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# A PSEUDOKARSTIC CAVE IN KUMALAR MOUNTAIN: ÇAKMAKTEPE CAVE (KUMALAR MOUNTAIN-SANDIKLI-AFYON-TURKEY)

*KUMALAR DAĞI'NDA PSÖDOKARSTİK BİR MAĞARA: ÇAKMAKTEPE MAĞARASI (KUMALAR DAĞI-SANDIKLI-AFYON)*

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**Abstract**

Çakmaktepe Cave is located in source area of Kovalık Creek, which originates from western slopes of Kumalar Mountain in the east of Sandıklı town. The cave developed in partially altered trachytic lava. However, it is a pseudokarstic cave formed by dissolution of relatively easily soluble silicate minerals (feldspars), particularly of sanidine mineral contained by trachytic lava and transport of weathering products (kaolin) by water. Although the cave contains shafts, lateral galleries etc., which are typically found in karstic caves, it contains no stalactite formations. Çakmaktepe Cave formed according to local morphological base level, which showed a downward movement, at the sections where highly altered subvolcanic trachytes exhumed from cover rocks, crop out. Çakmaktepe Cave, which is a morphologically horizontal cave, is important due to its karst morphology; its rare and extraordinary characteristics in respect of cave formations. There are known cave formations, in which chemical dissolution plays an important role in various silicate rocks. In these rocks, chemical dissolution of particularly quartz and feldspars plays an important role in the formation of caves and galleries. However, there are some differences between the cave formation in silicate rocks and cave formations in chemically soluble rocks. The issue remains controversial. Çakmaktepe Cave is of great importance as it will be the first in the world literature to investigate the caves in trachytic lava, where dissolution processes play an important role in cave formation. This study deals with formation of Çakmaktepe Cave through the evaluation of the cave with its surrounding.

***Key Words:*** Çakmaktepe cave, Kumalar Mountain, Sandıklı, pseudokarstic cave, trachytic lavas

***Öz***

Çakmaktepe Mağarası, Sandıklı doğusunda, Kumalar Dağı'nın batı yamaçlarından doğan Kovalık Deresi'nin kabul havzasında yer alır. Mağara kısmen altere olmuş trakitik lavlar içersinde gelişmiştir. Ancak mağara, trakitik lavların bünyesindeki nispeten kolay çözülebilen silikat minerallerin (feldispatlar) özellikle sanidin mineralinin çözülmesi ve ayrışma ürünlerinin (kaolin) su hareketleri ile taşınması ile oluşan psödokarstik bir mağaradır. Mağarada tipik karstik mağaralarda bulunan şaftlar, yan galeriler vb bulunmasına karşın damlataş oluşumlarına rastlanmaz. Çakmaktepe Mağarası, ileri derecede altere olmuş trakit ve trakiandezit örtü kayalarından sıyrılmakta olan subvolkanik trakitlerin yüzlek verdiği kesimde, alçalmakta olan yerel morfolojik kaide seviyesine göre oluşan bir mağara niteliğindedir. Morfolojik olarak yatay mağara niteliğindeki Çakmaktepe Mağarası, karst morfolojisi ve mağara oluşumu açısından az rastlanan bir örnek olup sıra dışı özellikleri nedeniyle önem taşımaktadır. Çeşitli silikat kayaçlarda kimyasal çözülmenin önemli rol oynadığı mağara oluşumları bilinmektedir. Bu kayaçlarda mağara ve galeri oluşumunda esas olarak kuvars ve feldispatların kimyasal olarak çözülmesi önemli rol oynamaktadır. Ancak silikat kayalarda mağara oluşumu ile kimyasal olarak çözülebilir kayaçlardaki mağara oluşumu arasında bazı farklar da vardır. Bu konuda tartışmalar halen sürmektedir. Trakitik lavlarda, oluşumlarında çözülme süreçlerinin de önemli rol oynadığı mağaralarla ilgili bir çalışmaya dünya literatüründe rastlanmaması nedeniyle Çakmak Tepe mağarası ayrı bir öneme sahiptir. Bu çalışmada Çakmaktepe Mağarası'nın oluşumu, çevresiyle birlikte değerlendirilerek ele alınmıştır.

***Anahtar Kelimeler:*** Çakmaktepe Mağarası, Kumalar Dağı, Sandıklı, psödokarstik mağara, trakitik lavlar

## INTRODUCTION

Çakmaktepe Cave is located in western slope of Kumalar Mountain, at an air distance of approximately 9 km to Sandıklı district of Afyon province, on Sandıklı-Başören-Şuhut road, which runs along Sel Creek valley. Entrance section of the cave in the vicinity of Çakmaktepe passage has an altitude of 1820 m above sea level. The cave is in the vicinity of source area of Kovalık Creek, which forms the upper course of Sel Creek. It is surrounded by Kurtkayası T. (2117), Ulu T. (2137) and Küçükūfürük T.

(2018) in the north and Oğlaklıgedik T. (1922) and Düğünlük T. (2016) in the south. Uplands region in elevations higher than 2000 m in Kumalar Mountain are located in the east of the cave. Sandıklı depression, which has an altitude of almost 1000 m above sea level, is situated in the west of the cave (Figure 1).

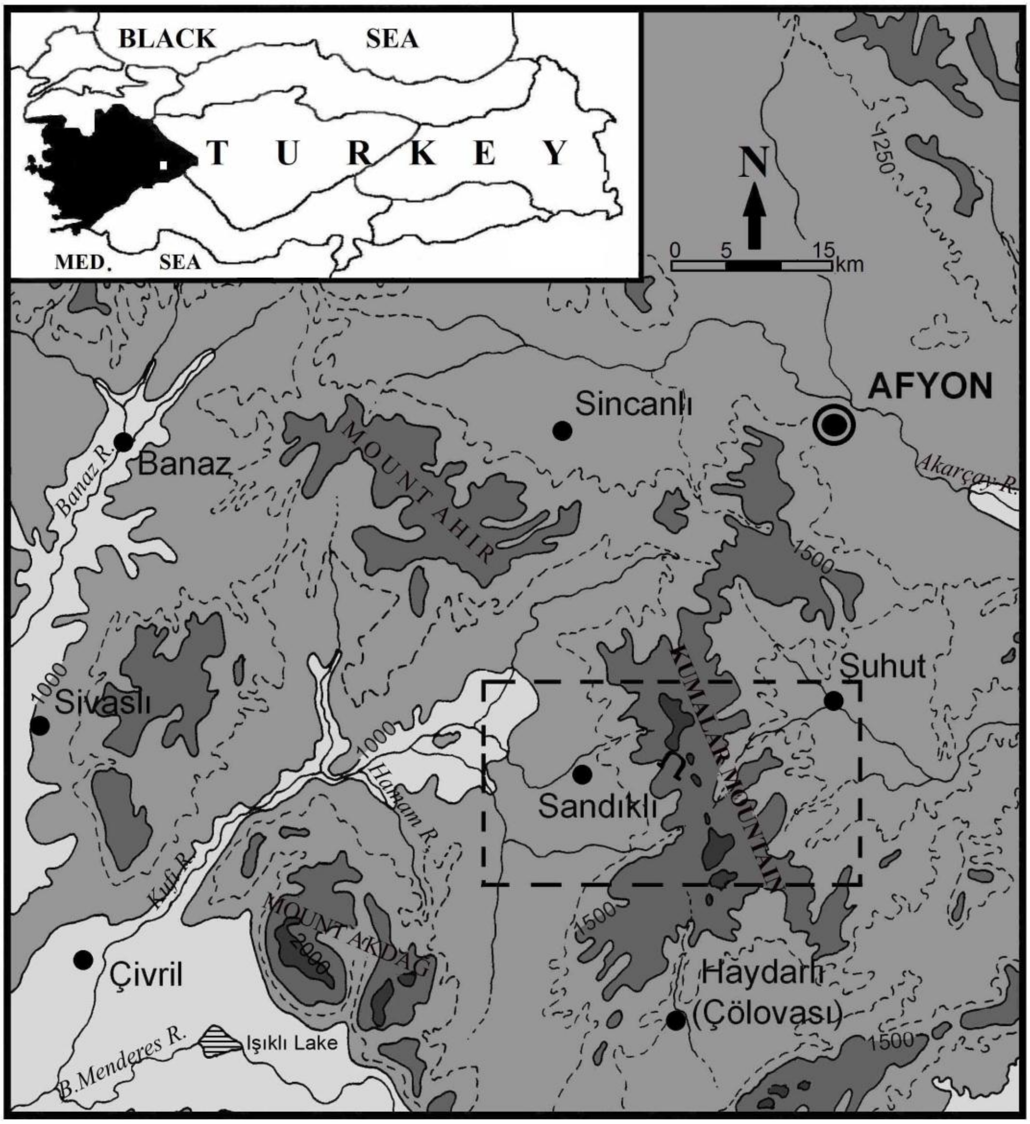


**Figure 1.** Location map of the study area and its near surrounding

The cave developed in exhuming Pliocene trachytic lava intrusion. Upper Miocene-Pliocene aged highly altered trachyte and trachy-andesitic lava, ignimbrite and tuffites cover a wide area in its near surrounding. Upper-Miocene-Pliocene lake sediments are common in the west, in the margins of Sandıklı depression. Sedimentary metamorphites of Afyon Zone, which exhumed from Neogene volcanites, crop out in places in the north of the study area. In the south, underlying Mesozoic and Lower Tertiary clastic units and carbonates exhumed from volcanic cover units and crop out in places (Figure 2, 3). Çakmaktepe Cave and smaller caves in its near surrounding were formed by the dissolution of sanidine, which is potassium feldspar (ortgoclase) and other feldspars (plagioclase) by the atmospheric waters and surface waters moving inside crack systems in Pliocene trachytes.

Çakmaktepe Cave is a fossil and horizontal cave, which developed in partially altered and younger intrusive trachytes inside relatively older, highly altered trachytes and trachyte-andesites, which constitute the wall and roof rocks. The cave formed according to karstic base level. There are smaller caves, which were formed and develop by similar process (Image 1).

Ronner, who carried out one of the first studies on Sandıklı locality, attributed the formation of Sandıklı plain to tectonic movements and faulting in Pre-Miocene and Miocene, between Miocene-Pliocene and Quaternary. Ronner, suggests that trachy-andesitic Sandıklı volcanic mass in the east of the basin is the same age with volcanic intercalated pre-Miocene/Miocene basin fillings (Ronner, 1962).

Results of a comprehensive study on metamorphic and volcanic rocks of Afyon locality revealed that Sandıklı volcanic mass consist of two stratovolcanoes in the north and south of Sandıklı-Şuhut line. Volcanic activities in stratovolcano complex were evaluated as pre-caldera and post-caldera activities (Erkan et al., 1996)

In a study on the radiometric dating of lava and pyroclastic materials in the locality, it was reported that the age of the volcanism was 8.5-14.5 Ma (Erkan et al., 1996 according to Keller, 1997).

A study on the seismicity and kinematics of side faults of the study area, sedimentary cover formation, which formed in Miocene-Middle Pliocene fluvial-lacustrine environment, are also included in old tectonic (basement) units. On the other hand, almost all of horizontal Late Pliocene-Quaternary units are defined as new tectonic period units (Koçyiğit et al., 2001).

The results of the study "The Geomorphology of Afyonkarahisar Region" show that volcanites and limnic and fluvio-terrestial formations are maximum Lower-Pliocene dated and all of them overlies Pre-Pliocene aged uneven basement below discordantly (Ardos, 1978).

Generally, the caves in carbonated rocks and soluble rocks such as gypsum and rock salt are common. However, caves can develop also in relatively insoluble silicate rocks such as granite, quartz and sandstone through the alteration of low or high amount of soluble minerals (feldspars, quartz etc.) they contain. Since the caves, which formed in rocks in both groups are formed by dissolving effect of particularly acid-containing waters, they are included in true karstic caves by some researchers. However, since chemical dissolution alone is not sufficient in formation of caves and galleries in silicate caves and produced weathering products need to be mechanically transported, various refreshers include these types of caves in pseudokarstic caves. Some researchers believe that these types of caves should be included in a separate category between pseudokarstic and real karstic caves. In conclusion, the role of caves and galleries which develop in silicate caves is still controversial. Discussions on this subject are explained below in detail.

Lava tunnels, glacier caves, sea caves etc. are termed as pseudokarstic caves as they are formed by certain physical processes rather that chemical dissolution processes (Kastning, 2005). The caves included in pseudokarst were discussed in International Congress of Speleology in 1997. Certain additions were included in following years. Primary pseudokarstic cave formations are listed below (Halliday, 2007).

1. Pseudokarst on lava flows (rheogenic Pseudokarst)
2. Glacier pseudokarst
3. Badland and piping pseudokarst-including loess
4. Talus pseudokarst
5. Permafrost pseudokarst
6. Crevice pseudokarst (including littoral pseudokarst)
7. Consequent pseudokarst (pseudokarst related with mining extraction sites and abandoned mining sites)

Various similar examples can be added to these cave formations. For example, voids under rock blocks that collapse on top of each other, primary or secondary voids under landslides, avalanches etc. and doline-like pits formed by collapse are pseudokarstic caves or formations. In conclusion, under light of above given examples, each cave that might resemble karstic caves, however, in which dissolution processes aren't effective or doesn't play a dominant role are pseudokarstic caves (Halliday, 2007).

Dissolution caves are also found in various silicate rocks. Formation of the caves and other dissolution figures in these rocks are the same as the processes in limestone and similar soluble rocks. However, there are also certain differences. The fact that caves and quartzite are found the most in silicate caves is attributed to dissolution of quartz. Dissolution is observed to be intensified in crystal joints, linear joints and surface layers in surface and near-surface sections as atmospheric waters can penetrate into these sections. This process continues by the expansion of joints. This type of dissolution distinguishes itself from formation of caves and galleries within classical limestone, gypsum and rock salt. Basically, dissolution is associated with dissolution of the bonds in crystal contacts; release, transport and removal of quartz particles. The fact that quartzite dissolution is limited to the surface and near-surface sections is related with the prevention of deep penetration of dissolution processes by the silicate-saturated solution. Quartz weathering cannot penetrate deeper sections unless the excessively saturated solution is not completely filtered from the environment. In addition, good solution of quartz in quartzite depends on mono-mineralic properties of the rock. If it contains another silicate mineral (like the feldspars) even in trace amount, dissolution of quartz is prevented (Martini, 2000). A variety of research emphasized that chemical dissolution in quartzite is limited to the surface (according to Pye and Frinsley, 1985; Hurst and Bjorkum, 1986, Ghosh, 1991; Wray, 2003). In conclusion, cave formation in quartzite joints isn't primarily considered as an outcome of chemical dissolution (Martini, 2000).

Cave and gallery formations are also observed in granites among silicate rocks and acid intrusive, due to dissolution of feldspars. In granites, quartz is produced (released) without disintegration (arenization, sanding) while feldspar turns into kaolinite. This is related with the prevention of quartz dissolution by excessive saturation of the water in the solution by the feldspar (Martini, 2000). Like in quartzite, ground water flowing in fracture and crack systems in granites cause chemical dissolution and produced weathering products are mechanically removed from the environment. Free water flow due to enlargement of joints by this process forms caves and gallery systems. However, cave and gallery formation in granites is not possible in phreatic zone, for which ground water level should be replaced in downward direction (Romani and Rodriguez, 2007). pH changes in granites controls organic and biologic activities in addition to dissolution and sedimentation processes. For example, crystalline quartz is transformed into biogenic opal, which is another silicate polymorph, through bacterial activity. Opal is less stable and more soluble than quartz (Romani and Rodriguez, 2007). Similarly, studies which used electron microscope in orthoquartzite, where caves and galleries developed under humid tropical conditions of Venezuela, found biologic corrosion in quartz and cement. In this process, the void among the particles is enlarged layer by layer through acidic corrosion in quartz and silica. Thus, the bond between the particles dissolve and become released (Chalcraft and Pye, 1984). In another study carried out in the same region, it was reported that quartz first transformed into more soluble opal as a hydrate and then is transported and removed in the solution (White et al., 1966). However, Chalcraft and Pye (1984) reports that quartz and silica cement are directly dissolved without being hydrated.

Under light of these explanations, although silicate mineral such as quartz and feldspar undergo chemical dissolution in silicate rocks such as sandstone, quartzite and granite, the caves and galleries formed in these rocks are considered as pseudokarstic caves by various researchers due to primary reasons explained below. Caves and galleries develop in near-surface sections and over the phreatic zone in silicate rocks. While a homogenous dissolution surface is the case in soluble rocks such as carbonated rocks, gypsum etc, silicate rocks generally show a heterogeneous structure, which mainly involve different dissolution processes generally intensifying in some mineral/crystal elements in the rock. Dissolution processes in silicate rocks are generally highly complicated; different silicate minerals affect dissolution of each other. Various silicate minerals can be ready to be transported and removed following a long chemical dissolution period under the control of pH changes. Rather than directly mixing into aqueous solution, dissolution products are first transformed into clay and loose-particle structure by chemical dissolution and then removed from the environment by free water flow. Unlike silicate rocks, cave formation in soluble rocks like limestone, starts with chemical dissolution during pressurized water movement along crack and fracture systems and layer surfaces in upper sections of phreatic zone (Erinç, 1971; Nazik, 1998; Nazik, 2005; Semenderoğlu, 2011). Furthermore, unlike soluble rocks such as limestone, gypsum, salt rock etc, silicate rocks fall into the category of insoluble rocks and dissolution occurs very slowly. Generally based on above given reasons, various researchers such as Martini, 2000; Vaqueiro Rodriguez, 2004; 1985; Osbome and Branagan, 1992; Yanes and Bricefto, 1993; Vidal Romani and Rodriguez, 2007 call caves and galleries that develop in silicate rocks as pseudokarstic caves rather than true karstic caves.

On the other hand, some researchers concentrate on the chemical dissolution of silicate minerals in silicate rocks and insist that the caves and galleries in silicate rocks should be considered as true karst caves and galleries. These researchers especially point out to the caves and galleries which developed in silicate rocks like quartzite and granite in humid tropical regions under hot and humid climatic conditions with a total length of a few thousand meters. For example, in Brazil, the caves and galleries which developed in mica quartzites by downward movement of base level and thus phreatic zone following stabile periods, which are interconnected by vertical shafts, have a total length of 2750 m (Corrêa Neto, 2000). Wray (2003) acknowledges that transport of dissolution product particles in silicate rocks by free water flow through chemical dissolution plays an important role in formation of caves and galleries, however, reports that dissolution and transports of silica in solution plays a greatly important role in formation of caves and galleries. Similarly, Kastning (2005) includes the karst, which develops in rocks such as granite and quartzite; and includes the caves which develop in these rocks in the category of dissolution caves in genetic classification. However, the researchers, who believe that the caves and galleries in silicate rocks like quartzite's and granites cannot be considered as true karstic, report that these types of caves and galleries are developed by the piping process along the joint and layer surfaces, instead of by chemical dissolution processes (Martini, 2000). The term "piping" refers to transport and removal of poorly cohesive, loose clastic units especially under the surface by mechanical erosion through free water flow. This term is preferred to distinguish the caves and galleries which develop in silicate rocks from those which develop in soluble rocks like limestone, particularly by the researchers who do not consider these caves and galleries as true karstic caves (Corrêa Neto, 2000, Vaqueiro Rodriguez, 2004 et al.). The debate on whether the caves and galleries that develop in silicate rocks are true karstic or pseudokarstic caves haven't yet ended. Chemical dissolution is either completely non-existent or plays a very slight role in the caves which develop in bandlands topography and loess deposits, in less cohesive units like slope deposits, and in those formed by ground water (piping), lava tunnels and glacier caves. Nobody doubts that these caves and other caves, which develop by other processes apart from chemical dissolution, are pseudokarstic caves. However, although it is controversial, the role of chemical dissolution has either a small or a great role in formation of caves in silicate rocks. Like in soluble rocks, formation of caves and galleries in silicate rocks are related with water movements along discontinuities such as cracks, fractures, layer surfaces and foliation surfaces. For these reasons, it was suggested that the caves and galleries which develop in silicate rocks can be included in karst-like terrains (Wray, 2003 according to Twidale, 1984). Another definition was karst-related solutional forms (Ortvos, 1976). In fact, it can be stated that the caves which develop in silicate rocks are between true karstic caves or solutional caves and pseudokarstic caves; however with a higher resemblance with true karstic caves.

Only a low number of silicate rocks were reported to be formed by chemical dissolution apart from sandstone, quartzite and granites. These reports were generally based on old-dated studies. According to Otvos (1976), these are granodiorite (Branner, 1913), syenite (Udden, 1925), diorite (Le Grand, 1952), andesite (Bleahu, 1972) and basalt (Bartrum and Mason, 1948). The literature mentions dissolution pits with a mean diameter of 10-15 cm on trachytes in Afyon locality, which were mainly formed by the solution of sanidine crystals, potassic feldspar, by hydrolysis (Ardos, 1978). Pekcan, reports that these dissolution pits developing on trachytes are pseudokarstic forms (Pekcan, 1999). The literature contains no study on dissolution forms which develop under the surface in trachyte and trachy-andesites in the form of caves and galleries.

Although there is a limited literature in Turkey on the caves developing in soluble carbonated rocks which are appropriate for karstification, there is no literature on the formation of caves and galleries which develop in insoluble rocks. There are certain known landscapes and cave formations in some acid magmatic rocks and other silicate rocks (like quartzite, sandstone etc) by chemical dissolution, due to partially soluble minerals (silicate minerals such as feldspars and quartz). Çakmaktepe Cave is of great importance as it will be the first in the world literature to investigate the caves in trachytic lava, where dissolution processes play an important role in cave formation.

**Material and Method**

The study used 1/25.000 and 1/100.000 scaled topographic maps of General Command of Mapping and related sections of 1/25.000 scaled geological maps of General Directorate of Mineral Research and Exploration and literature data as the study material. 1/25.000 scaled geological map supplied from Department of Geological Research of General Directorate of Mineral Research and Exploration were simplified and used to prepare geological maps. Land observations, geological and topographic maps and map of Ardos (1978) showing the locality and its vicinity were used to prepare geomorphological map. A variety of measurements, analyses, observations were conducted and literature was reviewed in detail to identify cave properties. Plan and sections of the cave were prepared based on collected data.

**Geological-Geomorphological Properties of Çakmaktepe Cave and its Surrounding**

Rocks composed of Paleozoic metagranitoid, metavolcanite and various schists constitute the oldest units of the study area. In the south, in Kükürt Mountain and its east, Mesozoic lands exhumed from Neogene volcanites (limestone, dolomitic limestone, sandstone, conglomerate, mudstone and mélange series along thrust zones) are located. Lower Tertiary (Paleogene) lands are also represented in the south of the study area by clastic units (conglomerate, sandstone, mudstone etc.) and carbonates (limestone, cherted limestone). Paleozoic, Mesozoic and Lower Tertiary rocks are the basement rocks of Sandıklı volcanic complex. Miocene, is represented by Upper Miocene tuffites, volcano-sedimentary formations, various volcanites and terrestrial deposits in the study area. On the other hand, Pliocene is represented by terrestrial deposits and various volcanites. The youngest units of the study are includes Plio-Quaternary clastic units, cone and fan deposits, colluvial deposits (slope deposits) and alluviums (Figure 2).

Study area is included in Afyon Zone in tectonic terms. Afyon Zone is a low-degree metamorphic belt. It starts from Menderes Massive in the west and extends to Afyon and then Central Anatolia massive along the north of Sultan Mountains over the North of Denizli, Uşak and Sandıklı (Erkan et al., 1996 according to Tolluoğlu and Sümer, 1995). Tavşanlı and İzmir-Ankara Zone is located in the south and Tauride belt is located in the South of Afyon Zone (Koçyiğit et al., 2001).

Koçyiğit et al., (2001) reported that volcano-sedimentary formation in base of the graben might have begun to form in Early-Middle Miocene and to continue by volcanism thus forming the sequence composed of river-swamp-lake (terrestrial) sediments intercalated andesite, trachyte, basalt lava and tuffite levels until Middle Pliocene.

The researchers called these units as the youngest units of paleotectonic era according to tectonic differences and termed them as "Late Paleo tectonic units". They further divided Late Paleo tectonic units into two as "Akın Formation" with predominant volcanites below and "Türkbelkavak Formation" with upper sedimentary sequence. They called these two sequences with transitional contact relationship as "Sandıklı Group". On the other hand, poorly consolidated Late Pliocene-Early Quaternary terrestrial units, which overly Sandıklı Group with angular discordance, , underwent no deformation and have almost horizontal position were called "New tectonic units" (Koçyiğit et al., 2001).

Özpınar (2008) reports that the sequence, which is composed of Neogene deposits and pyroclastics in the south of Sandıklı shows lateral transition and is cut and overlained by basalt, basaltic andesite, trachy-andesite and andesite. Özpınar called volcanite and volcano-sediment units as "Sandıklı volcanites" and reports that Sandıklı volcanites can be Middle-Miocene?-Upper Miocene aged (Özpınar, 2008).

Ardos (1978), on the other hand, reached much different results, stating that Neogene formations (Sandıklı Group) which are composed sediments intercalated with volcanites and terrestrial sediments on top are formed by filling of pre-Pliocene? tectonic depressions caused by vertical dislocations, which also cause volcanism. Paleontological and particularly pollen analysis results reveal that the series, which were suggested to be Miocene series are in fact Lower and Upper Pliocene aged. The first volcanic activities in Sandıklı mass started with tuffs in almost all sections. These were followed by trachytic, trachy-andesitic and andesitic lava after the eruption of various pyroclastics. The last tuffite and other volcanic rocks were injected with trachyte and thrachy-andesites. A considerable part of the volcanites that form Kumalar mountain erupted in Miocene-Lowe Pliocene limit and during Lower Pliocene; multistage volcanism continued until the end of Pliocene (Ardos, 1978). Accordingly, the author suggests that volcano-sedimentary, sediments and volcanites are maximum Lower Pliocene aged.

Results of the study of Cihan et al., (2003) are slightly parallel to those of Ardos (1978). The authors believe that Akın Formation which overlies Pre-Miocene basement with angular discordance began to form in Early Late Miocene (Tortonian). The authors report that following the formation of Akın Formation, Sandıklı Graben began to form after a short, however effective erosion period due to the start of extensional tectonics regime, in Early Lower Pliocene (approximately 5 million years before). In addition, they described Upper Pliocene aged Ballık formation and younger units as the basin (graben) fills (Cihan et al., 2003).

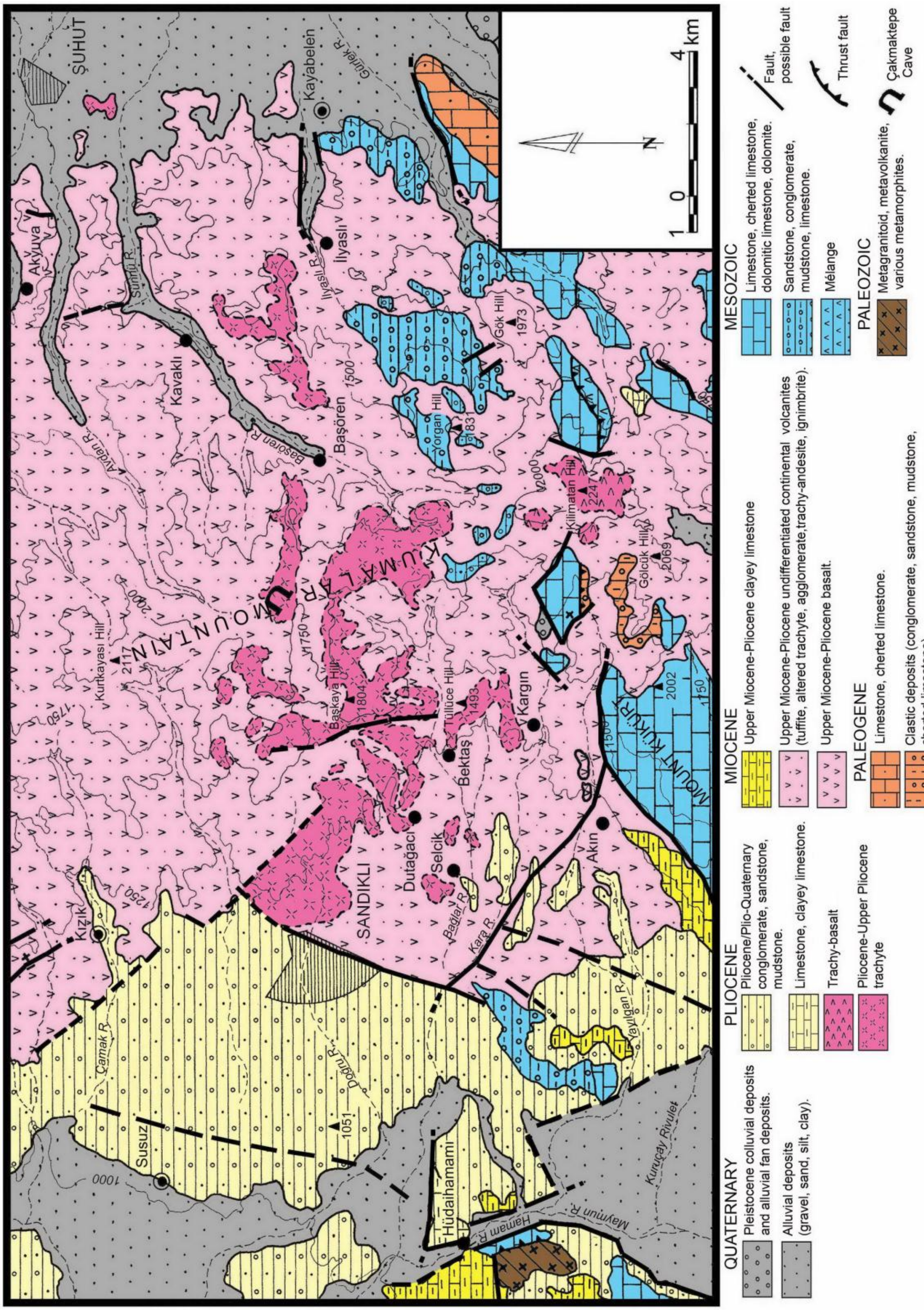


Fig. 2: The geological map of study area and its surroundings.

According to Ardos (1978) morphological development of Sandıklı Plain and Kumalar Mountain volcanic mass is as follows:

Prior to Young Neogene sedimentation, in Upper Miocene-Lower Pliocene limit, probably in Attic phase, the section which corresponds to current plain, generally collapsed along with NE-SW and N-S directional faulting. The mountains at the edge of the plain, Like Kükürt Mountain, uplifted. Widespread tuffites emplaced on Pre-Pliocene basement, which collapsed at this time. A lake regime appeared in the basin between Lower and Middle Pliocene; lake sediments formed on the tuffites (Figure 2, 3). NE-SW directional faults, which caused formation of Kükürt Mountain during sedimentation period occasionally moved, during which fissure volcanism and multistage explosive volcanism occurred in the east of the plain. Kumalar Mountain, the extension of Afyon volcanites, was formed by accumulation of volcanic materials on top of each other. Following the sedimentation stage (Upper Pliocene and at the end of Upper Pliocene) plain base collapsed due to epirogenic-cratogenic movements which cause inclining, flexuring and even thrusts along with the movement of old faults and formation of new faults, thus further uplifting Sandıklı mass. Following these movements, which lasted during Pliocene, a short, tectonically stable, however an excessive erosion period prevailed probably in Villafranchian (Lower Quaternary). During this age, while the area was a closed basin, Lower Quaternary (Villafranchian) erosion surface, which partially cuts soft formations of the old basement in addition to Pliocene formations occurred. After the formation of this surface, tectonic movements in the middle of Quaternary occurred again; the western section of the surface slightly collapsed along the NE-SW and N-S directional faults and post-Villafranchian (Middle Quaternary) surface formed in the western part of the surface. Alluvial formations occurred in western part of the collapsed block. Following this, the basin was captured by Büyük Menderes River in a very recent period and was connected to external drainage. The fact that young surfaces with a cover containing transverse layers of fluvial origin were cut by faults indicates that the base of the basin is still unstable and active in terms of tectonics (Ardos, 1978).

Apart from these formations, there are three separate erosion surfaces in the form distinct steps in the slopes of Kumalar Mountain overlooking graben floor. These surfaces must have formed according to changing base level conditions in erosion-accumulation periods following the tectonic movements during Upper Miocene and Pliocene. Upper Miocene and Pliocene aged Volcano-sedimentary and sedimentary formations which were formed in sedimentation periods in the base of graben are the correlates of these erosion surfaces. The youngest of these erosional surfaces is the same age as Ballık formation. There are exhumed surfaces on pre-Pliocene basement which exhumed from volcanites, where generally tuffite, ignimbrite and altered lava prevail in the south and south-east of the study area. These fossil surfaces observed on Mesozoic and Paleogene carbonated rocks and mélange series seem to be dislocated and largely tilted by tectonic movements in pre-Pliocene and especially Pliocene and Quaternary. For example, the surface on Kükürt Mountain is severely tilted and dislocated in southeast direction. Presence of Paleozoic and Mesozoic formations under Sandıklı volcanic mass at various depths is also concerned with this. This indicates that there is no young or semi-mature topography under Sandıklı volcanic mass; on the contrary, erosion surfaces of different ages developed on old basement, however they are dislocated by tectonic movements and were covered by volcanites. Similar exhumed fossil surfaces which expose in Sandıklı volcanic mass are also observed in the north of the study area, on Paleozoic formations (quartzite, quartzite schist, calc schist etc.).

Kumalar Mountain, which extends roughly in NW-SE direction, contains peak and hills corresponding to necks and domes, which were exhumed later by erosion and differential erosion. It is strongly probable that, this line, which extends in the side closer to Sandıklı graben of the mountain, corresponds to the direction of fissure line, which today remains under the volcanites. Trachytic, trachy-andesitic and trachy basaltic domes are probably subvolcanic formations in the form of intrusion domes in the final stage of volcanic activities (Upper Pliocene) in Kumalar Mountain. For example, one of them is a trachy-basaltic intrusion dome which cooled relatively fast, in a section near the surface in Kilimatan Hill (2247 m), which constitutes the highest peak of Kumalar Mountain. The fact that skirts of the mountain are deeply cut by the rivers to the region of peaks are related with uplift by tectonic movements in stages during Pliocene and Quaternary (Figure 3).

The fact that although volcanic rocks in the locality were rich in alkali, they had different chemical composition (they contain less silica and more MgO) is interesting (Başarır and Kun, 1982). Trachytic porphyric lava domes-flows are observed at the beginning of the second era following the subsidence of caldera in Sandıklı volcanic mass (post-caldera period). Sanidine megacrystals and phenocrystals are common in Afyon stratovolcano. In the South, no megacrystals are found in trachytes and they are more homogenous (Erkan et al., 1996). Çakmaktepe Cave in the south probably developed from trachytic porphyric lava which formed in the first post-caldera stage. It was observed that primary mineral in the lava in the locality was sanidine among potassium alkali feldspars, oligoclase, which is a calci-sodic feldspar in plagioclase group and basaltic hornblende. Accessory minerals were zircon, sphene and apatite. Secondary minerals which are formed by the transformation or alteration of other minerals were found to be calcite, hornblende and chloride (Özpınar et al., 1999; 102). Pyroxene (augite) generally transformed into basaltic hornblende. Basaltic hornblende over 5% formed as primary mineral and secondary mineral. Chlorite and low amount of quartz were found in places where crystals hematitised (Özpınar et al., 2002). Matrix composed of microlites constitute almost half of the rock (42%) (Özpınar et al., 2002). Among primary minerals, plagioclase, biotite and basaltic hornblende are found in the form of phenocrystals. Sanidine, in alkali feldspar (K-Feldspar) group, constitutes more than 10% of the rock. However, plagioclase is the phenocrystal with the highest content in the rock (Özpınar et al.., 2002). Lava is the products of alkali series rich in silica; they are alkaline and contain a high amount of potassium (Erkan et al., 1996). As the volcanic rocks in the locality get younger, their alkali amount increases (Özpınar et al., 2002). According to another study, more felsic compositions appear in post-caldera period (Erkan et al., 1996).

Oxidation, which is effective with water, plays a role in weathering of trachytic lava, hematitisation and limonitisation of iron containing mafic minerals and in the study area. Hydration generally occurs with oxidation and hydrolysis. While feldspars are dissolved with hydrolysis, they expand with hydration on the other hand. Hydration causes volume and pressure changes and further increases fragmentation. It also increases the effectiveness of other chemical weathering types along the discontinuities. Hydrolysis plays the primary role in chemical dissolution of silicate rocks and silicate minerals. In hydrolysis, in addition to being an agent to transport dissolved materials, water is a chemical agent itself (Erinç, 1982).

Effectiveness degree of hydrolysis depends on the amount of $H^+$ ions. Diluted $CO_2$ increases $H^+$ ions and thus acidity and makes hydrolysis more active. $CO_2$ combines with water and transforms into carbonic acid ($H_2CO_3$). Feldspars in fact dissolve by hydrolysis. Calci-sodic feldspars (plagioclases) like orthoclase, which is potassium feldspar, are rapidly hydrolyzed in acid reaction water. At the end of hydrolysis, feldspars transform into clay minerals, molten silica and molten potassium or calcium bicarbonates according to type of feldspars and thus dissolve. Among these, clay minerals are stable and they remain in sections where dissolution occurs. A large portion of released potassium either joins the clay mineral or is used by plants. On the other hand, sodium, calcium and bicarbonate ions are washed away (Erinç, 1982).

$SiO_2$, which is released by weathering of silicate minerals, is transported from the environment in the form of silicic acid and join the structure of other minerals. Kaolinite minerals with $Al_2O_3/SiO_2$ proportion of ½ forms in acidic environment while montmorillonite mineral with $Al_2O_3/SiO_2$ proportion of 1/3-4 form in basic environment. Acidic environment is generally achieved by carbonic acid, sulfuric acid and humus acid in kaolin formation. Kaolin forms in well ventilated, relatively porous and permeable environments, where alkali products in the solution are easily removed. Montmorillonite forms in environments with inadequate alkaline, oxidation and washing, where $Mg^{++}$ ions cannot be sufficiently removed; illite forms in environments with high $Ca^{++}$ ions. The processes, which make the environment neutral and basic are evaporation of , $CO_2$, increase of $H_2O$ amount, presence of basic rocks and limestone in the neighborhood and melting of ions like $Na+$ and $K+$ released from feldspars (Seyhan, 1971).

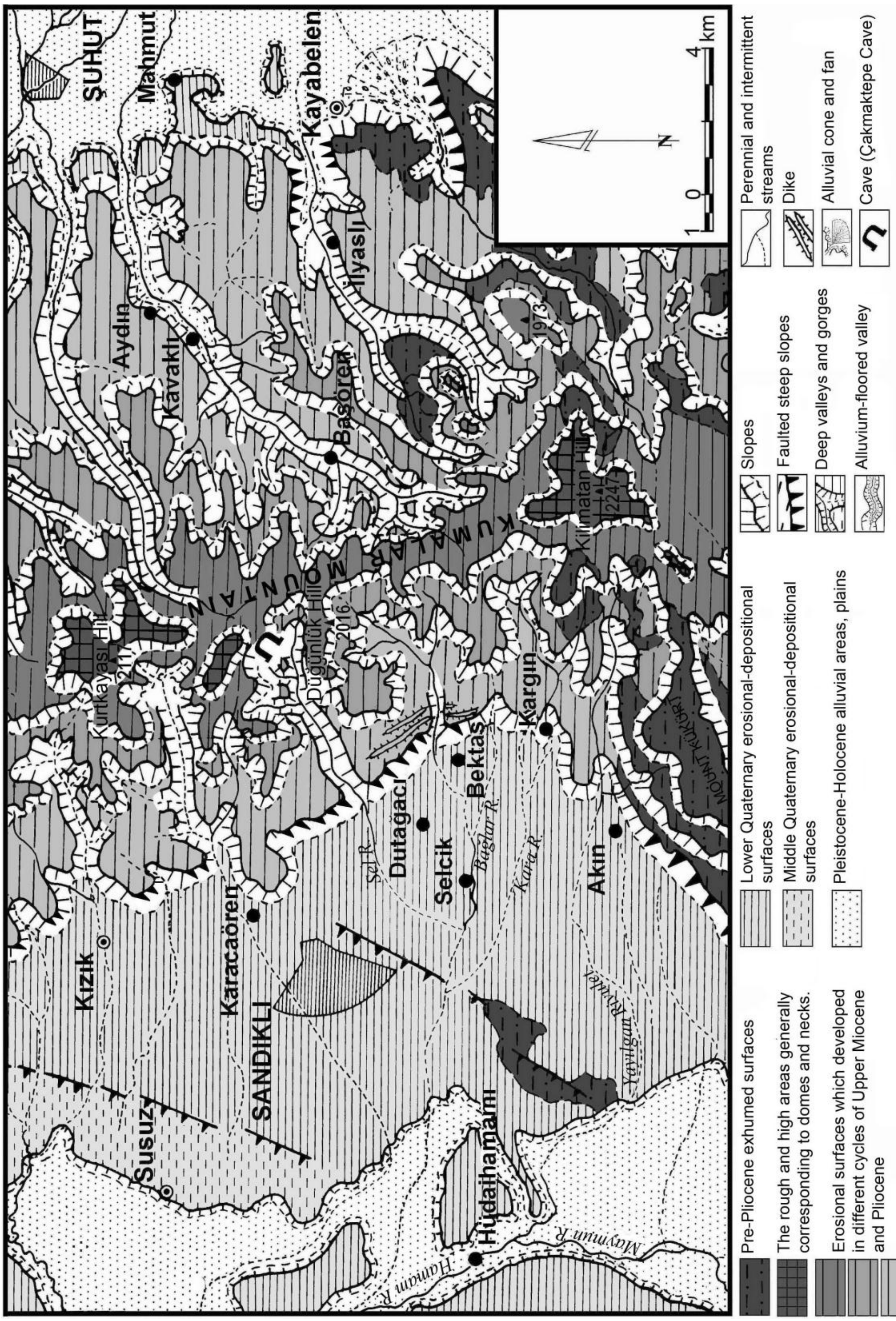


Fig. 3. Simplified Geomorphological map of study area and its close surroundings.

**Findings**

Trachytic lava mass, in which the cave formed, looks like an intrusion that intruded altered trachyte and trachy-andesites probably in post-caldera period. Western section of the subvolcanic intrusion that extends roughly in SW-NE direction is explicitly exposed, by partially exhumed from altered lava through erosion (Image1, 2). The fact that the lava displays flow structures, points out to the presence of near-surface intrusion. Outer layer of trachytic lava is dark gray due to oxidation and lichens, while fresh surfaces are yellowish-beige due to alteration. Intensive sanidine crystals with the dimensions of a few mm and 1.5 cm are visible in partially altered porphyric lava. Small ones are more common. Apart from these, plagioclase and scarcely biotite phenocrystals are visible. Small caves formed in areas where probably the same trachytic intrusions outcrop in 20-50 m south of Çakmaktepe Cave.

Cooling joints which form the structure of trachytic lava played an important role in formation of caves. Among these, concentric cracks consist of nested parallel crack surfaces, which more or less fit to the surface of lava mass. On the western side where the caves are located, they form highly steep ($60^0$-$80^0$) sloped surfaces to southwest direction. The distance between parallel concentric cracks varies between 1.25 and 2.40 m. For this reason, they give the mass composed of trachytic lava a layered structure. They played a significant role in the formation and form of the cave since they make downward penetration of atmospheric waters along the sloped convex surfaces. There are also leaning or oblique crack systems which cut vertical concentric crack systems however make a horizontal narrow angle ($25^0$-$30^0$ ), despite having the same direction. These cracks probably have an original connection with flow structures as they are parallel to flow structures. When compared to concentric cracks, the discontinuities formed by these denser and irregular crack systems cause the waters leaking from vertical concentric crack surfaces in downward direction to linger and provided backward movement of water into deeper sections of the rock. In other words, they played an effective role in development of cave to deeper sections. In addition, there are also radial crack systems, which vertically cut other crack systems. Radial cracks are less dense and more irregular than others. However, they played an important role in vertical movement of atmospheric waters together with concentric crack systems (Figure 4, 5). All crack systems must have been loosened by considerable exhumation of older and extremely altered lava, which forms roof and wall rocks, by erosion (release of pressure) and played a more effective role in cave formation.

Çakmaktepe Cave has a rough rectangular or parallelogram form with a longer axis in NNW-SSE direction. Its entrance overlooks southwest, to Sandıklı plain (Figure 6, 7). Long axis of the cave is 14.4 m; it has a length of 9.9 m from the entrance to inner sides. Entrance section has a width of 7.4 m. The cave contains a large saloon of approximately 140 $m^2$. The floor of the cave is slightly sloped to the outside (entrance).

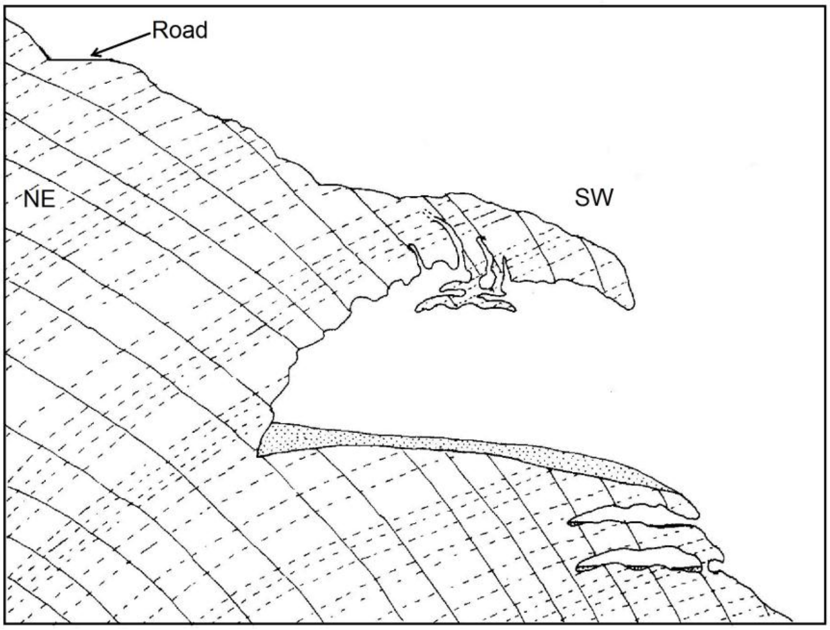


**Figure 4.** Cross-section of Çakmaktepe Cave (scaleless).

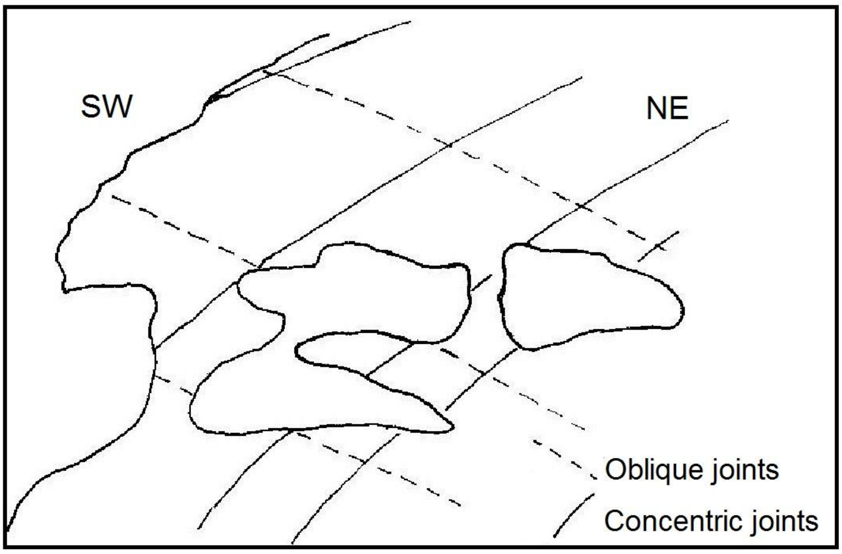


**Figure 5.** Two-floor small cave in the South of Çakmaktepe Cave (scaleless cross section)

Elevation difference between entrance floor and deepest floor is 1.2 m. As for the elevation between the ceiling and the floor of the cave, a different situation is encountered. There are hanging remants corresponding to different periods of cave development, which are the ceiling and floor of each other (Image 3). There is an elevation difference of 6.9 m between the floor and the highest ceiling. However the cave isn't only composed of these.

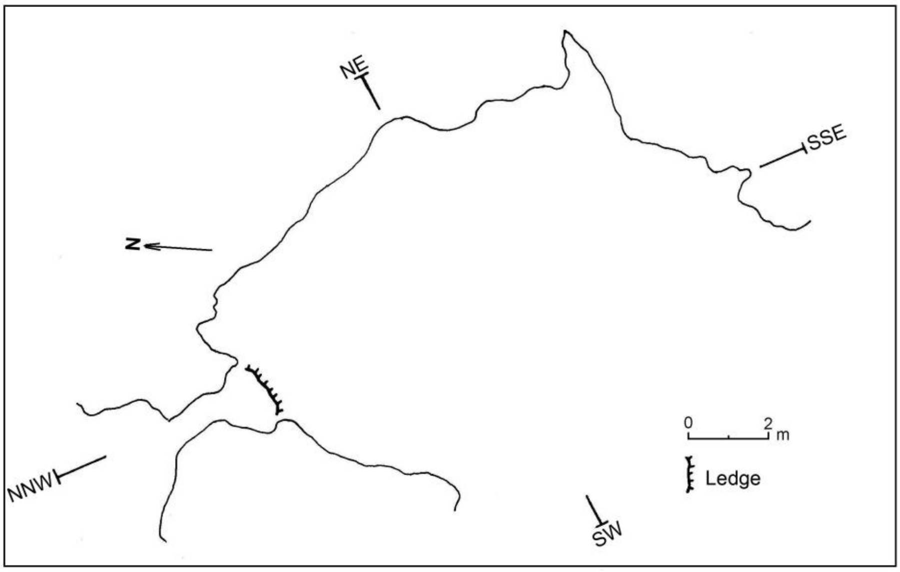


**Figure 6.** Plan of Çakmaktepe Cave

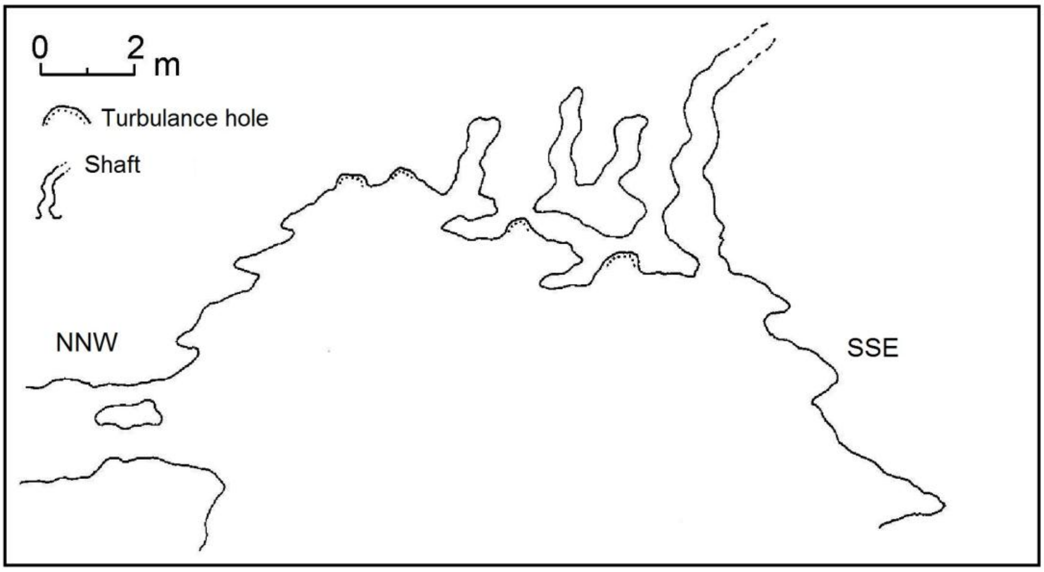


**Figure 7.** Cross-section of Çakmaktepe Cave in NNW-SSE direction

There are four shaft (vent) formed by water leakage along the cracks from the ceiling of the cave which sometimes caused strong water flows. Although the shaft to the right of the entrance (south) extends in the ceiling making curves, its minimum 5 m. section can be observed (Image 4). These shafts do not open outside on the roof of the cave; they are probably blocked by soil and weathering products. In fact, strong penetration of surface waters on the roof of the cave, which serves as a terrace, during the first formation stages of the cave, caused expansion of vertical cracks and development of shafts. In other words, shafts correspond to old swallow holes which are formed at the initial phase and open to the primary cave void. However, water leakages from the shafts still continue.

Similarly, there are smooth-surfaced turbulence holes in the ceiling of the cave, formed by the turbulence of rising turbulent waters. The diameter of turbulence holes vary between 20 and 70 cm (Image 4). The turbulence holes are visible in lower sections, also in hanging ceiling parts.

On the other hand, the two horizontal lateral galleries on top of each other in NNW direction of the cave are located at a higher position than cave floor. Lateral galleries correspond to the entrance points of external waters according to an old morphological base level. Galleries are reached via a 90 cm wide terrace through a large saloon. This terrace belongs to the period, during which the fourth floor was present, in horizontal development stages of the cave. The two galleries have an approximate length of 1 -m. Of these cylindrical galleries, the larger one below has a diameter of 75-80 cm. A small saloon which widens to the exterior is reached via the exit of the gallery. The distance between gallery exit and exterior side of small saloon is 2.65 m. The small saloon has a width of 1.85 m where the galleries open to outside. It has a width of 3.5 m in outer edges. The elevation between the floor and roof of the small saloon is 2.05 m. The distance from the terrace in the large saloon to the outer edge of the small saloon is 4.55 m in total (Image 5).

It was understood that the cave generally developed in stages by the downward movement of hydrological zones. The ceiling, which is 6.9 m higher from the floor, is the first ceiling at the initial formation of the cave. On the other hand, the hanging remnant below this ceiling is the floor of the first cave and is 5.6 m higher than the actual floor. The second cave floor formed under the first floor (by the ground swallow holes or shafts which are nonexistent today) through the downward movement of morphological base level and thus hydrological zones. In this case, the first floor at higher position became incorporated in the ceiling of the second floor. The turbulent holes on the surface of the oldest ceiling and at the lower sections of the hanging floors indicate that waters coming from vertical shafts raised by occasionally filling the initial cave voids and that pressurized waters created strong turbulences. It is difficult to explain this with rain water, which requires a creek bed where the water is channeled. More precisely, topographic conditions in the period, during which the trachytic intrusion newly began to exhume from cover formations on top of it should be considered. It is strongly probable that Kovalık Creek in the north was on the altered lava which covers trachytic intrusion in the past. Following the exhumation of erodible cover, creek bed must have contacted harder rocks and slowly withdrawn to lateral direction (northwest). The residues of the third floor are observed along the sides of the cave in the form of small terraces or projections in some places; at a height of 3.6 m from the actual floor. On the other hand, the fourth floor is 1.60 m higher from the terrace to the left of the cave entrance opening to lateral galleries and at a height of 2.3m from the right side of the cave.

The relationship between the fourth floor and lateral galleries should be explained. The fourth floor corresponds to the cave ground in the period when lateral galleries were exposed to water movements from the northern side. Creek bed withdrew from the top of the roof to the side (north), strong water entrance from vertical shafts ended and the vents (shafts) were filled with soil. Meanwhile, erodible cover formations were eroded by erosion; topography around the intrusion lost elevation; morphological base level and thus hydrological zones were dislocated in downward direction. Two galleries on top of each other are related with the stages of the process. Development of cave was accelerated by water entrance from lateral galleries and thus cave floor widened. This also widened cave exit where the waters left the cave. However, the effective role of water movements ended due to the movement of the creek to the north and active development of the cave ended. The fifth floor currently forms the actual floor of the cave. In fact, cave ground which is inclined towards the entrance, was leveled by the filling composed of weathering residuum and swallow dung. Water leakage from the cracks corresponding to fourth base level to the cave ground continues even in summer (Image 6). Weathering product kaolin is visible along the sides. Waters leaking from cave ground played a role in the formation of two small caves under the fifth floor.

There are two other small and broad-shaped horizontal caves on top of each other under Çakmaktepe Cave. These caves are related with the continuing downward movement of morphological base level. They developed by water leakage and chemical weathering. Due to lack of adequate water movement to remove weathering products, the floors of the caves are covered with kaolin and weathering residuum mineral particles (Image 7). These have a maximum height of 50 cm and intrude approximately 2.80-2.90 m under the floor of the large cave. The one on the top has a width of 4.10 cm while the one at 1.5 below has a maximum width of approximately 4.60 m. Both of these small caves were formed by the water leaking from the ground of the larger cave on top. For this reason, they can be considered as the developing sixth and seventh floors of Çakmaktepe Cave. However, they have a highly slow development process. It is evident that they took their present form in a long time (Figure 4).

There are similar small and horizontal caves in the South of Çakmaktepe Cave (Image 8). These caves are similarly situated in partially altered trachytic lava which exhumed from altered lava. These developed in trachytic lava in sections with dense chemical weathering alone the partially or completely horizontal crack platforms of water leaking from vertical cracks (Figure 5). Despite their small size, they are older than they look. Kaolin formation is visible in floors of the caves due to chemical weathering. They develop in sections where trachytic lava exhumed from soft formations the ones which previously formed in upper sections along the exposed slope become damaged. Soft formations which are eroded by erosion serve as a base level in formation of caves. Micro-scale natural bridges are found by the collapse of roofs in some caves. The small cave with a distance of 20 m to Çakmaktepe Cave has two floors and is connected to the cave below with a shaft (Figure 5). The upper flow is divided into two sections with a column; however this column is different from the columns in karstic caves, which are formed by the combination of stalactites and stalagmites in karstic caves. It is only apart remaining from chemical weathering. The height between the floor and roof of the small cave is maximum 50 cm. Although it has a width of approximately 4 m, it extends to the inner sections for further 2.20 cm. These caves resemble small caves under Çakmaktepe Cave. This indicates that leaking waters along the cracks alone is not adequate to form large cave and gallery systems in trachytic lava. This process also requires abundant free water flow, which removes weathering products from the environment. On the other hand, water leaking along the cracks, might be adequate to form caves in trachytic lava, although to a small extent.

Chemical processes which play a significant role in formation of Çakmaktepe Cave should also be dealt with. High elevation of the location of the cave (1820) and its situation on the western slope of the mountain increased amount of rainfall. Melting snow waters in spring and spring rains are effective in chemical dissolution along the discontinuities in trachytic lava. In addition to $CO_2$ and thus carbonic acid ($H_2CO_3$) in cold water, organic acids from the plants in upper sections of the cave (sub-alpine vegetation) and from the soils with rich organic substance (acidic mountain-grass soils) increase the acidity of the environment. Water leakage, which shows acidic reaction continues along the crack systems in summer (temperature is particularly low in summer nights). This ensures cations, which are weathering products, to be easily washed away. Rugged terrain facilitates air and water circulation in porous and permeable alteration zones along the joints. Under these conditions, kaolin forms from the feldspars (orthoclase and plagioclase) in trachytic lava. A certain amount of clay is released during the weathering of mafic minerals (hornblende, biotite). The cations (Ca, Mg, Na ions) that are produced during the weathering of all these silicate minerals are easily removed from the environment. $SiO_2$ is transported from the environment in molten and silicic acid form or joins the composition of partially residuum products or newly formed minerals. On the other hand, potassium is partially absorbed by residuum products. The prominent residuum product, which remains in weathering environment (discontinuities), is kaolin. Detritic products composed of the weathering of feldspars and other minerals can fall into this category. Chemical weathering is effective on mineral crystals deep into periphery of joints to certain points. An alteration zone with increased porosity and permeability, which is composed of the minerals with loose bond due to chemical weathering, occurs along the discontinuities.

Although weathering products are partially washed away, these conditions are not enough for the formation of caves and galleries. It might also require physical processes.

**Result and Discussion**

Formation of Çakmaktepe Cave, which developed in semi-altered trachytic lava, greatly resembles formation mechanisms of caves and galleries in other silicate rocks like granite and quartzite. However, instead of weathering of quartz, weathering of feldspars gains prominence (quartz and silica cement in quartzites, quartz an feldspar in granites are exposed to chemical dissolution). This stems from the composition of trachytic lava. Chemical dissolution starts in near-surface sections along the joints like in granites (Romani and Rodriguez, 2007) and quartzites (Corrêa Neto, 2000, Martini, 2000) however, cave and galleries cannot form in phreatic zone. Caves and galleries in trachytic lava begin to form by downward movement of base level, which is caused by expansion of joints due to removal of weathering products by the free water flow staring over phreatic zone. The cations that are produced by the weathering of silicate minerals and partially molten silica are removed by water in partially dissolved state; however, the produced clay (particular kaolin) and weathering product mineral residue are transported by free water flow. When free water flow is not enough in trachytic lava, since leakage waters fail to remove weathering products, only small-scaled caves can form. Thus, it is determined that Çakmaktepe Cave, which formed in semi-altered trachytic lava, developed in three separate stages like in other silicate rocks.

In the first stage, trachytic intrusion was in phreatic zone, sometime before it exhumed from the cover on top it. Pressurized ground water slowly circulating along cooling cracks caused chemical weathering in a restricted zone. However, chemical composition was extremely slow in this period. The weathering intensified in contacts of silicate crystal which form the rock. Silicic acid, which is produced by the weathering of silicate minerals, must have joined the composition of newly formed minerals, rather than being removed from the environment.

As the soft rocks around the trachytic intrusion are eroded by erosion, hydrologic zones were dislocated in downward direction. Before the intrusion exhumation from cover formations, it must have remained in transition zone for a certain time, where groundwater level seasonally changed location in vertical direction. Thus, free water flow began to be provided in joints which occasionally remained in vadose zone. At this stage, chemical processes must have been more complicated. However, weathering and transport was more intense than subsidence. In other words, weathering products began to be actively transported. Free water flow, which can exit when the top section of trachytic intrusion exhumed and is exposed, must have created the initial cave void which forms the ceiling of the actual cave.

In later stages, when the top section of the intrusion remained in vadose zone, following the entrance of canalized surface waters to the roof of the developing cave, since weathering products are easily removed from the joints, crack systems began to expand. However, dislocation of hydrological zones in downward direction also caused base level to dislocate at the same direction. Cave development re-intensified by the entrance of surface waters into the cave from lateral direction. However, when abundant water entrance stopped, vertical and horizontal development of the cave extremely slowed down. Meanwhile, small caves in two layers developed due to the downward dislocation of morphological base level. However, cave formation in trachytic lava by leakage waters cannot further develop as the weathering products cannot be transported at an adequate level. This is the same for soluble rocks such as limestone. Large cave and galleries in carbonated rocks can develop by abundant under-surface or ground water flow. However, chemical erosion is more prominent and the weathering products (bicarbonates) are removed in almost completely dissolved form.

In Turkey, six main karst regions were determined according to primary or original factors which identify karst environment (geological factors) and secondary factors (geomorphology, climate, vegetation and time). There are also "karst areas" corresponding to sub-regions due to certain differences in primary and secondary factors in karst regions (Nazik et al., 2005). The study area is located in the northern section of "Western Taurus Karst Area" (TKb), under "Taurus Mountains Karst Region" (TK) according to karst regions in Turkey. However, this site neighbors "Western Anatolia and Thrace Kars Region" (BTK) and "Central Anatolia Karst Region" (OK).

Çakmaktepe Cave and the small caves in its surrounding fall into the group of natural caves; they are also secondary caves since they developed after the formation of rocks in which they formed. These caves are fossil caves in vadose zone according to the classification based on hydrological properties. They developed according to morphological base level. Çakmaktepe Cave can be considered as a one-floor cave according to development periods, as the floors belonging to old periods are damaged. If the two small caves below are considered to be included in the development of Çakmaktepe Cave, it can be considered as a multi-floor cave. However, Çakmaktepe Cave and surrounding caves display damage more than development. On the other hand, according to classification based on topographic properties, Çakmaktepe Cave and surrounding fall into the group of horizontal caves.

Like the caves which from in other silicate rocks, chemical dissolution played a significant role in the formation of Çakmaktepe Cave. However, whether it played a primary role is controversial. Cave and gallery formation on phreatic zone is in fact limited to being on vadose zone and near the surface. The rock shows a heterogeneous structure and involves complex chemical processes. In addition, excessive weathering products should be physically removed. Therefore, it is a pseudokarstic cave. However, the properties such as the role of water movements along the discontinuities like crack systems, development according to hydrological ones based on dislocating morphological and karstic base level in downward direction and effective role of chemical dissolution greatly resemble formation mechanisms and properties of true karstic caves, which develop in rocks like carbonated rocks.

As for the weathering product solid, detritic remains in silicate rocks (clay, semi-weathered mineral particles etc) always a certain amount of similar remnants are produced even in the purest limestones. These are clayey residuum containing aluminum and iron, which take red color due to oxidation and they are highly visible in sections where they cannot be removed (terra rossa). Only the type, composition and amount of these residuum are different. Maybe, they can be categorized in the group of karst-related solutional forms, as proposed by Ortvos (Ortvos, 1976). However, it would be more appropriate to form a category of silicate rocks (under karst-related solutional forms proposed by Ortvos). As we mentioned earlier, this is still controversial; the researchers have not yet reached consensus.

Çakmaktepe Cave and other caves in its surrounding are important in terms of tourism, nature education and scientific studies. They should be registered and protected as natural heritage.

**REFERENCES**

ARDOS, M., 1978, Afyonkarahisar Bölgesinin Jeomorfolojisi. İ. Ü. Yay., No: 2418, İstanbul.

BAŞARIR, E. ve KUN, N., 1982, Afyon Kalesi Çevresindeki Volkanitlerin Petrografik İncelemesi, K.T.Ü Yerbilimleri Derg., 26, 27-36., Trabzon.

BESANG, C., ECKHART F. J., HARRE, W., KREUZER, H., MULLER, P., 1977, Radiometrische Altersbestimmungen An Neogenen Eruptifesteinen der Türkei, Geol. Jb., 25, 3-36.

CHALCRAFT, D. and PYE, K., 1984, Humid tropical weathering of quartzite in southeastern Venezuela. Zeilschrift fur Geomorphologie, 28, 321-332.

CİHAN, M., SARAÇ, G., GÖKÇE, O., 2003, Insights into biaxial extensional tectonics: an example from the Sandıklı Graben, West Anatolia, Turkey, *Geological Journal*, 38, 47-66.

CORRÊA NETO, A.V., 2000, Speleogenesis in Quartzite in Southeastern Minas Gerais, Brazil. Speleogenesis (Evolution of Karst Aquifers), January 2000 Edition; Editors; Alexander B. Klimchouk, Derek C. Ford, Arthur, N. Palmer, Wolfgang, Drybrodut, (s 452-488), ISBN: 1-879961-09-1, National Speleogical Society. Inc, Hunstville-Alabama-USA.

ERCAN, T., (1986), Orta Anadolu'da Senozoyik Volkanizması. *MTA derg.*, S 107, s 110-140, Ankara

ERİNÇ, S., 1971, *Jeomorfoloji II*. İstanbul Ün. Yay. No: 1628, İstanbul.

ERİNÇ, S., 1982, Jeomorfoloji I. İ. Ü. Ed. Fak. Yay. No: 2931, İstanbul.

ERKAN, Y., BAYHAN, H, TOLLUOĞLU, Ü., AYDAR, E., (1996), Afyon Yöresi Metamorfik ve Volkanik Kayaçlarının Jeolojik, Petrografik ve Jeokimyasal İncelemesi. Tubitak Yer, Deniz, Atmosfer ve Çevre Araştırmaları Grubu, Proje No: YBAG-0044/DPT, Ankara.

HALLIDAY, W.,R., (2007), Pseudokarst in The 21st Century. Journal of Cave and Karst Studies. S 69, No 1, s 103-113.

KASTNING, E., H., (2005), Very Small and Eclectic Caves: Conservation and Management Issues. 17th National Cave and Karst Management Symposium, Albany, New York, USA.

KEMPE, S., and HALLIDAY, W.R., 1997, Report on the Discussion on Pseudokarast, in Proceedings of the 12th International Congress of Speleology, v. 6, Basel, Switzerland, Speleoprojects.

KOÇYİĞİT, A., CİHAN, M., ÖZACAR, A., (2001), Dombayova ve Sandıklı (Afyon) Grabenlerinin Depremselliği ve Kenar Faylarının, Kinematik Analizi. Tubitak Yer, Deniz, Atmosfer ve Çevre Araştırmaları Grubu, Proje No:YDABÇAG-199Y007, Ankara.

MARTINI, J.E.J., 2000, Dissolution of Quartz and Silicate Minerals. Speleogenesis (Evolution of Karst Aquifers), January 2000 Edition; Editors; Alexander B. Klimchouk, Derek C. Ford, Arthur, N. Palmer, Wolfgang, Drybrodut, (s 171-174), ISBN: 1-879961-09-1, National Speleogical Society. Inc, Hunstville-Alabama-USA.

NAZİK, L., 1998, Mağaraların Enine ve Boyuna Kesitlerinin Belirlediği Jeolojik ve Jeomorfolojik Özellikler. 2. Ulusal Speleoloji Sempozyumu Bildiriler Kitabı. Mağara Arş. Dern. Yay. No: 2, 1-5, Ankara.

NAZİK, L, 2005, Mağara Nedir, Nasıl Oluşur? Ulusal Mağara Günleri Sempozyumu, 24-26 Haziran 2005, Bildiriler Kitabı, s 7.

NAZİK, L., TÖRK, K., TUNCER, Ö., İNAN, H., SAVAŞ, F., 2005, Türkiye Mağaraları. Ulusal Mağara Günleri Sempozyumu, 24–26 Haziran 2005, Bildiriler Kitabı, s 31–46.

OSBORNE, A. and BRANAGAN, D., 1992, Pseudokarst in the Sydney Region. Twenty Sixth Newcastle Symposium on "Advances in the Sydney Basin", Newcastle, Department of Geology, The University of Newcastle, 95-102.

OTVOS, E. G., JR., 1976, Pseudokarst and Pseudokarst Terrains: Problems of Terminology. Geological Society of America Bulletin, v. 87, p. 1021-1027, 5 figs., July 1976, Doc. no. 60708.

ÖZPINAR, Y., ÇOBANOĞLU, İ., BOZKURT, R., 2002, Sandıklı Zeolitik Tüflerinin Petrografik, Petrokimyasal ve Teknolojik İncelenmesi. Tubitak Proje No: YDABÇAĞ-198Y102.

ÖZPINAR, Y., (2008), Sandıklı (Afyon) Yöresinde, Şabazit ve Fillipsit Mineral İçeren Tüflerin, Mineralojik, Petrografik ve İyon Değiştirme Özellikleri ve Tarımda Kullanılması (GB Anadolu-Türkiye). MTA Derg., 137, 27-47, Ankara.

PEKCAN, N., 1999, Karst Jeomorfolojisi. II. Baskı. Filiz Kitabevi, İstanbul.

RONNER, F., (1962), Sandıklı Ovası Çöküntüsü-Genç Tektonik ve Volkanik Durumlar. MTA Dergisi, S 59, s 69-88, Ankara

SEMENDEROĞLU, A., 2011, Ege Bölgesi'nin Mağaraları. Çantay Yayınları.

SEYHAN, A., (1971), Volkanik Kaolin Oluşumu ve Andezit Problemi. TJK. Türkiye 25. Jeoloji Kongresi, Şubat 1971, s 124-134, Ankara.

URBANI, F., SZCZERBAN, E., 1974, Venezuelan Caves in Non-Carbonate Rocks: A new Field in Karst Research. NSS News (Natl. Speleol. Soc., Huntsville, Ala.), v. 32, p.233-235.

VAQUEIRO RODRIGUEZ, M., 2004, Karst in siliceous rocks: Pseudokarst landforms and caves in the quartz dyke of Pico Sacro (Boqueixon, Galicia). Caderno Lab. Xeolóxico de Laxe Coruña. Vol. 29, pp. 247-264.

VIDAL ROMANI, J. R., RODRIGUEZ, R., 2007, Types of granite cavities and associated speleothems: genesis and evolution. Nature Conservation, Institute of Nature Conservation, Polish Academy of Sciences n 63, p 41-46, Krakow-Poland.

WHITE, W. D., JEFFERSON G. L. and HAMAN J. F. 1966, Quartzite Karst in Southeastern Venezuela. International Journal of Speleology 2, 309-314.

WRAY R. A. L., 2003, Quartzite dissolution: karst or pseudokarst? Cave and Karst Science, V 24, No 2, 1997, 81-86.

YANES, C. E. and BRICEFTO H. 0., 1993, Chemical weathering and the formation of pseudo-karst topography in the Roraima Group, Gran Sabana, Venezuela. Chemical Geology 107, 341-343.

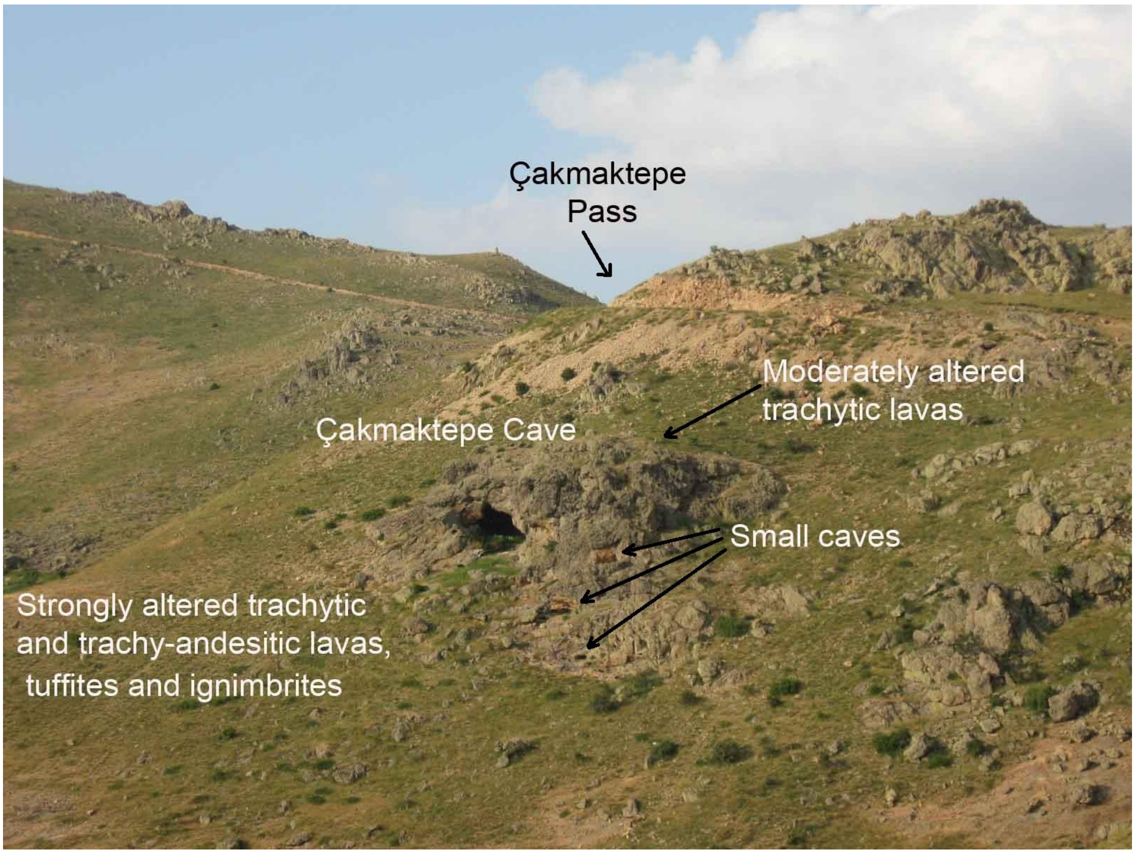


**Image 1.** General image of Çakmaktepe Cave and its near surrounding

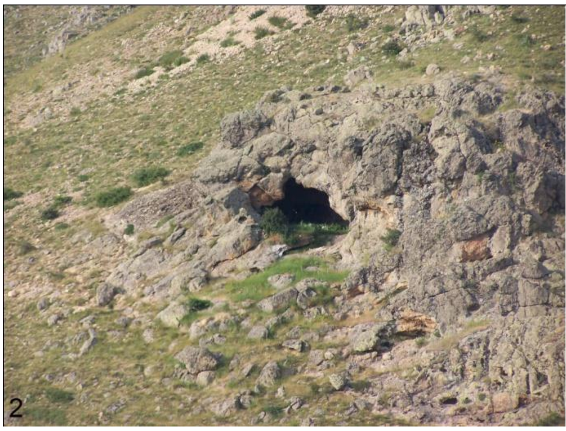



**Image 2.** Close-up image of Çakmaktepe Cave and its entrance

**Image 3.** Hanging remnants belonging to previous development stages of Çakmaktepe Cave


**Image 4.** One of the shafts on the ceiling. Turbulence holes are visible on the left.

**Image 5.** Lateral galleries in the West of Çakmaktepe Cave.

**Image 6.** Water leaking from inner sides of the cave, along the crack surfaces in summer.


**Image 7.** Chemical weathering product kaolin and semi-weathered fragments in small caves right below Çakmaktepe Cave

**Image 8.** One of the small caves with a similar formation process, in the south of Çakmaktepe Cave.