The role of regional tectonics in structural caves, Simorgh Cave, Sofeh Mountain (Iran)

Arash Sohrabi[1*], Soheyla Beygi[1], Alireza Nadimi[2], Mehrdad Hajihashemi[3]
1- MSC, Department of Geology, University of Isfahan, Isfahan.
2- Assistant Professor, Department of Geology, Faculty of Science, University of Isfahan.
3- Islamic Azad University, Dolatabad Branch, Isfahan, Iran.
* Corresponding Author: arashshrbi@yahoo.com

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Abstract

The Sofeh Mountain in the south of Isfahan (Iran) has a development of shafts (vertical cave). Simorgh cave with a depth of 42 m and a length of 52 m has developed along significant fault structures. Structural analysis indicates relationships of orientation between the faults and fractures and shafts and Chambers geometries. Considering the main NE-SW trend of tectonic structures in the area, the faults have been classified in three sets: longitudinal, transverse, and oblique faults. In this research, the role of tectonics in forming the Simorgh cave has been investigated and a 3D model and a cave map (scale 1:250) are prepared for the first time. Diagrams of the faults and direction of the cave show that the formation of Simorgh cave has been controlled by faults and fractures directed to NE-SW.

Keywords: Shaft, Tectonics, Structural control, Cave survey, Sofeh Mountain, Isfahan.

1–Introduction

Caves are very special environments where traces of different speleological events can be preserved for over 10^6 years. However, caves are also dynamic environments. Karst waters forming underground passages use preferentially structural geological elements such as bedding planes, especially slipped bedding planes, fissures, faults, folds, etc (Knez, 1996; Sebela, 1998; Kogovsek and Sebela, 2004; Sebela *et al*., 2004; Petric and Sebela, 2004). The largest and most common caves are solution caves that formed by chemical reaction between circulating groundwater and bedrock mainly of limestone, dolomite and evaporite rocks. A number of caves, called tectonic caves are formed by a mass movement of the bedrock (Palmer, 2007).

Tectonic caves occur in many geologic settings and in great numbers, since they are produced by minor slippages in the outcrops of massive sandstones, granites, basalts, and even limestone. Most such caves measure from several meters to a few hundred meters in length. Many of them consist of a single passage that extends into hillsides along major fractures. Some of the larger tectonic caves have a grid or network pattern that matches the pattern of the fractures or joints (Palmer, 2007). Tectonic caves are rarely noticed or catalogued. Some examples of tectonic caves described from different countries are included: Bini *et al*., 1992; Gilli and Delange, 2001; Mocchiutti, D'Andrea, 2002; Plan *et al*., 2005 and Ballesteros, 2011; 2014).

In vast areas of Iran, several caves and karstification phenomena have been recognized and described during recent years (e.g. Rezaei and Zamani, 1998; Salimi, 2008; Karimi and Taheri, 2009). These areas, including Zagros, Alborz and Central Iran mountains, are partly made of carbonate rocks, which are the main sources of providing drinking water in the arid and semi-arid provinces of the country. The exploration of shafts in Iran is emergent and there are only several publications of several speleological studies on the Zagros Mountains (Mohammadi and Field, 2009). In addition, researches about the relationship between karst and tectonics are rare in the world. In Iran, Nadimi and Sohrabi (2009, 2012) have studied some caves and sinkholes. Also, Beygi and Sohrabi (2014) in the Isfahan showed that brittle deformation and karstification processes have created a suitable area for cave formation. Therefore, karst systems from this area represent an ideal natural laboratory for studying tectonics.

The aim of this paper is introduce of the Simorgh cave for first time and the fractures set which developed the cave and its geological units, by the analysis of the fractures pattern and correlation with geological information of the cave.

2– Geological setting

The Turkish–Iranian Plateau is an actively deforming zone that has resulted from the collision between the Arabian and Eurasian plates within the greater Alpine–Himalayan collisional belt (Fig. 1A). The collision resulted in major crustal thickening, folding, thrusting and strike-slip faulting. The collision between the Arabian and Eurasian plates following the closure of the Neo-Tethys Ocean resulted in the development of the Zagros orogeny (e.g. Berberian and King, 1981; Agard *et al*., 2005). The Zagros orogen is subdivided into several tectonic units that include: the Zagros simply folded belt, the Zagros imbricate belt, the Sanandaj- Sirjan zone, and the Urumieh-Dokhtar magmatic arc (e.g. Stocklin, 1968; Berberian and King, 1981; Agard *et al*., 2011; Mouthereau *et al*., 2012).

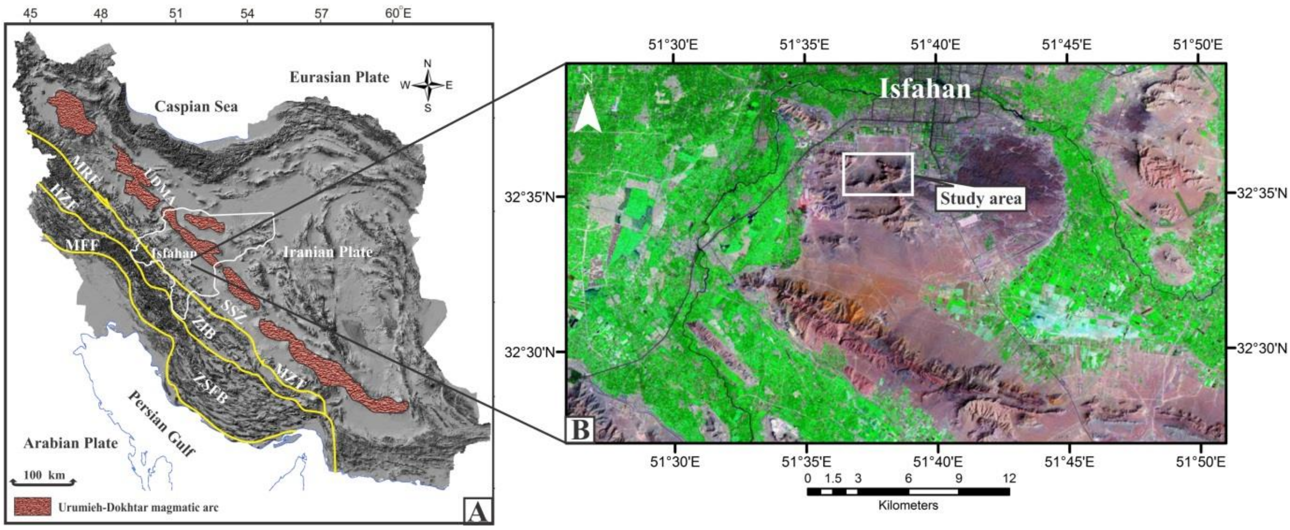


Figure 1A) Digital Eelevation Mmodel (DEM)-based topographic relief and tectonic map of the Zagros Orogen. Tectonic zones of the Zagros Orogen: ZSFB- Zagros Simply Folded Belt, ZIB- Zagros Imbricate Belt (High Zagros Belt), SSZ Sanandaj-Sirjan Zone, UDMA- Urumieh-Dokhtar Magmatic Arc. Major faults: MZT- Main Zagros Thrust (Berberian and King, 1981, Alavi, 1994; Berberian, 1995; Agard et al., 2005); B) Situation map of the Sofeh Mountain and locations of study area in South of Isfahan.

The Simorgh Cave (32˚35' 37" N, 51˚38' 39" E, 2,015 m asl) is located on the northern part of the Sofeh Mountain, in the South of Isfahan, in the Sanandaj-Sirjan zone (Figs. 1B, 2). The 85% of the cavity consists of two levels of galleries and the 15% correspond to three vertical shafts of 52 m width and 42 high. The galleries represent development of the cave. The passages follow the NE–SW direction in the cavity.

The bedrock consists of 500 m of lower Cretaceous limestone (Fig. 3). During the Alpine– Himalayan orogeny, some of the faults were reactivated and caused the rotation of some thrust sheets, leading to the formation of the main landforms. Geological formations in the Sofeh basin belong to Mesozoic Era, and microfossils investigations have shown that the limestone of Sofeh was deposited over the Lower Jurassic shale (Fig. 4). Lower Cretaceous dolomite and limestone are the most important rock units and have a wide distribution in this basin. The grey limestone contain orbitolians and ammonites. This formation shows different karst features that have an important role in controlling the storage and direction of underground water. So, most of the large springs in the region occur in this formation (Zahedi *et al*., 1987). Late Cretaceous tectonic movements led to the renewal of old faults activities (Vali *et al*., 2010). There is a dominant fault system in the Sofeh basin that formed many joints and fractures parallel to the NE-SW-trending fault.

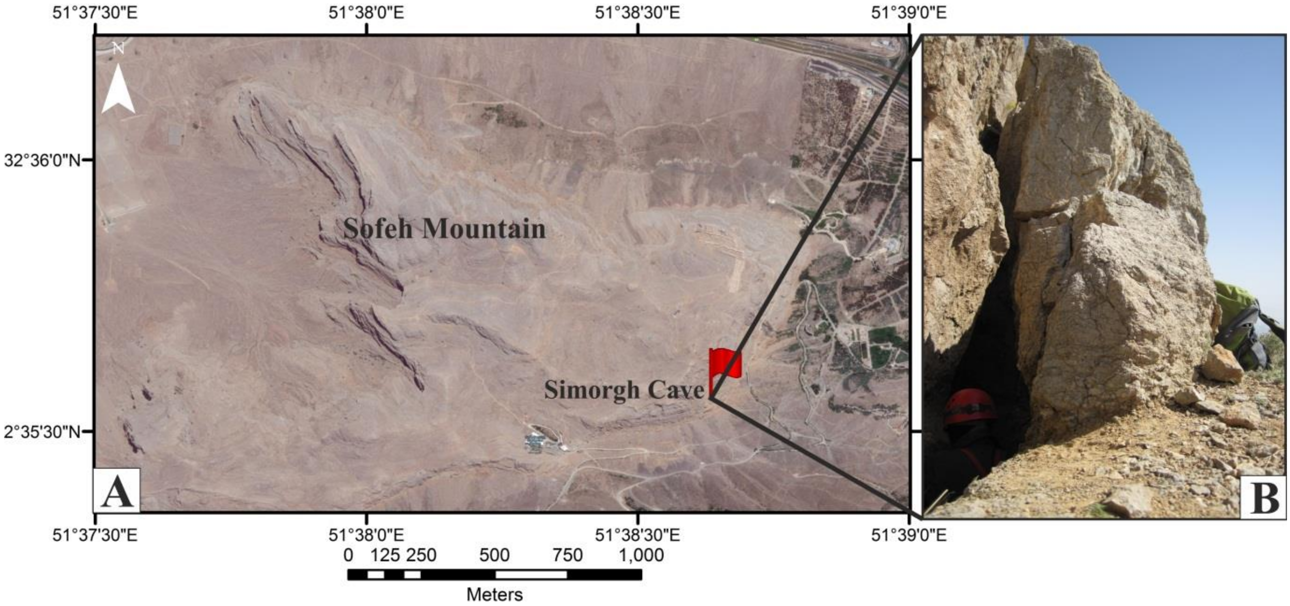


Figure 2A) Location of the Simorgh Cave in the Sofeh Mountain- south of Isfahan; B) Entrance of the Simorgh Cave.

The effects of this tectonic phase are included: formation of the slip surface of fault, existence of numerous joints and fractures in the basin, change in the direction of carbonate layers in formations, fractures filled with silica and calcite.

3–Methodology

The used methods in this research classified into several parts: 1- Speleological studies 2- study and analysis of the fractures. The primary stages of research were identification of the cave for the first time, definition of groups of cave conduits and the mapping of the cave at a scale of 1:250 by using the software Pocket Topo. In the second step every observed fault trace was mapped as accurately as the scale of the maps allowed. Fault traces were identified mainly in places where they cut competent rocks. Based on the length of faults and its role, they were separated into principal displacement zones, and minor faults. Shear sense along the faults was recognized during field studies from analysis of slickenlines and drag of beds along the faults. Fault-slip data obtained from slickenlines and calculated by the software Fault Kin. Joints have harvested inside and outside of the cave and were processed by the STREONET2000 software to show direction of stretch.

4–Discussion

In this research, the relationship between faults and the Simorgh cave genesis is discussed. Mainly, vertical tectonic movements are responsible for karstification and the formation of karst landforms (Atalay, 2003).

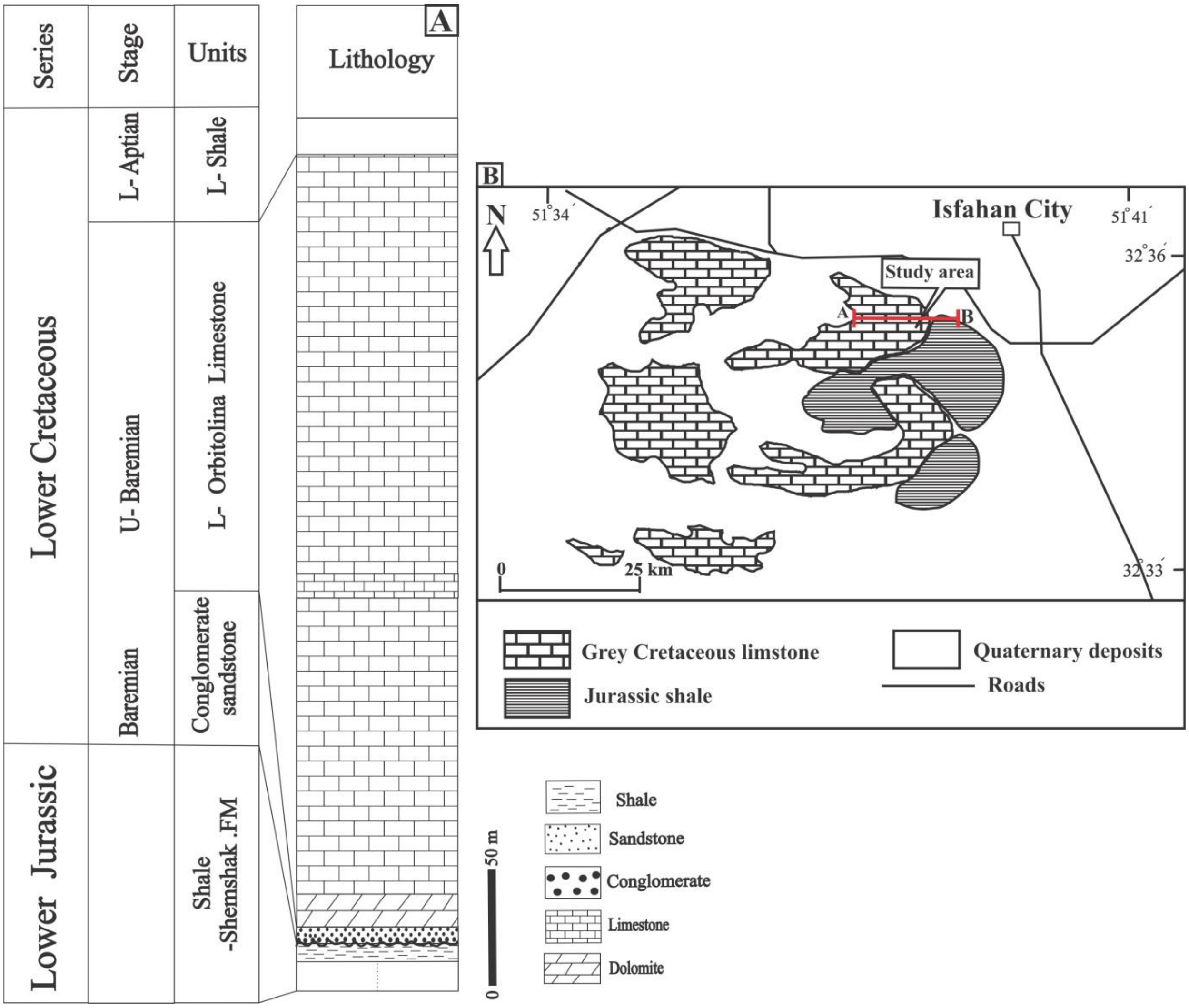


Figure 3A) Simplified stratigraphic column of the Sofeh Mountain; B) Geological map of the Study Area.

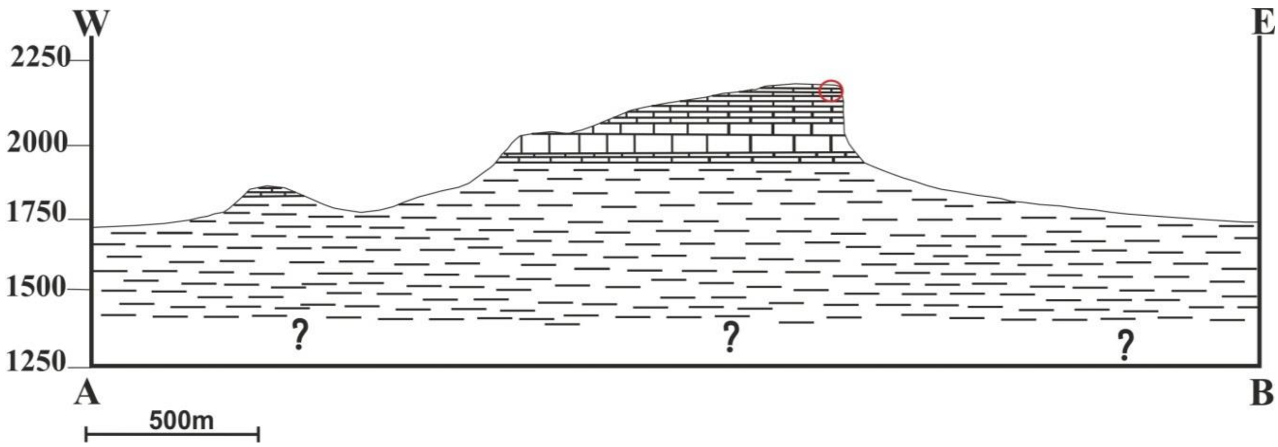


Figure 4) Geological cross-section through the Sofeh Mountain locating its position in Fig. 3.

In the end of Mesozoic Era, the Sofeh mountain range was completely uplifted (Vali *et al*., 2010). Thus, in this area, water draining has begun to dissolve limestone along the crack system and fault lines. Then, the groundwater system and caves have been developed and the main shaft was formed, especially along the weak zone fitting fault lines (Fig. 5). In the south of Isfahan, the fault pattern consists of major NE- SW trending (Zahedi *et al*., 1978; Safaei, 2009). These faults dissect Mesozoic-Cenozoic rocks, and specially, in some places, Pliocene to Quaternary rocks and sediments (Nadimi and Kanon, 2012).

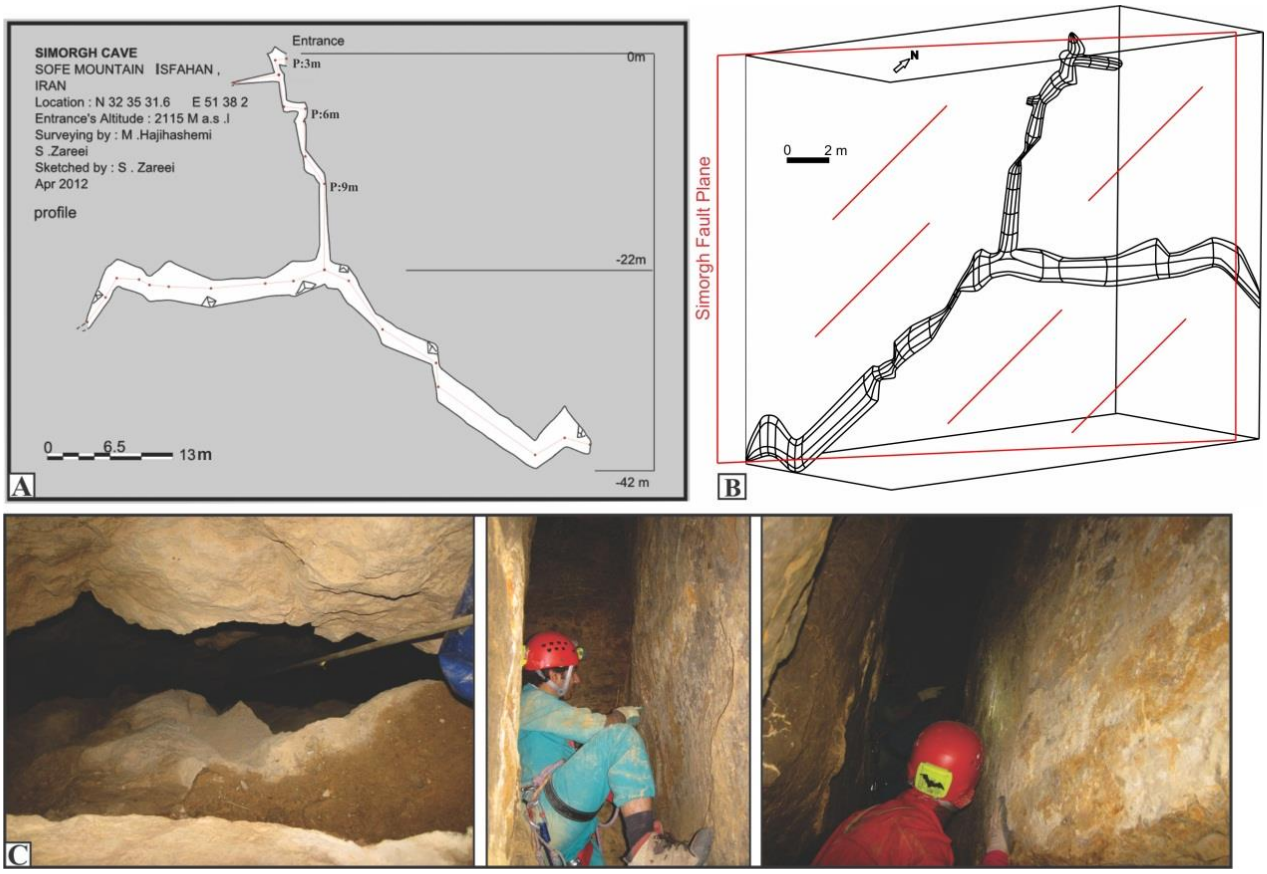


Figure 5A) Details of the cave map in plain view; B) 3D model of the Simorgh cave; C) Views of the cave along the Simorgh fault.

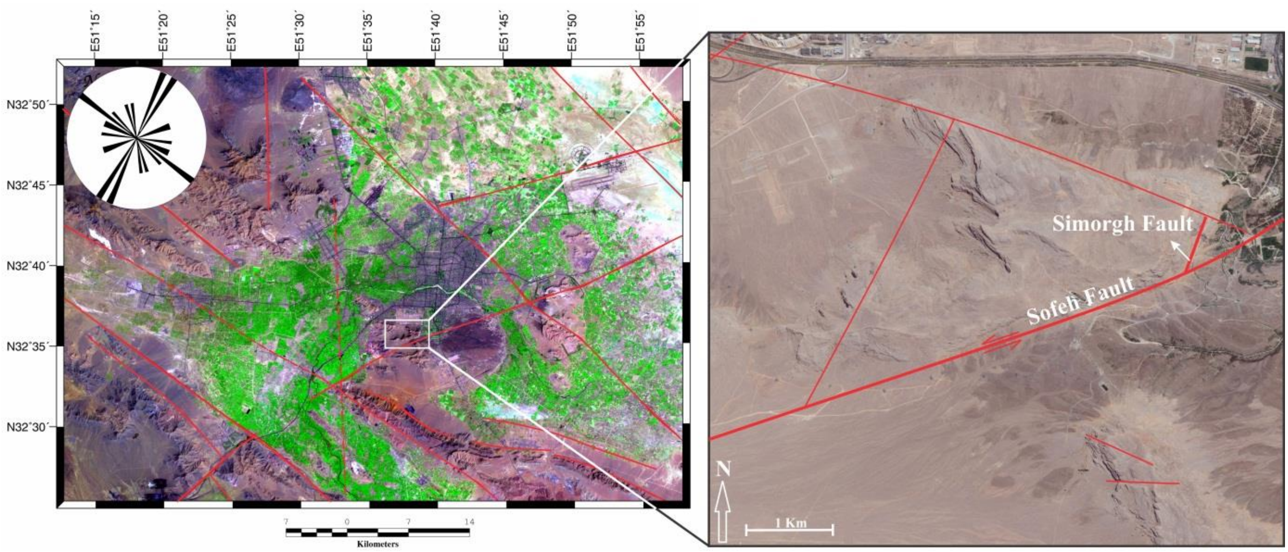
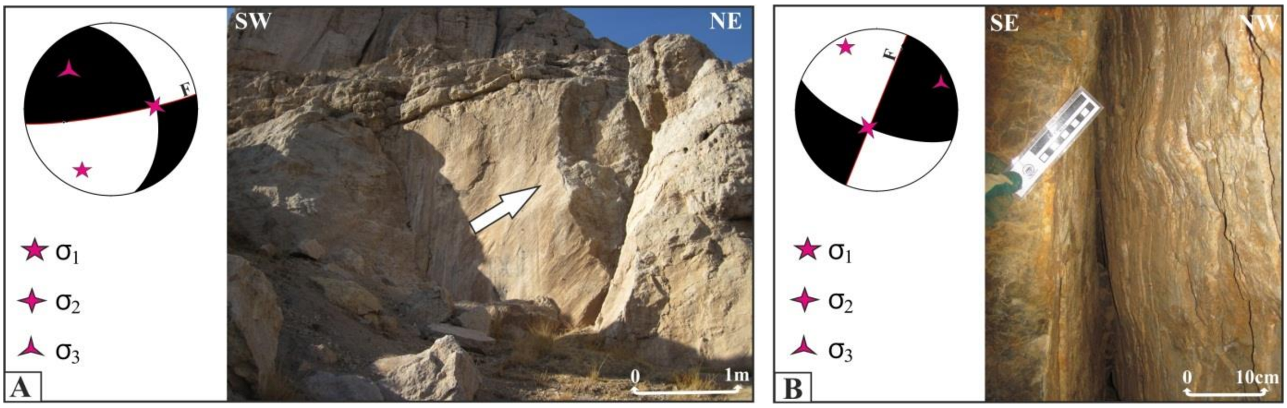


Figure 6A) Fault pattern in the Sofeh Mountain, South of Isfahan on the SRTM (Shuttle Radar Topographic Mission) image and Rose diagram of faults; B) A map of faults in the vicinity of Simorgh Cave on the SASPlanet image.

Considering the main NE-SW orientation of the tectonic structures in the area, the faults are classified into three sets: longitudinal, transverse, and oblique faults (Fig. 6) and the rose diagrams of fault orientations were drawn based on their lengths for each part (Fig. 6). The Sofeh fault (NE- SW trending) is 165 km long and crosses Isfahan city. The trace of the fault is easily visible as an evident line on the Landsat imagery. Along this fault, the Jurassic and Cretaceous rock units were uplifted during thrusting and the fault cuts Quaternary sediments (Fig. 6). Field data and analysis of the Landsat satellite images indicate that the fault has been developed on a N 60-70°E strike and 75-85°SE dip. The fault shows both of the sinistral strike- slip and reverse movements which were calculated on the fault plane (Fig. 7A).



A) Stereoplot of the Sofeh Fault plane, Stars indicate stress axes and Sofeh Fault planed in Cretaceous limestones. The arrow shows the sense of the fault lineament. B) Stereoplot of the Simorgh Fault plane, Stars indicate stress axes and Simorgh Fault plane in Cretaceous limestones inside the cave.

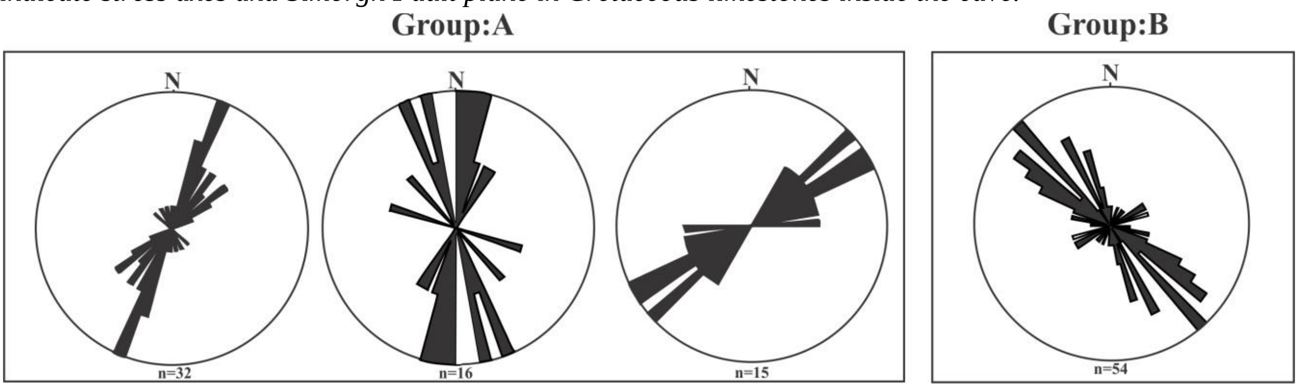


Figure .8: Rose diagrams of fractures in the study area. Group A: The rose diagrams of fractures, outside the cave. Group B:The rose diagram of fractures, inside the cave.

The Simorgh fault (NE-SW trending) is a major fault in this region and presenting for first time. Field data indicate that this fault is directed on 22° strike and 90° dip, inside the cave. The fault shows a sinistral strike-slip and reverse movement. The trace of fault is a crushed zone and slickenlines on the limestone layers (Fig. 7B). The geological investigation of the adjacent area shows a significant slope deformation on the northeastern of the Sofeh Mountain. This deformation appears to reflect the underlying influence of the Simorgh Fault. This fault system is now known to have influenced the development of passages in the Simorgh Cave as the cave system follows the strike of the fault.

Figure 8 shows rose diagrams of fractures in the study area. The rose diagrams of the outside data show three sets of fractures in directions: NE–SW, N–S and NW–SE (Fig. 8, Group: A). The first group represents 75% of the whole fractures and the second and third groups represent the remaining 25%. The rose diagrams show that dominant orientations of joints are parallel to the Simorgh fault direction. The direction of the cave passages are analyzed by the rose diagram Group: B. The plots show two sets of fractures in directions: NW–SE and NE–SW (Fig. 8, Group: B). Rose diagrams show that the blocks are bounded by NW–SE joints. The imbricate joints appear between Simorgh and Sofeh faults in 320˚ direction. Diagrams of faults and direction of the cave show the Simorgh cave has been controlled by faults and fractures directed to NE- SW.

It is clear, that new fractures in the cave deposits are due to blocks movements. In addition, the preserved slickensides inside the cave helped us to determine the fault mechanisms. Also, the broken slabs and slickensides have been used to recognize the mechanism of the fault displacement. These data revealed sinistral strike-slip movements along the main fault on the NE-SW direction. Therefore, we deduced that the recent stress has compressed the area approximately on the N-S orientation. The noticed, vertical displacements along the faults show the ongoing subsidence in the NE of the Sofeh area. Indeed, formations of deep and large karstic shafts are related to the vertical tectonic movement in this area.

5– Conclusion

The fault pattern in the south of Isfahan is dominated by the NE-trending faults. The Sofeh and Simorgh faults are the most important faults in the study area. The faults show a sinistral strike- slip and reverse movements. Surveys of the geological maps and cross-sections and also relationships between cave conduits and the geological setting, show that the cave system has developed along significant fault structures. According to the information, it is believed that the Simorgh cave has been formed by faults and fractures directed to NE- SW.

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