Jeomorfolojik Araştırmalar Dergisi
Journal of Geomorphological Researches
© Jeomorfoloji Derneği www.dergipark.gov.tr/jader E - ISSN: 2667 - 4238

Araştırma Makalesi / Research Article

BASE-LEVEL POLJES IN THE SİVAS GYPSUM KARST, TÜRKİYE
Sivas Jips Karstındaki Taban Seviyesi Polyeleri, Türkiye

Uğur DOĞAN[a], Serdar YEŞİLYURT[b], Gönül MUTLU[c], Ali KOÇYİĞİT[d]

[a] Ankara University, Faculty of Languages and History-Geography, Department of Geography, Ankara
geoankara@gmail.com https://orcid.org/0000-0002-1300-3484
[b] Ankara University, Faculty of Languages and History-Geography, Department of Geography, Ankara
serdar_yesilyurt@yahoo.com https://orcid.org/0000-0002-2896-9644
[c] Ankara University, Faculty of Languages and History-Geography, Department of Geography, Ankara
gmutlu@ankara.edu.tr https://orcid.org/0000-0002-4280-4950
[d] Middle East Technical University, Active Tectonics and Earthquake Research Lab., Department of Geological Engineering, Ankara
alikocyigit45@gmail.com https://orcid.org/0000-0002-0026-2831

Makale Tarihçesi
Geliş 2 Haziran 2022
Kabul 20 Haziran 2022

Article History
Received 2 June 2022
Accepted 20 June 2022

Anahtar Kelimeler
Taban Seviyesi Polyeleri, Kızılırmak Nehri, Jips Karstı, Tödürge Gölü, Sivas.

Keywords
Base-Level Poljes, Kızılırmak River, Gypsum Karst, Lake Tödürge, Sivas

Atıf Bilgisi / Citation Info
Doğan, U., Yeşilyurt, S., Mutlu, G., Koçyiğit, A. (2022) Base-Level Poljes In The Sivas Gypsum Karst, Türkiye, Jeomorfolojik Araştırmalar Dergisi / Journal of Geomorphological Researches 2022 (9): 19-37

doi: 10.46453/jader.1125343

ABSTRACT

The Sivas Basin, Central Anatolia, includes one of the most outstanding gypsum karst terrains in the world. The fact that the polje shapes, which are commonly seen in the limestone karst terrain, are also seen in the Sivas gypsum karst area. It increases the geomorphological importance of this area. This study is focused on the explanation of the morphometric properties and morphotectonic formation mechanism of poljes around the allogenic Kızılırmak River and Acısu stream in the Sivas gypsum karst area. The geomorphological evolution of the Sivas gypsum karst area was controlled by the Kızılırmak River drainage system formed in the Early Pliocene. Polygonal doline karst is common on the High Karst Plateau formed during this evolution process, while subsidence dolines, hanging valleys, and poljes are common on the Low Karst Plateau. A total of 14 poljes, most of which are drained underground, and a corrosion plain were identified around the Kızılırmak River in the Low Karst Plateau. The boundaries of some poljes, and also the area of largest poljes up to the area 6,3 km^2 are controlled by faults. These poljes are base-level poljes, which bases are approximately at the river level and developed in the epiphreatic zone. In addition to the structural lines in the formation of the poljes, the beginning of a blind valley-like karstification process, especially in the lower parts of the hanging paleovalleys, mostly as a result of the bedrock collapse doline formation, changes in the water table level in the epiphreatic zone, and the precipitation, the aggressive river floodwaters that invaded the polje floor were effective. Due to the rapid dissolution of gypsum, the development of polje must have been affected by the incision and deposition periods of the river. The Lake Tödürge depression most probably has been shaped by the bedrock collapse dolines.

1. INTRODUCTION

Poljes are the largest closed depressions in karst areas. However, some poljes are opened to external drainage from their one or two ends (Ristic, 1976). Karst drainage is effective in poljes with wide alluvial floors (Sweeting, 1972; Ristic, 1976; Gams, 1978; White, 1988; Ford and Williams, 1989, 2007; Doğan, 2003; Gracia et al., 2003; Bonacci, 2013; Doğan et al., 2019; Şimşek et al., 2020). The long axis of the alluvial floors of poljes in limestone areas ranges from a few hundred meters to tens of kilometers. The waters entering the polje from karst springs are discharged by means of ponors. Despite this, the inflow of water that occurs above the carrying capacity of the ponors or the rise of the water table may lead to the formation of permanent or temporary lakes in the poljes (Alagöz, 1944; Sweeting, 1972; Ford and Williams, 2007; White, 1988;

Doğan, 1996, 2003; Gracia et al., 2003; Doğan et al., 2017; Doğan and Koçyiğit, 2018).

Numerous classifications of polje types have been made (e.g. Gams, 1969, 1973, 1978; Ristic, 1976; Ford and Williams, 1989), and studies evaluating them have also been revealed (e.g. Doğan, 2003; Şimşek et al., 2020). These classifications were grouped into three types by Ford and Williams (1989) border, structural, and base level poljes. However, some studies conducted in recent years have shown that, unlike them, some poljes are semi-graben in the neotectonic period (Gracia et al., 2003) or have been determined that they are structural (tectonic) poljes formed in grabens and that the hangingwall blocks forming the floor of the polje are also formed of limestone (e.g. Doğan et al., 2019). It has also been shown that all or some parts of these poljes have a structural border polje character (Doğan et al., 2017, 2019; Doğan and Koçyiğit, 2018; Şimşek et al., 2020, 2021). For example, it has been determined that some of the 175 poljes in the Taurus Mountains in Türkiye are formed structural (tectonic) and border poljes (Şimşek et al., 2021).

In contrast to limestone karst, polje formations in gypsum karst worldwide have been identified only in the Salinas-Fuente Camacho (Spain; Calaforra and Paludo-Bosch, 1999) and Sivas (Türkiye; Waltham, 2002; Doğan and Özel, 2005; Doğan and Yeşilyurt, 2019, 2021) evaporite karst sites. Of course, this case must be related to the fact that not common enough thick gypsum formations with suitable structural conditions for polje formation on earth, unsuitable lithological properties of gypsum, rapid dissolution of gypsum (2,531 g/1 in pure water at 20°C; Klimchouk, 1996) and therefore, with the rapid destruction of the formed karst forms (e.g. Ford and Williams, 1989; 2007; Klimchouk, 1996, 2013; Doğan and Özel, 2005; Guerrero et al., 2008; Gutiérrez et al. 2008a, b; Cooper and Gutiérrez, 2013; Gutierrez and Cooper, 2013; Doğan and Yeşilyurt, 2019).

Sivas gypsum karst area is located in the eastern part of the Central Anatolia. This area, which developed on the thick Late Eocene gypsum formation (Legeay et al., 2019), has an exposure area of approximately 2,140 km^2 around the city of Sivas (Figure 1). The gypsum karst area, which extended in the ENE and WSW directions is approximately 280 km long and 55 km wide (Doğan and Yeşilyurt, 2019).

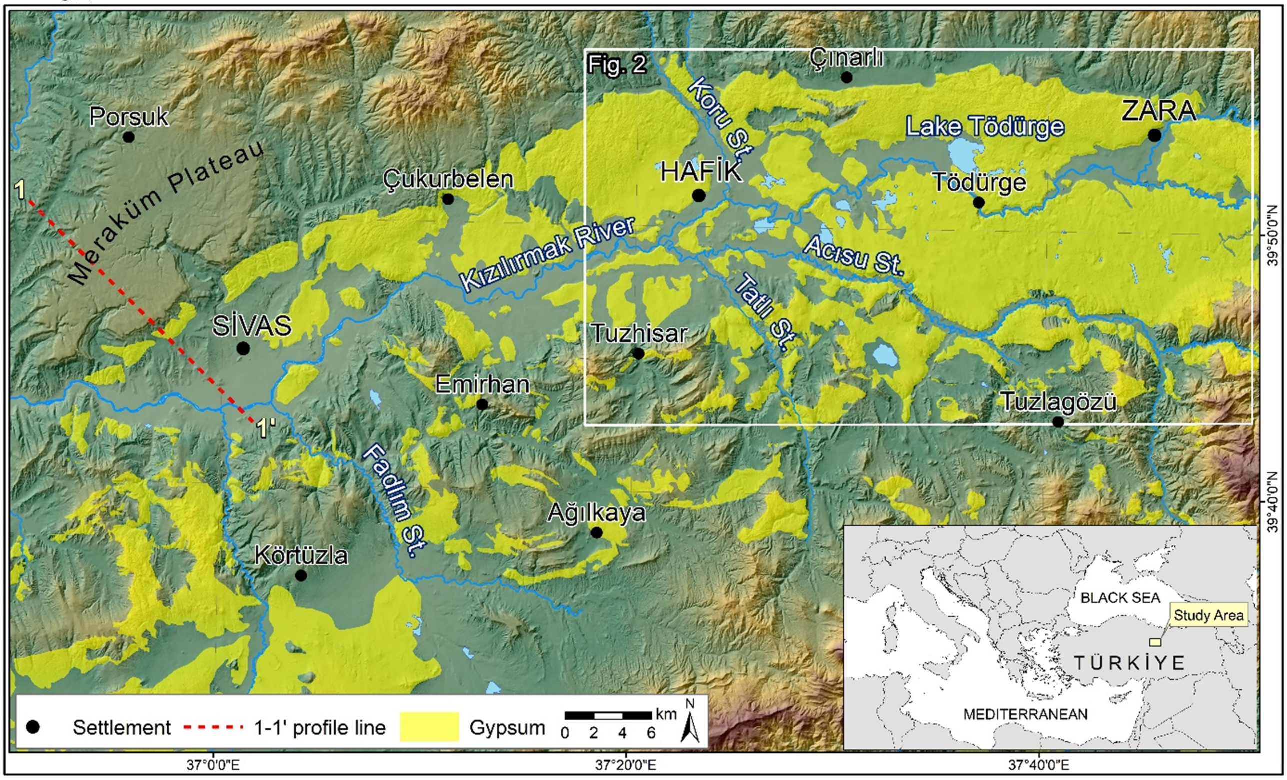

Figure 1. Location map of the study area

The waters of the Sivas Basin are mainly drained by the Kızılırmak River and its tributaries. Therefore, the river also controlled the geomorphological evolution of the karst area (Doğan and Özel, 2005). It is possible to see together all the characteristic surface and underground forms of gypsum karst in this area. In the Sivas gypsum karst area, karren, dissolution dolines, bedrock collapse dolines, bedrock sagging (Drahor, 2019), alluvial dolines, cover collapse dolines, uvalas, ponors/sinkholes, karst springs, karstified paleo-valleys, caves, unroofed caves, gorges, blind valleys, pocket valleys, corrosion plains, and poljes are found. All these karst shapes make the Sivas gypsum karst area stand out throughout the world as well as in Türkiye (Doğan and Özel, 2005; Doğan and Yeşilyurt, 2019, 2021). For this reason, numerous study have been carried out on Sivas gypsum karst (e.g. Alagöz, 1967; Kaçaroğlu et al., 1997; Karacan and Yılmaz, 1997; Çubuk and İnan, 1998; Günay, 2002; Waltham, 2002; Doğan and Yeşilyurt, 2004, 2019, 2021; Doğan and Özel, 2005; Yılmaz, 2007, 2012; Keskin and Yılmaz, 2016; Darıcı and Özel, 2018; Drahor, 2019; Özel and Darıcı, 2020; Gökkaya et al., 2021; Poyraz et al., 2021).

Two of the poljes in the Sivas gypsum karst area were first described by Waltham (2002). He stated that these basins, which are located between two rivers and have underground drainage, once meandered loops or perhaps were true poljes. Then, most of the poljes in this area were introduced by Doğan and Özel (2005), and the formation mechanisms were briefly discussed and mapped. This study, based on the available data, was aimed to re-map, determine their morphometric and morphotectonic properties, and explain the formation processes, of the gypsum karst poljes located on both sides of the Kızılırmak River around Hafik.

2. METHOD

To understand the level difference and hydrological relations between the Kızılırmak River of the poljes discussed in the study, profiles were generated from DEM data with sub-meter sensitivity. In addition to field observations, Red Relief Image Map and aerial photographs were used to determine the geomorphologic and tectonic features of the study area. To understand the alluvial thickness at the valley floor and the dissolution mechanism, that forms collapse and subsidence dolines, the data revealed by Drahor (2019) were used.

3. Geologic, Tectonic and Geomorphologic Outline

The oldest evaporitic rocks in the Sivas Basin (Tuzhisar Formation) overlying the Bozbel and Tokuş formations, which date back to the Late Eocene (Lutetian-Bartonian) (Legeay et al., 2019). These thick evaporitic rocks (gypsum, salt, etc.) were deposited in the sabkha environment (Kurtman, 1973; Poisson et al., 1996; Çiner et al., 2002; Gündoğan et al., 2005; Sirel et al., 2013; Callot et al., 2014; Legeay et al., 2019). The apparent thickness of the gypsum around Acıçay stream has been determined as 500 m. (Doğan and Yeşilyurt, 2019). In this thick gypsum series, there are salt deposits in the form of interlayers (Alagöz, 1967; Çubuk and İnan, 1998; Günay, 2002; Doğan and Yeşilyurt, 2004; Callot et al., 2014; Legeay et al., 2019; Doğan and Yeşilyurt, 2019, 2021). A large number of saline or extremely saline water sources in the region are also an indicator of this (Alagöz, 1967; Ocakoğlu,1999; Doğan and Yeşilyurt, 2021).

The salt tectonic structures are described in the Sivas Basin (Çubuk and İnan, 1998; Ocakoğlu, 1999; Doğan and Yeşilyurt 2004, 2019, 2021; Callot et al., 2014). The central and eastern sectors of the Sivas Basin display a typical wall and basin structure; i.e., minibasins separated by vertical evaporite walls generated by the salt flowage. Some of the best examples of wall and basin structures are located around Emirhan and Karayün (Callot et al., 2014). Several evidence suggests that the gypsum walls and diapirs are still active around the central and eastern part of the Sivas Basin where the main minibasins developed, displacing the sabkha and lacustrine deposits at their present altitude on top of active structures (Callot et al., 2014).

On the other hand, the Sivas Basin and its sedimentary fill were deformed by a contractional tectonic regime and thrown into a series of anticlines and synclines with approximately E-W trending axes owing to the principal compressive stress operated in the N-S direction during the late Miocene-early Pliocene period. Starting from the late Pliocene-early Quaternary, the Sivas Basin underwent the control of the strike-slip neotectonic regime and then started to experience the second phase of deformation characterized by prominent strike-slip faulting and also rarely high-angle reverse faulting (Koçyiğit and Beyhan, 1989). The previously deformed Sivas Basin and its fill were redeformed once more by the NE, NW, and EW trending faults originating from the strike-slip neotectonic regime. In this new regime the NE, NW, NS, and EW trending faults are sinistral strike-slip faults, dextral strike-slip faults, normal faults, and high-angle reverse faults respectively (Figure 2). The western section of the Sivas Basin was displaced in a sinistral direction by the NE trending strike-slip fault included in the Central Anatolian Fault System, while its eastern section was displaced in a dextral direction by the NW trending strike-slip fault. However, the central section of the northern margin of the basin was thrusted by the pre-Miocene rocks, mostly ophiolitic melange, from the north towards the south along with the E-W trending and northerly dipping reverse faults. The Sivas Basin is situated within the active Central Anatolian Fault System (Koçyiğit and Beyhan, 1989). For this reason, the deformation of the Sivas Basin is still continuing under the control of the strike-slip neotectonic regime.

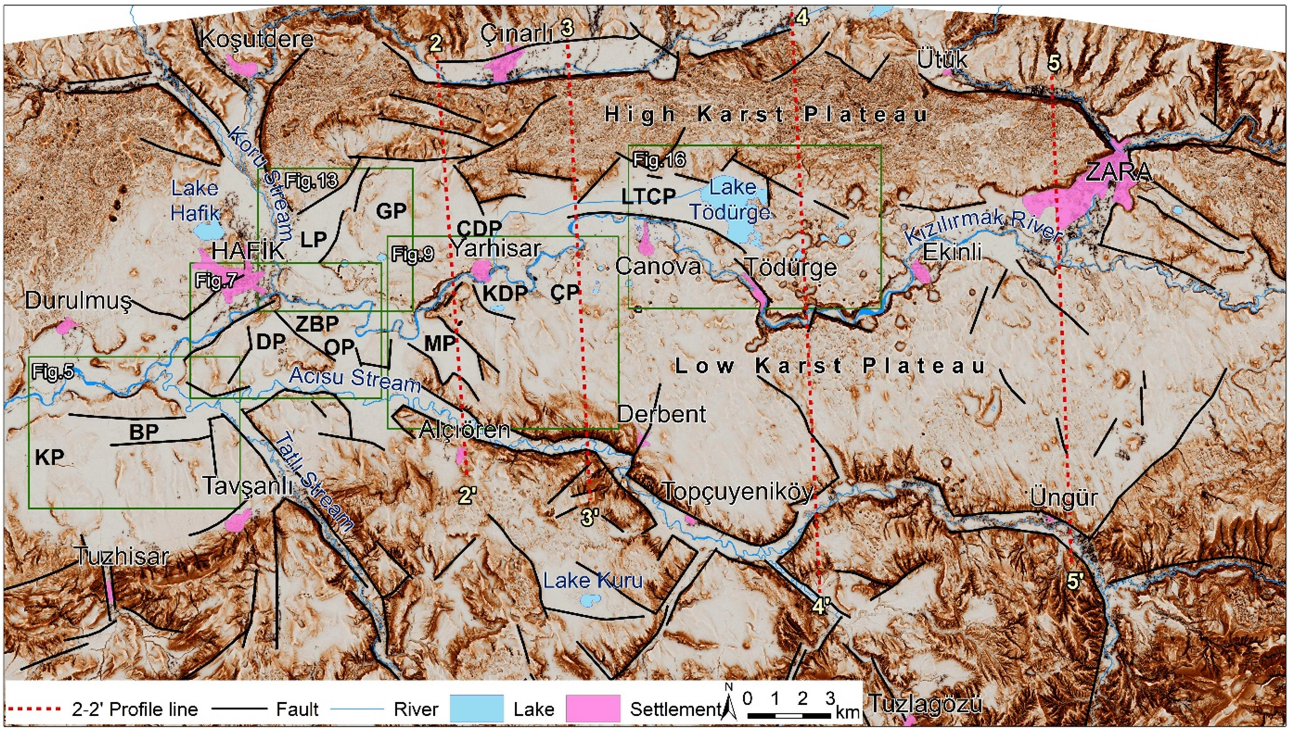

Figure 2. Red Relief Image and simplified structural map of the study area. It also illustrates some geomorphic features in terms of abbreviations on map: **KP**-Küpecik polje; **BP**-Büyükçayır polje; **DP**-Dışkapı polje; **ZBP**-Zogar Bataklığı polje; **OP**- Odinikdüzü polje; **LP**-Lota polje; **GP**-Göl polje; **MP**-Mağaragölü polje; **KDP**-Kulakdüzü polje; **ÇP**-Çimenyenice polje; **ÇDP**-Çatakdüzü polje; **LTCP**- Lake Tödürge corrosion plain.

The establishment of the Kızılırmak River drainage system has an important role in the geomorphological evolution of the region. The late Miocene-early Pliocene closed basins of the Central Anatolia were connected to the external drainage in the Early Pliocene by the Kızılırmak River drainage system (Doğan and Şenkul, 2020; Brocard et al., 2021). The Meraküm lacustrine limestone, which forms a cover in the Sivas Basin, indicates the presence of a Pliocene lake in this area (Poisson et al., 1996; Çiner et al., 2002; Doğan and Özel, 2005; Legeay et al., 2019; Doğan and Şenkul, 2020; Brocard et al., 2021; Gökkaya et al., 2021). The basalt flows, which crop out along the margins of the Kızılırmak Valley in the west of Sivas (northwest of Lake Tuzla) and cover the Upper Miocene deposits, were dated as an approximately 4,22 Ma in age (Brocard et al., 2021). For this reason, this age was also accepted as the onset age of the Kızılırmak Valley in this area. According to this age data (4,22 Ma), the incision rate in the Kızılırmak Valley, downcutting the lacustrine Early Pliocene Meraküm limestone in the north of Sivas, is 0,09 mm/yr (Figure 3). In a previous study (Gökkaya et al., 2021), this incision rate was calculated as 0,11 mm/yr. As a result, the deep valley incision process in the Sivas gypsum karst area started after the establishment of the Kızılırmak River drainage system in the Early Pliocene.

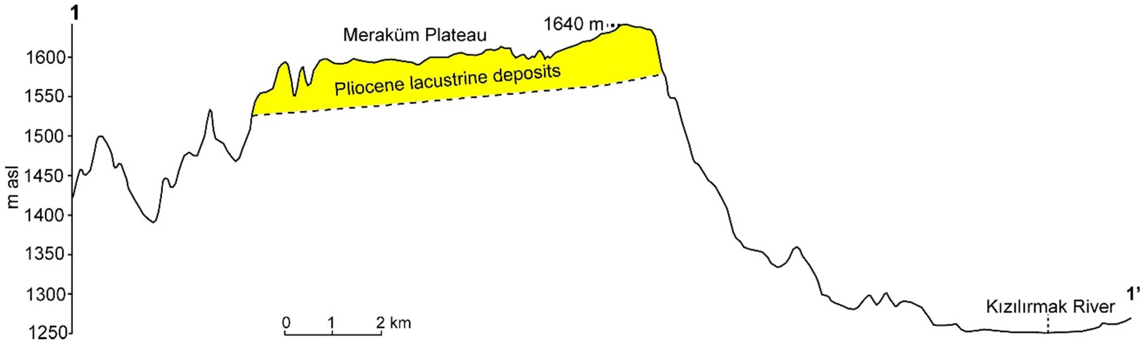

Figure 3. The profile shows the amount of river incisions that occurred after the early Pliocene near Sivas (see Figure 1 for location).

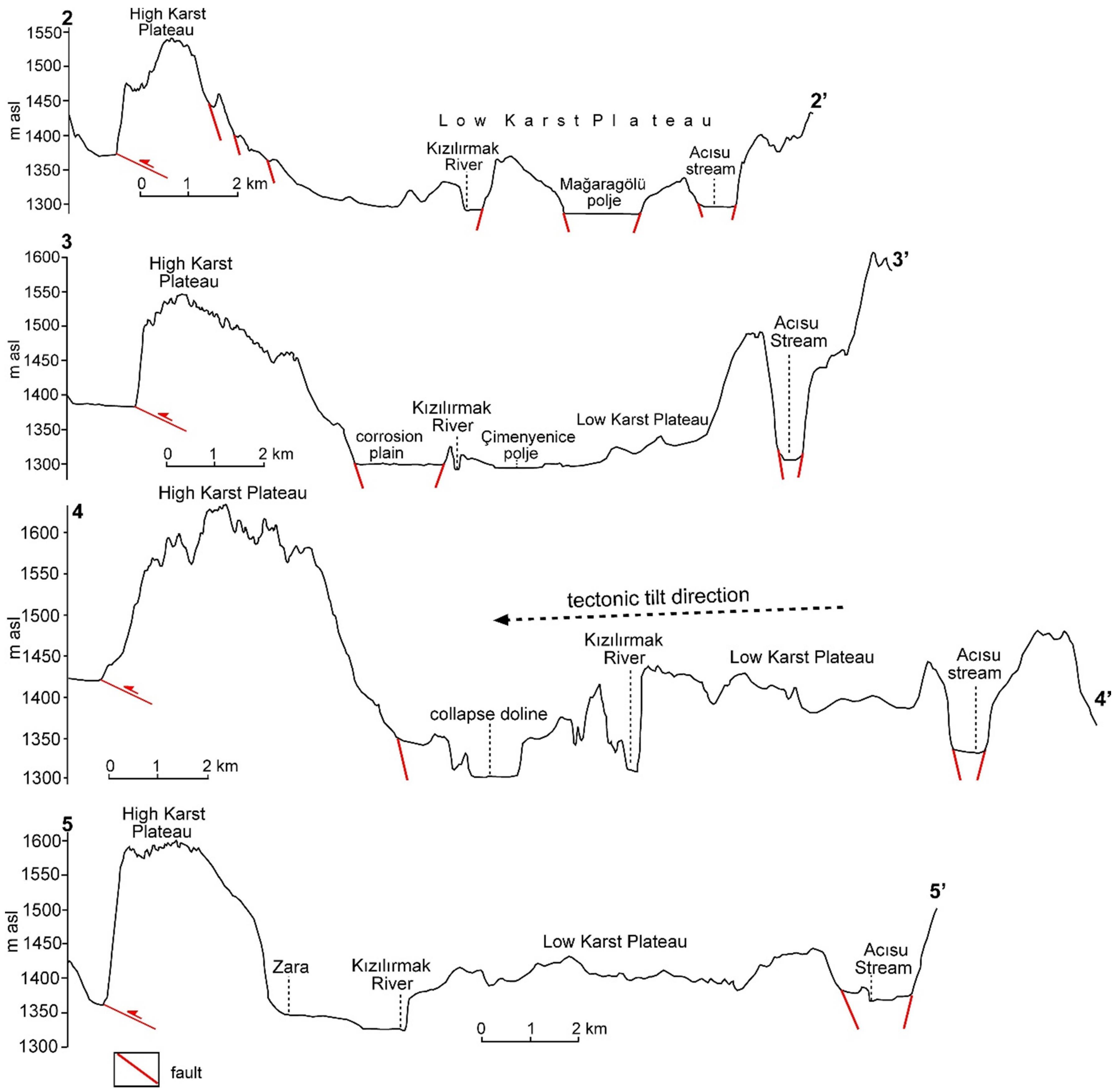

Figure 4. The profiles show the main morphotectonic features formed in the gypsum karst area between the Hafik and Zara (see Figure 2 for locations).

Due to the tectonic uplift/ river incision process in the area, denudational surfaces called High and Low Karst Plateau (Figures 2 and 4), which remained high and developed in relatively stable periods, were formed (Doğan and Özel, 2005; Doğan and Yeşilyurt 2019). Polygonal doline karst has developed on the High Karst Plateau (Doğan and Özel, 2005; Poyraz et al., 2021). These surfaces and the karstic landforms developing on them have been controlled by the change in the water table level of the unconfined aquifer fed by autogenic water input and thus by the process of incision the valley of the Kızılırmak River. After the formation of the Low Erosion Surface in the Middle Pleistocene, the tributary valleys on this surface karstified by turning into hanging valleys due to the rapid downcutting of the valley of the Kızılırmak River (Doğan and Özel, 2005 in Fig. 3). A large number of collapse dolines (sinkholes) have been found on the Low Karst Plateau, some of which are lakes, and some others are merged with the neighboring doline (Doğan and Özel 2005; Doğan and Yeşilyurt 2019; Gökkaya et al., 2021).

On the other hand, a very detailed study was conducted by Drahor (2019) in Sivas gypsum karst using the method of electrical resistivity tomography. In this study, the presence of bedrock collapse dolines, bedrock sagging dolines, alluvial/cover subsidence dolines, cover collapse dolines, and sagging-type cover collapse dolines were determined. In addition, the development processes of the dolines, the underground cavities that produced them, and the material that collapsed or transported into the cavity are indicated. However, in this study, unfortunately, the poljes could not be modeled due to their very large size.

4. Formation of Poljes, Corrasion Plain and Lake Tödürge

In Sivas gypsum karst, there are open or closed poljes covered with detrital sediments (with alluvial and dissolution residue soils) in the Low Karst Plateau. Totally, there are 14 poljes and a corrosion plain. Ten of them are in the south and five in the north of the Kızılırmak Valley, which extends approximately E-W, between the villages of Küpecik in the west and Tödürge in the east (Doğan and Özel, 2005; Figure 2; Table 1). Apart from these, there are also three hanging paleo-poljes (Hacıçukuru, Alçıören (Köyünönü Yazısı) and Salaorddüzü) in the south of Acıçay stream.

Table 1. Some metrics values of gypsum poljes, Lake Tödürge corrosion plain, and Lake Tödürge

Name	Area (km^2)	Short axis length (m)	Long axis length (m)	Lowest elevation (m asl)	River floodplain level (m asl)
Küpecik polje	1,7	1992	1287	1276	1274,6
Büyükçayır polje	4,9	5000	1431	1283	1282,6
Kızıldüzü polje	0,36	748	650	1291	1281,5
Dışkapı polje	2,67	1000	3230	1283,3	1286
Zogar Bataklığı polje	0,55	500	1518	1285,3	1286,4
Odinikdüzü polje	1,19	1558	1060	1287,3	1288
Küçüktürükyazısı polje	0,43	450	1050	1289	1289
Mağaragölü polje	3,3	1665	2750	1283,4	1289,2
Avutmuşyazısı polje	0,45	500	1000	1285	1293,7
Kulakdüzü/Yarhisar polje	0,84	840	1550	1291,2	1293,7
Çimenyenice polje	2,5	2500	2000	1293	1294,6
Lota polje	6,3	3000	3280	1283	1285,5
Göl polje	1,9	1750	1500	1304	1285,5
Çatakdüzü polje	3,4	2700	2400	1293,6	1293
Lake Tödürge corrosion plain	5,3	1302	6125	1298	1298
Lake Tödürge	3,2	2380	2490	1299,1	1303

4.1. Büyükçayır Polje

This polje is located southeast of the Hafik, south of the junction of the Kızılırmak River and Acısu stream (Figure 5). The length of Büyükçayır polje in the E-W direction is 5,55 km and its width in the N-S direction is 2,56 km (Table 1). Since the northern slope of the polje is bounded by two E-W trending thrust faults, it extends approximately flat (Figure 6). The expansion of the valley floor in the lower parts of the streams reaching the polje from the south caused the polje floor to form inlets towards the south. The lowest part of the polje (1283 m asl), which was opened to external drainage from its eastern edge, and the Acıçay stream floodplain level (1282,6 m asl) are close to each other. The waters of the polje, which has a large basin, overflow from a temporary lake formed in the eastern part and reach the Acıçay stream. The opening of the polje to the external drainage should be related to the dissolution of gypsum during the overflow of polje waters and the lateral erosion process at the valley floor of the Acıçay stream.

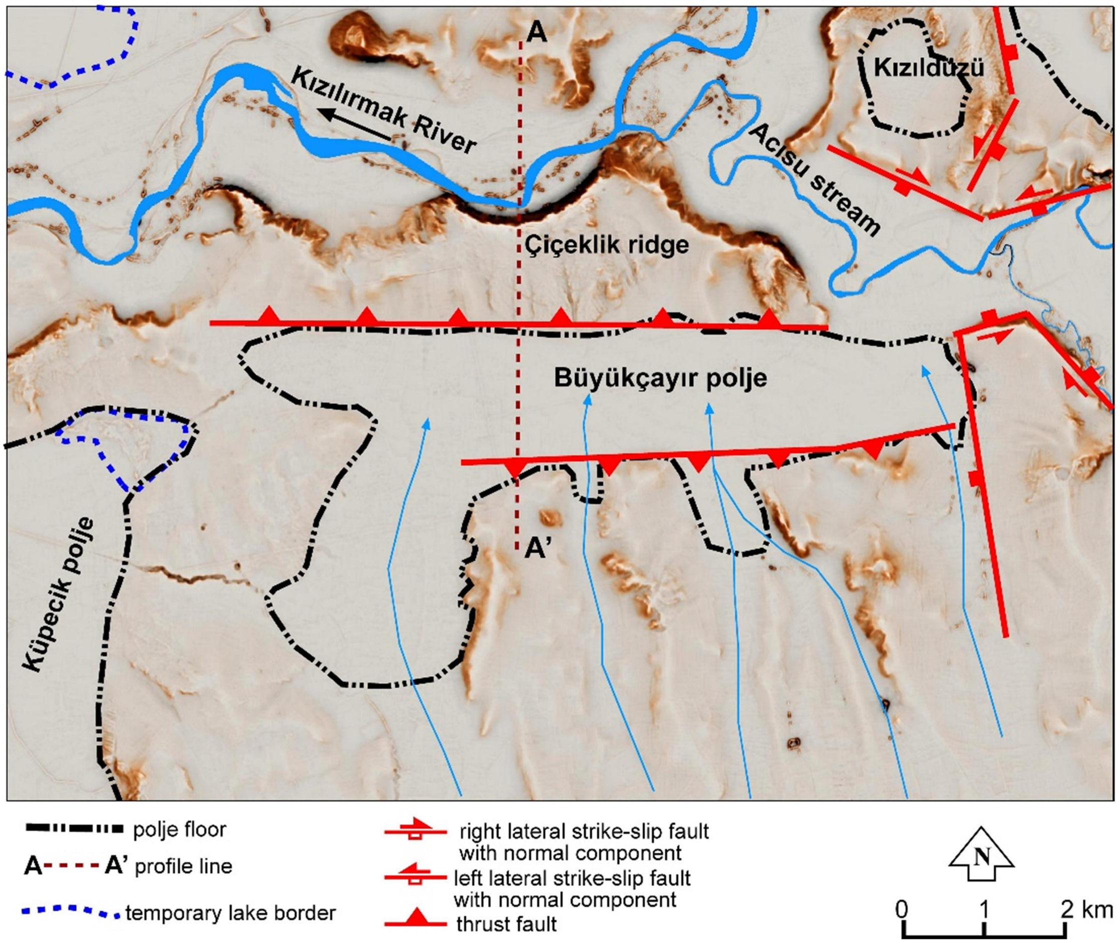

Figure 5. Geomorphological map of Büyükçayır polje and its surroundings.

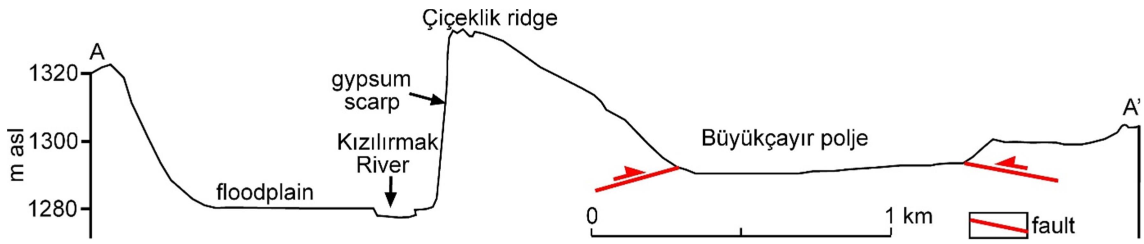

Figure 6. Büyükçayır polje is bounded by thrust faults from its north and south. The polje is located at nearly the same level as the Acısu stream, but it is located above the Kızılırmak River floodplain.

4.2. Dışkapı Polje

Polje, which has a NE-SW extension, is located south of the Kızılırmak River (Figure 7). The length of the polje, which is closed to external drainage from the surface, in the NW-SE direction is 3,23 km and its width in the E-W direction is approximately 1 km (Figure 8). In the southwestern part of the Dışkapı polje, there is a gulf-shaped section with a base of approximately 800 m, extending in the NW-SE direction. It is understood that this section was formed by the dissolution around the collapse doline which formed in a paleovalley. This section was formed as a result of the water overflowing around the doline dissolving the surrounding gypsum when the water table was high. The lowest part of the polje floor is 1283,3 m asl and ~2,7 m below the level of the Kızılırmak River floodplain (1286 m asl). The western and northern slopes of the polje are bounded by faults. The Dışkapı Polje is a base-level polje shaped by corrosion formed by the water collected on its floor during rainy periods, the floodwaters of the Kızılırmak River (Figure 8) and perhaps Acısu stream, and the temporary lake formed on the floor of the polje when the water table rises.

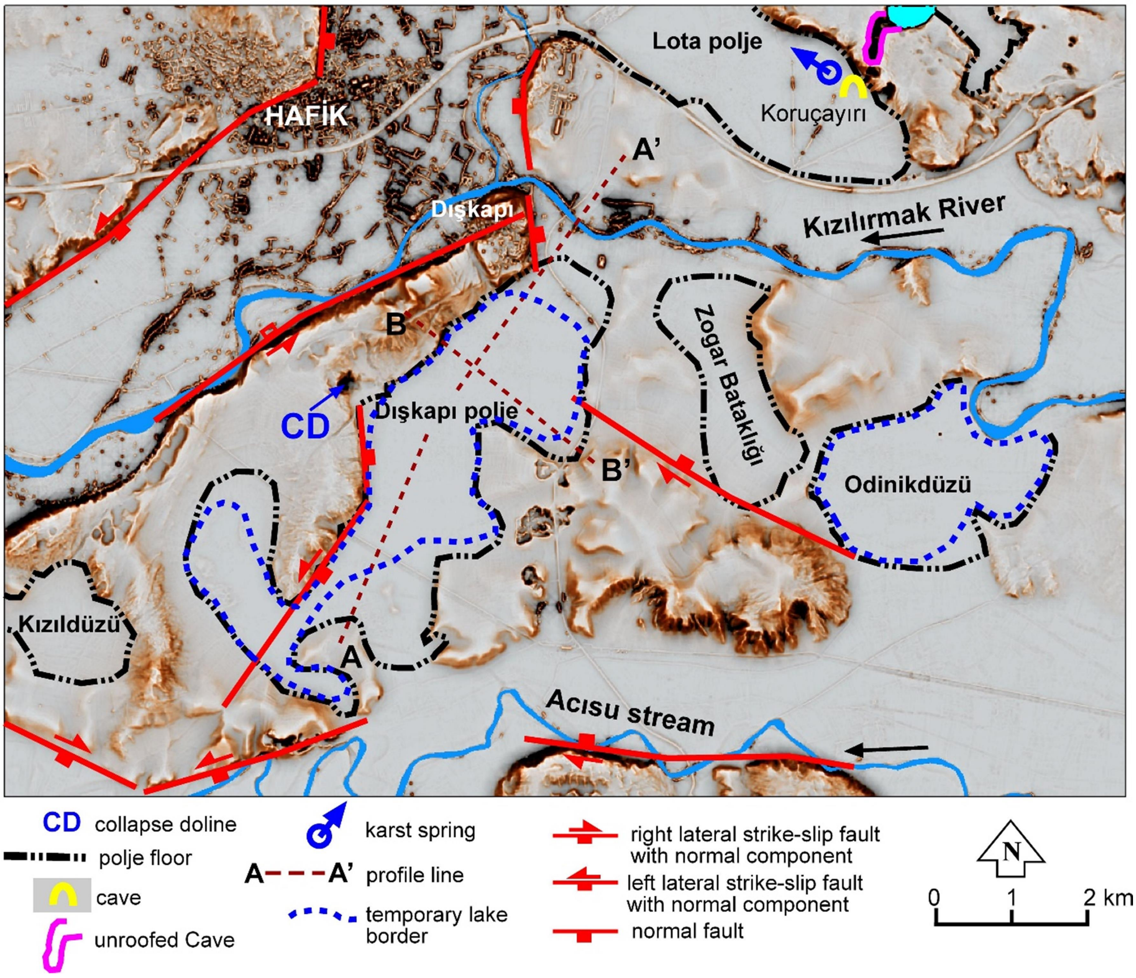

Figure 7. Geomorphological map of the poljes in Hafik and its surroundings.

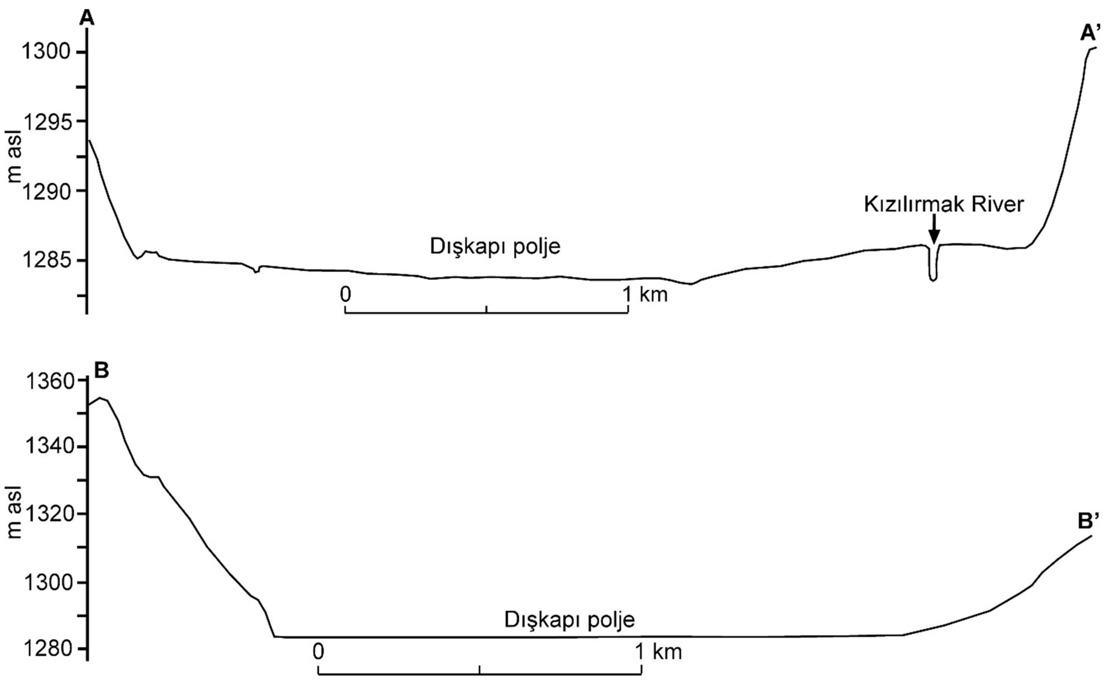

Figure 8. SW-NE (A-A') and NW-SE (B-B') trending profiles of the Dışkapı polje and its surroundings.

4.3. Zogar Bataklığı Polje

The NW-SE trending polje floor is divided into two parts with a 2 m threshold within itself (Figure 7). The floor of the polje (1285,3 m asl) with an area of approximately 0.6 km^2 is approximately 1 m below the floodplain of the Kızılırmak River (1286,4 m asl). The northern part of the base-level polje was formed by corrosion around an old collapse or subsidence doline. The floodwaters of the Kızılırmak River must have made a significant contribution to the corrosion formed on the floor of the polje.

4.4. Odinikdüzü Polje

This polje is separated from the Zogar Bataklığı Polje by a threshold of approximately 3 m (Figure 7). The long axis of the polje in the E-W direction is approximately 1,5 km, and its width in the N-S direction is 1 km. The floor of the polje (1287,3 m asl), with a total area of approximately 1,19 km^2, is 1 m below the level of the Kızılırmak River floodplain, and approximately 2 m below the level of the Acıçay floodplain. For this reason, the depression, that has disappeared as a result of the fluvial erosion of both slopes, is an open polje. The gypsum dissolution caused by the floodwaters of the two rivers must have been effective in the formation of the polje.

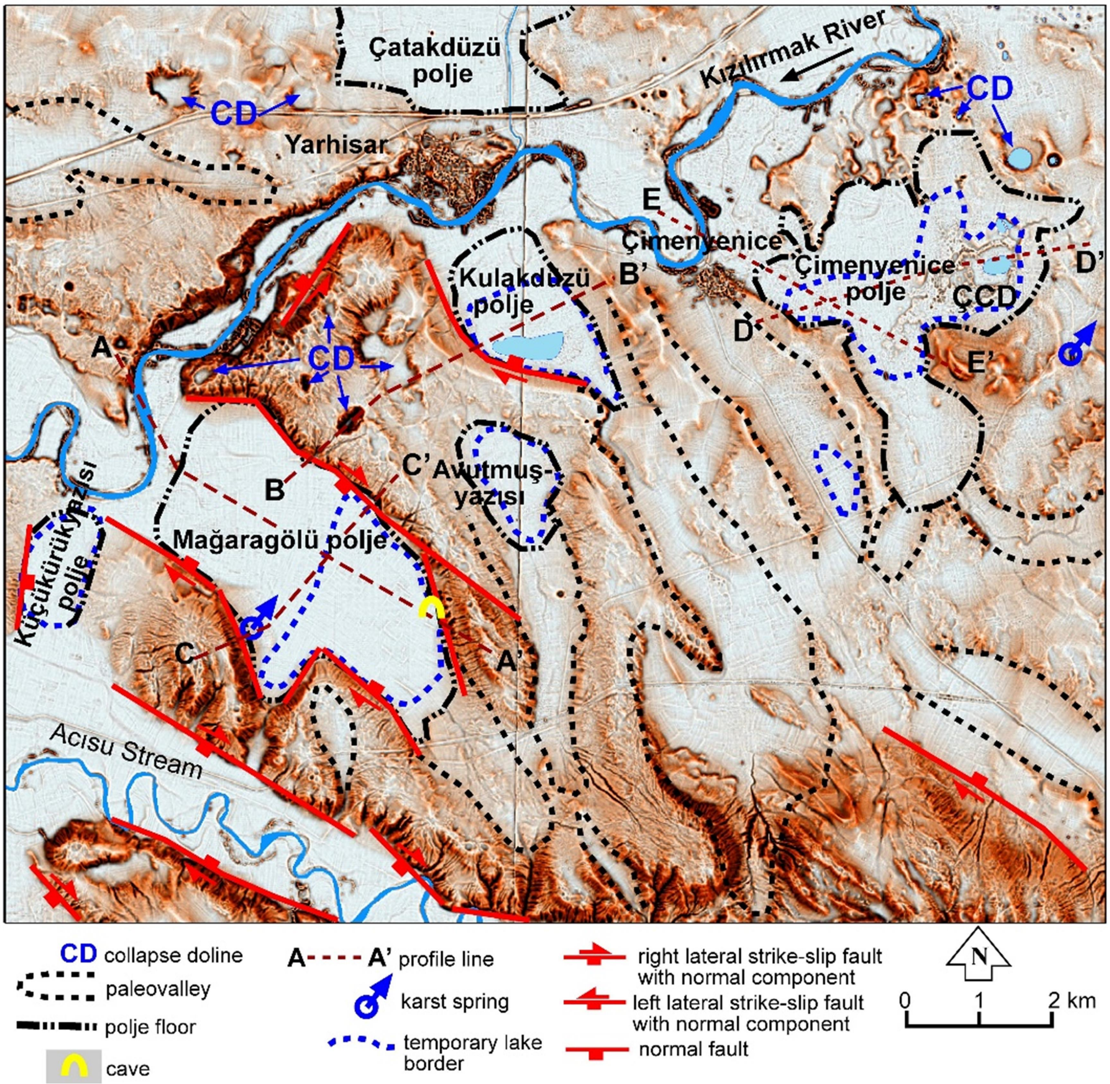

Figure 9. Geomorphological map of the poljes in the surroundings of Hafik. Çimenyenice collapse doline is illustrated with the abbreviation (ÇCD) on map.

4.5. Mağaragölü (Türük Yazısı) Polje

The northwestern border of the polje, which is 2750 m long in the NW-SE direction and 1665 m wide in the NE-SW direction, must have been eroded by the river during the evolution process of the Kızılırmak Valley in the Late Quaternary (Figure 9). The steep northeastern and southwestern slopes of the polje are bounded by NW trending right lateral strike-slip faults. The lowest point of the floor of the polje is in front of Lake Bezirci (1283,4 m asl; Figure 10). This level is approximately 5,8 m lower than the level of the Kızılırmak River floodplain (1289,2 m asl; Figure 11). Although the northwest slope of the polje has been eroded, the waters at the floor of the polje have no surface connection with the Kızılırmak River except for during flood periods. Therefore, its drainage is provided underground (Waltham, 2002). In the southeastern part of the polje, a temporary lake is formed when the water table is high (Figure 9). It is understood that the polje developed within a fault-controlled NW trending hanging paleo-valley. Therefore, it can be said that the formation of polje started with the development of a possible blind valley. In the development of the polje, which floor is below the level of the river, the contribution of the aggressive river floodwaters has been great, as well as the increase in the groundwater level.

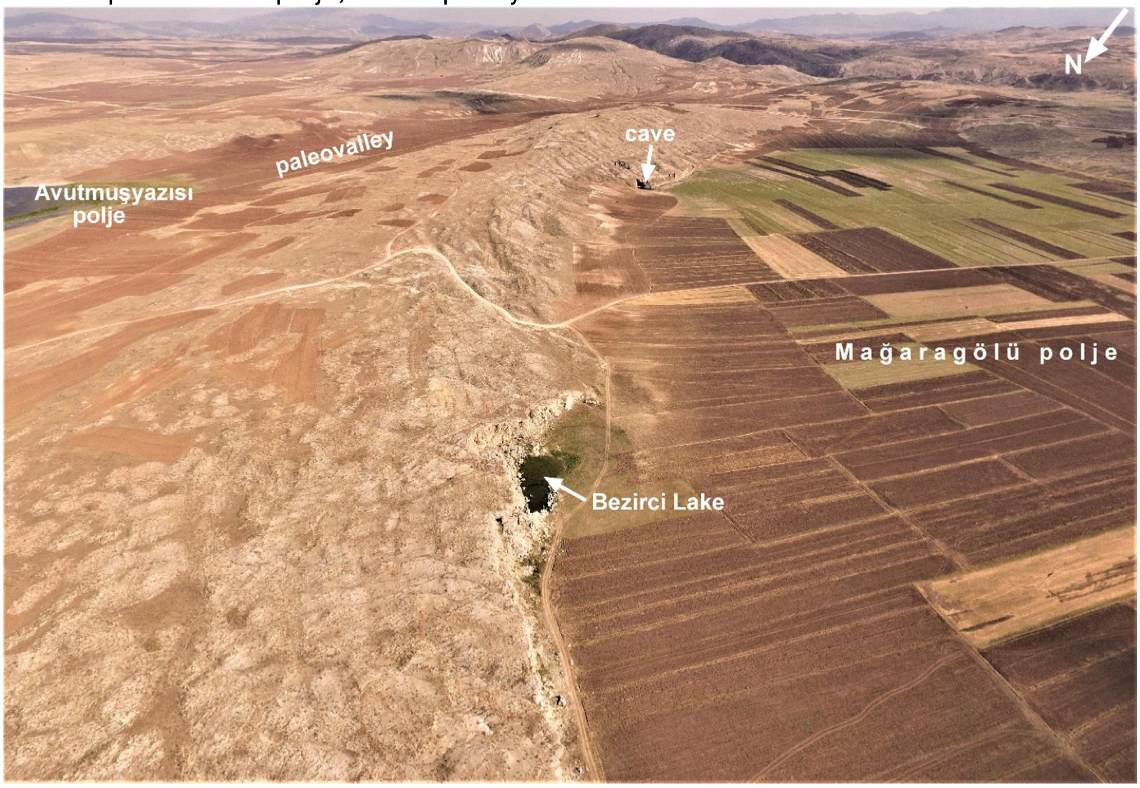

Figure 10. The oblique aerial photograph of the Mağaragölü polje and its surroundings

In the western part of Lake Tödürge, geophysical data (ERT imaging) and drilling data taken from the floodplain of the Kızılırmak River show that the thickness of the alluvium deposit is 30 m (Drahor, 2019). Since we do not know exactly which part of the river bed is represented by this data, the possibility of a higher alluvium thickness should also be taken into account. Therefore, it is understood that there is an elevation difference of ~30 m between the valley floor in the last incision phase (during the Last Glacial period) and the present valley floor in the Kızılırmak Valley. For this reason, we can say that the last development stage of the polje is shaped by karstification that develops depending on the old and new epiphreatic zone. In this case, we can suggest that the other poljes (as in the case of the Mağaragölü Polje) have undergone ~30 m thick alluvial aggradation on the valley floor (or to the upward displacement of the epiphreatic zone) during and after the Last Glacial period. In this case, we can suggest that alluvium and residual soil accumulated on the floor of the poljes related to the fluvial deposition process in the valley floor (or to the upward displacement of the epiphreatic zone) during the time period between the Last Glacial Age and the present.

Based on all these data, mainly due to the level fluctuations in the water table, it can be said that the Mağaragölü Polje is a tectonically controlled base-level polje formed as a result of the dissolution in the epiphreatic zones in the middle-late Pleistocene and the present. However, as in the case of collapse or subsidence dolines in the karst area (Drahor, 2019), it is not known whether the bedrock sagging or subsidence processes due to possible dissolution in the phreatic zone affect the formation of polje. With a similar inference, it can be said that the caves to the east of polje may have served as ponor during the period when the river level was lower in the Late Pleistocene.

4.6. Kulakdüzü (Yarhisar) Polje

The length in the NW-SE direction of the polje is 1200 m and its width in the E-W direction is approximately 950 m (Figure 9). The base level (1291,2 m asl) is approximately 2,5 m below the Kızılırmak floodplain level (1293,7 m asl; Figure 11). The polje was formed as a result of the dissolution that developed around the collapse doline that occurred in the lower part of an N-S trending hanging paleo-valley. For this reason, it can be said that the polje, which we think is in the beginning or development stage, has started to take shape with the formation of a blind valley. Due to this feature, this figure has been included in the poljes since it exhibits a feature that can reflect the first formation stages of some poljes. The same case is also valid for the Avutmuşyazısı in the east of the Mağaragölü Polje.

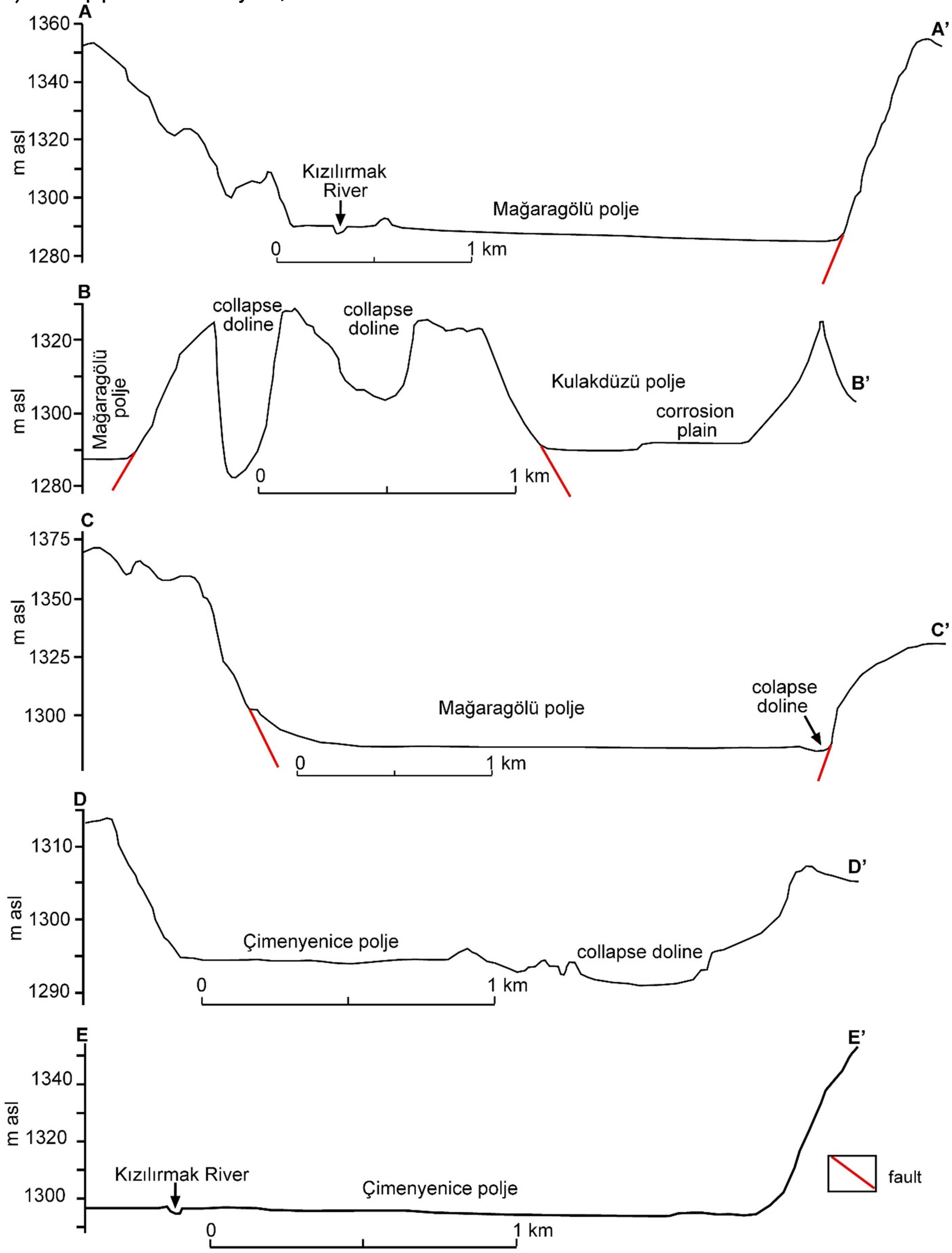

Figure 11. The profiles show main morphologic and morphometric features of the Mağaragölü, Kulakdüzü and Çimenyenice poljes

At present, the area corresponding to the northern part of the Kulakdüzü polje must have been eroded by the river before or after the formation of the doline. The floodwaters of the Kızılırmak River make an important contribution to the development process of the polje.

4.7. Çimenyenice (Gölün Yazısı) Polje

The length of the polje floor in the E-W direction is 2,5 km, and its width in the N-S direction is 2 km. It was formed in the NW-SE extending paleo-valley, and the Çimenyenice collapse doline has an important role in the formation of the polje (Figures 9 and 12).

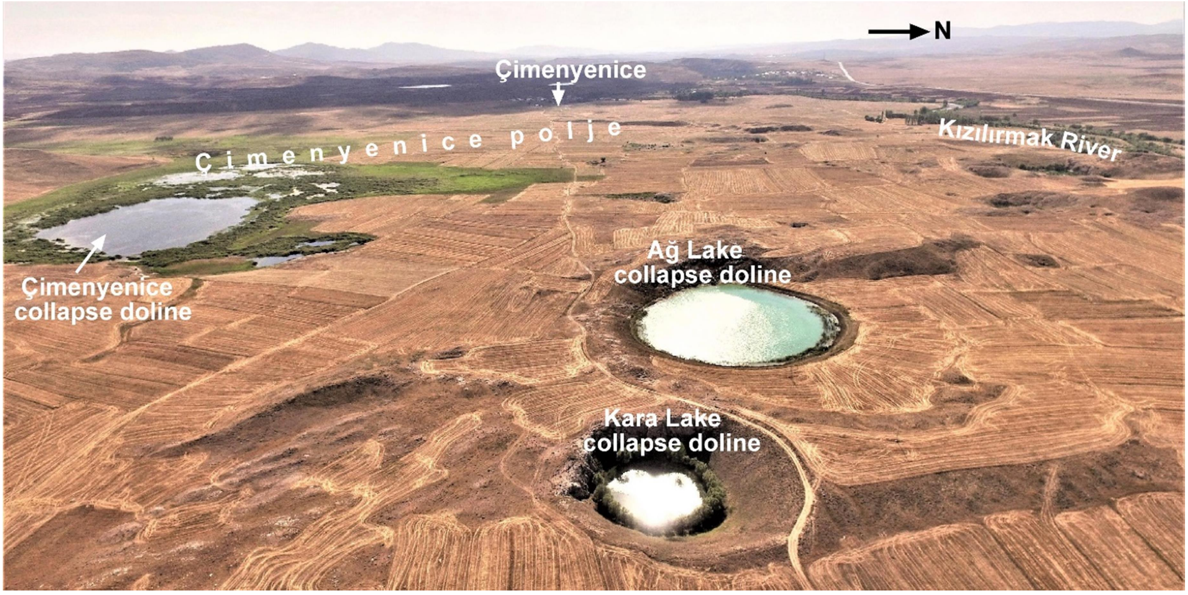

Figure 12. The photograph shows the northeastern part of Çimenyenice polje

Although there is no obvious slope between it and Kızılırmak in the northwestern part of polje, they are not connected hydrologically from the surface. The elevation of the floor of the polje is 1293 m asl around a bedrock collapse doline located southeast (Figure 12). Accordingly, the floor of the polje is approximately 1,5 m below the river floodplain level (1294,6 m asl). In periods when the water table rises and the water input due to precipitation increases, the surrounding of the doline turns into a temporary lake and marsh environment, which is caused corrosion plain at the polje margin. This leads to an increase in the dissolution of gypsum in this part of the polje. In the north of the collapse doline, there is a corrosion terrace that remained from the old base level of the polje.

In conclusion, the Çimenyenice Polje is a base-level polje shaped by the karstification of a paleo-valley and the corrosion that developed around the doline. The floodwaters of the Kızılırmak River and water table rise also have contributed to the development of the polje.

4.8. Lota Polje

Lota Polje is located north of the Kızılırmak River and east of the town of Hafik (Figure 13). Since the western and southern slopes have been eroded by the effect of the river, the borders are not clear in these sections. The base of the polje, which area is ~6.3 km^2, is located at 1283 m asl in the Koruçayırı marsh. There is not a direct hydrological connection from the surface between the waters at the floor of the polje and the Kızılırmak River (1285,5 m asl) in its south. The peninsula-shaped Gelgeç Ridge, in which the Western Lota collapse doline is formed, separates the Koruçayırı area in the southwest of the polje and the Lake Bıttık marsh (between the Lota Collapse dolines) in the northeast (Figure 14). The northern edge of the polje and the northwest slope of the Gelgeç Ridge is bounded by faults. In the formation of this base-level polje; faults, floodwaters of Koru Stream and Kızılırmak River, periodic streams reaching the polje from the northeast, and rising epiphreatic zone waters have been effective. The Lota lakes within the Lota bedrock collapse dolines are the water table window. The ceiling of a large part of the epiphreatic cave passage formed above the West Lota doline collapsed and a narrow natural bridge remained from the cave (Alagöz, 1967; Doğan and Özel, 2005; Doğan and Yeşilyurt, 2019, 2021; Figure 14). The excess waters of the Western Lota collapse doline lake pass through this unroofed cave and natural bridge and reach the Koruçayırı area (Figure 15). Bedrock collapse dolines and cave ceiling collapses, which are formed between the East and West Lota lakes caused to shape of the embayment this section of the polje.

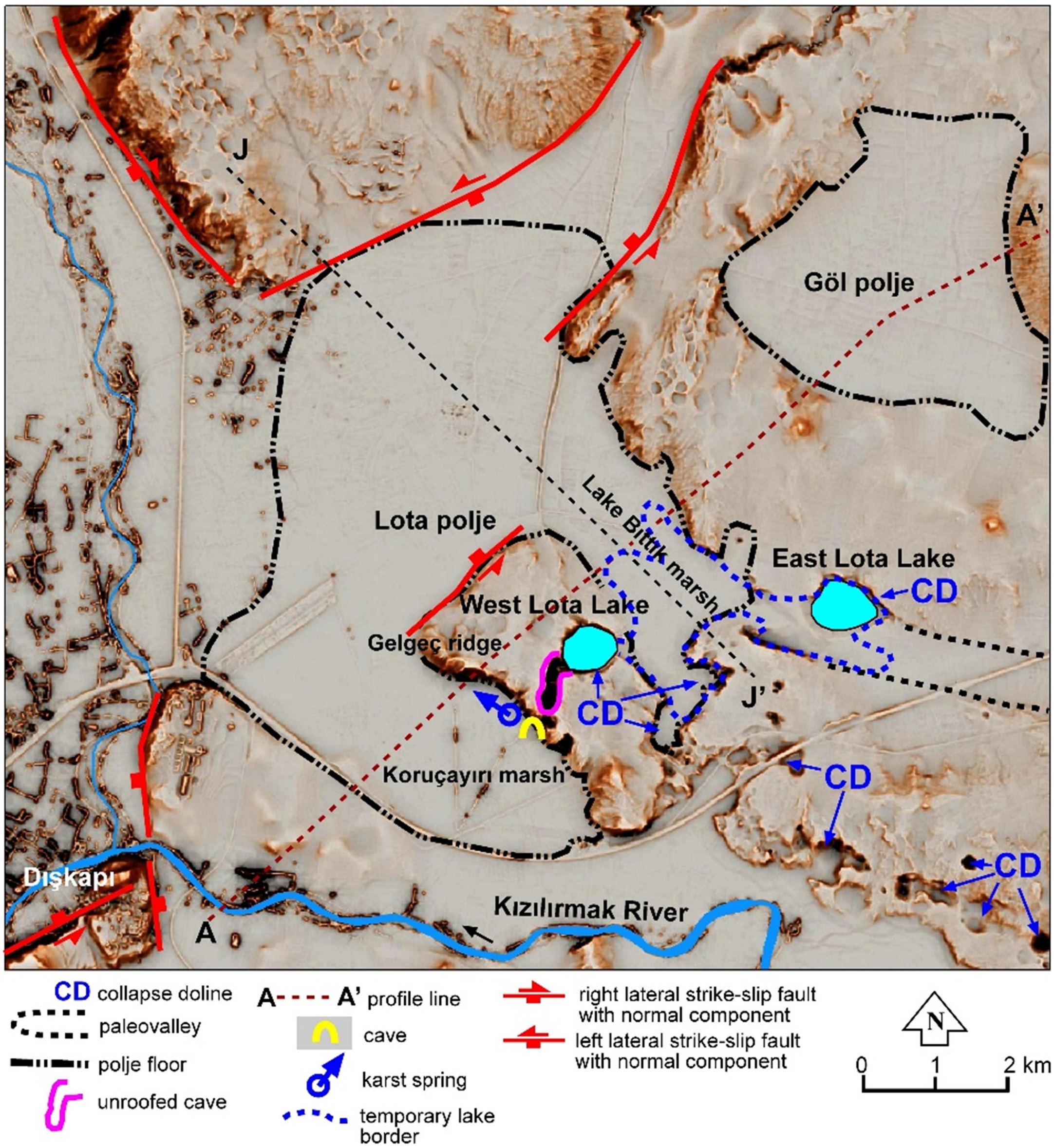

Figure 13. Geomorphological map of Lota and Göl poljes and their surroundings.

4.9. Göl Polje

This polje is located northeast of the Lota polje, and the waters in the polje do not flow from the ground surface (Figure 13). The floor width of the polje is 750 m in the E-W direction and 1500 m in the N-S direction. The waters of the polje, which is located at a floor level of 1304 m asl (Figure 15), should probably be reaching the Lota Polje from underground.

4.10. The Lake Tödürge Corrosion Plain and Lake Tödürge

The surroundings of the Lake Tödürge are located in the east of Lake Tödürge corrosion plain. It does not show a characteristic gypsum polje feature like the others (Figure 16). For this reason, the plain located the west of Lake Tödürge has been called a corrosion plain. This section, which is approximately at the present river level, was formed by the dissolution of gypsum as a result of the overflow of the lake waters and the Kızılırmak River. Lake Tödürge is located in the eastern part of this plain, which is bounded by faults on both sides.

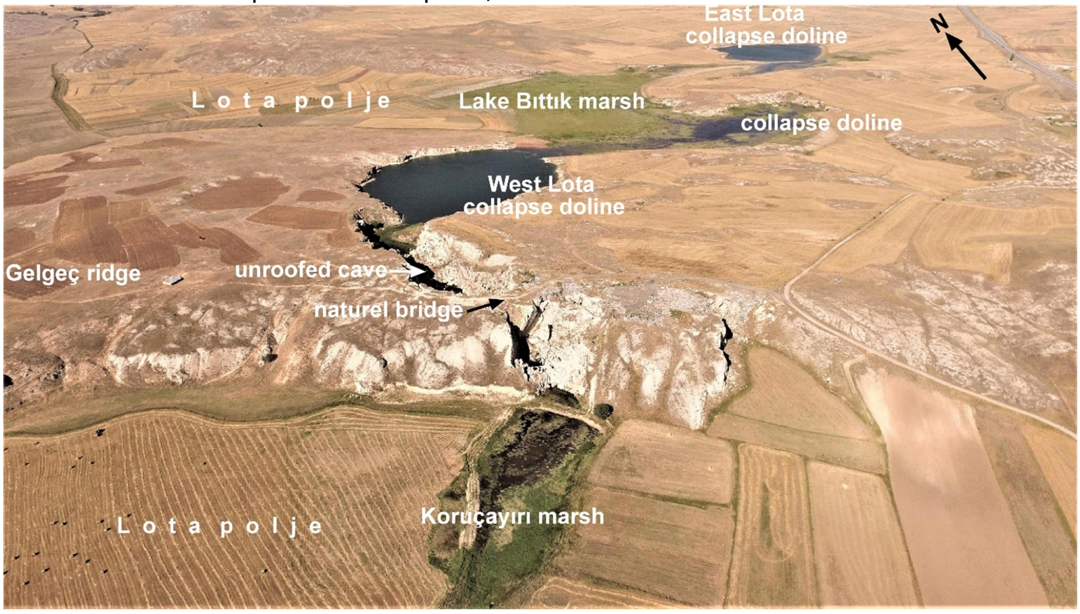

Figure 14. The field photograph shows the same geomorphologic and hydrologic features of the Lota polje.

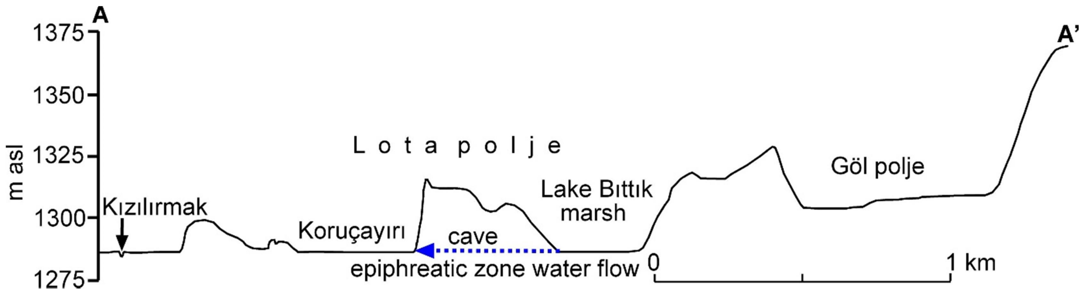

Figure 15. NE-SW trending profile of both the Lota and Göl poljes

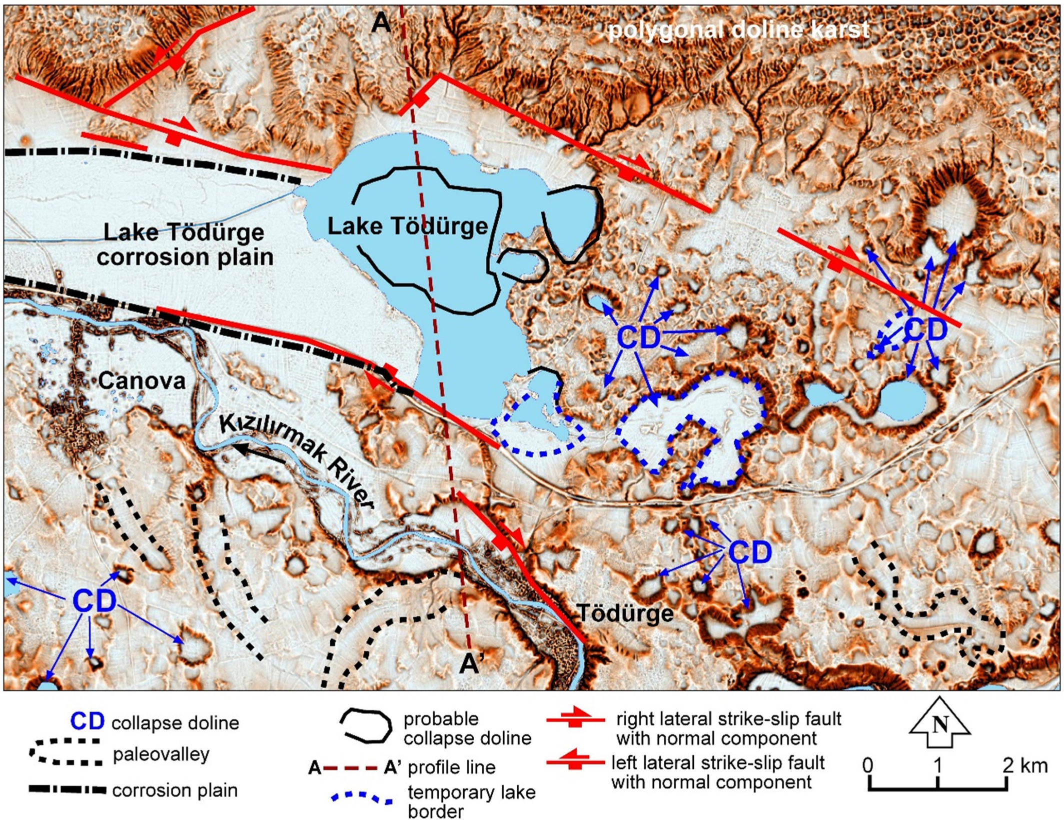

Figure 16. Geomorphological map of the Lake Tödürge and its surroundings.

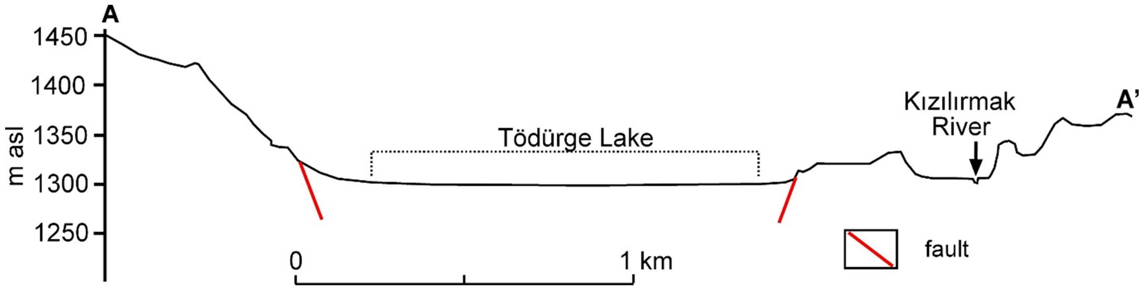

Figure 17. Lake Tödürge is located around 4 m below the Kızılırmak River.

Lake Tödürge, together with the narrow corrosion plain around it, has a circular appearance with a diameter of about 3 km. It is understood that the lake is located in a depression formed mainly due to the collapse dolines. The lake surface (1299,1 m asl) is located approximately 4 m below the level of the Kızılırmak River floodplain (1303 m asl; Figure 17). The lake probably submerged collapse dolines and/or combined collapse dolines. It is stated that the depth of the lake in the northern part is 28 m (Alagöz, 1967). In the Google Earth satellite image of December 1985, the shapes of the dark and deep areas in the lake resemble collapse dolines. In addition, Alagöz (1967), who did bathymetric measurements in the lake, made a similar inference. The fact that the thickness of alluvium in the valley floor of the Kızılırmak River near Tödürge village is 30 m (Drahor, 2019) indicates that there may be a relationship between the formation of the Lake Tödürge and the base level of the Kızılırmak River in the Last Glacial period. However, the fact that Drahor (2019) revealed the presence of collapse and subsidence dolines formed in the shallow phreatic zone in the Sivas Gypsum karst area which shows that the formation of the Lake Tödürge Basin may also be affected by the dissolution in the shallow phreatic zone. Accordingly, we can say that the karstic dissolution, that forms Lake Tödürge, and as a result of this, the collapse dolines may be related to bedrock collapse. They developed according to the Kızılırmak River level and karstic cavities in the phreatic zone during the Last Glacial period.

The formation of large collapse dolines in the Lake Tödürge and its east and southeast must be related to the fact that the movement of groundwater is controlled by the river and faults in this area. The NW trending faults in this section might have caused the Low Karst Plateau to tilt towards the northwest. For this reason, the topographic profile and lake-river levels taken from this area indicate that the regional water table slopes in the NW direction (Figure 4). For example, a section taken between Acıçay stream and High Karst Plateau shows that the floor of the composite collapse dolines are located at the east of Lake Tödürge is slightly lower than the Kızılırmak River level.

5. DISCUSSION

In the Low Karst Plateau, around the Kızılırmak River, poljes, most of which are directly closed to external drainage or are drainage provided from underground, have been identified and mapped. In addition, the morphometric and morphotectonic properties of these poljes have been revealed. Of course, these poljes are not as large and characteristic as the poljes in the limestone areas (Gracia et al., 2003; Bonacci, 2013; Doğan et al., 2017, 2019; Doğan and Koçyiğit, 2018; Şimşek et al., 2020, 2021). However, the poljes composed of gypsum are mostly surrounded by slopes on their three sides, and the width of the base covered with alluvium and residual soil varied between 0,8 and 6,5 km^2. In some poljes, on the parts of the eroded slope, there are thresholds of a few meters between them and the rivers. On the other hand, temporary lakes are formed on the closed polje floors, which drainage is provided from underground, due to rainy periods, seasonal rises in the water table, and river floods. As in limestone poljes, prominent ponors were not detected in gypsum poljes. The reason for this is related to the fact that the floor levels of the poljes are approximately at the level of the river or a few meters below. On the other hand, cracks that are well developed due to the dissolution in gypsum during the periods when the groundwater level is low can meet this need. All these features indicate that the poljes are base-level poljes located approximately at the river level in the low gypsum plateau. However, it has been determined that tens of poljes developed due to the limestone karst, which is quite common in Türkiye, have structural (tectonic)-border, and border polje characteristics, and their drainage is provided by ponors (Doğan, 2003; Şimşek et al., 2020, 2021).

In the development of a significant part of the poljes, especially in the lower parts of the hanging valleys, in the initiation of a blind valley-like karstification process mostly as a result of the collapse doline formation, changes in the water table level, and aggressive river floodwaters that flood the polje floor have been effective. Therefore, it is seen that at least two of these three factors are effective in the formation of most of them.

The data obtained show that most of the Sivas gypsum poljes are fault-controlled. The development characteristics of fault-controlled structural poljes (Gracia et al., 2003; Doğan et al., 2017, 2019; Doğan and Koçyiğit, 2018) and polje developments due to blind valley formation (Doğan, 2003) are well known from studies related to limestone karst. The much higher solubility of gypsum than limestone must have led to the rapid expansion of such blind valleys, which floors are close to the local base level, and their rapid transformation into polje or polje-like karst depressions. This also shows why the slopes of the poljes, which are mostly adjacent to the rivers forming the local base level, do not have or that the polje is separated from the river by a threshold of only a few meters. On the other hand, the collapse dolines at the floor of some of these depressions also contributed to the expansion of the corrosion plains forming the polje floor. While these dolines worked as ponors during periods of low water table level, the waters rising from the dolines during periods of high water table must have caused spread to the floor of the polje and led to the formation of temporary lakes or marshs. This situation caused the lowering and enlargement of the polje floors through corrosion (lateral solution planation) in the area where the temporary lakes are located.

We think that the regional watertable level change during the Last Glacial period was also important in taking the final shape of the poljes. Therefore, the phases of the river incision and aggradation on the valley floor are affected by the polje evolution process. The Kızılırmak River in the western part of the Lake Tödürge showed that the thickness of the alluvium on the floor of the valley is 30 m (Drahor, 2019). This thickness may be even greater in the middle part of the valley floor. In boreholes drilled on the valley floor near Gülşehir in the middle part of the Kızılırmak River valley, the thickness of the alluvium was found to be approximately 18,3 m (Doğan, 2010). This study concluded that the river incised its valley during the Last Glacial period and the alluvium on the valley floor was deposited in about the last 19 ka. Therefore, the last valley incision process in the Sivas Basin must have occurred during the Last Glacial period, as well as near Gülşehir. In this case, it can be noted that there was an elevation difference of approximately 30 m between the polje floors and the valley floor (and thus the water table level of that day) in the Last Glacial. In such a case, it is possible that the drainage of the polje floor occurred with ponors or wide crack systems during the period when the stream bed is lower. For this reason, it can be said that some polje floors are slightly below the present river level due to the dissolution of gypsum in the polje floor during the low water table period. In addition, most of the thick alluvial deposits in some polje floors are deposited during the valley floor rise after the Last Glacial Maximum.

On the other hand, according to the valley floor level of the Kızılırmak River during the Last Glacial period may formed some bedrock collapse, sagging, alluvial, and cover collapse dolines. Therefore, the formation of the dissolution, which is effective in the formation of the Lake Tödürge, which has a depth of around 28 m, must be related to the possible collapse dolines. In addition, these dolines may have formed on the karstic cavities in the water table fluctuation zone (epiphreatic zone) and the shallow phreatic zone in the Last Glacial period. The formation processes of bedrock collapse, bedrock sagging, etc. dolines associated with karst dissolution in the phreatic zone in the Sivas gypsum karst area were revealed by Drahor (2019).

Despite the results and inferences obtained from this study, as noted by Drahor (2019), it would be useful to conduct new studies, including geophysical methods, to elucidate the depression of the Lake Tödürge, the possible relationship between the formation of gypsum poljes and shallow and deep karst processes.

6. CONCLUSIONS

Around the Kızılırmak River, 14 poljes and a corrosion plain were identified, the areas of which ranged from several hundred square meters to 6,3 km^2. The high dissolution rate in gypsum karst has enabled to the well developed (mature) poljes (e.g. Mağaragölü and Dışkapı) and developing (youthful) poljes (e.g. Kulakdüzü and Avutmuş Yazısı) to be seen together. The poljes that are approximately at the river level are the base-level poljes that developed within epiphreatic zone. In the Sivas Basin, which has been under the control of the strike-slip neotectonic regime since the Late Pliocene, the orientation and borders of a significant part of the gypsum polje were largely controlled by tectonic grain. In addition, in the development process of the polje, it is understood that a blind valley, which is triggered mostly by the collapse of the doline, especially in the lower parts of the hanging valleys, which are not much higher than the base level, is effective. When the water table is high, the groundwaters overflow from the dolines to the paleo-valley floor, and this process leads to the high dissolution of the gypsum at the valley floor margin. High the water table and also floodwaters come from allogenic rivers that invaded the polje floors made an important contribution to the expansion of polje by lateral corrosion process. Also, the formation of a number of bedrock collapse doline (as in Lota Polje) may be contributed to the rapidly developed of poljes. The development of poljes buried in the Low Karst Plateau and especially the corrosion and alluvium-detritus material deposition on polje floors during the late Pleistocene-Holocene can be said to have progressed parallel to the incision rate in the valley of the Kızılırmak River in the mid-late Pleistocene and the alluvium deposition processes on the valley floor. It is possible that ponors worked effectively on polje floors during the river incision period, which reached 30 m. This is related to the rather rapid dissolution of gypsum compared to limestone.

Lake Tödürge is located in the north of the Low Karst Plateau, where the groundwater flow is directed due to the tectonic tilt, and therefore the groundwater level is the lowest. It can be said that the lake depression is related to the bedrock collapse dolines that occur due to the karst cavities in the epiphreatic and/or phreatic zone.

REFERENCES

Alagöz, C. A. (1944). Türkiye Karst Olayları Hakkında Bir Araştırma, Türk Coğrafya Kurumu Yayınları, Sayı: 1, Ankara.

Alagöz, C. (1967). Sivas çevresi ve doğusunda jips karstı olayları, 175. Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Yayını, 126 pp.

Bonacci, O. (2013). Poljes, ponors and their catchments. In: Shroder, J. (Editor in Chief), Frumkin, A. (Ed.), Treatise on Geomorphology. Academic Press, San Diego, CA, vol. 6, Karst Geomorphology, pp. 112–120.

Brocard, G.Y., Meijers, M.J.M., Cosca, M.A., Salles, T., Willenbring, J., Teyssier, C., Whitney, D. L. (2021). Fast Pliocene integration of the Central Anatolian Plateau drainage: evidence, processes, and driving forces. Geosphere, 17: 739–765. doi: 10.1130/GES02247.1

Calaforra, J. M., Pulido-Bosch, A. (1999). Gypsum karst features as evidence of diapiric processes in the Betic Cordillera, Southern Spain. Geomorphology 29, 251–264.

Callot, J.P., Ribes, C., Kergaravat, C., Bonnel, C., Temiz, H., Poisson, A., Vrielynck, Salel, J.P., Ringebach, J.C. (2014). Salt tectonics in the Sivas Basin (Turkey): crossing salt walls and minibasins. Bulletin de la Societe Géologique de France, 185: 33-42. doi: 10.2113/gssgfbull.185.1.33

Çiner, A., Koşun, E., Deynoux, M. (2002). Fluvial, evaporitic and shallow marine facies architecture, depositional evolution and cyclicity in the Sivas Basin (Lower to Middle Miocene) Central Turkey. Journal of Asian Earth Sciences, 21: 147-165.

Cooper, A.H., Gutiérrez, F. (2013). Dealing with gypsum karst problems: hazards, environmental issues, and planning. In: Shroder JF (ed) Treatise on geomorphology. Elsevier, pp 451–462.

Çubuk Y, İnan, S. (1998). İmranlı ve Hafik Güneyinde (Sivas) Miyosen Havzası'nın Stratigrafik ve Tektonik Özellikleri. MTA Dergisi, 120: 45–60.

Darıcı, N., Özel, S. (2018). Examination of the structural characteristics arising in gypsums by the GPR and MASW methods (Sivas, Turkey). Nat Hazard, 68: 1–16.

Doğan, U., Koçyiğit, A. (2018). Morphotectonic evolution of Maviboğaz canyon and Suğla polje, SW central Anatolia, Turkey. Geomorphology, 306: 13-27.

Doğan, U. (1996). Polye ve Fluvio-Karstik Depresyonlar (Seydişehir'in Güneybatısından Örnekler). Türkiye Coğrafyası Araştırma ve Uygulama Merkezi Dergisi, 5: 229-246.

Doğan, U. (2003). Sarıot Polje, Central Taurus (Turkey): a border polje developed at the contact of karstic and non-karstic lithologies. Cave and Karst Science, 30: 117-123.

Doğan, U. (2010). Fluvial response to climate change during and after the Last Glacial Maximum in Central Anatolia, Turkey. Quaternary International, 222: 221-229.

doi: 10.1016/j.quaint.2009.08.004

Doğan, U., Koçyiğit, A. (2018). Morphotectonic evolution of Maviboğaz canyon and Suğla polje, SW Central Anatolia, Turkey. Geomorphology, 306: 13–27.

doi: 10.1016/j.geomorph.2018.01.001

Doğan, U., Koçyiğit, A., Gökkaya, E. (2017). Development of the Kembos and Eynif structural poljes: Morphotectonic evolution of the Upper Manavgat River basin, central Taurides, Turkey. Geomorphology, 278: 105-120.

doi: 10.1016/j.geomorph.2016.10.030

Doğan, U., Özel, S. (2005). Gypsum karst and its evolution east of Hafik (Sivas, Turkey). Geomorphology, 71: 373-388.

doi: 10.1016/j.geomorph.2005.04.009

Doğan, U., Şenkul, Ç. (2020). When did the drainage system of the Kızılırmak River form in Cappadocia (Anatolia, Turkey)? A revised geological and geomorphological stratigraphy. Turkish J Earth Sci, 29: 1100-1113.

Doğan, U., Yeşilyurt, S. (2004). Gypsum karst south of Imranlı, Sivas, Turkey. Cave and Karst Science, 31: 7-14.

Doğan, U., Yeşilyurt, S. (2019). Gypsum karst landscape in the Sivas Basin. C. Kuzucuoğlu et al. (eds.), Landscapes and Landforms of Turkey, World Geomorphological Landscapes. Springer Nature Switzerland AG.

Doğan, U., Yeşilyurt, S. (2021). Sivas jips karstı sahasının jeomorfolojik özellikleri. Jeomorfoloji Derneği Bülteni, 5: 35-47.

Doğan, U., Koçyiğit, A., Yeşilyurt, S. (2019). The relationship between Kestel Polje system and the Antalya Tufa Plateau: Their morphotectonic evolution in Isparta Angle, Antalya-Turkey. Geomorphology, 334: 112-125.

Drahor, M.G. (2019). Identification of gypsum karstification using an electrical resistivity tomography technique: The case-study of the Sivas gypsum karst area (Turkey). Engineering Geology, 252: 78-98.

Ford, D.C., Williams, P.W. (1989). Karst Geomorphology and Hydrology. Unwin Hyman, London. 601 pp

https://www.degruyter.com/database/IBR/entry/ibr.ID609763647/html?lang=en

Ford, D.C., Williams, P.W. (2007). Karst Hydrogeology and Geomorphology. Wiley, Chichester, 562 pp.

doi:10.1002/9781118684986

Gams, I., (1969). Some Morphologıcal Characteristics of the Dinaric Karst. Geographıcal Journal, Vol. 135, P.4, 563-572.

Gams, I. (1973). Die zweiphasige quarterzeitliche Flachbildung in Poljen und Blindtalern des nordwestlichen Dinarischen Karstes.-Geog. Z. Beh.: Neue Ergebnisse der Karstforschung in den Troppen und im Mittelmeerraum, 32: 143-149, Weisbaden.

Gams, I. (1978). The Polje: the Problem of Definition. Zeitschrift für Geomorphologie, 22: 170-181.

Gökkaya, E., Gutiérrez, F., Ferk, M., Görüm, T. (2021). Sinkhole development in the Sivas gypsum karst, Turkey. Geomorphology.

Gracia, F.J., Gutiérrez, F., Gutiérrez, M. (2003). The Jiloca karst polje-tectonic graben (Iberian Range, NE Spain). Geomorphology, 52: 215–231.

Guerrero, J., Gutiérrez, F., Bonachea, J., Lucha, P. (2008). A sinkhole susceptibility zonation based on paleokarst analysis along a stretch of the Madrid–Barcelona high-speed railway built over gypsum- and salt-bearing evaporites (NE Spain). Engineering Geology, 102(1): 62-73.

Günay, G. (2002). Gypsum karst, Sivas, Turkey. Environ Geol, 42: 387– 398

Gündoğan, İ., Önal, M., Depçi, T. (2005). Sedimentology, petrography and diagenesis of Eocene-Oligocene evaporites: the Tuzhisar Formation, SW Sivas Basin, Turkey. Journal of Asian Earth Sciences, 25: 791-803.

doi: 10.1016/j.jseaes.2004.08.002

Gutiérrez, F., Cooper, A.H. (2013). Surface morphology of gypsum karst. In: Shroder JF (ed) Treatise on geomorphology. Elsevier, pp 425–437 doi: 10.1016/B978-0-12-374739-6.00114-7

Gutiérrez, F., Cooper, A.H., Johnson, K.S. (2008a). Identification, prediction and mitigation of sinkhole hazards in evaporite karst areas. Environ Geol 53: 1007–1022

doi: 10.1007/s00254-007-0728-4

Gutiérrez, F., Guerrero, J., Lucha, P. (2008b). A genetic classification of sinkholes illustrated from evaporite paleokarst exposures in Spain. Environ Geol, 53: 993–1006 doi: 10.1007/s00254-007-0727-5

Kaçaroğlu, F., Değirmenci, M., Cerit, O. (1997). Karstification in Miocene gypsum: an example from Sivas (Turkey). Environmental Geology, 30: 88-97. doi: 10.1007/s002540050136

Karacan, E., Yılmaz, I. (1997). Collapse dolines in Miocene gypsum: an example from Sivas (Turkey). Environmental Geology, 29: 263-266. doi: 10.1007/s002540050125

Keskin, İ., Yılmaz, I. (2016). Morphometric and geological features of karstic depressions in gypsum (Sivas, Turkey). Environ Earth Sci, 75.

doi: 10.1007/s12665-016-5845-5

Klimchouk, A. (1996). The dissolution and conversion of gypsum and anhydrite. Int J Speleol 5:21–36 (In: Klimchouk A, Lowe D, Cooper A, Sauro U (eds.) Gypsum karst of the world).

doi: 10.5038/1827-806X.25.3.2

Klimchouk, A. (2013). Evolution of intrastratal karst and caves in gypsum. In: Shroder JF (ed) Treatise on geomorphology. Elsevier, pp 438–450

doi: 10.1016/B978-0-12-374739-6.00123-8

Koçyiğit, A., Beyhan, A. (1998). A new intracontinental transcurrent structure: the Central Anatolian Fault Zone, Turkey. Tectonophysics, 284: 317-336.

Kurtman, F. (1973). Sivas-Hafik-Zara ve İmranlı bölgesinin jeolojik ve tektonik gelişimi. MTA Dergisi, 80: 1 – 32.

Legeay, E., Pichat, A., Kergaravat, C., Ribes, C., Callot, J.P., Ringenbach, J.C., Bonnel, C., Hoareau, G., Poisson, A., Mohn, G., Crumeyrolle, P., Kavak, K.S., Temiz, H. (2019). Geology of the Central Sivas Basin (Turkey). Journal of Maps, 15(2): 406-417. doi: 10.1080/17445647.2018.1514539

Ocakoğlu, F. (1999). Evaporitlerden kaynaklanan sünümlü deformasyona ilişkin bazı veriler (Zara, Sivas doğusu). MTA Dergisi, 121: 83–95.

Özel, S., Darıcı, N. (2020). Environmental hazard analysis of a gypsum karst depression area with geophysical methods: a case study in Sivas (Turkey). Environmental Earth Sciences 79: 115-129.

doi: 10.1007/s12665-020-8861-4

Poisson, A.M., Guezou, J.C., Öztürk, A., Inan, S., Temiz, H., Gürsoy, H., Kavak, K., Özden, S. (1996). Tectonic setting and evolution of the Sivas Basin Central Anatolia, Turkey. International Geology Review 38: 838 – 853.

doi: 10.1080/00206819709465366

Poyraz, M., Öztürk, M.Z., Soykan, A. (2021). Sivas jips karstında dolin yoğunluğunun CBS tabanlı analizi. Jeomorfolojik Araştırmalar Dergisi, 6: 67-80. doi: 10.46453/jader.863090

Ristic, D. M. (1976). Water regime of flooded karst poljes. 301-318 in Karst Hydrology and Water Resources, V. Yevjevich (ed.) (Colorado: Water Resources Publication).

Şimşek, M., Doğan, U., Öztürk, M.Z. (2020). Polyelerin sınıflandırılması ve toroslardan örnekler Jeomorfolojik Araştırmalar Dergisi (5): 1-14.

doi: 10.46453/jader.733500

Şimsek, M., Özturk, M. Z., Doğan, U., Utlu, M. (2021). Toros polyelerinin morfometrik özellikleri. Cografya Dergisi, 42: 101-119.

doi: 10.26650/JGEOG2020-834461

Sirel, E., Erdem, N.Ö., Özgen, N. (2013). Systematics and biostratigraphy of Oligocene (Rupelian-Early Chattian) foraminifera from lagoonal-very shallow water limestone in the eastern Sivas Basin (central Turkey). Geologia Croatica Online 66: 83-109. doi: 10.4154/gc.2013.07

Sweeting, M.M. (1972). Karst Landforms, MacMillan Press, London.

Waltham, T. (2002). Gypsum karst near Sivas, Turkey. Cave Karst Sci., 29: 39–44.

White, W.B. (1988). Geomorphology and Hydrology of Karst Terrains. Oxford University Press, Oxford. 464 pp.

https://global.oup.com/ushe/product/geomorphology-and-hydrology-of-karst-terrains-9780195044447?cc=tr&lang=en&

Yılmaz, I. (2007). GIS based susceptibility mapping of karst depressions in gypsum: a case study from Sivas Basin (Turkey). Engineering Geology, 90: 89-103. doi: 10.1016/j.enggeo.2006.12.004

Yılmaz, I. (2012). On the value of dolines in gypsum terrains as a “Geological Heritage”: an example from Sivas Basin, Turkey. Environmental Earth Sciences, 65: 805-812.

doi: 10.1007/s12665-011-1125-6