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THE INFLUENCE OF GEOLOGY ON BATTLEFIELD TERRAIN AND IT'S AFFECTS ON MILITARY OPERATIONS IN MOUNTAINS AND KARST REGIONS: EXAMPLES FROM WW1 AND AFGHANISTAN

UTJECAJ GEOLOGIJE BOJNOG POLJA NA VOJNE OPERACIJE U PLANINSKOM I KRŠKOM PODRUČJU: PRIMJERI IZ PRVOG SVJETSKOG RATA I IZ AFGANISTANA

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Key words: Military geology, "geological intelligence", mountain warfare, karst regions, terrain analysis

Abstract

During the World War I conflict between the Austrian and Italian army, Austrian engineer units constructed hallways in the karst region of Soča river. Those hallways, karst phenomena (caverns, caves) and other fortifications, gave the Austrian army a tactical advantage. The construction principle of caverns is the consequence of the geological structure of the terrain. We are watching another military conflict in Afghanistan. In country where many armies in history have been defeated, where the terrain morphology condition a guerilla tactic, where the function effect of modern military technology is limited by battlefield configuration and with low military value of individual target, we are creating a "picture" of the possible view of the future battlefield. Al-Qai'da operatives in east Afghanistan take advantage of the opportunity of geological structure of the terrain and construct tunnel network across natural caves. Although the tunnel network in Afghanistan is constructed mostly in sandstones and metamorphic rocks, we may partly compare it with Austrian hallways. In that sense this work shows the influence of geological structure of the terrain on the effect of military operations in mountains and karst regions, and the analogy between military operations on the Soča river and military operations in Afghanistan.

Ključne riječi: Vojna geologija, "geološko izvješćivanje", ratovanje u planinama, krška područja, analiza terena

Sažetak

Tijekom 1. svjetskog rata u sukobu između talijanske i austro-ugarske vojske na rijeci Soči, austrijske su inženjerijske postrojbe izgradile tunele u kršu. Takvi umjetni objekti (tuneli) i prirodni krški fenomeni (kaverne, prirodne spilje), kao i druge fortifikacije omogućile su austro-ugarskoj vojsci prednost u taktičkom smislu. Princip izgradnje tunela i formiranje kaverni posljedica je geološke građe terena. U Afganistanu smo svjedoci još jednog vojnog sukoba. U području gdje su kroz povijest ostale poražene mnoge vojske velikih sila i gdje morfologija terena diktira gerilsku taktiku vođenja rata, gdje je učinak djelovanja moderne vojne tehnike ograničen oblikom bojišnice ali i niskom vrijednošću pojedinačnog cilja, stvara se "slika" promišljanja o mogućem izgledu bojišnice budućnosti. Operativci Al-Qaide u istočnom Afganistanu iskoristili su pogodnost geološke građe bojišnice i izgradili mrežu tunela kroz prirodne spilje. Premda su sustavi tunela u Afganistanu izgrađeni pretežno u pješčenjacima i metamorfnim stijenama, može se izvršiti usporedba s austrijskim obrambenim objektima izgrađenim u vapnenačkim stijenama oko rijeke Soče. U tom smislu ovaj rad ima za cilj prikazati utjecaj geološke građe terena na izvođenje vojnih operacija u planinskom i krškom području, i dati usporedbu između vojnih operacija vođenih oko rijeke Soče i vojnih operacija vođenih u Afganistanu.

Introduction

Military geology observes underlying geology structure effect on terrain for military operations, bedrock to use both as fortification and tunnelling, and which can also be utilized for building material (Jungwirth, 1995 c; Jungwirth & Zečević, 2003). More recently, military geology observers study local geology for analysis of bomb and projectile penetration, and investigate ways of detecting and destroying underground military infrastructures (Zečević, 2004a).

In military history the science of geology has been used for more than 200 years, first documented during Napoleon's invasion of Egypt in 1798. Three naturalists with geological knowledge were attached to Napoleon's expeditionary forces; e.g. Diedonné (Déodat) Sylvain-

Guy Tancrède de Gratet de Dolomieu, Pierre Louis Antoine Cordier and François Michel de Rozière (Rose, 2003). The first military operation guided by geologic terrain analysis by Professor K.A. von Raumer was the defeat of Napoleon's troops near the Katzback River in Silesia by the Prussian general von Blucher in 1813 (Kiersch & Underwood, 1998). In 1820, the geologist and military officer Johann Samuel Gruner (Bülow et al., 1938) wrote a memorandum on the relationship between geology and military science (*Verhältnis der Geognosie zur Kriegswissenschaft*) which was published posthumously in 1826. This paper is the fundamental publication on military geology in the early 19th century (Bülow et al., 1938; Häusler & Kohler, 2003). British Major-General and geologist Joseph Ellison Portlock (1848) of the Royal Engineers similary thought like Gruner in his «Geognosy and Geology» (Hristov, 1969; Kiersch & Underwood, 1998). Geologic knowledge continued to play an important role in military operations in the American Civil War (Coloman, 2004). The first extensive use of geology in military operations was during the Russo-Japanese War (1904–1905), when the Russian Army used geologists to provide advice on the construction of fortifications.

During World War I the use of geological information became very important. Successful military mining beneath enemy earthworks and fortifications required an understanding of subsurface geology, including hydrogeology (Kiersch & Underwood, 1998). During World War I, Germany's superior use of military geology employed professional geologists, for example, Major Walter Kranz and Kurt von Bülow. The latter published "Wehrgeologie", the superior manual of military geology in Leipzig in 1938. During World War II, military geology became a well-developed science, Germany in particularly using over 400 geologists by the end of hostilities (Rose et al., 2000). After World War II, military geology became a constantly evolving field, from the Cold War onwards (Rose et al., 2000, Jungwirth & Zečević, 2005). During the modern era, military geology has become particularly important in the search for Taliban and Al Qaeda forces in Afghanistan, where the U.S. Geological Survey estimates there are more than 10,000 caves (Leith, W., 2002).

Military geology applied geological knowledge to solve military problems. The knowledge of geological processes and mechanism is important for tactical terrain intelligence. In past wars which had been waged, geology has had an important role in; survivability and penetrability of fortifications and facilities, landscape trafficability, cross-country mobility of vehicles, potable water supply and terrain analysis for both defensive and offensive purposes (Zečević, 2003, 2004 a,b).

In this paper the authors consider the influence of underlying geology on terrain and its effect on military operations in mountainous and karst regions. The first example given is military operations on the Soča River (1915-1917) with the second military operations in Afghanistan (2001-2006).

Features of battlefields, caverns manufacture and their moment in karst: Military operations on the Soča river, World War I

The map of Italy and the Austro-Hungarian Empire (Figure 1a) shows a relatively diverse and morphologically developed terrain (including mountain massifs, hills, lakes, canyons and meander rivers). Underlying geology and topographic effect will greatly influence military maneuvers. Geological maps are thus important sources of information. They have information on the natural constituents of materials, rock formations and groundwater resources. Mesozoic limestone rocks constitute the major part of the Adriatic karst region (Figure 1b). The Alps were formed during the Oligocene and Miocene epochs as a consequence of the pressure exerted on the Tethyan geosyncline, as its Mesozoic and Cenozoic strata were squeezed against the stable Eurasian landmass by the northward-moving African landmass. The resulting terrain reflects this complex geological history.

The approximately hundreds of kilometres-long valley of the Soča (Isonzo) River running from the Julian Alps, south to the Adriatic Sea coast, represents the only practical area for offensive operations by the Italian Army against the Austro-Hungarian forces during World War I. The rest of the mountainous, 650 kilometres length Front was dominated by Austro-Hungarian forces. Along the Soča River, a canyon and sequences of ridges and valleys result in limestone rocks. There are additionally two denuded carbonate plateaus, the Bainsizza and the Carso plateaus. This area is a Karst type locality and is locally called *Krš*, *Carso*, *Karst* or *Kras*, which means rocky place. All areas with similar geology are called karst areas (Figure 2). Geographically, karstic terrain describes an arid, stony and mostly bleak territory between Gorizia and the Adriatic sea, bordering the Gulf of Trieste from Monfalcone almost to Trieste. The number of caves and caverns in the Soča River region can only be estimated. They exist mostly in Triassic and Cretaceous limestones.

In the WW1 Austro-Hungarian army, geologists were attached to the general staff (a geological corps of specialists was created) that included the prominent geologists of the Austro-Hungarian Empire: Emil Tietze, Guido Stüche, Lucas Waagen and Herman Vetters. They helped survey the most probable battlefield sites east of the Carpathians and along the upper Adriatic even before 1914 (Pittman, 1998). They also assessed bedrock for fortification construction.

Offensive and defensive tunnel-mining activities, as part of tactical elements of warfare, were incorporated into Austro-Hungarian military doctrine during World War I. The Austro-Hungarian army predicted the possibility of war in these mountainous and karstic regions. Accordingly, the Austrian officers had prepared a detailed rulebook about cave manufacture in karst regions. The caverns had the purpose of protecting Austrian troops from hostile artillery. Fifty mining teams were called in to fortify the Austrian army, which consisted of 6 – 8 sappers. The rulebook composed both a general tactical and technical plans.

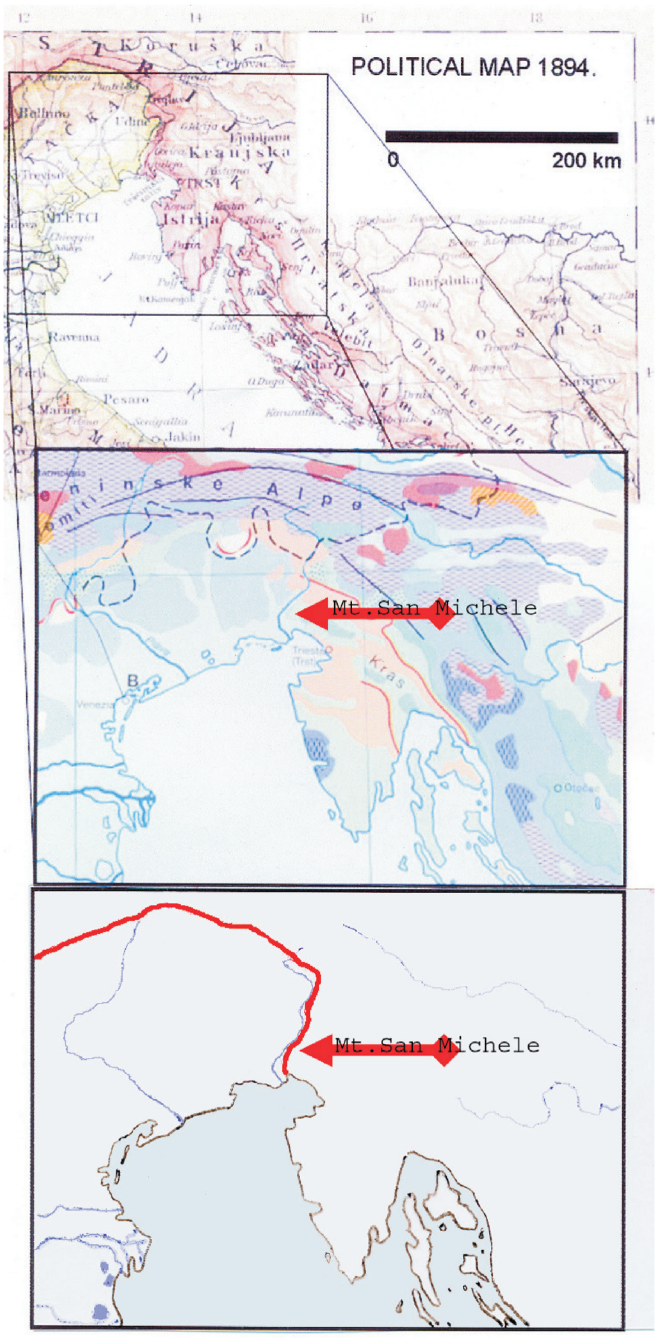


Figure 1.a Political map (Hoić, 1894)

***Slika 1.a** Politička karta (Hoić, 1894)*

Figure 1.b Geological map (Jelić & Kalogijera, 2001)

***Slika 1.b** Geološka karta (Jelić & Kalogijera, 2001)*

Figure 1.c Sitation map

***Slika. 1.c** Situacijska karta*

Battle-field line between Austrian and Italian army 1915/1916.

Crta bojišnice između Austrijske i Talijanske vojske 1915/1916.

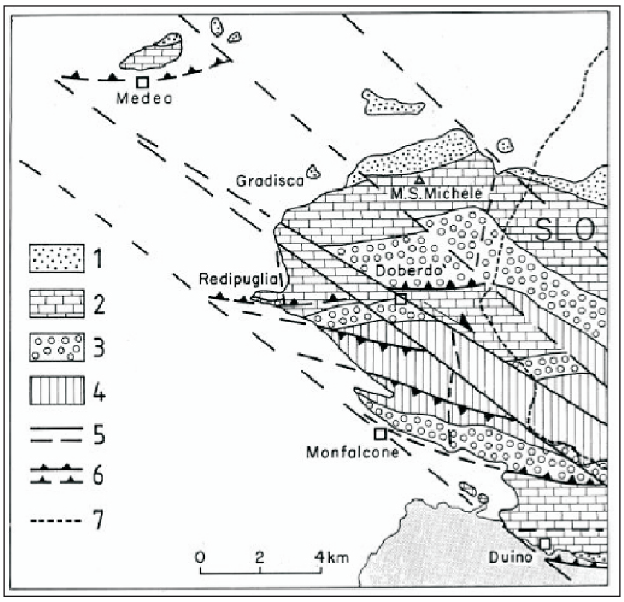


Figure 2 Drawing of the geological structure of the terrain around Mt. S.Michele

Slika 2. *Crtež geološke građe terena u području planine S. Michele*

Legend:	*Legenda:*
1 - Paleocene - Early Eocene	*1 - Paleocen – donji eocen*
2 – Senone – Turone	*2 – Senon - turon*
3 – Cenomane	*3 - Cenoman*
4 - Early Cretaceous	*4 – Donja kreda*
5 - Normal fault	*5 – Normalni rasjed*
6 - Reverse fault	*6 – Reversni rasjed*
7 - Recent state boundary	*7 – Današnja granica država*
(Tentor et al., 1994)	*(Tentor et al., 1994)*

The general tactical plan included information about recommended cavern building localities, the specific number, optimum format, size and cavern order. The technical plan included information relating to the number of required experts and workmen, mechanization and tools (fulgurate and sapper), construction materials and transportation methods (Jungwirth & Zečević, 2002, 2003). During First World War hostilities between Austria and Italy, Austrian engineer units constructed monumental hallways in karst regions around the Soča River (Jungwirth, 1995 b, c). Austro-Hungarians troops were commanded by General Svetozar Borojević von Bojna who conducting a competent defence given tactical advantages such as control of the mountains around the Soča River.

Many WW1 battles ware waged for Mt. Kuk (Mte Cucco), Mt. San Michele, Mt. Santo, Mt. Krn (Mt. Nero), Mt. Sabatino and the towns Tolmin (Tolmino), Gorica (Gorizia) and Kobarid (Caporetto) during this period. In many assaults, the Italian infantry had heavy casualties. The terrain was challenging for assault troops. The "Krš" is depicted as "a howling wilderness of stones sharp as knives". The limestone rocks increased shrapnel effects from artillery bursts. Near-surface bedrock in mountainous areas (and especially in denuded karst areas) disproportionately increased shrapnel effectiveness. When artillery bursts hit exposed rock, it would fracture and cause a 50 % increase of eye and head injuries than in ordinary battlefields (Ciciarelli, 1994). In addition, Italian artillery support in many assaults were not able to neutralize Austro-Hungarian forces which were always well fortified, taking advantage of the many caverns provided by the geological terrain (Figure 3.a,b). An example of a good fortified artillery position was the Austro-Hungarian forces on Mount St. Michele (Figure 4.a,b, redrawn 4c, 4d and 4e). In preparation of defensive lines, the Austro-Hungarians were a year ahead, having been on a war footing since July 1914 and they were also much more experienced at preparing defensive trenches and bunkers than the Italians. General Svetozar Borojević von Bojna stopped, in total, 11 Italian offensives and defeated the main Italian Army on the Soča River (1917).

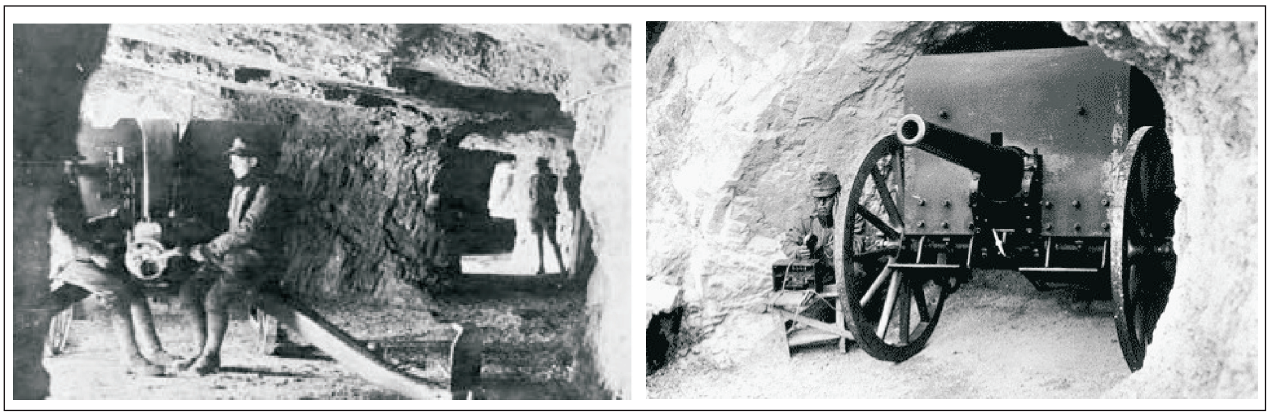


Figure 3 Austro-Hungarian military caverns

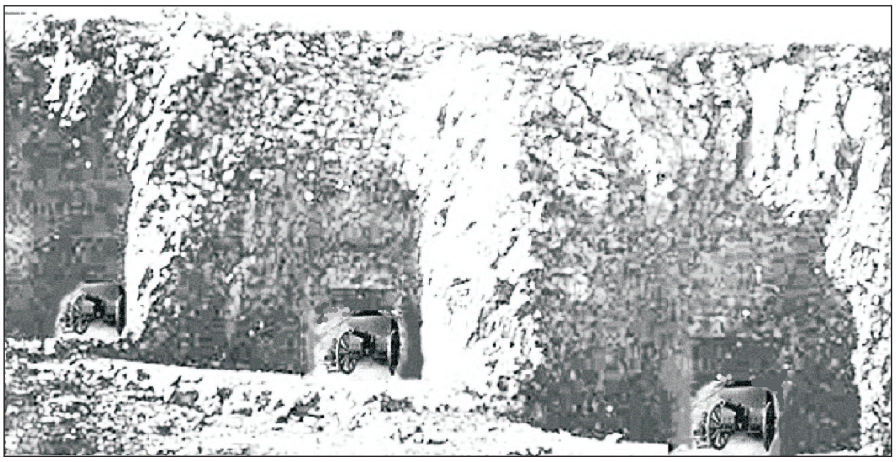
Slika 3. *Austro-ugarske vojne kaverne*

Figure 4.a Fortified artillery position in Mt. S. Michele (outside view)

Slika 4.a *Utvrđeni topnički položaji na planini S. Michele (pogled izvana)(Gariboldi, 1926)*

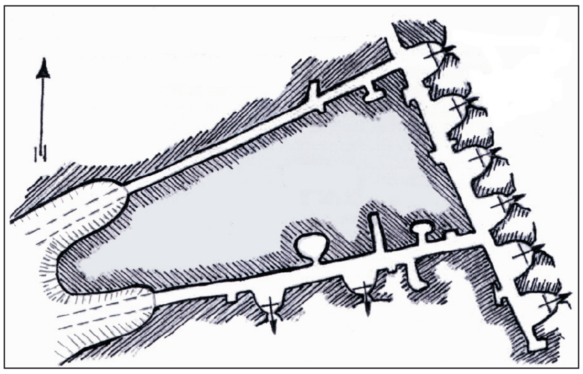
Figure 4.b Fortified artillery position in Mt. S. Michele (inside view)

Slika 4.b *Utvrđeni topnički položaji na planini S. Michele (pogled iznutra) (Gariboldi, 1926)*



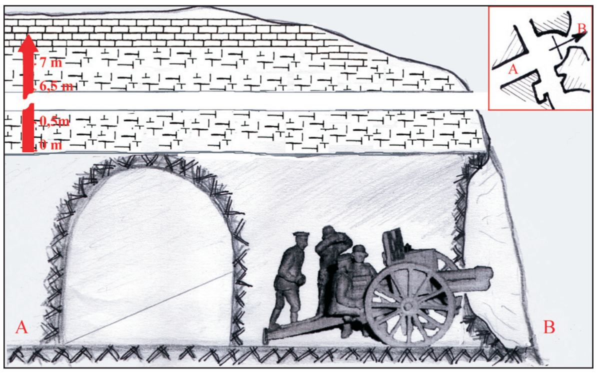
Redrawn 4.c Idealistic reconstruction of the Austro-Hungarian forces artillery position

Rekonstrukcija 4.c *Idealistička rakonstrukcija topničkog položaja Austro-ugarske vojske*



Plan 4.d (Modified after Tavagnutti, 2002)

Tlocrt 4.d *(Izmijenjeno nakon Tavagnutti, 2002)*



Profile 4.e Idealistic profile-reconstruction of Austro-Hungarian forces artillery position in limestones

Profil 4.e *Idealistički profil-rekonstrukcija topničkog položaja Austro-ugarske vojske u vapnencima*

Figure 4 The fortified artillery position of the Austro-Hungarian forces on Mte. S. Michele (figure 4.a, 4.b, redrawn 4.c, plan 4.d, profile 4.e)

Slika 4. *Utvrđeni topnički položaji Austro-ugarske vojske na planini S. Michele (Slika 4.a, 4.b, rekonstrukcija 4.c, tlocrt 4.d, profil 4.e)*

An extensive tunnel system in Mount St. Michele consisted of a headquarters complex, storage areas, as well as interconnected and fortified artillery fighting position protected under 7+ meters of limestone bedrock, which created impressive and almost impregnable WW1 fortress. Therefore, in this case, karst areas proved advantageous for defense troops and a significant disadvantage for assault troops.

Geological aspects of Afghanistan battlefields

We are observing another military conflict in Afghanistan (2001-ongoing). In an inhospitable country where many previous invading armies have been defeated (e.g British colonial army in 1842 and 1980s USSR Soviet army), where terrain morphology favours guerilla tactics, where modern tactics are limited by constricting battlefields and indigenous individual soldiers are of limited significance, we are perhaps observing how potential future battles may occur (Zečević & Jungwirth, 2003a).

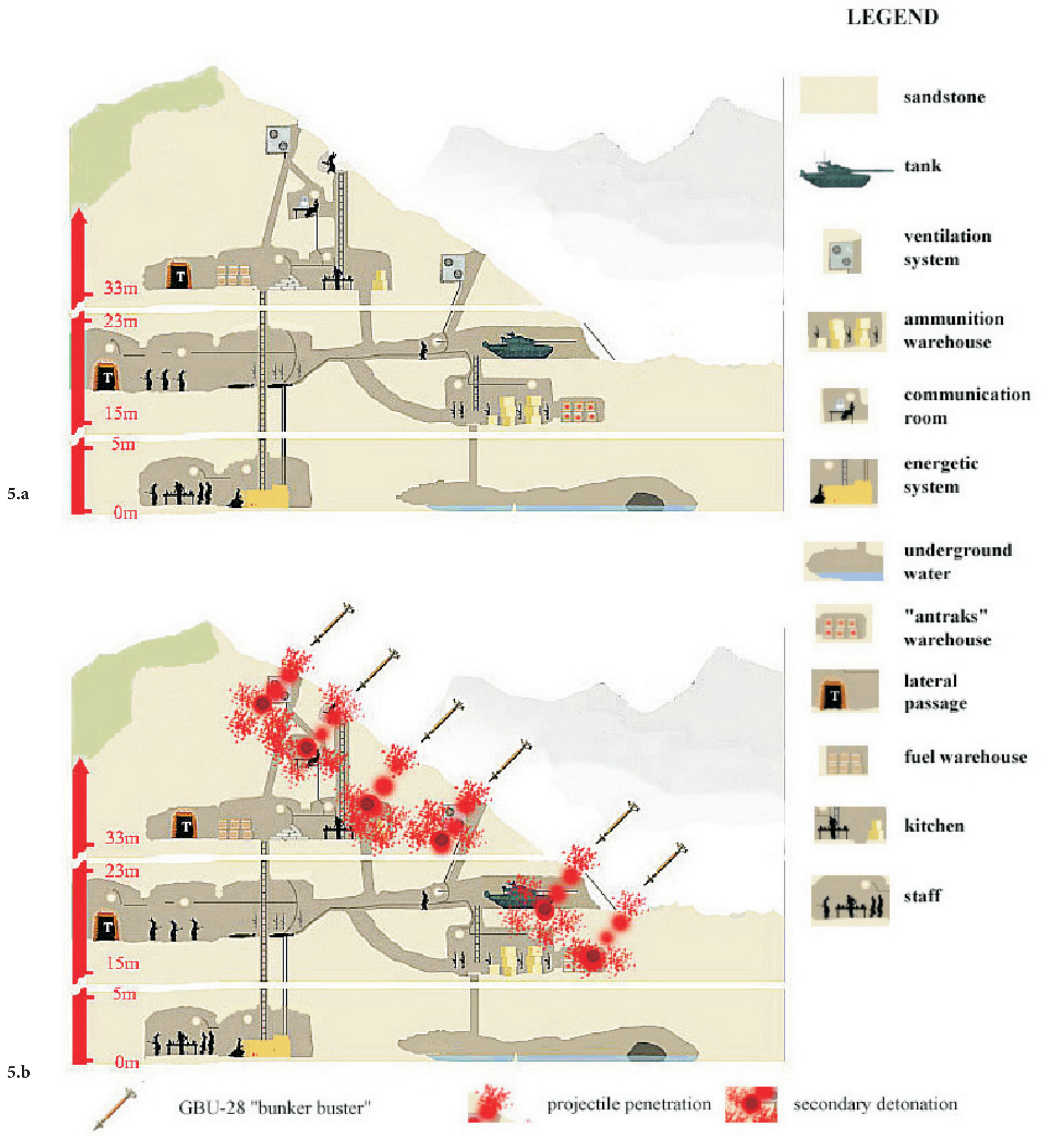


Figure 5 Idealistic profile-reconstruction of a fortified multilevel Al-Qai'da base in sandstone rocks of east Afghanistan (Modified after ZEČEVIĆ, 2004)

Slika 5. *Idealistički profil-rekonstrukcija utvrđene višerazinske vojne baze Al-Qai'de u pješčenjacima istočnog Afganistana (Izmijenjeno nakon ZEČEVIĆ, 2004)*

Tunnel systems, caverns and caves are located in the White Mountains and Zawar Kili region of Paktia province in Eastern Afghanistan and in Shah-i-Khot Valley in the Southeast. The Tora Bora stronghold is a system of tunnels and chambers enhancing existing cave systems in the White Mountains Southwest of Jalalabad, in Eastern Afghanistan, near the border with Pakistan. The name Tora Bora is translated as "black dust". Cliffs, overhangs and the deep cave system makes it almost impregnable from surface bombardment. The area surrounding Tora Bora is known as Spinghar Mountain. The dominant lithology in Southeast Afghanistan is Tertiary sandstones, Mesozoic and Paleozoic metamorphic gneisses and schists. The tunnels themselves were mostly constructed 20 years ago during the Soviet invasion of Afghanistan. Tunnel systems were then further expanded by Al-Qai'da forces, using hard-rock engineering mining techniques (Schindler, 2002; Zečević & Jungwirth, 2003a,b; Bahmanyar, 2004).

Al-Qai'da forces in East Afghanistan (Figure 5) then used these tunnel networks to store munitions, food and even vehicles such as tanks in large caverns. Tapping of potable underground water for local water supply. Fresh water resources cannot be easily polluted by surface military operations, so enabling prolonged subsurface habitation by guerrillas. Constant cave temperatures also make them useful to withstand the harsh Afghanistan winters.

Discussion and conclusions

Although Afghanistan tunnel networks are constructed mostly in sandstone and metamorphic rocks, they may be partly compared with Austrian monumental hallways in the karst region of the Soča River. The difference from a tactical view is that the Austro-Hungarian position was just below the surface in solid rock, whereas Afghanistan networks can be much deeper (up to 350 meters in places). Depth of such structures depends on the local underlying geology, engineering knowledge and potential offensive weapon effectiveness. 21st century military technology has "smart" projectiles which have the ability to penetrate to 30 meters below ground, through 6 meters of solid rock and have a time-delay mechanism to detonate 300 kg of high explosives packed in the rear of the casing (the GBU-28 "bunker buster" projectile). However, unless tunnels are relatively shallow, guerilla positions and their infrastructure would remain intact.

Geologic vulnerability of underground military facilities can be thus be considered to be primarily a function of three variables: depth below ground level, rock-mass strength and surface-layer penetrability (Eastler et al., 1998). However, sandstone must be separately evaluated as it has highly variable physical properties. For example, quartz sandstone and silt has high shear strength. For example, fortifications on such material withstood months of land and river bombardment from the some of the largest guns of the US Union's Army in American Civil War in the siege of Vicksburg in 1863 (Coloman, 2004).

Projectile penetration and explosive power for bombs and projectiles will depend upon both soil and bedrock type. Projectile penetration effect will depend upon whether the terrain is natural or has been constructed. Another factor is potential reinforcement as sub-surface structures may well survive bombardment. Tunnel entrances are, however, very vulnerable to conventional and penetrating bombs, although there is usually more than 1 exit to tunnel systems. Blasting the main entrance may therefore not have the desired 'trapping' effect. For modern and especially complex cave systems, ventilation systems may be installed which might be the most vulnerable part to bombardment. Figure 5 details an idealistic profile-reconstruction of a fortified multilevel Al-Qai'da base in sandstone rocks of east Afghanistan.

The tunnel systems and caves located in the Zawar Kili region and Shah-i-Khot Valley are constructed in sandstones, limestones or other clastic sediments. There are two main types of techniques for finding underground spaces: remote-sensing or direct, i.e. ground-based methods. Remote-sensing methods can use either satellite (typically multi- or hyper-spectral data) to accurately characterize both surface topography and likely near-surface geology. Ground-based methods include shallow geophysical methods (e.g. ground-penetrating radar or electromagnetic surveys) and direct measurements by hand-held, infrared sensors to find and characterize a hostile underground facility (Llopis et al., 2003). Ground-based methods are usually more effective but difficult to acquire in mountainous territory such as Afghanistan and more vulnerable to attacks.

Accurate topographic and geological maps and knowledge of terrain is an integral and critical part of all military planning processes. For defensive purposes, it's importance lies in knowing where enemy has placed their logistical supply and reacting in time to position own forces so as to be able to disable potential aggressors. For offensive operations, it involves knowing where the weakest disposition is of the enemy so as to be able attack most effectively. Recent developments of digitally integrated battlefield software now makes it possible to predict important military geology parameters from combinations of military, geologic, topographic and soil data. These predictions can then be used for further geologic analysis, 3-D computer visualization, or input to surface and underground military installation simulations. The methodology of integration of data may be implemented in Military Decision Making Processes (MDMP) where the information portrayed and terrain model techniques available can enhance the military leader's visualization of the battlefield through the integration of multiple dimensions (Doyle, 2003). It is important to realize that rapid advances have been made in the management of battlefield over the past few years (Zečević & Jungwirth, 2003a; Jungwirth & Zečević, 2005). In future conflicts, information superiority will be essential for victory. Information technology can help military planners and military commanders to better understand geologic factors and influence of geological structure of the terrain on battlefield situations. The analysis of data will become important factors in providing armed forces with a military advantage.

Military decision makers need "geologic intelligence" at the strategic, operational, and tactical levels (Zečević, 2004a). The next development step for terrain and map analysis will provide commanders with the information that they need to make the decisions that will win battles, save equipment and soldier lives. Geographic Information Systems (GIS) and associated Global Positioning System (GPS) technology can improve the speed and quality of decisions, in full view of terrain-related activities. Geographic information system (GIS) can be used to accurately locate and integrate tactical, soil, geologic and topographic data, natural resources, and other types of battlefield features (Figure 6). The emphasis in military geology for both detecting underground military installations and assessing potential weapon effectiveness and target vulnerabilities is very important. Mathematical modelling of the terminal interaction between the attacking weapon mechanisms and the protective measure of a target can also be undertaken. Satellite or aircraft-based, remote sensing technology can provide multi-spectral satellite imagery, which can be used to identify specific features in data, such as minerals and rocks. The information about the geologic setting of an enemy underground military facility can be used to select the best weapons and successful methods of attack.

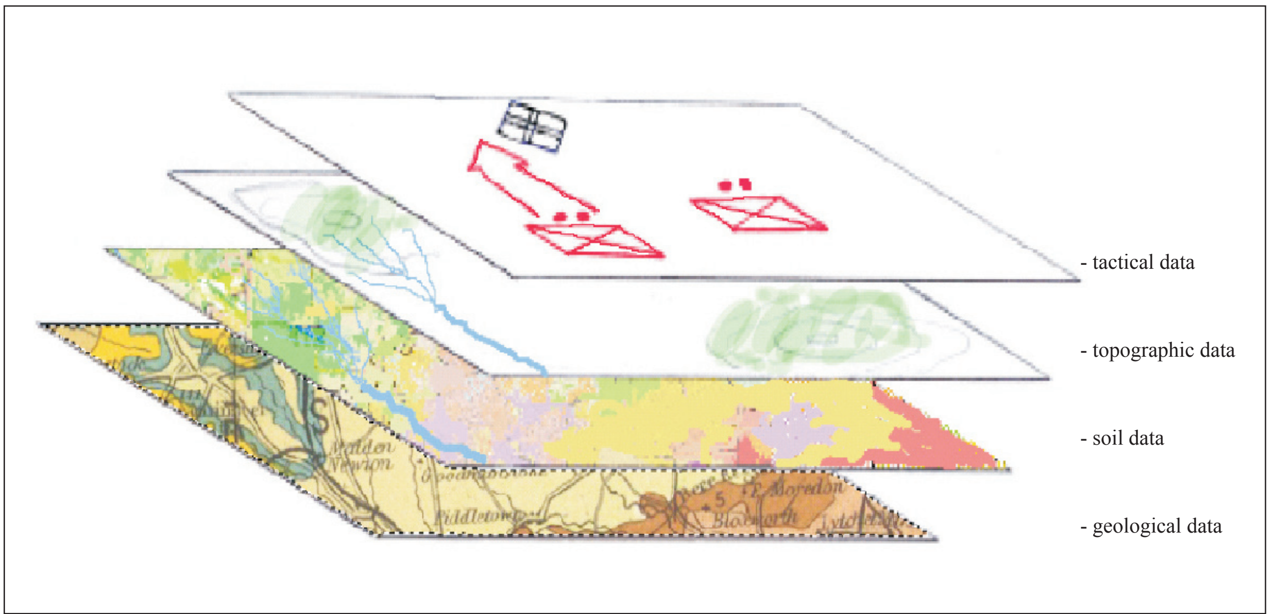


Figure 6 Integration of tactical, topographic, soil and geologic data

Slika 6. *Integracija taktičkih, topografskih, pedoloških i geoloških podataka*

Military planners and strategists need geologic knowledge for reviewing the influence of geological structure of the terrain on the effect of military operations. In the case of Afghanistan, "geologic intelligence" can analyze the geological structure of the terrain, slope stability, rock compactness characteristics, locations and characteristics of caves, ground water hydrology, and make an evaluation of weapon effectiveness. Military geologists can use techniques, particularly remote sensing, to find and characterize a hostile underground facility, and geologic maps to collect information related to geological structure of the terrain. Geologic maps and profiles depict many geologic or geologic-related conditions, such as the nature and distribution of soils and rocks, the geotechnical characteristics of materials, and classification of rocks and associated soils which influence army maneuvers.

From the presented examples we can see the influence of geological structure of the terrain on the effect of military operations in mountainous and karstic regions. It was also shown that geologists could give relevant information relating to military operations on challenging terrain and solve many complex problems related to entrenchment and preparation of battlefield. Military analysts and strategists predict in future conflicts with few short contacts and significant application of artillery, "smart" projectiles and conventional bombs. These future battlefields provide geologist's with new tests, utilization of new information technologies and employment of geological experience from past waged wars.

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