MGPB

The Mining-Geology-Petroleum Engineering Bulletin
UDC: 550.8
DOI: 10.17794/rgn.2016.1.1

Original scientific paper

The influence of geology on the course and outcome of the Third Battle of Ypres (Flanders, WW1)

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Summary

Geological structure of the terrain as a ground for a battlefield could be a significant factor for the success or failure of a military operation. The geology of the Belgian town of Ypres was an important, maybe even crucial factor, of the failure of the WWI Allied Powers offensive military operations against German Axis forces in 1917. The Early Eocene clays found at the ground surface at Ypres, coupled with excess precipitation, turned out to be utterly inappropriate for the fortification, movement, fighting and manoeuvring of all military units, especially the armoured units that were directed towards hardly passable routes. With selecting the unsuitable and hardly passable terrain, that is the direction of the attack, the British army had losses of the available combat potential and armoured forces were ineffective during the battle. The total number of Allied casualties was 448,000 dead, wounded, imprisoned and missing. This paper offers other possible solutions that would, from a military geographic and military geological viewpoint, have made a better solution for achieving the strategic goal required by the Allies on the eve of the Third Battle of Ypres in 1917.

Key words
Military geology, military geography, military terrain analysis, tank manoeuvrability, military history

1. Introduction

Military geology is a discipline of geology that analyses manoeuvrability in battlefields, the supply of military units with potable water and mineral raw materials, determines favourable locations for the construction of fortifications, i.e. entrenching of the military units (**Zečević & Jungwirth, 2007; Zečević, 2011a**). Military geologists can also give useful advice regarding the construction of military roads, airports and helipads, in logistics during the planning of the most favourable routes for transportation and movement of various types of vehicles, while analyzing satellite images and various thematic maps and map charts for a specified purpose, during terrain cleaning and protection of the environment during and after conduct of the military operation, as well as during detection and assessment of the vulnerability of subsurface military facilities (**Zečević, 2011b**). While solving a military problem by using geological knowledge, military geology applies a geological approach and methodology in the context of the analysis of military processes affected by the geological structure of the terrain, i.e. it observes the interaction of the geological and pedological basis of the battlefield and military machinery and manpower that move on that basis or engage by fire on the battlefield with various types of projectiles. Military geology analyses features of the geological and pedological basis as an environment in which various geotechnical facilities such as military trenches are constructed as well as more complex entrenched facilities such as deeply dug in command posts or bunkers (**Zečević & Jungwirth, 2007; Zečević, 2011b,c**). During that process, military geology also applies experience, knowledge and methods of other technical and natural sciences as well as achievements of military sciences and war skills. Military-geological analyses of the terrain includes, in addition to the application of geological knowledge, knowledge of tactical-technical features of the military weapons and equipment (tanks, artillery, engineering machines, airplane bombs) and their use is greatly affected by characteristics of the land (**Halsall, 2000; Rose et al., 2006; Zečević, 2011b,c; Mather 2012**).

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The aim of this paper is to show that the geological structure underlying battlefield terrain can be a significant factor for the success or failure of a military operation. An example for a battle in which the geological structure of the terrain had a significant influence on the outcome discussed here is the Third Battle of Ypres in 1917. The motive behind the battle, that is the goal of the military operation, was the occupation of the strategically important coastal harbours of Ostende and Zeebrugge. These harbours were anchorages and logistic centres for the submarine war enabling the range of operation of the German submarines. The geology of the Ypres battlefield, coupled with excess precipitation, turned out to be utterly inappropriate for the fortification, movement, fighting and manoeuvring of all military units, especially the armoured units that were directed towards hardly passable routes. Despite the total number of casualties of the Allied Powers (Entente Powers) during the Third Battle of Ypres was 448.000 dead, wounded, imprisoned and missing (**Trnski, 2009**), the strategic goal was not achieved.

In this paper the methodology of military geological and military geographic analysis of the terrain was used as well as historical references such as available books, scientific and professional works, and approximately four hundred original photos of the Ypres battlefield shot during World War I representing the negative impact of subsoil geology on the military operations. Likewise, historical atlases describing the Ypres battlefield in World War I or a wider area (West European battlefield) have been analysed. By comparing topographic and geological charts of a certain terrain, the impact of the terrain - battlefield on the military operation is shown more clearly. The paper analyses how the clay on the surface of the terrain as a ground of the battlefield, in the interaction with precipitation influences the role and task of a service or a branch of the armed forces, e.g., tank units, artillery, infantry, cavalry, engineering and logistics. The main issue of this paper is to analyse and understand the reasons why the Allied Powers used tanks on the unfavourable geological ground at Ypres, where all branches of the land forces had problems in fortification, movement, firing and manoeuvring during 1914 and 1916, and started an offensive in the second half of 1917. Moreover the paper searches for answers on the influence of the unfavourable geological ground of the battlefield during the course and outcome of the battle, as well as considering other potential military geographic routes which may have been a better option for the achievement of strategic goal with regards to positive features of the geological ground that could enhance combat effectiveness through the synergy of the different branches on the battlefield.

2. The motive and historical context of the Third Battle of Ypres

The motive behind the Third Battle of Ypres, also known as the Battle for Passchendaele, was an order given to the British Expeditionary Force (BEF) from the British Navy to capture two strategic harbours at the Belgium coast (Ostende and Zeebrugge). During 1914, the German Army advanced quickly through Belgium taking over the harbours of Ostende and Zeebrugge which were used by the German Navy to make these harbours strongholds and logistical centres for submarine warfare. These naval bases enabled German submarines to control Dover Strait and attack the Allied (Entente Powers) ships at the East coast of Great Britain. The war plan of the German Army was to surround the French Army in the area of the French – Swiss border by a quick penetration through Belgium and the North of France. However, in September 1914, the French and British Army stopped the German offensive on the river Marne Northeast of Paris whereas Belgium and British armies kept German units from Nieuport to Ypres (in the First Battle of Ypres). The entire battlefield of the two armies, from Nieuport at the Belgium coast to the town of Ypres was intersected by river flows and canals, a flood defence system, flood barriers and water level regulation systems. Therefore the area was flooded initially when the Belgium army was withdrawing, and to a lesser extent by the collapsing of drainage canals due to artillery shelling (**Johnson, 1921**). In some places, the terrain was very swampy. The retention of water at the surface of the terrain, i.e., slugged artificial and natural drainage of the soil after precipitation, together with other causes of military actions is due to the geological foundation of the terrain made of Ypresian clay from the Kortrijk formation (of Lower Eocenian age) and it is identical to London clay from the South of England (**Doyle, 2012**). The layers of clay are impermeable, so they do not allow water to permeate, and hence the plains retain water on the surface of the terrain.

During 1914, the war at the Western European battlefield stabilized gradually, and a demarcation line stretched from Dover Strait and the town of Nieuport on the Belgian coast through Ypres, and from Arras south towards the river Aisne, and to Verden, and further towards the French-Swiss border. At the end of 1914 and at the beginning of 1915, it was static trench warfare and movements on the Ypres Battlefield were ranging between a few hundred metres to ten metres at the advantage of one or the other side, only. After the first and the second battle of Ypres, the terrain was

covered with craters and the road infrastructure and construction facilities were damaged or destroyed North and Northeast of Ypres, in the area of approximately 125 square kilometres. The town Ypres itself was heavily damaged.

During 1917, German submarines had great success in sinking ships of the Allied Powers. This success in naval warfare could be substantiated with the fact that in 1917, when Germany proclaimed unlimited submarine warfare, the German submarines sank 6 million GRT (gross register tonnage) of the Allied Powers ships (**Ogorec, 2001**).
A successful submarine warfare was enabled by naval bases on the Belgium coast. The British Navy set up a strategic goal to overtake the Ostende and Zeebrugge harbours. The goal was considered in the context of inland conquering from the south from the direction of Ypres together with coordinated amphibious landing along the Belgium coast from the direction of Dover Strait, i.e., the combination of these two routes. However, the amphibious landing (Hush Operation) was cancelled. One of the reasons for the cancellation of the amphibious landing was the German stronghold on the coastline and strong coastal batteries around the Ostende and Zeebrugge harbours as well as the unsuccessful breakthrough of British-French forces from the South through West Flanders from Ypres towards the North. The plan of the battle of the Entente Powers was to break through the enemy positions advancing through Western Belgium and take over German submarine bases (**Trnski, 2009**).

French forces and the forces of the British Empire (composed of the armed forces of Great Britain, Australia, Canada, New Zealand and South Africa) participated in the preparation of the attack. On the eve of the Third Battle of Ypres, the German forces were composed of 15 divisions, whereas British and French had 36 divisions. A great advantage for the Allied Powers was the British Expeditionary Force (BEF) having 136 tanks at their disposal (**Evans, 2005**). *Mark IV* type heavy tanks of 28.4 tons participated in the preparation for the attack while the German forces did not have tanks at their disposal at that time. The British Field Marshal Douglas Haig decided to entrust the offensive military operation to General Hubert Gough, Commander of 5th British Army for whom he believed to be capable of conducting the planned attack. Gough's 5th British Army (a total of 18 divisions) was situated in the central part of the battlefield with the HQ in Ypres. Northwest, at the left wing of the attack there was the French Army (1st French Army with a total of 6 divisions) under the command of General Francois Anthoine, and in the South, at the right wing there was the 2nd British Army (a total of 12 divisions) under the command of General Herbert Plumer.

3. Military geographic description of the Ypres Battlefield

3.1. Relief

Lowland terrain between Ypres and the Belgian coastline that is only partly forested would be an ideal terrain for manoeuvring if it did not have the soil of the battlefield whose natural foundation is made of a clay cover with a dense hydrographical network. Manoeuvrable land is suitable for the movement of units outside the lines of communications, construction of fortification works, organizing of firing systems, that allows for the simple manoeuvring of units, and it made it easily passable with open spaces of lowland, hilly and mountainous land with no high vegetation and no large urban areas and swamps (**Pahernik, 2012**).

The mean height in the Ypres area towards the North is only 20 to 30 metres above sea level with only low-angle slopes down to the Belgium coastline towards the Ostende and Zeebrugge harbours. From Ypres toward the North the terrain is mildly hilly and east and southeast of Ypres, there is a ridge with a few smaller ridges. There was fighting to take over these elevations because by conquering them there is a significant tactical advantage for the side who takes them and not only because there is good visual control of the battlefield but because meteoric waters do not retain at the elevated terrain, while the terrain in the lowlands is soaked with water during the winter months.

South of Ypres the surface terrain is mildly hilly up to the carbonates aligned northwest southeast, with the mean plateau top at about 150 metres above sea level.

3.2. Hydrography

In the area of West Flanders from the town of Ypres toward the Belgian coastline, the hydrographic network is dense with many streams, drainage canals and rivers (**Figure 1**). One of the causes of this network is the clay ground that does not let the water under the soil but it keeps it on the surface. Because of that, the area of West Flanders is swampy in some places, and the swampy areas spread in the late autumn and winter.

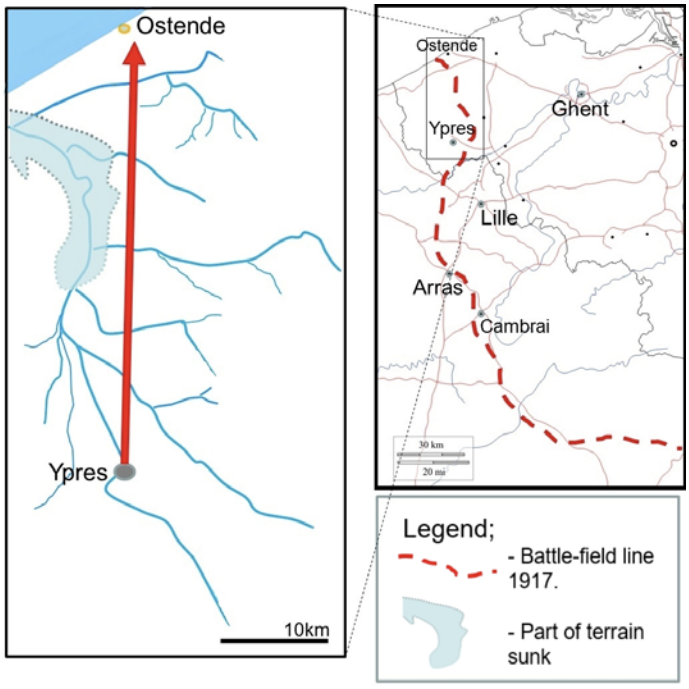


Figure 1 Schematic hydrographic map of Ypres area with the outlined direction of the attack in 1917

In the narrow area around the Ypres River Yser, one important canal passes through Ypres in the northwestern direction. The defence of the British forces was supported by that canal and they kept that position from 1914 until the beginning of the Third Battle of Ypres in 1917. This canal was important to the British in the previous defensive operation; however the density of the hydrographic network on the route of main efforts of the Entente Powers toward the Belgian harbours had an unfavourable effect (**Figure 1**). On the route of the attack from Ypres towards Ostende harbour, there is a water obstacle of several streams and rivers that had to be passed by force during the assault operations. Rivers, streams, canals and swamps that are on the way of the main assault are, due to their clay banks and sludgy bottoms, entirely unsuitable for the passing of tanks, and unfavourable for overbridging with engineering means.

3.3. The forested terrain and lines of communications (road and railroad network)

The terrain around Ypres was forested in the East only, with a ridge around 60 m high, and even that forested area was heavily damaged in previous battles because the demarcation line went through these forests in 1914 and 1915. Forested terrain in the broader Ypres area, with regard to its position and surface area, did not present a significant barrier for the movement and manoeuvring of infantry and tanks in the direction of the main effort of the Entente Powers from Ypres towards the Belgian harbours.

During World War I, Ypres had a well-developed road and railroad infrastructure but the quality of the roads was poor and unsuitable for the movement of heavy tanks of *Mark IV* type. These were the macadam roads on clay soil towards Passchendaele. Macadam is a type of road construction with single-sized aggregate layers of gravel, with a coating of binder as a cementing agent. During the Third Battle of Ypres, the roads were wet, and the layers of gravel on the clay surface were too thin to withstand the movement of heavy tanks of *Mark IV* type (**Figure 2**).

Figure 2 British tank sunk in the mud at the entrance to Poelcappelle **(URL1)**

4. Preparation and the course of the Third Battle of Ypres

The Third Battle of Ypres, (the Battle for Passchendaele) was conducted from July 31st to November 10th, 1917. Preparations for the battle started two months before. During the planning and preparations for the battle, the command of the British armoured forces (Tank Corps) warned that further collapse of the drainage canals around Ypres during the artillery shelling, as well as spreading of swampy areas during the autumn and winter, could jeopardize the conduct of military operations (**Hart, 1985**). However, the British Field Marshal Douglas Haig did not refrain from the planned route of attack from Ypres towards the Belgian harbours Ostende and Zeebrugge.

The shelling of the German defensive positions started on July 22nd, 1917 from 2,300 artillery weapons and lasted for ten days until July 31st when under heavy rain the British infantry went for an attack on the 25 km wide front (**Hart, 1985**). Before the start of the battle, the British shelled 4,283,550 grenades (**Evans, 2005**). Due to the long duration of shelling, there was no surprise moment and the soft clay soil of the terrain made the battlefield covered with deep shell

craters. When the British tanks attacked, a significant number of them got stuck in the mud (**Evans, 2005**). German combat lines were set up in a way that the least number of soldiers was killed from the enemy artillery, and the resistance of the defensive forces strengthened and an Allied breakthrough was unsuccessful. On the day of the attack, the terrain was soaked with water because 20 mm of rain fell down per square metre. Despite the rain that was falling, the British and French army achieved some success in the following weeks.

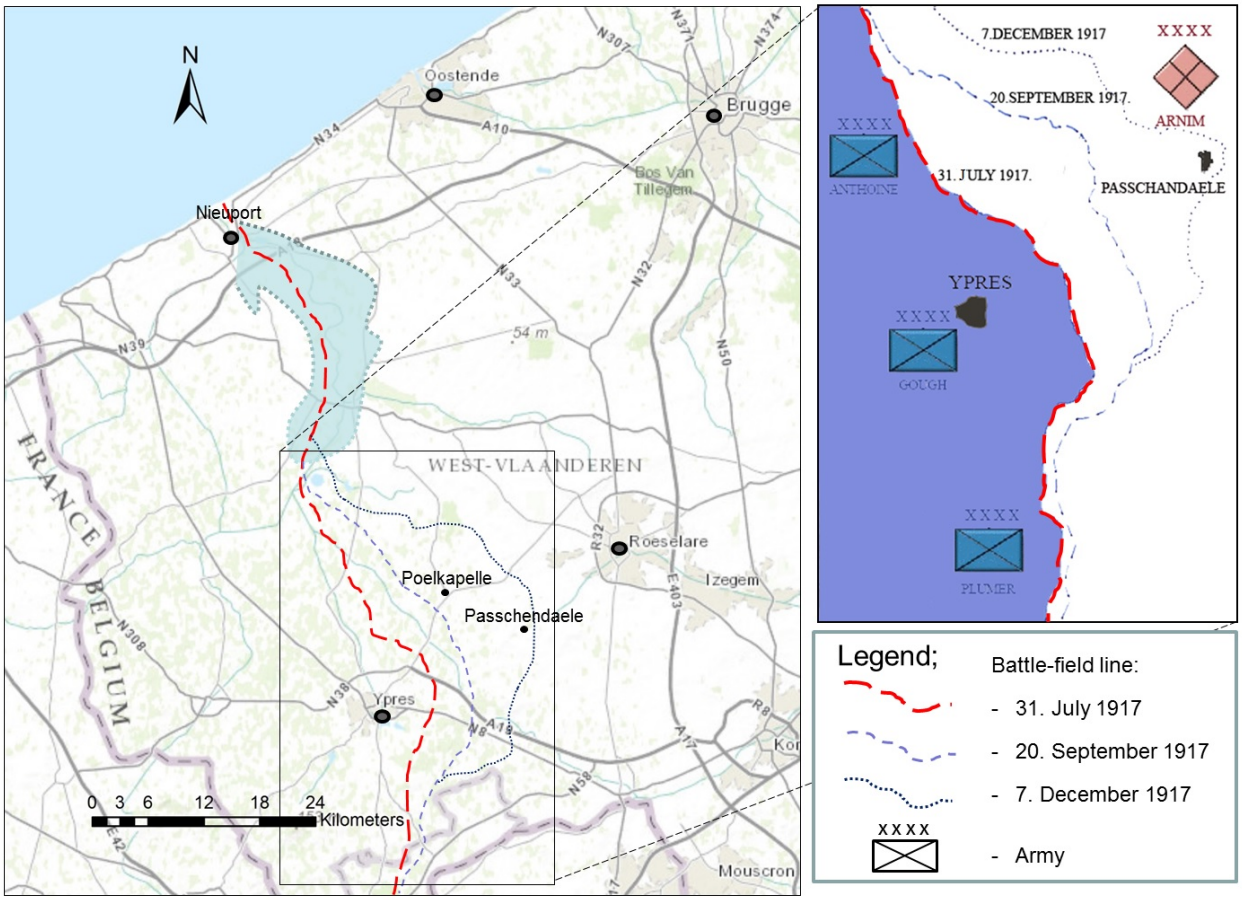
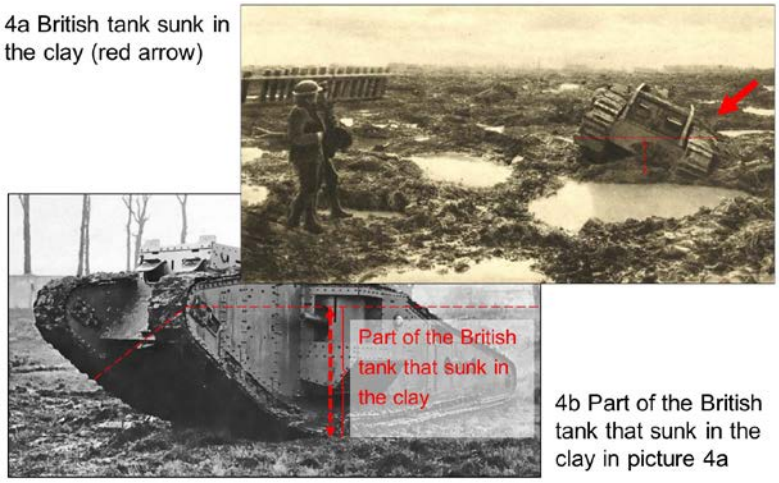


Figure 3 Schematic map of demarcation line, initial formation of forces and advances in the course of the battle

The German forces led frequent counter-attacks which resulted in original defence lines being retaken. In the first fifty days of the battle (July 31st until September 20th), the Allied Powers pushed about 4 kilometres into enemy territory (**Figure 3**) which was far from successful. Ostende harbour is approximately 45 kilometres away from the North of Ypres and as the course of the battle was going on, it became more and more obvious that the harbours of Ostende and Zeebrugge would not be achieved.

The Third Battle of Ypres could be divided into three stages. In the first stage, from July 31st until September 20th, during the first fifty days of the battle, the British forces, with great losses in the central frontline, penetrated 4 kilometres towards the North. That was far from the planned action and could not be called a success. If the German



lines were deeply penetrated, and if the British used their advantage and chased their enemy, that could be called a success. In that case, one British division would have landed southeast of the Ostende harbour, i.e., there would have been the amphibious landing (Hush Operation) for which special vessels had been designed for the landing of tanks (**Evans, 2005**). Operation of the amphibious landing could be conducted only during the high tide at the end of August or, in case of failure during the breakthrough in the South of Flanders, it would have been delayed for one month. Since the successful breakthrough had not been achieved in the first days, the landing was therefore cancelled.

Figure 4 The terrain in the lowlands is soaked with water (Figure 4a; **Stern, 1919**) and certain tanks became immersed in clay almost up to the half of the tank height (Figure 4b; **URL2**)

The initial stage of the battle was marked by heavy rainfall. In the first days of the battle, despite the problems with the terrain, the tank was recognized as an effective weapon. However, as time passed, the terrain became more and more muddy, wet and rutted by the artillery barrage and became unsuitable for the use of tanks (**Figure 4**), and certain tanks became immersed in clay (**Figure 4a**), i.e., almost up to the half of the tank height (**Figure 4b**). Road infrastructure was also partially destroyed by the artillery barrage, which presented a big problem for the movement of artillery and supply. During the attack on the village of St. Julien, initially the tanks took a farm and some German trenches south of the village, but the majority of the tanks got stuck in the mud at the south access roads to St. Julien. Engineering units also had problems building a temporary bridge over the river Steenbek because the old bridge on the road to St. Julien was destroyed. This temporary bridge sunk under the weight of two tanks passing over it and the bridge ended up in the water. The weakest advance was in the east at the road towards Menin where a forest was taken by the Allies and then repulsed by German forces nineteen times (**Evans, 2005**). At the end of this stage, the town of Langemarck north of Ypres was conquered but with great British and French losses.

Due to the unsuccessful outcome of the operation, Field Marshal Haig was disappointed in General Gough so he was replaced by General Plumer who began the second stage of the battle. Fierce battles were conducted in the following days for each ridge area and for the village of Gheluvelt in the lowlands of the ridge (**Evans, 2005**). The continuation of the advances along the ridge toward the North would have enabled the favourable conditions for the attack of Passchendaele. On October 2nd, there was heavy rain that continued falling almost every day until the end of the month. The land was saturated and surface terrain was made difficult by artillery. Macadam roads that were important for the movement of the army turned into a quagmire which made supply difficult, and the transport of artillery was almost impossible (**Figure 5**). In such conditions, the British and German infantry took turns with assaults in which bayonets were the main weapons utilised. During the following four days, 25 mm of rain per square metre fell down (**Evans, 2005**).

Figure 5 Handling an 18-pounder field gun through mud near Langemarck, October 16th, 1917 (**URL3**)

The third and final stage of the Third Battle of Ypres started on October 9th by an attack on Passchendaele. The terrain turned into a swamp. The conditions were unfavourable for the movements of tanks and artillery, and therefore the infantry could not attack effectively and there were no significant advances on the battlefield. However, Field Marshal Haig firmly decided to continue attacking, convinced that the German units were on the verge of collapse. German defence lines that were soaked with water were less disposed to artillery. As they regarded the swampy terrain and the level of the ground water, the Germans built concrete dugouts above ground around the Passchendaele village. The artillery that gave support to British infantry on October 12th, 1917 was ineffective (translated from **Evans, 2005**): "because, due to bad weather, the air surveillance was excluded, and the shelled grenades plunged deep into the mud while spurting forth the rain of mud but could not cut the barbed wire nor could they destroy the dugouts." Additional pressure was put on Field Marshal Haig and the BEF (*British Expeditionary Force*) after the information was given that the Central Powers grouped the army of forty two divisions on the Italian battlefield, and the BEF was asked to urgently bring additional forces. The second information that made Field Marshal Haig worry was that the state power of Russia was seriously shaken and that in the near future, German divisions could be transferred from the Russian battlefield to the West European battlefield. The Germans received strength support in the third stage of the battle from the Russian battlefield made of twelve divisions that were originally intended for the Italian battlefield.

During the attack that started on October 26th at 5.40 a.m., the British units (the 7th and 5th Divisions) moved through the swampy plain towards Passchendaele, and the Canadian 46th Battalion and the Australian 18th Battalion moved on the ridge towards Passchendaele. The attack began during the morning mist which was replaced by the rain during the day. German dugouts were on the elevated places above the swampy land. The Canadians were taking over one dugout after another on the bridge with great losses, and the British advanced more slowly through the swampy plain, also with great losses. During the first three days of the attack on Passchendaele, the Canadians lost 2,481 soldiers, of which 585 were killed (**Evans, 2005**). In the following few days, the Germans started a few counter-attacks but with no great success. According to the reports of the 6th Brigade of the 2nd Canadian Division, the depth of the swamp around the river Ravebeek at the roads toward Passchendaele was "knee deep, and in certain places waist deep" (**Evans, 2005**). During the attacks on November 6th, there were fierce battles to take over the dugouts at the entry in Passchendaele so that Canadian units took over the village at 08:45 after heavy battles. On November 10th, 1917, the British and Canadian

units repulsed the Germans several hundred metres north of Passchendaele and thus formed a wedge north of Passchendaele which was the last move during the Third battle of Ypres. With that, after 102 days of fighting, the Third battle of Ypres finished. The operation was officially ended on November 15th. The losses of the Allied Powers amounted to 448,000 soldiers (**Trnski, 2009**) while the strategic goal had not been achieved. The conquered terrain was partly swampy and the trenches were wet and muddy, and being in such conditions was extremely difficult for the army to keep those positions (**Horvat, 1967**). A significant number of British soldiers got sick during and after the battle as a result of moving through swampy terrain and staying in muddy trenches. The villages and road infrastructure at the conquered area was destroyed considerably and such wrecked and swampy terrain did not present a suitable operational basis for the potential breakthrough towards the North.

5. Analyses of the impact of topography and geology on the course of the Battle of Ypres

Both topography and subsoil geology had an important influence on fortification, the effect of artillery fire as well as movement and manoeuvrability in the Flanders battlefield.

5.1. Geological structure of the battlefield

The wider area of the battlefield around the city of Ypres is situated on clay soil that was locally termed "clay-cover". In general, the mineralogical composition of the Early Eocene Ypresian clay in Northwestern Belgium consists of a greater portion of smectite and ilite mica minerals, and a significantly smaller portion of kaolinite. In addition to clay minerals, grains of quartz-sands are also significantly represented with a very minor presence of calcium-carbonate minerals (**Van Marcke & Laenen, 2005**). Although by comparison of the mineral composition on single locations, Ypresian clay demonstrates certain heterogeneities, and it could be assumed that within the same geological formation in Belgium and Northern France, Ypresian clay had similar general geotechnical and engineering-geological characteristics on the conduct of military operations. Photographs taken in the battlefield clearly show that specific features of the clay-deposits such as clay swelling, plasticity and the phenomenon of sliding, dredging, creep or flow became prominent (**Figure 6)**. This negative influence of the clay as an environment in which military trenches are built was noticed by German military geologists (**Bülow et al., 1938**) who described their observations in the book "Wehrgeologie". The construction and maintenance of trenches and other fortification facilities on such geology can be rendered significantly more difficult due to deformations of the wall of the trench and the accumulation of meteoric water (**Figure 6**). The movement of tanks, artillery and other types of vehicles on such ground can also be significantly rendered more difficult and such ground may completely render any movement impossible. In general, clay saturated with water is plastic and in such a compact state, it is markedly unfavourable as a battlefield ground. In a completely dry state, the soil is solid and allows for movement and manoeuvring of the forces on the battlefield.

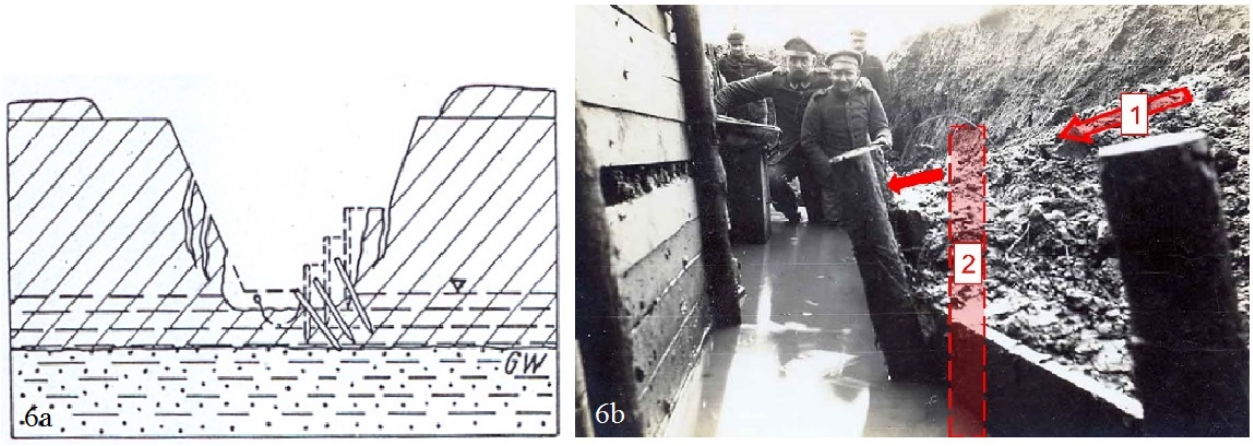


Figure 6 Profile of a trench (6a) dug in clay soil with displayed deformations on the trench wall (**Bülow et al., 1938**) and a trench dug in clay (6b) on which a sliding phenomenon is visible (1 – sliding direction, 2 – initial position of the stake) (**Photographer not identified; observations and marks on the photo were made by the author of the article**)

Holocene (Quaternary) sands in coastal-dunes are situated in the wider area around Ypres along the Belgian coast, the battlefield area around the city of Ypres is situated on clay soil formed of Eocene (Tertiary) "Ypresian clay", North of Ypres Eocene (Tertiary) sands. This can be found along the border to the Netherlands, situated North of Ypres and in some places South and East of Ypres. Layers built of Eocene (Tertiary) clays and sands (**Figure 7**) are found. In general, all the stated Quaternary and Tertiary sediment rocks and soils are not favourable for fortification, movement, firing and manoeuvring. Quaternary and Tertiary sediment rocks overlie Late Cretaceous calcareous rocks that are placed under the "clay-cover", and exposure of calcareous rocks are situated South of Ypres as calcareous upland sand in the Southeast in the calcareous plain.

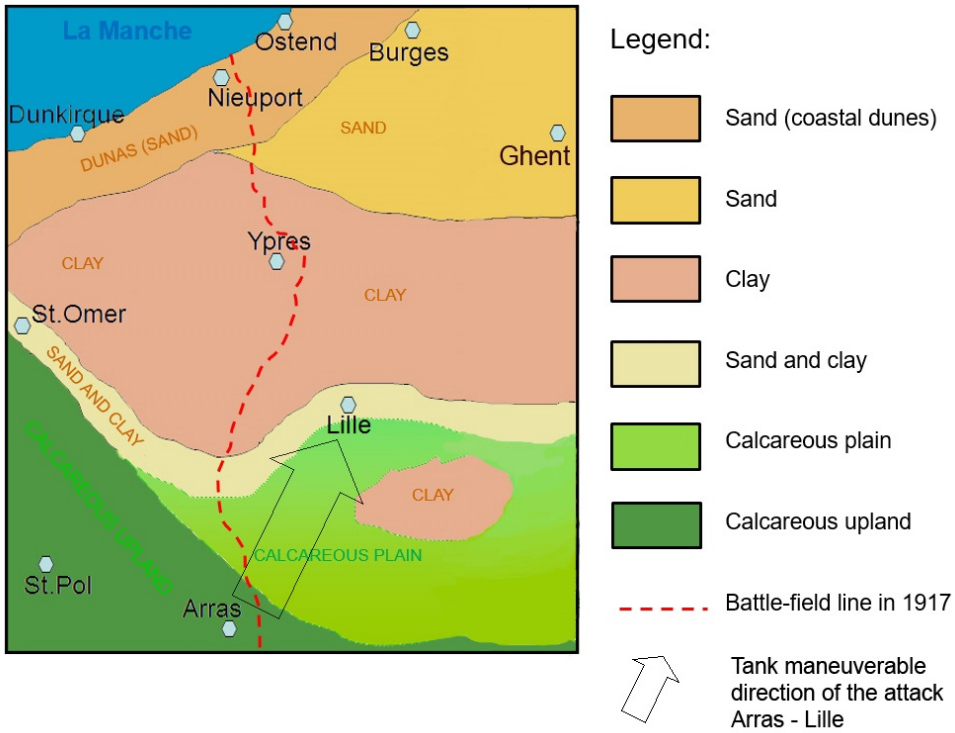


Figure 7 Geological (lithologic) terrain structure – battlefield of the wider area of Ypres (**modified after Johnson, 1921**)

5.2. The effect on fortification

From historical times, armies look to protect their troops, equipment and other resources from their opponents' operations. One of the manners of protection is the fortification of facilities. In a broader sense, the construction of fortification represents preparation of the position for defence of the units in a particular area and that includes engineering works on a specific geological ground (**Zečević, 2011c**). Geomorphologic, geological and hydrogeological characteristics of the terrain predetermine particular parts of the battlefield for various types of trenches and subsurface military facilities to be created, as well as the depth on which they can be built or entirely exclude any possibility of their construction. In some geological environments, construction of the systems of trenches, subsurface military facilities and tunnels will not be favourable or it will be carried out with great difficulty, either due to hydrogeological conditions (due to the character and level of the subsurface water), engineering-geological conditions (due to land-slide, scree, systems of faulting or cracks) or to geotechnical conditions (**Zečević & Jungwirth, 2007; Zečević, 2011a**). If a

trench is built on a soil that is too soft or in a rock as, for example, the example of clay and clay-marl, deformations of the rock mass or soil could occur due to meteoric and ground water (**Figure 6**). Entrenching in clays is also unfavourable from a viewpoint of the materials resilience (geotechnical basis) on artillery strikes of various calibre and bombing from the air. The occurrence of dredging and flow is frequently found within a military trench that is dug in clays as a consequence of the trench being soaked with meteoric and subsurface waters and this often causes caving-in or filling-in of the trench (**Figure 6**). Such occurrences render impossible the construction of other types of fortifications and auxiliary facilities as are, for example, entrenched, i.e. dug-in field ammunition warehouses. It is only possible to build trenches and above-land bunkers on elevated terrain. Due to that, the Germans built above-land bunkers of reinforced concrete on the upland area around Ypres where meteoric water was on lower parts of the terrain.

5.3. The effect on artillery fire

The state of the clay of the terrain – the battlefield during the Third Battle of Ypres, had a negative influence on the role of British artillery during conduct of the military operation. That resulted in the imprecision of artillery fire due to the instability of the fire positions, i.e. it had been impossible for the gun to be placed stably on the land and to deliver consistent fire. Artillery fire on the opponent's targets was also ineffective because shells penetrated the clay deeply and turned out mud so that after a shell exploded, there was no effect of covering a wider area of the terrain with shell fragments. Unlike clay, solid carbonates on the battlefield increases the radius of coverage and effect of the shell's explosion (**Zečević & Jungwirth, 2007**). In the Battle of Ypres, the effect of artillery during preparation for the attack was often counterproductive because after artillery fire, the soft clay of the terrain was covered with craters and rendered the movement of tanks and infantry more difficult. Equally so, a geological basis in interaction with meteoric water had an unfavourable effect on entrenching (digging-in) of the artillery positions, storage of the artillery ammunition on the battlefield in field warehouses, on supply of the artillery with ammunition (transportation of ammunition) and on movement of the artillery that accompanied tanks and infantry during advance.

5.4. The effect on movement and manoeuvre

Manoeuvring as a combat function is efficient if it is in synergy with the fire effect (joint fire). Combat power, among other things, also constitutes manoeuvre effects. The basis for the creation of manoeuvre effects is knowledge of the enemy and the manoeuvrability of the land, effective reconnaissance and other intelligence operations, efficient command and control, coordination of the forces and timely and sufficient logistic support. In the case of the Third Battle of Ypres, the manoeuvre effect had failed to take place as a consequence of hardly passable or in some places, impassable terrain on unfavourable geological ground, so that tanks could not become prominent. A great number of British tanks had already sunk in unfavourable clay on lines of departure or on no man's land and they were a good immobile target for adversarial artillery, and on one occasion were seized by the German army during counterattacks.

Roads are important for the movement and manoeuvring of forces. Macadam roads on clay near Ypres had been markedly unfavourable for the crossing of the *Mark IV* heavy tanks but also for other types of military vehicles during the wet seasons. Due to its nature, it had been very easy to inflict damage with artillery strikes to macadam roads near Ypres and repair was more demanding than in the case of macadam roads with solid ground. In some places, British units built military roads that were covered with wooden boards. In principle, military roads have a temporary character and differ from civilian roads by the manner, quality and dynamics of workmanship as well as by the length (steadiness) of duration.

6. Discussion

In the year 1917, in the Battle of Ypres, the Allied powers had not been able to combat efficiently through a synergy of operations of the branches and services in the battlefield. The cause had been due to poor planning, preparation and conduct of the military operation or rather inappropriately executed command and control through the chain of command from Field Marshal Douglas Haig down the command chain that also included bad assessment of the terrain influence – battlefield on the conduct of the military operation. During the Third Battle of Ypres, Field Marshal Douglas Haig had obstinately continued to attack the opponent in the same direction and on the same terrain on which he had already suffered a setback. Therefore, the Allied powers failed to engage the entire combat power in the most efficient manner on a passable terrain.

The geological basis of the battlefield, or rather "clay-cover", had been a problem for movement and manoeuvring of the armoury, artillery and infantry but also for cavalry as a branch of the armed forces in World War I. The "clay-cover" had a very negative effect on transportation (logistics) by trucks and horse-drawn carts. Widespread hydrographic networks (channels, streams and rivers) were an additional obstacle to all branches and particularly to armoured units. Artillery fire of the opposing armies had created a series of craters in soft clay and inflicted significant damage to road infrastructure. In addition to these, the effect of surprise failed to take place due to bombing that had been carried out for several days. The construction of trenches in clay was a big problem since trenches had caved-in due to dredging and flow. During the rainy autumn and winter, trenches were constantly soaked with water and mud so that life and work in such environments caused British soldiers to come down with various types of illnesses. The most frequent of these was the so-called "trench foot" that could even lead to the amputation of toes or feet. All these stated issues open a question of a possible more favourable direction of attack.

Field Marshal Douglas Haig could have given orders for attack in the direction on which three months earlier the British army had achieved a major success by deploying tanks on favourable geological ground near the town of Arras. During just one day (April 9th, 1917) the British army had made a deeper breach on a terrain that allowed for tank manoeuvrability East of Arras on carbonates (approximately 5 kilometres) and seized a greater area than during the first 50 days of the Third Battle of Ypres when British forces in offensive had penetrated only about 4 kilometres (between 2.5 miles to 3 miles) into enemy territory. The carbonates around Arras had been sufficiently compact for the crossing of the British *Mark IV* tanks that weighed 28.4 tons, although thin layers of clay could be found in some places on the carbonate plain, but they had not taken up a significant surface area that would stop tanks (**Fuller, 1920**).

6.1. An attack from Arras and Cambrai towards the Northeast – retrospective military-geological advice - for achieving the strategic goal

Limestones are in principle permeable and porous and total (primary and secondary) porosity of the Cretaceous carbonate rocks in France amounts to 30% and even45% (**UNESCO, 1984; Bačani, 2006**), in comparison to clays they do not retain water on the surface of the terrain and calcareous ground enables natural draining of the terrain surface. Calcareous ground is also considerably more compact than clay ground and enables tanks and other vehicles to cross the plain. The analyses and comparison of geological and topographical maps points to tank manoeuvrability of the land in a wider area of Arras towards the French town Lille and positive experiences of the British tank units during the Battle of Arras in April 1917 also represent an empirical confirmation about tank manoeuvrable land of the battlefield in a wider area of Arras. Macadam roads on calcareous ground are more robust, more resilient and it is easier to repair them than roads constructed on clay ground. Macadam roads would also render possible movement of tanks, artillery and logistic supply of the forward lines of the forces in attack.

British staff officers who had planned this military operation could come to that conclusion by comparison of the topographical and general-purpose geological maps drawn before World War I. The operation of cutting off German forces on the Belgian coast in the area of Ghent would have demanded flexibility or in the case of delay on the main direction, forces and reserve forces should have been moved to an auxiliary direction of attack if it provided greater prospects for success.

When discussions are held about alternative or rather hypothetical tactical directions that had greater prospects for attaining a strategic goal, it is important to emphasize that in April 1917, British units had made a major success by breaching German defence lines Northeast of Arras. However, British troops had neither taken advantage of that success, expanded the area they seized, nor committed an adequate reserve unit. Undefended areas had existed for several days in the German battle formation but British troops had not taken advantage of such a situation because their own success had surprised them. Germans had also been surprised by the success of the British troops and it had taken several days before they introduced reserve forces and formed a new defence line (**Fuller, 1920**). It had been only at that time that British troops committed one cavalry unit from the reserve that was successfully fought off by German units. The cavalry unit had not been an adequate reserve able to breach the established line of defence of the German defence reinforced by bunkers with heavy machine guns. British officers should have known that based on experience British army had gained during the assault of the light cavalry during the battle for Balaklava in 1854 in the Crimean war. At that time, a British light cavalry brigade had attacked Russian entrenched positions but it had been broken up by artillery and rifle fire. With the first appearance of the tank in the battlefield in 1916, it had become clear that armoured units represented the major force for manoeuvring because they could run down barbed wire and trenches, and their fire power could hit bunkers and other fortification facilities.

In view of the stated positive experience with the use of tanks on carbonates near Arras in April 1917, a more favourable possibility for attack had opened up on the direction Arras - Lille for employment of the armoured forces for an indirect approach manoeuvring towards strategic ports. Based on these experiences, the following scenario of an alternative British attack to reach the harbours of Ostende and Zeebrugge is given. In the first stage, British forces would have attacked through tank manoeuvrable calcareous plain from Arras towards the town of Lille and afterwards with infantry and, depending on meteorological conditions, with tanks across the "clay-cover" towards the town of Ghent; seizing that town would have cut off German forces from Belgian coast. Due to the fact that the German defensive positions had been placed on the calcareous plain between Arras and Lille, it could be anticipated that the decisive point of the battle would have taken place on tank manoeuvrable land.

For the proceeding of British troops to Ghent and Antwerp in 1917, two major directions of attack are discussed.

The first tank manoeuvrable direction would have been from the British sector (staging of forces) – Arras – Lille (**Figure 7 and 8**), and after seizing Lille, British forces deployed to the left flank of the main attack and would continue towards Ghent. French forces deployed to the right flank, would have moved from their sector parallel with the British direction of the attack towards the main, i.e. central direction Albert - direction Cambrai – Ghent – Dutch border. In the second stage, that direction of attack would have continued on the direction Cambrai – Ghent and reached the Belgian-Dutch border, thus German forces in Western Belgium would have been cut off from the rest of German army. This version would have demanded a breach of 140 kilometres and it would have lasted at a maximum of 40 days (on average 3.5 kilometres per day) before the main autumn rains commenced. For this alternative direction of attack (as compared to the direction that had been tested unsuccessfully from Ypres) that represents, from a military-geological and military-geographical viewpoint, a hypothesis about a more favourable direction for the implementation of the strategic goal.

The town of Ghent is particularly important because it connects the ports of Ostende and Zeebrugge through road and railroad infrastructure with Eastern Belgium (and Germany) and its seizure would have cut off those naval bases from the main body of the German forces. If those German forces had not surrendered in encirclement, a possibility would have existed to attack them from the Eastern direction from Ghent.

The starting point of the second auxiliary direction of attack (**Figure 8**) would have been South of Cambrai and in the second stage, after conquering Cambrai, the attack would have proceeded towards the town of Mons. After the seizure of Mons, French forces would have initiated defence and protected the flank of British and French forces until they reached the Belgian-Dutch border on the main direction of attack. On that direction of operations, the network of roads had been in one part built on a geological basis of higher quality, it had been denser and less damaged by artillery activities and hydrographical network was of lower density than in the wider area of Ypres. In the case of delay on the main direction of efforts towards Ghent, the forces should have continued the attack from Mons towards Brussels,

Antwerp and reached the Dutch border. However, success of the operation would have demanded, in addition to selection of the terrain with favourable geological ground, a change in the manner of engaging forces in the battlefield. That means better coordination of various branches of the armed forces, with more efficient dynamics of committing new forces in every stage of the breach. It also implies the concentration of tanks on the direction of main efforts with support of artillery, engineering, infantry and aviation.

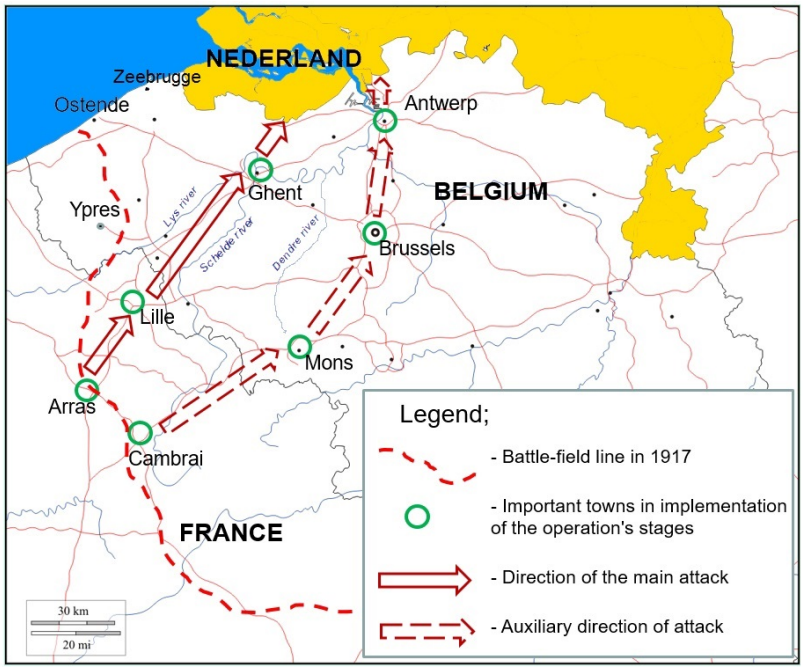


Figure 8 Suggestion for more favourable directions for achieving a strategic goal (conquest of strategically important coastal harbours of Ostende and Zeebrugge)

The weight of attack would have passed by the (British) left flank i.e. between the rivers Lys and Schelde (*Escaut*), and for the (French) right flank between the rivers Schelde (*Escaut*) and Dendre (*Dender*). Those rivers would form a natural baffle for the left and right flank of the British and French forces on the direction of the main efforts. A partition in military topography represents a topographic object that extends parallel with movement of the Allies own forces and that can have the role of a shield of the unit that carries out movement and manoeuvre, i.e. it protects the flanks of the forces in advance. The weight of attack in the first stage would have crossed tank manoeuvrable land and in the second stage, after Lille, it would have moved from tank manoeuvrable land to a land with unfavourable geological ground formed by the "clay-cover". However, that land would have had a well distributed hydrological network because the streams of the rivers Lys, Schelde and Dendre stretched all the way to the town of Ghent along the direction of the attack (**Figure 8**).

7. Conclusion

Although British units had penetrated approximately 10 kilometres and had seized about 200 square kilometres of land, that tactical "success" should be viewed through major losses in troops and equipment as well as in the time that had been lost without attaining it, i.e. seizing the strategic goal (the ports of Ostende and Zeebrugge). After fierce and exhausting combat, the village of Passchendaele had been seized by British units. The seized terrain had not represented a favourable operational ground for further advancement and the stated battle represents an operational and strategic failure for the Allied powers.

Due to the selection of an unfavourable and almost impassable terrain or rather direction of attack, British troops had suffered a loss of available combat potential and in particular the effect of armoured forces during the battle had not taken place. Geological surface terrain ("clay-cover") had also a negative effect on the delivery of fire (the effect of fire)

of British artillery and on movement of artillery as support to the manoeuvre. The additional negative effect of the artillery had been the manner in which it had been used during the first stage of the battle in which, due to lengthy (days-long) barrage fire and craters created in soft clay-land, the artillery had a negative influence on the movement of tanks, artillery and infantry, and the factor of surprise as one the essential principles of war had not taken place.

From a military-geological point of view, a more favourable direction of attack would have been, instead across the clay ground North of Ypres, across the calcareous plain East of Arras where limestone forms a basis of the land and it had already demonstrated to be a good ground for tanks in the Battle of Arras in April 1917 and Cambrai on November 20th, 1917. The effect of artillery fire on targets on calcareous ground would have been more effective because solid ground increases the radius and effect of the shell's fragments with the additional lethal effect of broken off sharp rock fragments.

Calcareous bedrock would also have facilitated repair of the damaged roads by engineering corps or construction of new roads and would have facilitated movement of the forces and supply of the forward lines. In the first stage and in the potential decisive point of the battle, the direction of the main efforts the Allied powers would have had a more favourable geological basis, and in the second stage, during movement and manoeuvring towards Ghent and the Dutch border, the hydrographical network would have been more favourably distributed than in the area of Ypres because the rivers Lys, Schelde and Dendre would have made a natural baffle on that direction of attack.

Calcareous bedrock provides considerably enhanced prospects for the successful conduct of the offensive military operation than clay ground. The Allied powers would have probably managed to multiply combat efficiency on other, tank manoeuvrable military-geographic directions through a synergy of operation of various branches of the armed forces on the battlefield. In the end, it would have augmented the capability of the British army to realize the set strategic goal.

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Sažetak

Utjecaj geologije na tijek i ishod 3. bitke kod Ypresa (Flandrija, 1. svjetski rat)

Geološka građa terena kao podloga bojnoga polja može biti iznimno važan čimbenik za uspjeh ili neuspjeh vojne operacije. Utjecaj geološke građe bojnoga polja kod belgijskoga grada Ypresa pokazao se kao važan, a možda i presudan čimbenik za neuspjeh ofenzivnih operacija postrojbi sila Antante protiv postrojbi Njemačkoga Carstva 1917. godine. Geološka građa bojišta, odnosno donjoeocenske gline koje se nalaze na površini terena kao podloga bojnoga polja kod Ypresa u interakciji s meteorološkim uvjetima (oborine) pokazala se kao izrazito nepovoljna za utvrđivanje, kretanje, paljbu i manevar svih postrojbi, a pogotovo oklopnih postrojbi koje su uporno usmjeravane na teško prohodne taktičke pravce. Zbog odabira nepovoljnoga i teško prohodnoga terena, odnosno smjera napada, britanska vojska imala je gubitak raspoloživoga borbenog potencijala, a posebno je izostao učinak oklopnih snaga tijekom bitke. Ukupni gubitci sila Antante iznosili su 448 000 mrtvih, ranjenih, oboljelih, zarobljenih i nestalih, a strateški cilj nije bio ostvaren.

Sile Atante 1917. godine u 3. bitci kod Ypresa nisu uspjele multiplicirati borbenu učinkovitost kroz sinergiju djelovanja rodova i grana na bojištu. Uzrok je loše planiranje, priprema i provedba vojne operacije, odnosno loše zapovijedanje i nadzor kroz zapovjedni lanac od feldmaršala Douglasa Heiga naniže, što uključuje i lošu procjenu utjecaja terena – bojnoga polja na provedbu vojne operacije. Feldmaršal Douglas Heig tijekom 3. bitke kod Ypresa uporno je nastavljao napadati protivnika na istome pravcu i na istome terenu na kojemu je već pretrpio neuspjeh. Zbog toga su sile Antante propustile angažirati cjelokupnu borbenu moć na najučinkovitiji način na prohodnome terenu. Geološka podloga bojnoga polja, odnosno glineni pokrivač pokazao se kao problem za kretanje i manevar oklopništva, topništva i pješaštva, ali i konjaništva kao roda oružanih snaga u 1. svjetskom ratu. Glineni pokrivač utjecao je izrazito negativno na transport (logistiku) kamionima i konjskim zapregama. Gusta hidrografska mreža (kanali, potoci i rijeke) dodatna su prepreka svim rodovima, a posebno oklopnim postrojbama. Topnička paljba suprotstavljenih vojski stvorila je niz kratera u mekanoj, glinovitoj podlozi, a i znatno je oštetila cestovnu infrastrukturu. Uz navedeno izostao je i efekt iznenađenja uslijed višednevnoga uvodnog bombardiranja. Izrada rovova u glini pokazala se kao velik problem, jer je dolazilo do urušavanja rovova zbog jaružanja i tečenja. Rovovi su za kišna vremena stalno bili natopljeni vodom i blatom, te je život i rad u takvoj sredini uzrokovao različite vrste bolesti kod britanskih vojnika, od kojih je najčešća bolest takozvanih „rovovskih stopala" koja je mogla dovesti i do amputacije nožnih prstiju. Sve navedeno otvara pitanje eventualnoga povoljnijeg smjera napada. U radu su ponuđeni drugi mogući taktički pravci koji su s vojnogeografskoga i vojnogeološkoga gledišta bolje rješenje za postizanje strateškoga cilja koji je bio postavljan pred zapovjednike država sila Antante uoči početka 3. bitke kod Ypresa 1917. godine.

S vojnogeološkoga gledišta povoljniji bi smjer napada bio, umjesto preko glinene podloge sjeverno kod Ypresa, preko vapnenačke ravnice istočno od Arrasa, gdje je u podlozi vapnenac koji se već pokazao kao dobra podloga za tenkove u bitci kod Arrasa u travnju 1917. godine i Cambrea 20. studenoga 1917. godine. Učinak topničke vatre po ciljevima na vapnenačkoj podlozi bio bi učinkovitiji, jer tvrda podloga povećava radijus i učinak fragmenata granate uz dodatni ubojiti učinak odlomljenih oštrih fragmenata stijene. Vapnenačka bi podloga olakšala inženjeriji popravak oštećenih cesta ili izradu novih, te bi olakšala kretanje snaga i opskrbu prednjih linija. Na smjeru glavnoga napora sile Antante imale bi u prvoj etapi, u odlučujućoj točki bitke, povoljniju geološku podlogu, a u drugoj etapi, pri kretanju i manevru prema Ghentu i nizozemskoj granici imale bi povoljniji raspored hidrografske mreže nego u području Ypresa, jer rijeke Lys, Schelde i Dendre čine taktičku pregradu, odnosno štite bokove snaga na tome smjeru napada. Na vapnenačkoj podlozi, ako se radi o ravnome terenu, znatno su veći izgledi za uspješnu provedbu ofenzivne vojne operacije nego na glinenoj podlozi, te bi sile Antante na drugim, tenkoprohodnim vojnogeografskim pravcima vjerojatno uspjele multiplicirati borbenu učinkovitost kroz sinergiju djelovanja različitih rodova oružanih snaga na bojištu, što bi u konačnici povećalo mogućnost britanske vojske da ostvari zadani strateški cilj.

Ključne riječi
vojna geologija, vojna geografija, vojna analiza terena, tenkoprohodnost, vojna povijest