Collapse dolines in miocene gypsum: an example from SW Sivas (Turkey)

E. Karacan · I. Yılmaz

Abstract This study investigated the formation mechanism of dolines. Dolines are caused by dissolution of gypsum in the study area, 50–220 m in diameter. Two systems were applied to determine the support necessary for natural underground opening of given span in a given rock mass. From the characteristics of the rock mass, a 5 m-wide unsupported span in the gypsum can be expected to stand up for over 9 years. The designed span of an artificial opening would normally be considerably less than the span of a collapsed natural opening in the same rock. Dolines in the study area play an important role in the groundwater flow system.

Key words Collapse · Doline · Gypsum · Rock mass · Dissolution · Stand-up time

Introduction

The study area is 5 km northeast of Sivas and on the I38-a4 section of the topographic map of Turkey scale (1:25 000; Fig. 1). This study investigated the formation mechanism and estimated the period of unsupported stand up. To achieve the above the objectives, first, geological mapping scale 1:5000 studies have been undertaken (Fig. 2). Following the geological studies, two recent empirical approaches were used: the design of the supports for tunnels Rock Mass Rating (RMR) and Tunneling Quality Index ("Q" classification system) to calculate the span of stable natural openings in the massive gypsum. From the characteristics of the rock mass, an unsupported span of 5 m diameter in the gypsum can be expected to stand up for over 9 years. Presumably the designed span of an artificial opening would normally be considerably less than the span of a collapsed natural opening in the same rock mass, because changes in rock are sufficiently slow in natural openings. The dolines in the study area are collapse dolines which had occurred due to the collapse of the roof of the caves formed by the dissolution of the gypsum. Gypsum in the study area has long nets of joint-controlled cave passages and numerous collapse dolines. The latter are primarily located along the faults (Fig. 2). Groundwater discharges to the Kızılırmak River.

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Geology

Massive gypsum is the oldest unit in the study area and was first described by Gökçe and Ceyhan (1988) who named it the Fadlım member in the Karayün formation of Miocene age. The Fadlım member rests stratigraphically on the Şahbey member. Marble and gypsum alternation in the lower part of the thick gypsum strata, including thin clay beds which occur in the middle part and gypsum interbedded with marble in the upper part, comprise the Fadlım member. The measured thickness of this member is about 250 m (Gökçe and Ceyhan 1988). Quaternary alluvium covers the massive gypsum with an angular unconformity and dolines occur in the massive gypsum.

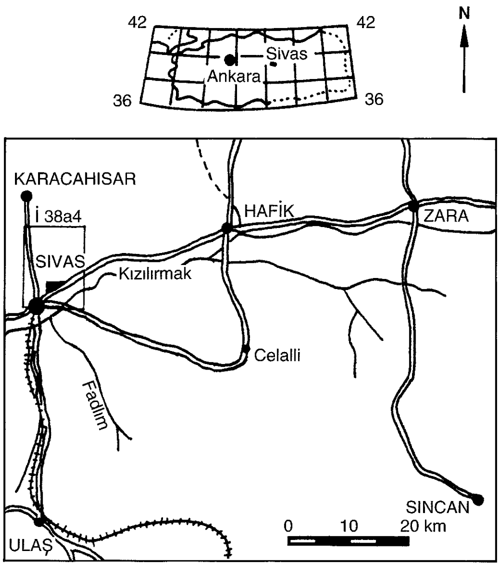

Fig. 1
The location of the dolines

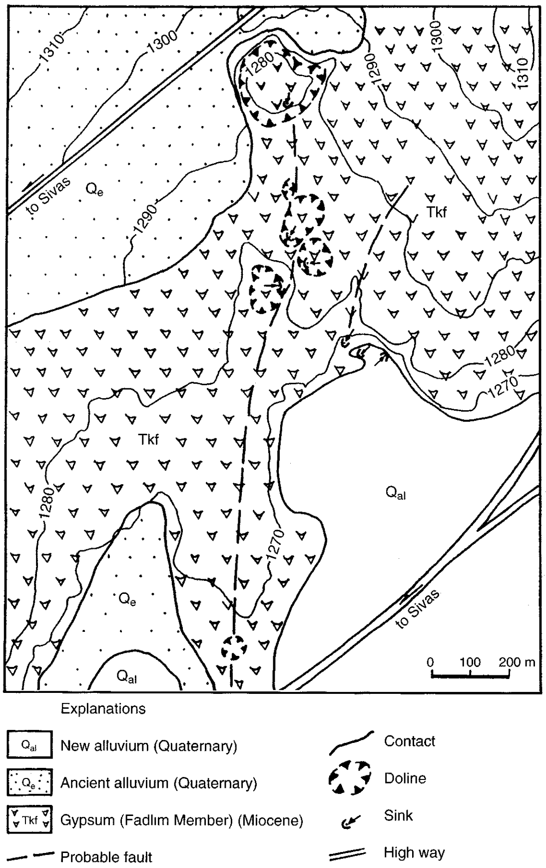

Fig. 2
Geogical map of the study area

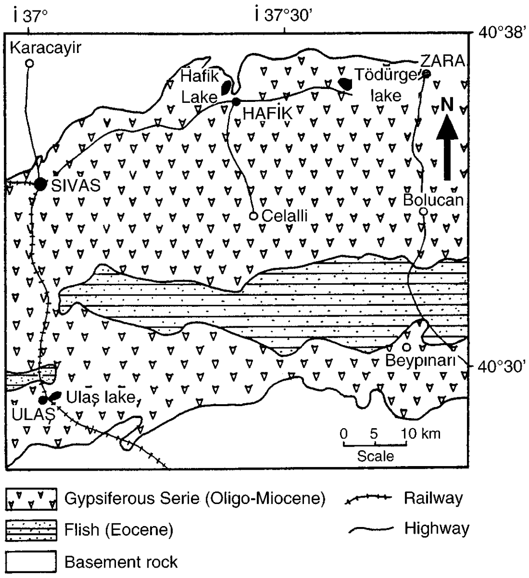

Fig. 3
Location map of the lakes which filled the karst depressions

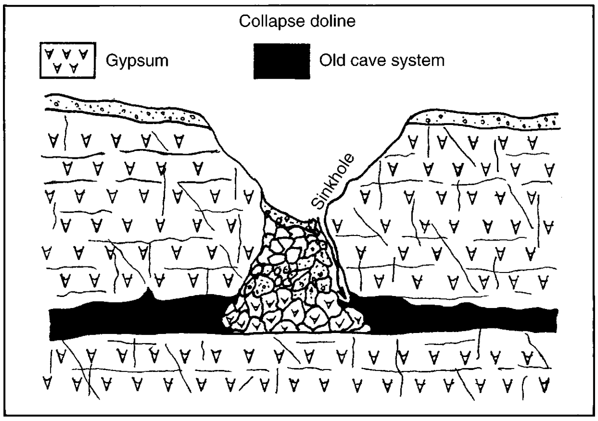

Fig. 4
Mechanism of the collapse doline

Collapse dolines, sinkholes and caves of various sizes are numerous in the study area. A large cave was discovered on the slope of gypsum close to the Sivas-Erzincan highway. Dolines are observed along a fault.

Formation mechanism of dolines

Gypsum in the study area is more soluble than limestone, as 2.5 kg gypsum can be dissolved in 1 m^3 water according to the following equation;

$$Ca\,SO_4 \cdot 2H_2O + H_2O \rightarrow Ca^{+2} + SO_4^{-2} + 3H_2O$$

Collapse passages are a characteristic feature peculiar to gypsum karst. Cover rocks start to collapse slowly, as a result of dissolution of the rocks (Bögli 1980; White 1988). Collapse passages are 100–1000 m in width and 1–15 km in length and developed longitudinally. These structures are caused as a result of the dissolution along the fault and fracture zones (White 1988).
Karst features in the gypsum usually consist of passages small in diameter and their nets (Culshaw and Waltham 1987). If the gypsum occurrences are massive and jointed, large openings occur along different flow routes. These kind of occurrences have been reported by several workers. Culshaw and Waltham (1987) documented that the gypsum beds in the Podolie region in Ukraine (Russia) include hundreds of kilometers of joint-controlled cave passages greater than 5 m in height and width.
Massive gypsum covers a large area around Sivas, Zara and İmranlı and is extensively karstified with numerous sinkholes and karst depressions. Hafik Lake to the east of Sivas, Tödürge Lake to the west of Zara and Ulaş Lake to the south of Sivas filled the karst depressions. Most of the sinkholes formed along the faults, and groundwater discharge to the river can be observed in some places (Alagöz 1967; İlhan 1976; Karacan 1989) (Fig. 3).
The dolines in the study area may be subdivided into three groups. The first group comprise partially collapsed dolines. The second group of dolines appear to develop together with the cracks on the surface. The third group comprise older dolines. The first two groups are, therefore, observed close to the latter. Based on the field ob-

servations, the formation mechanism of dolines is illustrated in Fig. 4.
Dolines in the study area play an important role in the groundwater flow system. The dissolved gypsum in the groundwater which reaches to the Kızılırmak River presumably causes the high salinity of the river. Industrial waste water in the study area which was discharged into the sinkhole of the dolines presumably causes the pollution of the Kızılırmak River following the same route as the groundwater. In other words, industrial wastewater also reaches the Kızılırmak River via the groundwater.

Estimating the unsupported span of the natural openings

Two recent empirical approaches were used to design of supports for tunnels and calculate the span of stable natural openings in the massive gypsum.
To apply the RMR (Bieniawski 1989), six classification parameters were determined and entered into the standard input data sheet: uniaxial compressive strength of intact rock material, rock quality designation (RQD), spacing of discontinuities, condition of discontinuities, groundwater conditions, orientation of discontinuities. As the classification parameters were determined, the ratings were assigned to each parameter according to the standard tables of Bieniawski (1989). The calculation of RMR is given in Table 1. Uniaxial compressive strengths of specimen from the gypsum in the doline were 140 kg/cm^2, so that a rating of 2 is possible for uniaxial compressive strength. Strength tests were carried out according to the International Society for Rock Mechanics (ISRM 1972). The RQD was estimated from average frequency by Priest and Hudson's formula (1976). RQD was determined as 60%, so that a rating of 13 is possible. The overall score (Final RMR), 70, is close to mid-point of the "good rock" range. In other words, the Rock Mass Class is 2, which indicates the "good rock".
The time a rock mass may remain unsupported in a tunnel or opening is called its stand-up time. Charts such as the Bieniawski (1989) rock mass ratings give the stand-up time of various unsupported spans. From the characteristics of the rock mass, according to Bieniawski, the unsupported span of 5 m in diameter in the gypsum can be expected to stand up for over 9 years.
The Q-system of rock mass classification is based on a numerical assessment of the rock mass quality using six different parameters: RQD, number of joint sets, roughness of the most unfavorable joint or discontinuity, degree of alteration or filling along the weakest joint, water inflow, and stress condition. These six parameters were grouped into three quotients to give the overall rock mass quality of *Q* as follows;

$$Q=(RQD/Jn)(Jr/Ja)(Jw/SRF)$$

The calculation of the tunneling quality index, Q, (Barton and others 1977) is given in Table 2. An RQD value of 60% has been assumed. According to the obtained value, Q = 3.

Table 1
Geomechanic classification of jointed rock mass (Bieniawski 1989)

Parameter	Description	Rating
Uniaxial compressive strength (kg/cm^2)	140	2
RQD (%)	60	13
Spacing of discontinuity	20–60 cm 0.6–2.0 m	12
Condition of discontinuity	very rough surfaces	30
Groundwater	none	15
Strike and dip orientation of joints	favorable	−2
Total rating	good rock	70

Table 2
Calculation of NGI tunneling quality index (Barton and others 1977). Q = (RQD/Jn)(Jr/Ja)(Jw/SRF) = (60/6)(3/4)(1/2.5) = 3

Parameter	Description	Value
Rock quality (RQD)	Fair	60
Joint sets (Jn)	2 joint sets + random	6
Joint roughness (Jr)	Rough or irregular, undulating	3
Joint alteration (Ja)	Softening or low-friction clay mineral coatings	4
Joint water (Jw)	none	1
Stress reduction (SRF)	Low stress, rear surface	2.5
Rock quality (Q)		3

Barton (1976) considered unsupported underground openings in detail. He suggested design limits on the span of various types of excavation given by:

$$SPAN=2\ ESR\cdot Q^{0.4}$$

From this equation, the span was calculated as 5.1 m. This indicates that 5.1 m in diameter for an unsupported span is stable.

Results and conclusions

Nets of joint-controlled cave passages were observed in the gypsum of the Fadlım member in the study area. Solution caused numerous collapse dolines which occurred along a line related to faulting.
Uniaxial compressive strengths of specimen from the gypsum in the doline were determined to have an average value of 140 kg/cm^2. Uniaxial compressive strengths

vary from 96 kg/cm^2 to 163 kg/cm^2. Results from the uniaxial compressive strength tests and field observations, and two empirical rock mass classification systems, RMR and "Q", were applied to determine the support necessary and the unsupported stand-up time. The RMR (Bieniawski 1989) results give a stand-up time of 9 years or more for a span of 5 m diameter. According to the "Q" classification system, a 5.1 m diameter unsupported span is stable. RMR results support the "Q" classification system results.

These results from the empirical classification systems are valid for artificial openings. Presumably, the designed span of an artificial opening would normally be considerably less than the span of a collapsed natural opening in the same rock mass. Natural methods of excavation cause less damage to the surrounding rock than artificial excavation methods such as rock blasting and boring. In the artificial excavation methods, the original strength of the rock mass decreases, although a natural opening formed by solution presumably causes only slight damage beyond the margins of the opening and changes in the rock mass sufficiently decrease.

Dolines in the study area play an important role in the groundwater flow system. Thus, discharge of the industrial wastewater into the sinkhole of the doline causes the pollution of Kızılırmak River in the study area. In studies concerned with the pollution problems of Kızılırmak, this system should be taken into the consideration.

Underground openings and their sizes should be investigated for stability before construction in the study area and its surroundings is initiated.

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