Gypsum karst, Sivas, Turkey

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Abstract The gypsum karst units which are spread over a large area in the vicinity of Sivas, and especially in the east of Sivas, are presumed to be of Miocene age. Geomorphological features include numerous collapse dolines. The Seyfe and Göydün springs have high discharge rates of water of unsuitable quality (EC: 13,000 mho/cm). Lakes are formed in the collapsed gypsum areas and the water quality of these lakes is poor (Hafik lake, Tödürge lake, Western Lota lake, Eastern Lota lake, etc.). The water quality of the Kızılırmak River, part of which is in this region, is not good enough for drinking water or irrigation.

Keywords Gypsum karst · Gypsum aquifer · Water quality · Sivas · Turkey

Introduction

Sinkholes characterize karst topography. A natural phenomenon, their development in carbonate rocks such as the limestones of Florida and Taurus Mountains and the Yucatan Peninsula of Mexico is well known. However, sinkholes which form in highly soluble evaporite rocks, such as gypsum and salt, are less commonly known. These sinks can be as dramatic and troublesome as those in carbonates (Martinez and others 1998).

Evaporite deposits form when various salts precipitate from evaporating water, mainly seawater. The principal evaporite rocks include gypsum (or anhydrite, its anhydrous form) and salt (halite), although potash (sylvite) and other rarer salts are locally important. Evaporites have the highest solubility of common rocks. Water which is unsaturated with respect to gypsum ($CaSO_4 \bullet 2H_2O$) or salt (NaCl) rapidly dissolves these rocks. Indeed, gypsum and salt are about 150 and 7,500 times more soluble than limestone, respectively. Such high solubilities enable subsurface dissolution channels and sinkholes to form in a matter of days or weeks, and catastrophic collapse can result. Evaporite rocks underlie about 35% of the United States and are found in 32 contiguous states. They are also found in Canada and Mexico, and are widespread on other continents (Martinez and others 1998).

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Paragenesis of gypsum and anhydrite

Gypsum is the most common of the sulfate minerals. Its main occurrences are as sedimentary deposits associated with limestones, shales, marls and clays, and in evaporite deposits. Seawater contains about 3.5 wt% dissolved materials, about 80% of which is sodium chloride and about 4% calcium sulfate.

In evaporites the calcium sulfate sometimes occurs as gypsum, sometimes as anhydrite, and very often as both minerals together. It appears that, in general, anhydrite is a secondary mineral produced by the dehydration of gypsum, a reaction which involves a decrease in volume of the solid phase; sometimes halite fills the resultant voids and a halite-anhydrite assemblage results. The water released by the dehydration of gypsum may result in the local solution, redistribution and deposition of the soluble salts of the surrounding evaporites. In many areas gypsum has been dissolved in percolating waters (the solubility is increased by the presence of NaCl or $CaCO_3$), which in the dry season are drawn to the surface by capillary action and are evaporated, leaving gypsum deposited as crystals, sometimes in aggregates described as "desert roses". Large gypsum deposits are also found in saline lakes and salt pans.

Anhydrite is usually secondary, whereas gypsum can be either primary or secondary. Gypsification of anhydrite occurs frequently along contacts of evaporites with carbonate rocks, and it proceeds along anhydrite cleavages, the textures showing that the gypsum is secondary. Where large volumes of anhydrite have been altered to gypsum by hydration, masses of gypsum are found with relict nodules of anhydrite.

Gypsum is sometimes produced by the action of sulfuric acid solution on the calcium in the rocks through which it is moving. In clays and marls the acid solution may be produced by the weathering of sulfides, and in metalliferous veins by the oxidation of sulfides. Gypsum is also found in deposits of native sulfur, and it is produced in volcanic regions by the action of sulfurous vapors on calcium-bearing minerals. Among the minerals which may be found in association with gypsum are halite, celestine, calcite, aragonite, dolomite, pyrite, sulfur and quartz.
The principal occurrences of anhydrite are as a constituent of evaporites and as a product of hydrothermal alteration of limestone and dolomite rocks. In evaporite deposits, anhydrite or gypsum may occur, and sometimes both are found together. According to the results of experiments on the solubility of anhydrite and gypsum, anhydrite should be deposited directly by the evaporation of seawater above 49 °C, or at a lower temperature from a more sa1ine solution. At lower temperatures and lower salinities gypsum should be deposited. Other experimental results, however, indicate that the primary precipitation of anhydrite from seawater is improbable, and that anhydrite is nearly always a secondary mineral produced by the dehydration of gypsum. Anhydrite also occurs in salt plugs and domes.

Natural sinkholes

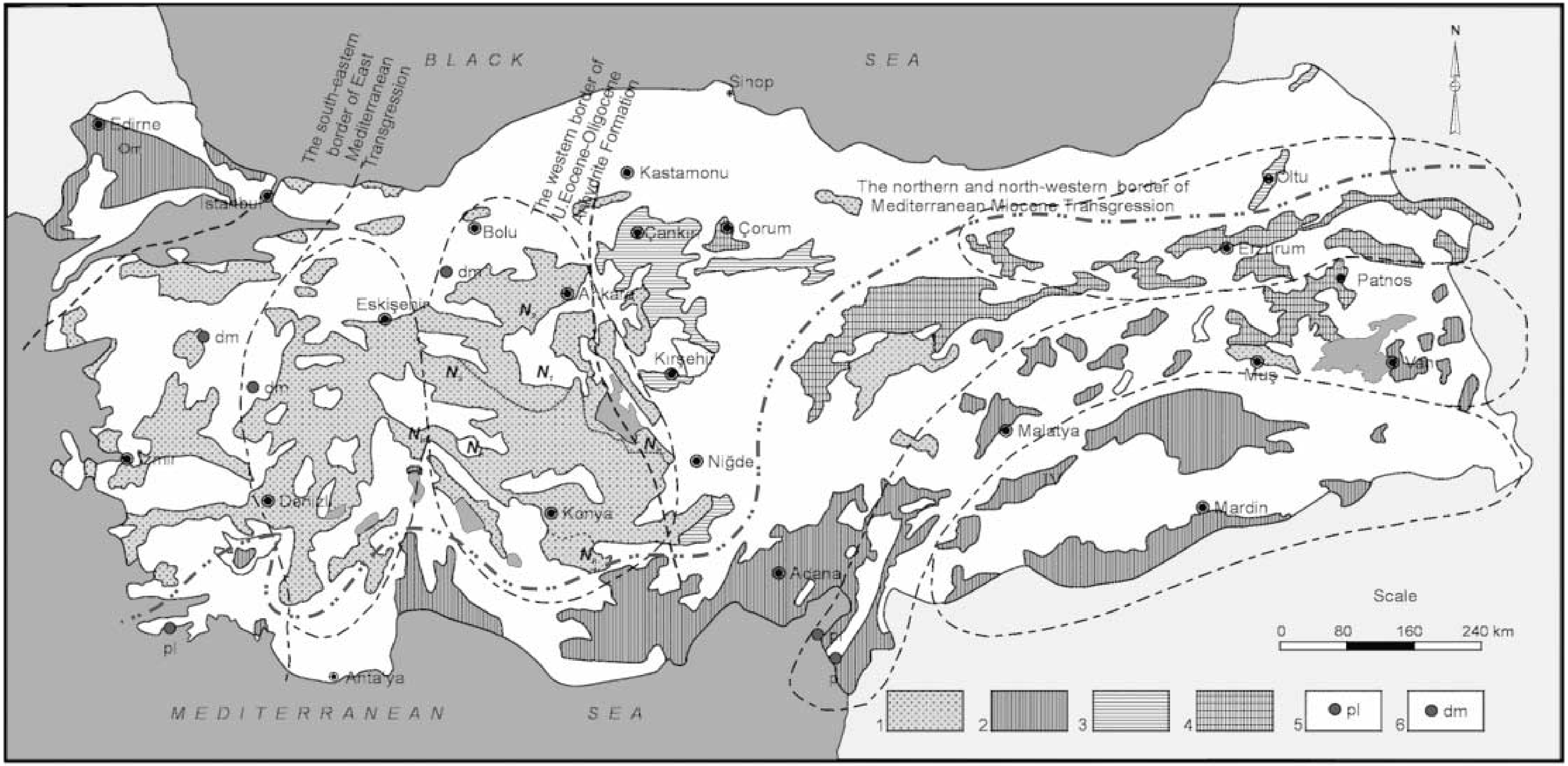
Natural sinkholes in evaporite rocks develop by the same processes which form sinkholes in carbonates (limestone and dolomite), except that they can develop much more rapidly. Water percolates over or through gypsum or salt and dissolves the highly soluble rock, leading to the formation of sinkholes, caves, natural bridges, disappearing streams, and springs. There are four basic requirements for evaporite sinkholes to develop: (1) a deposit of gypsum or salt; (2) water, unsaturated with $CaSO_4$ (calcium sulfate) or NaCl; (3) an outlet for escape of dissolving water; and (4) energy to cause water to flow through a porous system. Once a through-flowing passage forms in the evaporite rock, enlargement results from further dissolution and from abrasion by water-borne particles transported through the cavity.
Karst features, such as sinkholes, near-surface caves and collapse structures which form in water-soluble rocks, are potentially serious hazards. Groundwater in karst areas is an important resource which needs to be developed and protected.
Karst in rock gypsum is widespread in most parts of the world. Gypsum underlies about one-fourth of the world's land surface, and gypsum karst is documented in almost every nation where gypsum crops out or is within 100 m of the land surface. Gypsum is the second most soluble of the common rocks, second only to common rock salt or halite. Water percolates over or through gypsum and dissolves the highly soluble rock; and this causes formation of sinkholes, caves, natural bridges, disappearing streams, and springs. Hazards include damage and/or collapse of homes, buildings, and civil projects (such as dams, bridges, highways and farmlands). Such events can cause great economic hardship, disruption of lives, and even loss of life.
The Sivas Basin of central eastern Turkey is a classic area where the processes of gypsum karst have been studied. Gypsum karst in the Sivas Basin has developed in the Late Miocene Hafik Formation, which is locally covered by Pliocene and Pleistocene clastic sediments. The full ranges of gypsum-karst features are present in the region, and there are a number of striking examples of karst hazards and environmental problems.
Gypsum has a high level of solubility and there is a positive correlation between temperature, pressure and solubility. For these reasons, surface waters and groundwater which are in contact with gypsum become enriched with total dissolved solids (TDS) and basic ions such as calcium (Ca) and sulfate (SO_4). Gypsum formations, which contain interlayers of halite, cover large areas in the Kızılırmak Basin of central Anatolia. Some of these halite beds are situated southeast of Sivas and are used for halite production. In the Upper Kızılırmak Basin gypsum units cover almost 50% of the area, and the springs with high flow rates which emerge from this karstic unit (Seyfe and Göydün springs) flow into the Kızılırmak River. Because of the effects of these poor-quality waters, the Kızılırmak River becomes enriched in TDS and is not suitable for domestic, industrial or irrigation use. The drinking and domestic needs of the city of Sivas, the largest settlement in the Upper Kızılırmak Basin, are supplied from the wells drilled in alluvium in Tavra valley, 7 km north of Sivas (Kaçaroğlu and Şahin 1994).

Geological situation

The study area consists of sedimentary and metamorphic units of Paleozoic and Quaternary ages. In Fig. 1, the major Tertiary basins in Turkey can be seen. In Fig. 2, the distribution of evaporitic rocks in Turkey are shown. In Fig. 3, the area covered by gypsum in the study area is shown in the MTA map. In Fig. 4, the generalized stratigraphic section of the geological units in the study area is shown.
The Karaçayır Formation (Pmk), aged Upper Paleozoic–Lower Mesozoic, is composed of various schists, marble and quartzite, and is in the north of the study area. The Güldere Formation, aged Lower–Middle Eocene, generally contains detritic rocks formed by sandstone, claystone and siltstone and partly fossilized limestones. The Kömür member (Tkk) of the Lower Miocene Kemah Formation contains interlayers of carbonate and coal, and a sequence of sandstone-claystone-mudstone. The Middle–Upper Miocene Hafik Formation (Th) constitutes the gypsum unit and contains interlayers of halite. The Zöhrep Formation (Tpz) contains units of claystone and limestone and interlayers of pebble-sandstone of Pliocene age. The Travertine (Qt) and alluvium (Qal) are of Quaternary age.

▶

Fig. 1
Major Tertiary basins in Turkey (based on 1:500,000 Turkey Geological Map, MTA)



1- Lacustrine Neogene; N_k - Neogene-Quaternary Lacustrine Deposits
N_1 - Saliferous Neogene, N_2 - Pliocene with anhydrite intercalations
2- Marine Miocene; om - Marine and Saliferous Oligo-Miocene (Trakya)
3- Oligo-Miocene Anhydrite Formation
4- Anhydrite formation Marine Miocene with intercalation
5- Marine Pliocene Outcrops
6- Scattered Marine Miocene Fossil Locations

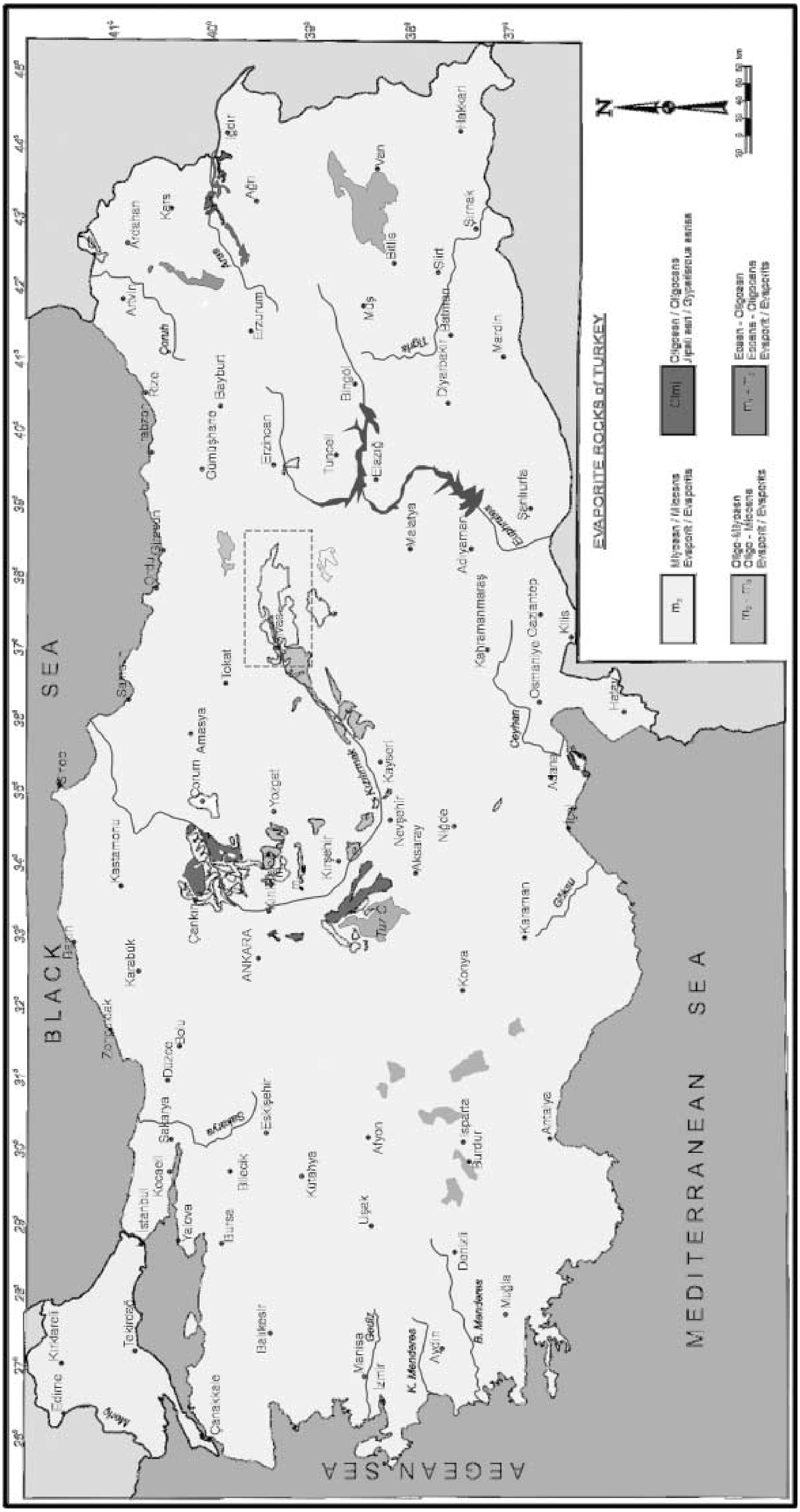


Fig. 2
Evaporitic rocks of Turkey

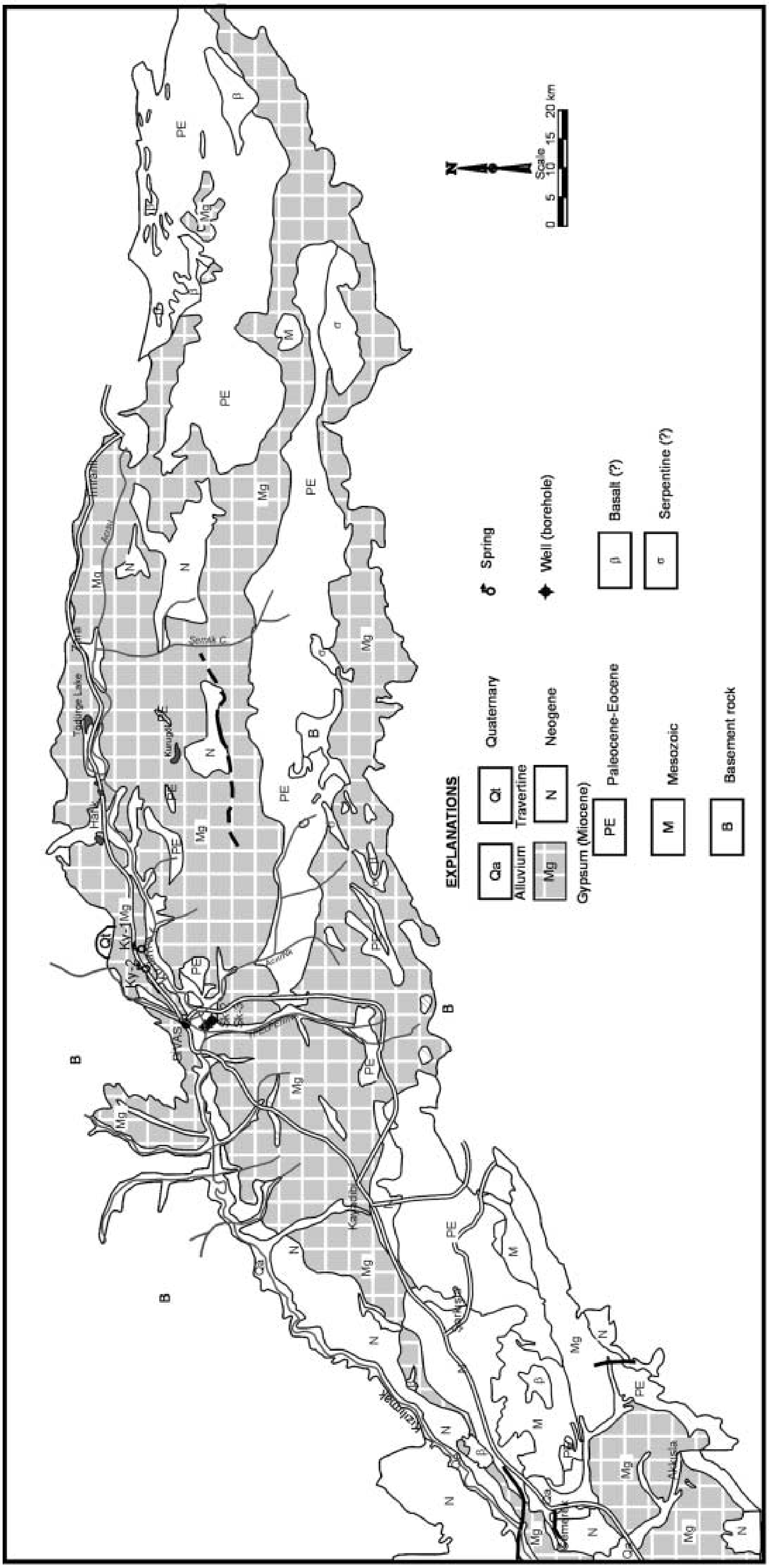


Fig. 3
Geological map of the Sivas Tertiary Basin

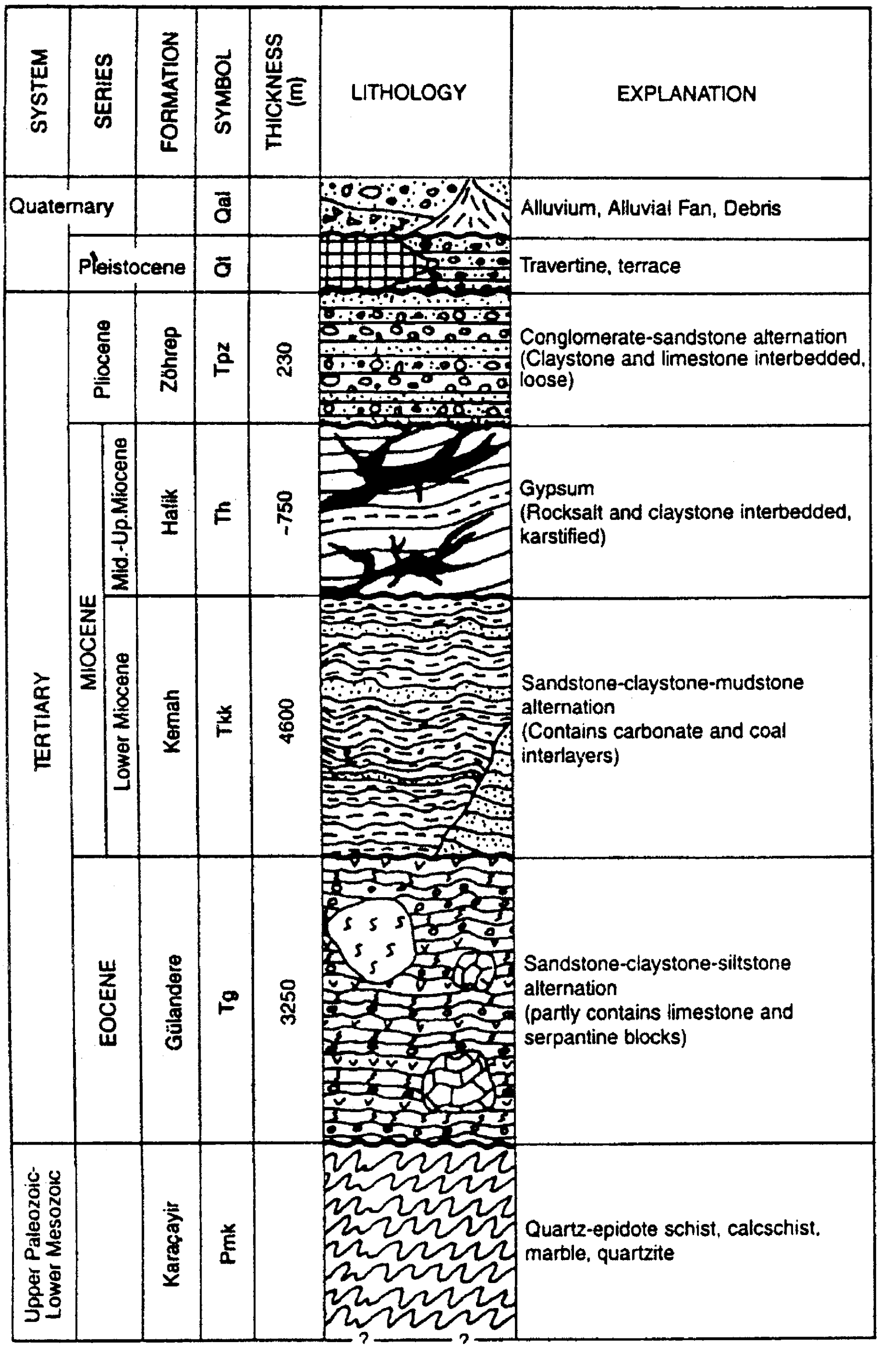


Fig. 4
Generalized stratigraphic column of the study area and its vicinity (modified after Kaçaroğlu and others 2001)

The central and southern parts of the study area are heavily faulted. The faults generally strike in NE–SW and NW–SE directions (Fig. 3), and most are oblique with strike greater than the dip components. A few normal faults have short elongations. The longitudinal depressions (troughs) are formed in the gypsum in direct relation to the faulting. The linear depressions in the gypsum around the Kızılırmak river valley and beneath the alluvium indicate the linear extension of the faults. The areal intensity of these depressions and intensively folded structures developed in the gypsum cause some difficulties for the determination of the character of faulting in the gypsum. Joint systems in the gypsum were measured at nine locations (Fig. 3).

The joints generally conform to the faults, and their strikes are in a NW–SE direction (Fig. 4). Most of the joints are vertical or nearly vertical, and solution cavities have developed along the joint zones (Kaçaroğlu and others 1997, 2001). The Sivas Tertiary Basin is one of the central Anatolian basins which formed over the collision zone between the Pontides and the Anatolide-Tauride belts. The basin, which is floored by southerly obducted Neotethyan ophiolite sheets onto the Taurides during the Late Cretaceous time interval, occupies a key position in the sedimentary record of the continental collision processes. The central and easternmost parts of the Sivas Basin around the Hafik (Sivas) and Kemah (Erzincan) regions have been studied with respect to tectonostratigraphy, tectonic style, and kinematics.

The tectonic style of the Sivas Basin is characterized mainly by polyphase thrust systems developed along a regional NNW–SSE shortening direction. The general transport directions are oriented toward the south and southeast. However, N-vergent thrust development in the Late Oligocene and Late Pliocene–Quaternary epochs occurred in the central part of the Sivas Basin where thrust propagation is controlled mainly by a dêcollement surface at the bottom of an Oligocene gypsum mass in the Hafik Formation. In the eastern part of the basin, thrust propagation is controlled by several dêcollement surfaces in the basin sequences (Temiz 1996).
This study demonstrates that the central and eastern parts of the Sivas Basin experienced significant shortening involving both basin deposits and basement. This contraction has been largely underestimated in previous studies, and the eastward-narrowing geometry of the basin can be related to an increasing amount of contraction toward the east. The age of thick gypsum-rich formations, previously attributed to the Late Miocene, is now restricted to the Oligocene by consideration of both the stratigraphic relationships with Lower Miocene shallow-marine formation and the geometry of the thrust systems (Temiz 1996).

Gypsum karst hydrogeology

The rocks which form the karstic units are composed of gypsum, anhydrite and halite, all having high levels of solubility. These are also referred to as evaporitic rocks. Other karstic units are composed of limestone and dolomite. Interior Anatolia is the second, most important karst region of Turkey. The karst features, however, are not the dominating forms of the topography and they show a different character than the Taurus karst. These features are restricted to the Tertiary gypsiferous deposits along the upper cause of the Kızılırmak River in the east and to the lacustrine limestone and marl sediments of the Miocene and Pliocene and the Mesozoic limestones around Konya.

Fig. 5
Miocene gypsum karst landforms 20 km east of Sivas

Fig. 6
Miocene gypsum karst landforms 18 km east of Sivas. Note large collapse doline in the foreground

Fig. 7
Solubility in the gypsum formations, east of Sivas around Middle Lota Lake

Table 1
List of the water samples collected in the study area. Sampling date: 16 August 2001

Parameter	Water sample							
	Seyfe spring	Göydün spring	Hafik lake	Tödürge lake	West Lota lake	East Lota lake	K.irmak (Sivas)	K.irmak (K.kale)
Temperature (°C)	13	13	20	25	24	26	29	24
Electrical conductivity (EC, μS/cm)	13,000	13,000	1,800	8,000	2,700	300	3,600	1,650
Na (ppm)	2,377.5	2,390.0	29.7	1,181.0	42.8	118.7	326.0	179.0
K (ppm)	5.25	5.00	0.70	7.10	6.29	4.79	4.00	4.90
Ca (ppm)	570.0	575.0	300.0	515.0	462.5	485.0	345.0	120.0
Mg (ppm)	42.5	40.0	28.0	45.0	34.0	30.0	34.0	29.0
CO_3 (ppm)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HCO_3 (ppm)	329.77	329.77	70.03	99.25	99.25	99.25	154.70	157.56
Cl (ppm)	3,598.50	3,704.53	24.82	1,790.23	42.54	164.84	549.48	228.65
SO_4 (ppm)	1,342.50	1,242.50	821.35	1,344.42	1,202.12	1,230.96	788.66	384.81
Σ Anion (mequiv/l)	134.50	135.78	18.95	80.12	27.86	31.91	34.46	17.05
Σ Cation (mequiv/l)	135.19	136.08	18.58	80.96	27.60	31.96	34.30	16.78

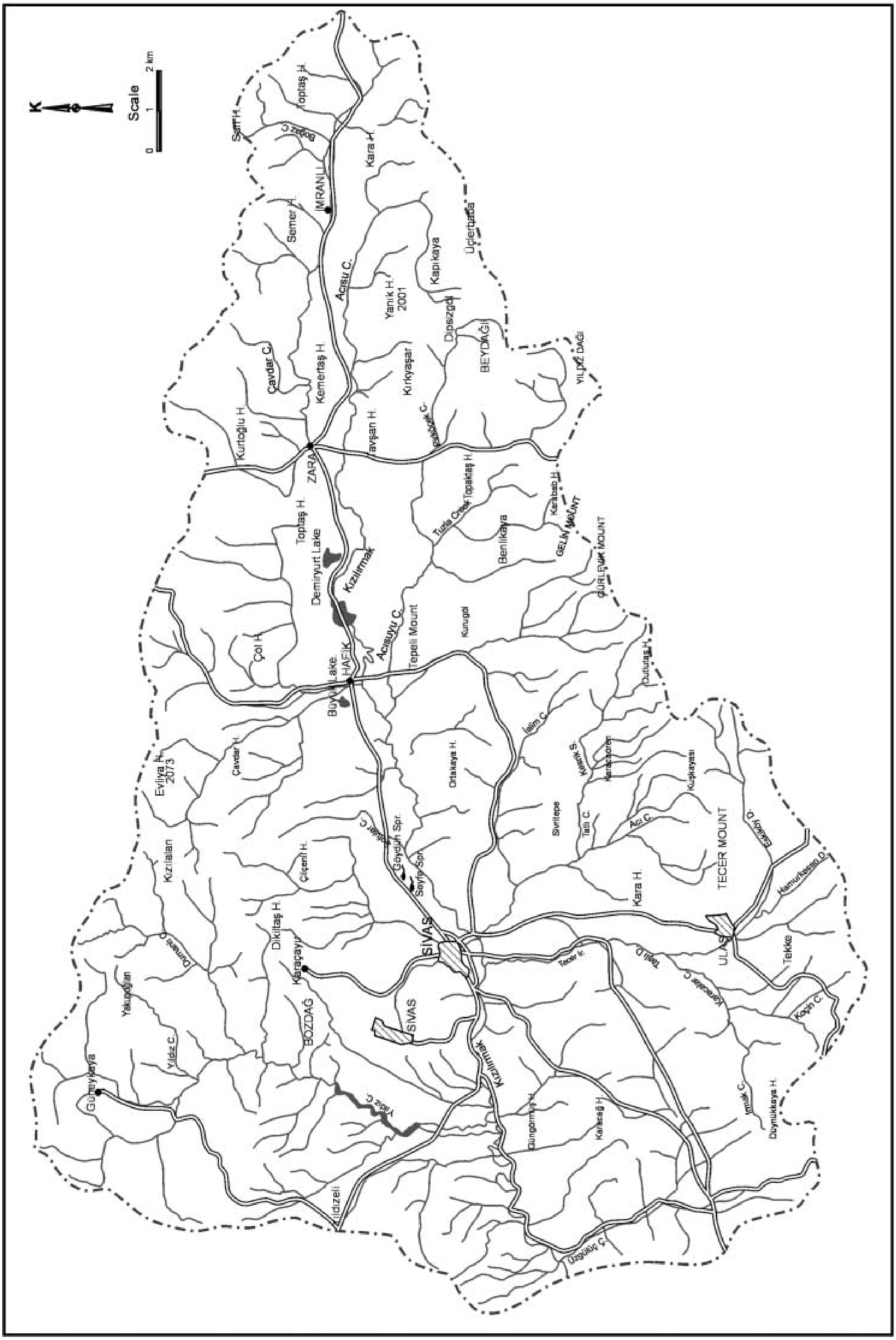
Additionally, one can find gypsum karst around Çankırı and in the NW parts of Kayseri (Alagöz 1967; Şengör 1975). Alagöz (1967) published a comprehensive account on the gypsum karst of Sivas. In this work he describes a great majority of the karst forms which are composed of numerous caves, dolinas, ponors, karstic springs, travertines, uvalas, karstic hills, canons, etc. which occur on both the limestone strata of the Pliocene and the gypsiferous deposits of the Tertiary.

The karst forms occurring on the Pliocene limestone are generally confined to the northwestern tracts of Sivas. Here, there are dolinas and related karst forms. In the canons of Tavra travertine stairs are present.

In the east along the upper course of the Kızılırmak River, on the other hand, numerous karst forms occur on the gypsiferous formations of the Oligocene and Lower–Middle Miocene and Pliocene (Figs. 5, 6). Caves are especially frequent in the southern regions of Hafik and in the vicinity of the canon of Tödürge. Large dolinas are spread throughout the region. It would suffice to name Başıbüyük, Osmaniye, Kurudeniz, Bedirviran and Çimenyenice, the smallest of which has a diameter of at least 1 km. Numerous karstic springs, which are locally given the names designating the bitterness of their waters, are especially grouped around Çirkin and Tuzhisar where several caves are also to be found. Canons, which were cut in gypsum, can be followed along the course of the Kızılırmak River, beginning from Zara and proceeding towards the west passing through the canons of Yarhisar, Kötnü and Seyfe. The karst hills are especially abundant along the course of the river. Approximately 10 km south of Zara there is an uvala called the uvala of Kalkan Çiftliği. As an addition to the above-mentioned karst forms of Sivas, numerous temporary lakes and swallow holes may be mentioned.

▶

Fig. 8
Drainage area of the Sivas Tertiary Basin and karstic gypsum lakes and karstic springs


K
Scale
0
1
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İMRANLI
Acısu C.
Kara H.
Semer H.
Toptaş H.
Kapıkaya
Yanık H.
2001
Dipsizgöl
BEYDAĞI
YILDIZ DAĞI
Kırkyaşar
Kemertaş H.
Çavdar C.
Kurtoğlu H.
ZARA
Tavşan H.
Toptaş H.
Demiryurt Lake
Kızılırmak
Tuzla Creek
Topaktaş H.
Benlikaya
GELİN MOUNT
GÜRLEVİK MOUNT
Acısuyu C.
Tepeli Mount
Kurugöl
Çol H.
HAFİK
Evliya H.
2073
Çavdar H.
Ortakaya H.
Kuşkayası
Sivritepe
Tatlı C.
Acı C.
TECER MOUNT
Kara H.
Çiçekli H.
Kızılalan
Dikiltaş H.
SİVAS
SİVAS
BOZDAĞ
ULAŞ
Tekke
Hamurkesen D.
Yakupdan
Yıldız C.
Yıldız C.
Kızılırmak
Güngörmüş H.
Yıldızeli

Fig. 9
Karstic Göydün spring outlet. The existing point has a very deep conic shape and it is an ascendant spring

Other areas which display gypsum karst in the interior Anatolia are around Çankırı on the WNW tracts of Ankara, in the NW regions of Kayseri and around Kırşehir. In the vicinity of Ankara no karstic forms have yet been reported.
The cave concentration centers of the interior Anatolia region, according to Başar (1972), are eastern tracts of Kayseri and NE of Sivas.
Gypsum karst phenomena in Turkey are seen mainly in the large areas in Sivas and its vicinity. Moreover, it is also seen, on a smaller scale, in central Anatolia, Adana, Çankırı, Kayseri, Konya and a few other areas (Fig. 2). Gypsum karst is also found in other countries such as Britain, Canada, the USA, Russia and Spain (Ford and Williams 1989).
The Miocene-aged gypsum in Sivas has features which may be commonly seen in other karstic carbonate rocks. In the study area, there are a large numbers of dolines, ponors, solution cavities, and depression areas. The karrens, which are frequently found in carbonate rocks, are very rare in Miocene-aged gypsum.
Although only rarely, a number of caves are also seen in the gypsum area. When the natural cross sections in gypsum units are studied (Fig. 7), the formations developed by solution processes can be observed. The solubility of gypsum is 10–30 times larger than that of limestone, and the rate of solubility is also higher. The density and solubility rates are controlled by the quantity of water which is in contact with gypsum. The effects of precipitation may easily be seen in gypsum formations. Although karren formations develop in gypsum, their traces disappear due to the soft structure of gypsum formations.
Closed collapse areas are commonly observed in gypsum karst. In general, these are large and shallow. Collapse dolines and land collapses develop in relation to the dissolution structure in the main rock. Collapse features are very common in evaporitic karst. These are combined structures and generally have widths of 10–100 m and lengths of 1–15 km. Their depths vary between 5 and 50 m. It is believed that these collapse features develop along fault and fracture lines.

Gypsum karst springs

In the study area, the development of two karstic springs with high productivity is observed. These springs are ascendant-type springs which are discharged from several outlets. Seyfe spring is 23 km east of Sivas and 2.7 km south of the highway. It is discharged from the gypsum solution cavities through several outlets and its mean flow rate is 300 l/s. After flowing through a swamp area, the waters of this spring join the waters of the Kızılırmak River, located 3 km away in a southerly direction. The temperature of the spring is 13 °C and its EC value is 13,000 μmho/cm (Table 1). Seasonal variations between the dry and wet periods do not cause significant changes in the flow rate of the spring. The elevation of the spring is 1,305 m (Fig. 8).
Göydün spring is situated 3 km away from the Kızılırmak River (elevation: 1,302 m), 28 km east of Sivas and 1.5 km south of the highway. The spring is an ascendant-type spring and it emerges from a conic-shaped cave 8–10 m deep. The mean flow rate of the spring is 1.1 m^3/s and it has a temperature of 13 °C. There are no significant differences between the flow rates of the spring in summer and winter (Figs. 9, 10). The EC value of the spring is 13,000 μmho/cm. The elevation of the spring is 1,306 m. The EC value of the Kızılırmak River at this point is 3,600 μmho/cm.

Gypsum lakes

One of the most important aspects of the Sivas gypsum karst area is the presence of collapse lakes. All of these lakes are located at three points along the Sivas-Zara highway. In the west there is Hafik lake, in the middle the Lota lakes, and to the east in an area near Zara there is the Demiryurt (Tödürge) lake.
The Hafik (Koçhisar) lake is located 3 km north of Hafik at an elevation of 1,308 m (Fig. 11). Its temperature is 20 °C. Its area is less than 1 km^2, its water is fresh (EC: 1,800 μmho/cm) and it is connected to the Kızılırmak

Fig. 10
Karstic Göydün spring, close-up scenery

River by a canal which is situated in the east of Hafik. The depth of the lake varies between 2 and 3 m. It is thought to be connected to a groundwater system.
About 2.7 km after Hafik, which is located 34 km east of Sivas, a road diverges towards the Western Lota lake. After 1.7 km on this road, is the Western Lota lake, its elevation being 1,309 m and its temperature 24 °C. The EC value of the water is 260–2,700 μmho/cm (Fig. 12). To the north-west of the lake, which has a length of 200 m, there is a spring which recharges the lake. The shape of the lake is circular and its banks are steep cliffs. It is obvious that the lake is a collapse lake. It resembles the obruk lakes of Konya. The lake has a diameter of 250 m and an area of 50 ha (Alagöz 1967). The depth of this lake varies between 5.5 and 8.5 m. Approximately 1 km east of this lake, and within the same collapse rock, there is the Middle Lota lake. Some parts of this lake are swamp areas and its sides are dry. Its elevation is 1,314 m.
The Eastern Lota lake is situated about 2 km east of the Western Lota lake. It is also located 1 km north of the Hafik-Zara highway. It is very difficult to see the lake from the highway. The Eastern Lota lake is a typical obruk lake. It has a circular shape, a temperature of 26 °C, an EC value of 3,000 μmho/cm, and an elevation of 1,334 m. Its width ranges between 11 and 35 m. It is understood that the water level increases by 3 m in spring. It is presumed that the lake is a typical karstic obruk (jama).
Demiryurt lake is located on the Sivas-Erzincan highway, to the north of the highway 15 km away from Zara. Demiryurt lake is the largest lake in this region. The lake consists of two interconnected parts having areas of 318 and 12 ha, which totals up to 330 ha. The depth of the lake varies between 1.75 and 6 m. Its elevation is 1,334 m, its temperature 25 °C, and its EC value 8,000 μmho/cm. To the east of the Demiryurt lake, there is a large collapse area which is formed by dry lakes.

Fig. 11
Hafik lake is situated about 35 km east of Sivas

Fig. 12
Western Lota lake is situated about 50 km east of Sivas

When approaching Ankara, water samples were taken from the Kızılırmak River for the purpose of measuring the water quality. According to the results, the EC value of the water is 1,650 μmho/cm, its temperature is 24 °C, and its elevation 765 m. This means that as it approaches Ankara, the water quality of the Kızılırmak River is improved.

Conclusions

This study aimed at explaining the general geology, tectonics and the hydrogeology of the Sivas gypsum karst area, and particularly the features of the Seyfe and Göydün karstic springs and Hafik, Lota and Tödürge lakes. The Sivas gypsum karst area is one of the rare gypsum karsts in Turkey and in the world. Various geomorphological structures are observed. The presence of two karstic springs, three collapse lakes and several dry lakes makes this area especially important. Some of the collapses in the area are caused by dissolution processes which occur in the interlayers of halite.
The area is worth seeing for those scientists who study gypsum karst. Especially for the purposes of workshops and field seminars, the area is considered to be the best site to show gypsum karst.

Appendix

Definitions of gypsum karst terms

Evaporite.
One of the sediments which are deposited from aqueous solution as a result of extensive or total evaporation of the solvent.

Gypsum.
Alabaster, selenite, satin spar, a mineral, $CaSO_4{\bullet}2H_2O$, monoclinic, a common mineral of evaporities. It is used in the manufacture of plaster of Paris.

Gypsum flower.
Curved, twisted crystal growths of gypsum resembling flowers.

Anhydrite.
A mineral, anhydrous calcium sulfate, $CaSO_4$, orthorhombic, commonly massive in evaporite beds.

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