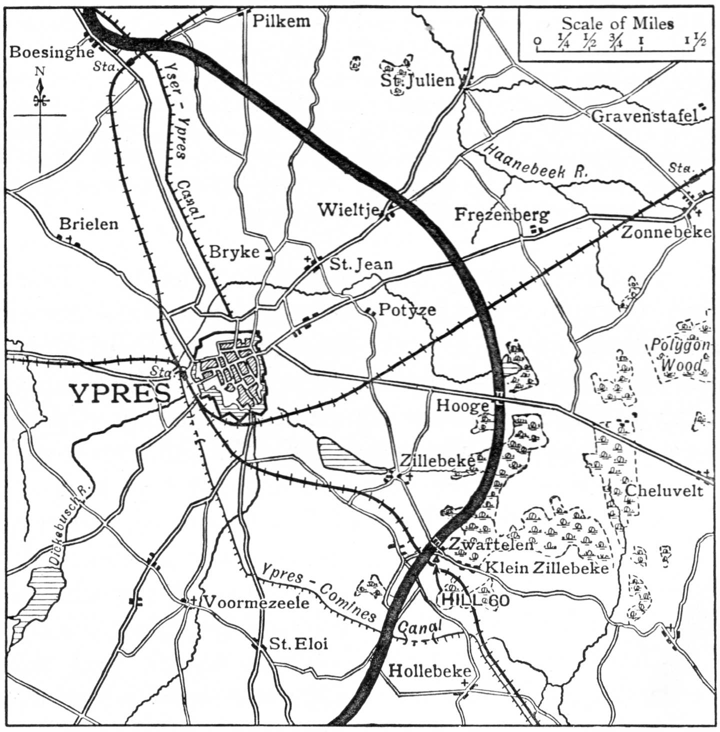

Fig. 2. The front line in front of the British-held Belgian town of Ypres. The German lines were constructed to hold the high ground, composed of mixed sand and clay units of the Gent and Tielt Formations, the British held the flat clay plain, composed of the clays of the Kortrijk Formation.

Fig. 3. British machine gunners (wearing gas helmets), in a contemporary colourized image, pose in shallow trenches on the Somme. Trenches here cut through variable Quaternary soils to the white chalk beneath.

Fig. 4. Model of a frontline trench system made c.1917 for the Canadian army, showing the frontline, communication trench, and support line, and the use of firebays and traverses

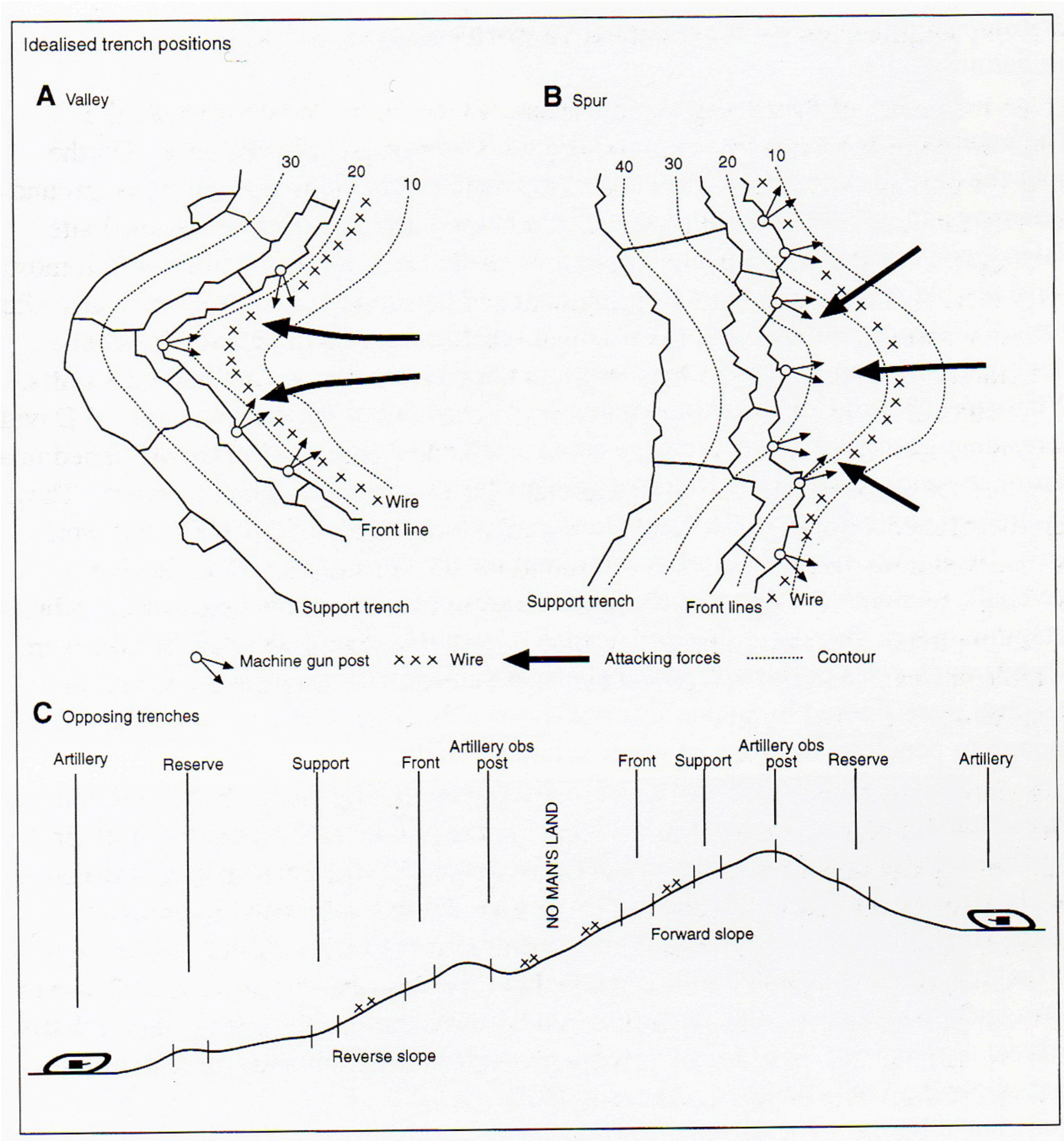

Fig. 5. Idealized positioning of trench lines relative to topography (from Doyle, 1998)

Fig. 6. Excavated British trenches cut through Ypresian clays and Quaternary cover in the Ypres region, showing the complex timber inverted A-frame system that was necessary to both support the trench sides, and to provide the means of constructing a system of duckboards that allowed men to walk above the level of saturated ground. (Image: Peter Doyle)

Fig. 7. Excavated German trenches cutting through mixed sediments of the Gent Formation near Messines, near Ypres. The trench is floored with timber slat duckboards, and has been revetted using timber reclaimed from destroyed houses. (Image: Peter Doyle)

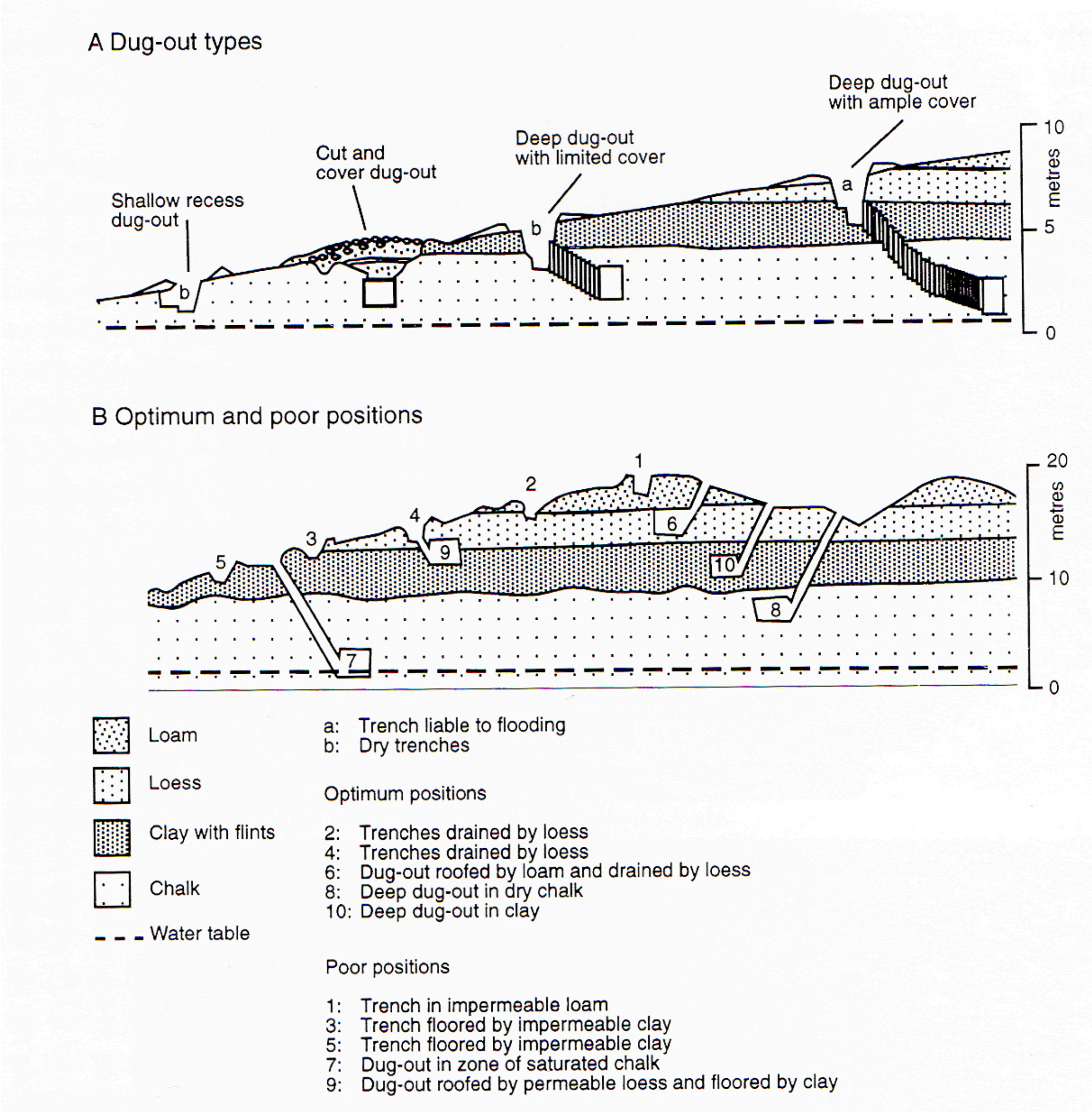

Fig. 8. The position of dugouts in the Ypres area, relative to geology. (From Brooks 1919, Doyle 1998)

Fig. 9. Steps down into a dugout on the Passchendaele Ridge, cutting through glauconitic sediments of the Gent Formation. The dugout has been excavated and unroofed. (Image: Johan Vandewalle)

Fig. 10. Shallow German tunnel excavated at Messines in 2012, showing its strong German timber construction. (Image: Peter Doyle)

Fig. 11. Australian concrete fortification at Hill 60, near Ypres, constructed using flint aggregates. It is built on an earlier German concrete blockhouse, with mixed aggregates derived from the Rhine valley (Image: Peter Doyle)