3 Natural Sciences in the Caves of Turkey

Abstract

Karstic lands cover the %40 of the total area of Turkey. Examination of these areas situated in the Alpine–Himalayan Orogenic Belt plays a key role in shedding a light on the tectonic evolution of this huge area that elongates from Europe to Asia, besides the tectonic evolution of Turkey. The research of the karstic lands exerts a great importance for the urban policies within the cities and villages settled in these geological regions, in order to require rigorous approaches to the engineering problems during the stages such as road and freshwater system construction or wastewater treatment. The most well-known karstic formations and caves exert a great impact on the development of landscapes as underground drains, since caves have been investigated in the context of geomorphological setting, lithology and geologic structure, groundwater chemistry and hydrology, aquifer type as well as regional tectonics, climate research, biology, microbiology, and in-cave environmental conditions. The historical background of the particular research for each selected caves from Turkey is given in Chap. 4 of this book. As comprehensively treated in Chap. 2, the state of the art in cave archaeology was excluded from the contents of this chapter.

3.1 Introduction

Karstic lands that cover the %40 of the total area of the country are divided into six regions in Turkey: Taurus Mountain, Thrace and Black Sea Mountains, Western Anatolia, Central Anatolia, Eastern Anatolia, and Southeastern Anatolia (Chap. 4). First two of the regions which carry traces of Turkey's paleotectonic evolution that started in the Permian–Triassic period and continued in Mid-Miocene, and traces of the Alpine Orogenesis that belongs to Oligocene–Miocene period, present most of the karstic areas in Turkey. Conditions shaped through processes occurred like the formation of the Pontids and the Anatolid-Torid block in paleotectonic period, the collision of the Anatolid-Torid Platform with the Pontid island arc by which N–S crustal shortening and in crustal deformations of the Anatolid-Torid block began during Late Paleocene–Early Eocene, the uplift of the Anatolids during Upper Eocene–Lower Miocene period due to the ongoing compression in N–S direction, the closure of the southern branch of the Neo-Tethys in Late Cretaceous, and finally the collision of Arabian and Eurasian Plates, set the stage for the neotectonic period that contains recent earthquakes (Şaroğlu & Yılmaz, 1986). There is a suit of well-detailed publications on these concepts (such as Okay, 2008; Şengör & Yılmaz, 1981), which are of the mechanism that lightly referred herein to make an emphasis on the importance of the researches conducted on the areas that form karstic landscapes of Turkey. Examination of these areas situated in the Alpine–Himalayan Orogenic Belt plays a key role in shedding a light on the tectonic evolution of this huge area that elongates from Europe to Asia, besides the tectonic evolution of Turkey.

From north to south, the karstic topography in Turkey harbors many villages, towns, and city centers, which is another factor that increases the importance of karstic research. There are many highland villages found at up to 1500 m of altitude on the Taurus Mountains that elongates along the shore of the Mediterranean in the south of Turkey and on the mountains that elongate on the shores of the Black Sea in the north. Moreover, the most important touristic cities and ports of Turkey are located on Mediterranean shores on the south of the Taurus Mountains from east to west. Similarly, there are many villages and cities on the Obruk Plateau (the Konya Closed Basin (KCB), Central Anatolia), which is another important karstic area. All these circumstances compel to elucidate the surface and subsurface geomorphology of the karst within these regions and the factors that formed the features of it, to maintain the durability of these settlements. The extent and intensity of

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karstification in Turkey are driven by a hierarchy of influences with a differentiating order in each region, such as climate parameters (the type and amount of precipitation, temperature, etc.), the spatial pattern of the features of tectonism and the stratigraphic/lithologic features of the rock, and hence, the features of the landscape dramatically change within short distances. Through regions, the unique complex reliefs as combinations of badlands, deep valleys, and the other karstic surface features in addition to large cavities and underground water systems emerge engineering problems during the stages of urban planning with all the services including road and freshwater system construction as well as wastewater treatment. The situation requires the technical examinations of karstic areas such as the evaluation of soil and bedrock stability, as well as the permeability, solubility, and aquifer yield assessments. In this sense, beyond searching for answers to questions of science that scale in billions of years, karstic researches have critical importance on the determination of short- and long-term governmental policies of urbanization.

The most well-known karstic formations and caves exert a great impact on the development of landscapes as underground drains. Harboring over 2000 known caves, Turkey is thought to have over 20,000 caves dispersed in karstic areas. For this reason, there are many studies conducted on karst hydrology, geology, and geomorphology in Turkey; qualities of these areas are studied with frequent and detailed geochemistry and geophysics studies, and there is an increase in the numbers of cave studies in recent years (Günay, Güner, & Törk, 2015). Caves have been investigated in the context of geomorphological setting, lithology and geologic structure, groundwater chemistry and hydrology, aquifer type as well as regional tectonics, climate research, biology, microbiology, and in-cave environmental conditions. The historical background of the particular research for each selected caves from Turkey is given in Chap. 5 of this book. As comprehensively treated in Chap. 2, the state of the art in cave archaeology was excluded from the contents of this chapter. Additionally, as it is given in Chap. 2, the concepts and region-specific processes related to geology, hydrology, and geomorphology of Turkey were not explained in this chapter.

3.2 The Research with Perspectives of Cave Geomorphology, Geology, and Hydrology

The oldest study that examines a cave with referring to its structural features, also the first known publication about cave research in Turkey, is Abdullah Bey's study conducted in Yarım Burgaz Cave in 1969 (see Chap. 2). Since then, there have been many studies on geological, geomorphological, geochemical, and hydrogeological properties of cave environments along with the effects of surface processes on cave morphology in the course of 50 years (Bekdemir, Sever, Uzun, & Elmacı, 2004; Kopar, 2009; Semenderoğlu, 2013; Semenderoğlu & Aytaç, 2013; Uzun, Zeybek, Yılmaz, & Bahadır, 2015). The impact of surface processes over cave structure was represented by an exemplary study in Central Taurus (Mediterranean Turkey). The observations of the study approached unroofing mechanism that transforms cave morphology in the context of exposure of vertical caves by cliffs, which is a rarely reported phenomenon in high mountains, as a result of the destruction of karst by glacial erosion in Aladaglar Massive (A. Klimchouk, Bayari, Nazik, & Törk, 2006). Important observations on regional hydrogeology and geomorphology as well as the evolution of Aladaglar Karst were reported, and the second deepest cave of Turkey in the date (Kuzgun Cave: 2080 m) was found within this study (Klimchouk, Nazik, Bayari, Törk, & Kasjan, n.d.).

Obruks of the Konya Closed Basin (KCB) (Central Anatolia), which are the particular type of dolines named after these examples in the international terminology, were studied to understand the structure and formation mechanisms (Bayarı, Pekkan, & Özyurt, 2009; Günay, Çörekçioğlu, Eroskay, & Övül, 2010). When the data gathered from hydrogeochemical analyses (depending on dissolution capacity of deep-seated waters) was interpreted considering the geology and hydrology of the area, it was concluded that the obruks found in the basin were formed by hypogenic mechanism (Bayarı et al., 2009; Özyurt & Bayarı, 2014). Moreover, the spatiotemporal distribution and the susceptibility of obruks within this plateau were evaluated by utilizing geographical information systems and geophysical methods (Özdemir, 2015, 2016). Collapse resistances and collapse conditions were focused on in the study conducted on obruks found in Sivas (Karacan & Yılmaz, 1997). Studies on the relation between caves and their connected aquifers are not limited to obruks only. The study that sheds light on hydrologic relation between İnsuyu Cave (Burdur, Turkey) and Çine Ovası Aquifer examined the change on the underground water table occurred due to the imbalance between recharge and discharge rates of the aquifer caused by the excessive pumping required to cover for increasing agricultural needs appeared because of the climate change. The effect of the semiarid climate effective in the region since 1986 on the underground water table is calculated through data gathered from VSR and direct measurements from wells, and the results could clearly be observed from the data gathered from these studies which are also important for shedding light on the mechanisms forming the unique pattern of the cave. In the cave that shows a complex structure as it is a combination of a network maze and big collapse galleries, these two morphologies are observed in two sections that cross from one to the other suddenly at a point close to the center of the cave (Taşdelen, 2018). It is a very rare condition for these two structures to be seen together. Detailed information gathered from the research focused on geomorphological structure of the some other caves mentioned in the context of this book and the related bibliography is given in Chap. 5.

Compared to terrestrial caves, geology and hydrology studies conducted in marine caves are limited in Turkey (Bayarı & Kurttaş, 2002; Bayarı, Özyurt, Hamarat, Bastanlar, & Varinlioglu, 2007; Coşkun, 1978; Elhatip & Günay, 1998; Elhatip, 2003; Hamarat, Ülkenli, Türe, & Bayarı, 1998). The most recent research was conducted by Bayarı and his team at the southwestern Mediterranean coast of Turkey (Bayarı et al., 2011). In this study, Patara–Kekova part of the coastal Western Taurus Region was examined in terms of freshwater discharges and waterfront-underwater caves. As an interdisciplinary approach, data related to geological, morphological, tectonic, and topographic features in addition to satellite imagery was used, reconnaissance diving to 0–30 m of depth was completed, in situ physical–chemical measurements were performed, chemical and isotopic compositions were determined through analysis in this study. As a result of the preliminary studies, it was determined that the examined area contained numerous freshwater discharges with the freshwater contribution up to 60% and 6 important anchialine underwater caves. Subsequently, Mivini and Altuğ Cave were profoundly studied to elucidate cave forming mechanisms and hydrodynamics of groundwater water discharge (Öztan et al., n.d., Özyurt, 2008). The study conducted in Gilindire Cave (İçel, Turkey), which is an important coastal cave and a tourist attraction, is also important for shedding light on the geomorphological evolution of the area (Nazik et al., 2001). The geomorphological pattern of the Gilindire Cave, which is situated in Cambrian aged dolomite and limestone lithology, reflects the forces that shaped the topography of the area on the south of the Mid-Taurus Karst Belt. The entrance of the cave found on the top part of a steep sea cliff is 46 m high from sea level, and the cave lies in three different sections developed in different periods with a total length of 555 m. These sections are comprised of the “entrance hall,” which is composed of narrow galleries and cascaded levels situated on the NNW–SSE direction fault line, the “dripstone hall,” which contains numerous speleothems composed of a kind of mineral sediment, and the “lake hall,” the youngest section with dimensions of 140 m × 18–30 m. In this state, the general elongation of the cave is observed to have been affected by the structure of the unit it is found within, which is fractured by faults and shows tectonic dissections, the development of fracture systems, the layer directions and descents of the rocks, the climate, and the Pleistocene sea-level oscillations (Özşahin & Kaymaz, 2014).

In addition to provide critical information about the lithology and stratigraphy of the units, the tectonic evolution, hydrology and aquifer structures of the areas in which they situated, caves are raised the interests with high tourism potential. Caves, encountered in many cultures as shelters, sanctuaries, or burial places since the prehistoric period, also attract tourists’ attention as historical remarks, geoheritage or thermal baths since the era of King Tiglath Pileser in 1100 BC (Cigna & Forti, 2013). By hundreds of examples around the World, touristic caves should meet a suit of condition including logistic convenience and structural stability. In this sense, studies are conducted to evaluate the stability of caves in Turkey as well. For example, Gilindire Cave was evaluated as a unique geoheritage with refers to its tourism potential with numerous cave features decorating the passageways (Özşahin & Kaymaz, 2014). In the Gökgöl Cave (Zonguldak, Turkey) and the Yazkonağı Cave (Ordu, Turkey) located in Black Sea Region, the lithology and tectonic structure with the fault-fracture system of the unit in which the cave developed were investigated to asses the stability of zones (Ersoy, Kirmaci, & Firat Ersoy, 2006; Geniş & Çolak, 2015). The Gökgöl Cave, in spite of receiving over 300,000 visitors since 2001, was reported with certain stability problems while the units cave developed within were in good quality, as a result of the examinations of geomechanical and physical properties of the cave and the numerical analysis (Geniş & Çolak, 2015). The radon level was also measured in the Gökgöl Cave in context of public health (Aytekin et al., 2006), due to being likely to be detected with high quantities in geologic formations such as caves, accumulate in closed environments and may cause lung cancer if it reaches critical values. For this reason, as in other countries (Solomon, Langroo, Lyons, & James, 1997; Szerbin, 1996), radon measurements in touristic caves are applied in Turkey. Radon measurements were also conducted in Karaca Cave in Gümüşhane, Çal Cave in Trabzon (Çevik et al., 2010), Tınaztepe Cave in Antalya (Çömlek, 2010) and Bulak Cave in Karabük (Haner, Yılmaz, Kürkçüoğlu, & Karadem, 2010). In another study conducted in the Bulak Cave, which is a 6 km long cave rich with speleothems and has a high potential for tourism (Y. Özdemir, 2005), the quality of air was also evaluated (Çetin, Sevik, & Saat, 2017).

3.3 The Research with Perspective of Speleothem Geochemistry

Cave sediments known as speleothems may be the top most attractive features of caves for the visitors. Speleothems in karstic caves are usually formed by the precipitation of calcium carbonates ($CaCO_3$). Meteoric water with dissolved CO_2 gas of the atmosphere is received by a basin as precipitation. While percolating through the soil zone, the waters absorb more CO_2 that is produced by the degradation of organic matters and a weak acid called carbonic acid (H_2CO_3) is formed. Carbonic acid causes dissolution of calcium carbonate ($CaCO_3$) rocks. The acidic surface waters become saturated with respect to calcium and enriched in carbonate (CO_{3-}) while leaking through the fissures of bedrock ($CaCO_3$). When seepage water (H_2O–CO_2–$CaCO_3$) saturated with calcite reaches the cold cave interior with less CO_2 partial pressure, CO_2 within dripping water releases into the cave atmosphere through degassing. At the same time, the water becomes supersaturated in bicarbonate (HCO_{3-}) and carbonate (Ca^{2+}) and calcium carbonate (CaCO3) is deposited by trapping the other free ions within the water that creates numerous subtypes in various colors and shapes (Ford & Williams, 2007) (Fig. 3.1). Speleothems may contain or be comprised of minerals including carbonates, silicates, nitrates, oxides and a variety of the other iron, magnesium, manganese and sulfur compounds (Hill & Forti, 1995). Besides, speleothem formation is also possible with ascending underground water by a similar mechanism in case of stability in high water level for a long time (e.g. anhydrite deposits, Dogtooth spar) or rapid evaporation (Fig. 3.1). Furthermore, the recent studies that reported microorganisms altering the rock geochemistry within cave environments brought a new aspect to the speleothem forming mechanism. The absence of solar radiation and primary production by photosynthesis within caves leads to alternative methods for organic carbon assimilation by the metabolic reactions referred to as chemosynthesis. Over years, the mounting evidence highlights the significance of chemosynthetic metabolism in bedrock dissolution/mineral precipitation processes within the context of microbe–mineral interactions (Barton & Northup, 2007; Carmichael, Carmichael, Santelli, Strom, & Bräuer, 2013; Engel et al., 2010; Legatzki et al., 2012). Mineralization mechanisms of speleothems are investigated by examination of speleothem morphology through visualization methods (e.g. SEM) as well as by detection of elements or markers that point out to factors, which may have a role in mineral precipitation, through geochemical and microbiological analyses (e.g. cultivation, isotopic measurement). Geochemical examination of a water sample gathered from the outermost layer of an active stalactite that continues its formation process, as in the study conducted in Küpeli Cave (Erdemli, Mersin, Turkey), represents an example for these methods.

Due to its formation mechanism, speleothem chemistry and structure is affected by (1) the source of the meteoric water involving the sediment precipitation as well as the topographic features and climate systems that the water encounters through its route until the cave area, (2) chemical properties and biological activities of the soil zone the water infiltrated through, (3) structural properties, lithology and geochemical characteristics of the bedrock (4) microclimatic properties of the cave ecosystem and (5) ongoing microbial activity in cave habitats (Fig. 3.1). Each of these elements leaves a chemical or physical fingerprint unique to itself. Being mostly isolated from the impact of short-term surface processes, speleothems with fingerprints like these may provide long-term data on surface and in-cave environmental conditions with good precision. Through the examination of cave sediments, studies that shed light on the past of micro and macro scale atmospheric events, climate trends, earthquakes and volcanic events in the nearby areas increase in number around the globe, while studies in this context are also conducted in Turkey (Baykara, 2014; Emery-Barbier & Thiébault, 2005; Göktürk et al., 2011; Rowe et al., 2012, 2020; Ünal-İmer, Shulmeister, Zhao, Uysal, & Feng, 2016).

Paleoclimate studies conducted with speleothems are highly popular globally, due to their quality of being high definition and well-protected long-term proxies (Baldini, Mcdermott, Hoffmann, Richards, & Clipson, 2008; Jones, Roberts, Leng, & Türkeş, 2006; Yang, Johnson, Griffiths, & Yoshimura, 2016). Many studies have been made on this subject also in Turkey, which has a complex climate regime developed under both global atmospheric teleconnections and regional topography. Turkey's climate regime, determined by air masses encountering atmospheric patterns. Turkey's climate, in general, is under the influence of the polar air mass during winter and the tropical air mass during the summer. Located in the Eastern Mediterranean Region, Turkey is affected by three major patterns of atmospheric teleconnections due to its geographical location. The first one is the North Atlantic Oscillation, which has an impact on winter. The North Atlantic Oscillation (NAS) is a large-scale meridional atmospheric circulation occurring under the influence of the climate system created by Icelandic Subpolar Low-Pressure Centre and the Azores Islands Subtropical High-Pressure Centre. The North Atlantic Oscillation, which affects the strength of the Western Atlantic Winds coming from the Mediterranean, increases the intensity of the Western winds in the negative phase and causes more humid and hot conditions in the Eastern Mediterranean (Göktürk, 2011). The North Sea-Caspian Pattern (NSCP), also taking effect in the winter period and generating from two constant pressure areas one of which is located in the North Sea and the other in the North of Caspian, is the second active climate component in Turkey. While this atmospheric connection pattern is in a positive phase—with the effect of Northern winds passing through Turkey—cold and dry weather conditions are observed (Göktürk, 2005). The last one is the influence of the monsoon (HM) originating in India. The summer climate regime in Turkey will be drier with the effect of India originating monsoon, which is an important part of the summer atmospheric circulation in the Northern Hemisphere.

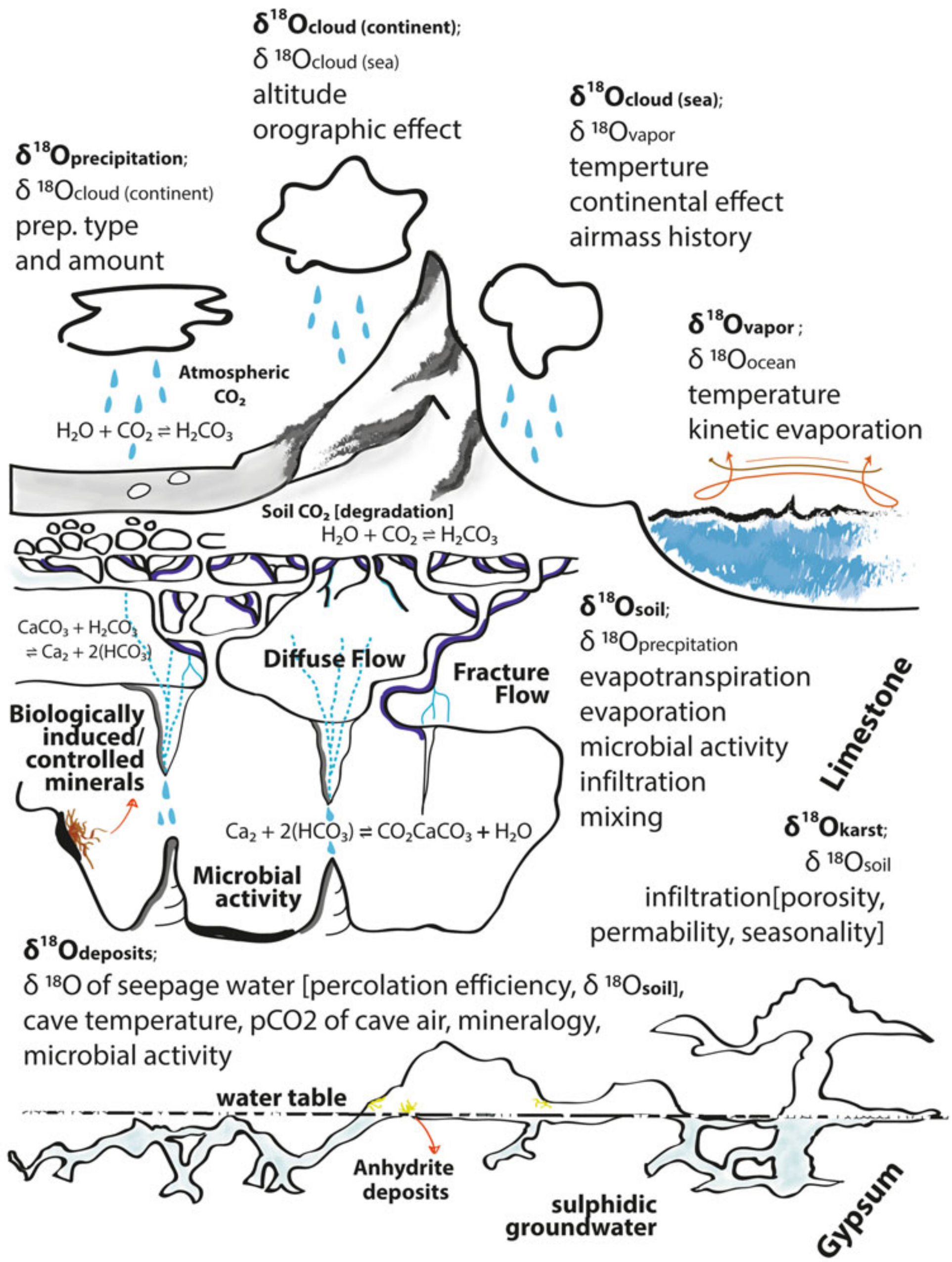

Fig. 3.1 Conceptual diagram of the atmosphere–surface–subsurface interactions and impacts within the perspective of cave environments. As an example of how landforms and landscape affect drip water and cave deposit geochemistry, the factors in the isotope fractionation of oxygen through the path from source to cave are described, herein. The mechanism of speleothem formation by meteoric water is given by the steps: (1) CO_2 adsorption from atmosphere and soil, (2) dissolution of limestone and enrichment of seepage water with Ca^{2+}, (3) cooling of seepage water, CO_2 degassing, and precipitation of $CaCO_3$ due to being water supersaturated. Two ways of water percolation through the rock are given as diffuse flow (generally in case of high permeability, more resistance to dissolution) and fracture flow. The other mechanisms of deposition are represented as biologically induced mineralization by microbial activity and mineral formation by acidic groundwater activity. Anhydrite deposits ($CaSO_4$) (illustrated with yellow sign, herein) are common features of hypogenic caves

Other than the aforementioned atmospheric teleconnection patterns and the motion of air masses, large mountain ranges and seas surrounding the three sides of the country affecting the climate conditions at an important scale, produced a complex climate regime that differentiates in each region (Fig. 3.2). The impact of the local elements on the active climate regime within the regions given; the north of the North Anatolian Mountain Belt, the southern part of the Taurus Mountain Belt and Central Anatolia, can be observed in speleothem records (Göktürk, 2011). For example, The North Anatolian Mountain belt forms as a natural barrier between the coastal Black Sea Region and the Central

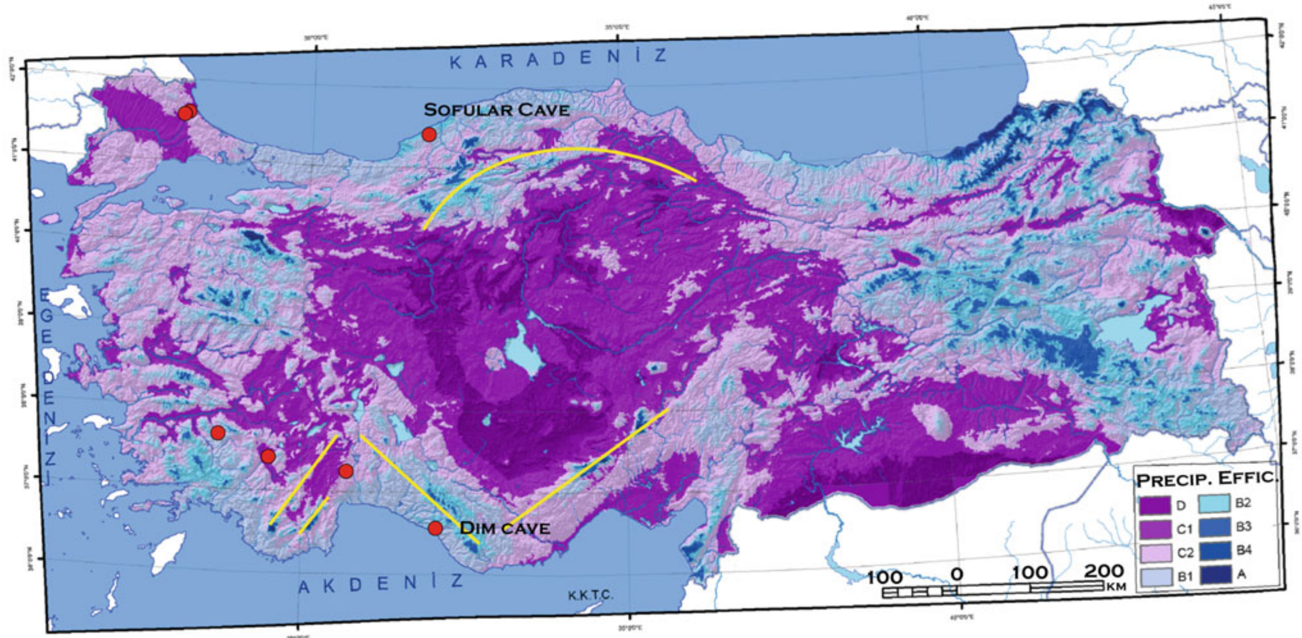

Fig. 3.2 Map of Turkey with the locations of the caves that investigated during the given paleoclimate researches: Göktürk (2011); Baykara (2014) and Ünal-İmer (2016). The relief basemap with the locations marked with red dots was prepared by E. Tok with QGIS v.3.12.0 software set the reference coordinate system to wgs84/UTM zone 36. The illustration that represents the precipitation efficiency zones of Turkey was modified from Yılmaz and Çiçek (2016). The colors are indicating the different rates of precipitation efficiency that are defined by Thornthwaite method. A: Perhumid; B1, B2, B3, B4: humid; C1: dry subhumid; C2: moist subhumid; D: semiarid. The yellow lines are indicating the mountain ranges; the Black Sea Mountains in the north and the Taurus Mountains in the south

Anatolia during the invasion of warm and humid maritime air that was initially a dry and cool continental air mass coming from the North that humidified while passing over the Black Sea. The moisture content releases as intense rainfall on the coastal slope of the North Anatolian Mountains while the air mass reaches the interior part of Anatolia as dry and warm.

This has led to discrepancies between the climate records from Turkey's Black Sea coasts and other regions on the impact of North Atlantic Oscillation over these areas. In the study conducted in Sofular Cave situated in this region, the δ^{18}O isotope composition attained from the stalagmite samples revealed the distinct nautical effect of the Black Sea on the local climate regime. It was seen that the δ^{18}O isotope composition attained from the stalagmite samples gathered from the cave was consistent with the data gathered from previous studies conducted in the Black Sea Region but, it didn't show any meaningful correlation with the general isotope profile that represents the North Atlantic Oscillation. As a result of comparison between similar studies conducted on cave sediments found in the East Mediterranean, records parallel to climatic processes effective on large areas were observed and it was remarked that the records were regional in fast climatic events due to the Black Sea's nautical effect. Furthermore, while the stable isotope δ^{13}C analysis and the radiochronologic dating methods point to the photosynthetic activity and the flora with dense δ^{13}C isotope values, which belongs to Early Holocene Period and was gathered from the examined stalagmites, in studies conducted in other regions, it was remarked that this distinct increase in flora started at a later period (Göktürk et al., 2011). Again, speleothems gathered from the Sofular Cave have been examined through synchrotron-radiation-based trace element analysis and the Minoan volcanic eruption's effect on the region, which had occurred between 1600 and 1650 BC, was researched (Badertscher et al., 2014). Furthermore, these stalagmites were examined to shed light on the timing and effect of Dansgaard–Oeschger events in Turkey (Fleitmann et al., 2009). Through the increasing number of speleothem researches, and thus the understanding of regional parameters that cause differences over proxies, these sediments that bear the qualities of well preserved, long-term climate archives would play a huge role in revealing Anatolia's detailed climate history.

Another component of orographic and continental effect that exerts a great importance on regional climate differentiation in Turkey is the Taurus Mountains (Fig. 3.2). Strong convectional rains are seen frequently in the region that generally has a mild and humid climate. The low value of the δ^{13}C isotope rate is accepted as the indicator in climate records for mild and humid climate regime that causes kinetic fractionation in countenance for light isotope through the enrichment of surface fauna and the increase in photosynthetic activity that comes with it. The results of the study conducted in Kocain Cave (Antalya, Turkey) point out to higher $\delta^{13}C$ isotope amount than expected in this region where C3-type vegetation and Mediterranean climate is dominant. The reason for this is shown to be low vegetation cover and ineffective infiltration, in the study conducted in Sofular Cave and the study conducted as a part of Göktürk's Ph.D. thesis presented in 2011 (Göktürk, 2011). The atmospheric teleconnection patterns, which were active during Holocene and the effect of local variables in the climatic conditions of the Eastern Mediterranean, were investigated. Efforts were made to interpret the regional effects of paleoclimatic processes in Turkey from speleothem records and to support the examinations being conducted in Uzuntarla and Yenesu Cave found in Thrace, Ovacık Cave found in Black Sea Region, Sofular Cave and Kocain Cave (Göktürk, 2011). In the research presented by Wickens as a Ph.D. thesis study in 2013, the reason for the geochronologic deviation seen on the stalagmite sample gathered from the study conducted in Dim Cave (Antalya, Turkey) found South of the Taurus Mountains is shown to be the local high rainfall that led to flushing events and recrystallization (Wickens, 2013). Within this study, the changes in the climate trend during the Permian Period (5 AD) were observed clearly. Another study conducted in Dim Cave presented the climate changes in the region of the last 80,000 years with high definition oxygen isotope data (Ünal-İmer et al., 2015, 2016). This study that traces the signs of the events included by eastern Mediterranean's climate history in this region, revealed that the fluctuations in $\delta^{18}O$ of speleothem record represent a correlation with that of the oceanic moisture source driven by latitudinal shifts in the westerlies. Within the Ph.D. thesis of Baykara in 2014, stalagmites gathered from Sırtlanini, Keloğlan and Dim Cave were aged by the U-Th method and formation processes of those were examined. In this study, the Permian Period and Holocene paleoclimate conditions were tried to be shed light on by the proxies of the stable isotopes (^{18}O and ^{13}C) (Baykara, 2014).

Earthquakes that made an effect in the region throughout history, are another ground system process that stalagmites show long-term record qualities over. Earthquakes may cause deviations on stalagmites growth axis by changing the dripping point of the dripping water that causes calcite accumulation during the stalagmite formation or by directly causing cracks and fractures on stalagmites. Chronologically compatible and angularly similar deviations detected on stalagmite samples gathered from the same cave or areas close by can point out to a past earthquake that affected the area when interpreted together with data like lamination thickness and color. As it has been hosting communities that shaped civilization throughout archaeological periods, shedding light on tectonic events occurred in Anatolia, bears great importance for the history of lands extending from Europe to Asia. Traces of three big earthquakes that occurred in the Mediterranean between 110 and 360 AD were detected on a stalagmite sample gathered from Kepez Cave (Mersin) (Akgöz & Eren, 2015). Bayarı and Özyurt (2005) point out that those stalagmite growth axis changes that depend on the changes of the primary stalagmite position with time are caused by tectonic raise or subsidence of the region. In this sense, speleothems provide opportunities to shed light on the history of tectonic processes through systematic studies conducted on regions related to specific tectonic systems.

One of the most important analyses applied in these aforementioned researches is dating. Chemical and biologic data gathered from various levels of the sediments are placed in an order and a timeframe so that the data pointing out to natural processes occurred on earth's crust and the atmosphere can be interpreted in historical context. In this sense, studies examining various methods used in the dating of cave sediments were also conducted. The study Engin and his team (2010) conducted in Keloğlan Cave (Acıpayam, Denizli, the southwestern part of Turkey) researched the usability of the ESR dating method.

3.4 The Research with Perspective of Cave Microbiology

Even though usually the $\delta^{18}O$ and $\delta^{13}C$ isotopes and trace elements are examined in paleoclimate studies, microorganisms protected in cave sediments also function as biomarkers for climatic conditions (Epure, 2015). Microclimatic conditions (which may be affected by long-term atmospheric conditions), along with composition and concentration of elements/nutrients available for microbes in cave environments, supports some particular niches and leads to a differentiation in the abundance and composition of the microbial communities (Schabereiter-Gurtner et al., 2004; Engel and Northup, 2008). Studies exhibits that cave conditions not suitable for photosynthetic life support surprisingly splendid chemosynthetic microflora (Tomczyk-Zak & Zielenkiewicz, 2016). Mineralization, during the formation of speleothems like stalactites, stalagmites and other cave sediments, can occur inorganically or biologically induced/controlled with the presence of the certain chemosynthetic microorganisms. Even if the early studies attributed the microbial life in cave environments only to heterotrophic consumption of organic carbon transported into caves from surface, surrounding rock or overlaying soil zone (Engel, Porter, Stern, Quinlan, & Bennett, 2004), the recent studies prove that the ecological function of microbial communities introduce diversity far more than that (Northup & Lavoie, 2001; Barton & Northup, 2007). Bacterial cave microflora is commonly composed of sulfur-oxidizing, iron-oxidizing, hydrogen-oxidizing taxa and taxa that play a part in the nitrite–nitrate cycle (Engel, 2015). Well-known with high adaptation capability, the classes Alphaproteobacteria, Gammaproteobacteria, Betaproteobacteria, Deltaproteobacteria and the groups Acidobacteria, Nitrospirae, Actinobacteria are the most encountered taxa in cave environments (Tomczyk-Zak & Zielenkiewicz, 2016). The major dominant group Actinobacteria is attributed to acicular aragonite/calcite crystals which develop on mats (Barton et al., 2004; Canaveras et al., 1999; Canaveras et al., 2001). It is known that some species belonging to Alphaproteobacteria class play a role in iron oxidation (*Hyphomicrobium* spp. *Pedomicrobium* spp. etc.), in nitrogen fixation (*Mesorhizobium* spp.), and in methane cycle (*Methylobacteria* sp.) (Barton et al., 2004; Carmichael et al., 2013). Some members of this class (Spingomonas) exerts an important role in biomineralization processes through the production of Extracellular Polymeric Substance (EPS) by metabolizing various aromatic compounds in caves (Canaveras et al., 1999; Canaveras et al., 2001; Northup & Lavoie, 2001). Betaproteobacteria class is represented by species that oxidize sulfur (*Thiobacillus* spp., *Thiobacter* spp.), nitrogen (*Nitrosomonas europaea*, *Nitrosomonas oligotropha*) and nitrate (Nitrotoga arctica) as well as methylotrophic (*Methylotenera* spp., *Methylophilus* spp., *Methylovorus* spp.) and denitrifying (*Denitratisoma* spp.) (Tomczyk-Zak & Zielenkiewicz, 2016). Besides the members of Gammaproteobacteria that oxidize sulfur are frequently reported in cave environments rich in oxygen and sulfur, some of the taxa (Pseudomonas spp.) are linked to ferromanganese deposits (Carmichael et al., 2013). The level of $O_{2(g)}$ in cave air exercises a critical role over niche differentiation of the species with sulfur-oxidizing metabolism of the class Epsilonproteobacteria, where thrive in oxygen limited environments (Macalady et al., 2008). Thus, it may be assisted that there is a two-way microbe–mineral relation in cave environments.

The distribution and abundance of cave microorganisms in Turkey represents a similar composition with the karstic caves around the World (Atakav, 2017; Güleçal-Pektaş & Temel, 2017; Tok, 2017). One of the first research focused on cave microflora was investigated 19 karstic caves located in different regions of Turkey (Yamaç, Işik, & Şahin, 2011). In the extent of this study, the distribution of streptomyces genus in Actinobacteria phylum was examined in these caves. Some of these streptomyces isolates were selected to be evaluated in terms of their antimicrobial activities (Yücel & Yamaç, 2010). Tillo Busto (Spain) and Cervi Cave (Italy) are examples of caves with rich Actinobacteria population (Groth, Vettermann, Schuetze, Schumann, & Saiz-Jimenez, 1999; Laiz et al., 2000). In a study conducted to examine the microbial diversity in İnsuyu Cave (Burdur) (Figs. 3.3 and 3.4), the most common class was observed to be the Alphaproteobacteria (% 89.23 of the total bacteria) (Tok, 2017). This class was followed by Actinobacteria (%3.94), Bacilli (% 2.92), Gammaproteobacteria (%1.69) and Betaproteobacteria (%0.74). The detected fourteen genus were identified as Methylobacterium (%88.83), Propionibacterium (%3.58), Dolosigranulum (%1.69), streptococcus (%1.10) and Pseudomonas (%1.13). Furthermore, the morphologies of the samples and dispersion of the population in this study were compared to the results gathered from other studies conducted in foreign countries. In another study examining the cave bacteria flora in Gilindire Cave (Mersin), the distribution was identified as Actinobacteria (39%), Proteobacteria (%33), Firmicutes (17%) and Bacteroidetes (5.5%) in addition to uncultured organisms (5.5%) (Atakav, 2017).

Fig. 3.3 Photograph from İnsuyu Cave, representing a sampling location of the research by Tok (2017), taken by A. Yamaç

3.5 The Research with Perspective of Cave Fauna

Besides the microflora, macro-organisms like bats, fish, insects and spiders in cave environments were also examined by biological studies in Turkey. First known biospeleology research is widely attributed to Macarlı Miralay Dr. Abdullah

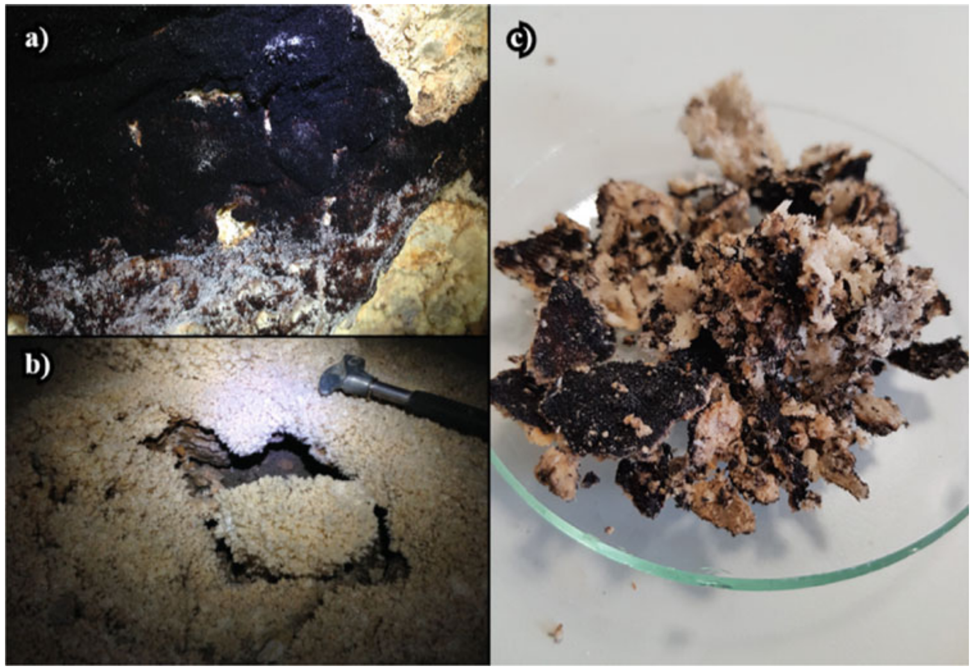

Fig. 3.4 Sediment photographs from İnsuyu Cave. **a** Black, velvet-textured deposit. **b** Acicular crystal deposit. **c** Preparation to laboratory analysis (Tok, 2017)

Bey with refer to his study in Yarımburgaz Cave (İstanbul, Turkey) in 1865 (Kunt, Yağmur, Durmuş, & Anlaş, 2010). On the other hand, the first study conducted with a systematic approach was conducted by the Spanish naturalist and insectologist Ignacio Bolivar on samples gathered by his colleague M. Martinez, who visit to Anatolia for his own studies. Among almost 100 different species of arthropods which were collected from the area that extends from İskenderun to Maraş and from the Taurus Mountains to the Binboğa Mountains, the species gathered from Yenicekale (Kahramanmaraş, Turkey) and Akbaş Caves (İskenderun, Turkey) are the very first macro-organisms sampled from

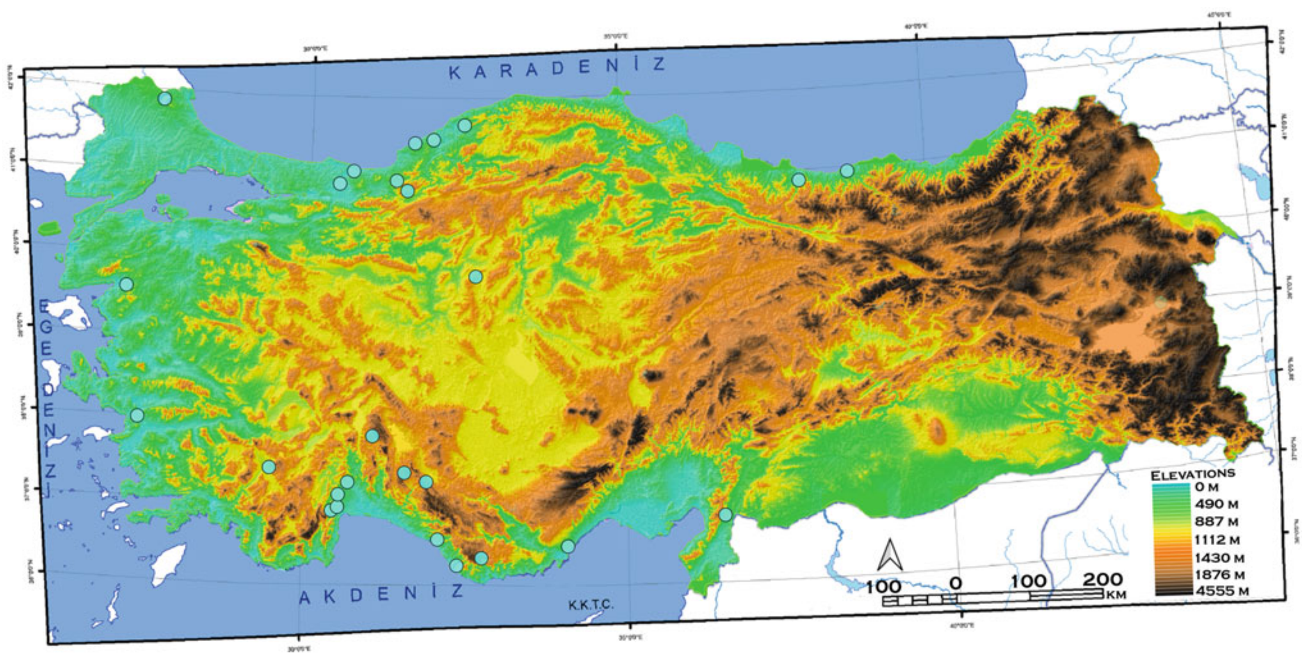

Fig. 3.5 Map of Turkey with the locations of the caves that investigated during the given arthropod researches: Di Russo, Rampini & Landeck (2007); Külköylüoğlu, Yavuzatmaca, Karacaoğlu & Telli (2014); Kunt, Özkütük, Elverici, Marusik, & Karakaş (2016); Ribera, Elverici, Kunt & Özkütük (2014); Taylan, Di Russo, Rampini, & Cobolli (2011); Taylan, Yılmazer & Şirin (2020). The relief basemap with the locations marked with blue dots was prepared by E. Tok with QGIS v.3.12.0 software set the reference coordinate system to wgs84/UTM zone 36. The colors are representing the elevations from sea level

cave environments in Anatolia. Primarily focused on cave crickets and arachnoids, there have been many arthropod studies conducted in various parts of Turkey since then (Taylan, Di Russo, Rampini, & Cobolli, 2011) (Fig. 3.5).

In one of these researches, the individuals identified as Discoptila beroni (Insecta: Ensifera: Gryllidae) were observed larger in body sizes within the Yalan Dünya Cave (Antalya, the southern of Turkey) than the ones detected in the nearby area (Köhler, Renker, & Luis, 2004). Among the two new species identified in another study conducted in Artvin (the Black Sea Region of northeast Turkey) in 2007, *Dolichopoda noctivaga* sp. n. was separated from the other individuals encountered in the area by the shape of its epiphallus, while the smaller body size compared to the ones nearby was the differentiating feature for *Troglophilus tatyanae* sp. n. (Di Russo, Rampini, & Landeck, 2007). A study on cave microclimate and distribution of cave cricket species was conducted by Taylan and his team (2020). In this study, three caves were selected from three different regions of Turkey; Geyikbayırı Cave (Antalya, the southern of Turkey), Sipahiler Cave (Bartın, the Black Sea Region of Turkey), Tuluntaş Cave (Ankara, central Turkey) were compared in terms of temperature, moisture and the climate regimes of the regions in which the caves are situated. The relationship between surface climate and microclimate was assessed and the impact of these environmental conditions on the distribution of cave crickets was interpreted. The annual mean temperature is the highest in Geyik Bayırı Cave, located in the Mediterranean region that is characterized by hot, moderately dry summers and mild to cool, wet winters; while it is the lowest at Sipahiler Cave located in the Black Sea Region with warm, wet summers and cool to cold, wet winters. Also, the relative humidity of cave zones in Geyikbayırı Cave is higher than that of its local climate regime. The region Tuluntaş Cave is located in, is described with continental climate regime with sharply contrasting seasons in temperature. The research assessed the cricket populations of these caves whether a correlation exists with these conditions while the other parameters are also taken into consideration such as vegetation cover and elevation (Taylan, Yılmazer, & Şirin, 2020). Aside from locusts, arachnoids (Kunt, Özkütük, Elverici, Marusik, & Karakaş, 2016; Ribera, Elverici, Kunt, & Özkütük, 2014) millipede (Antić, Çetin, Turantepe, & Gürbüz, 2016; Enghoff, 2006), amphipoda (Özbek, 2007, 2012a, 2012b; Özbek & Oktar Guloglu, 2005; Özbek, Yurga, & Külköylüoğlu, 2013; Özkan, 2009), fishes (Özdemir & Erkakan, 2014), ostracoda and planktons (Külköylüoğlu, Yavuzatmaca, Karacaoğlu, & Telli, 2014) were examined in various studies.

Bats composing of a large part of cave dwellers are studied all over the country (Fig. 3.6), with the records of *Barbastella barbastellus*, *Eptesicus serotinus*, *Hypsugo savii*, *M. bechsteinii*, *M. brandtii*, *M. daubentonii*, *M. nattereri*, *Miniopterus schreibersii*, Myotis blythii, *Myotis capaccinii*, *Myotis emarginatus*, *Myotis myotis*, *Myotis mystacinus*, *Nyctalus leisleri*, *Pipistrellus kuhlii*, *Pipistrellus pipistrellus*, *Plecotus austriacus*, *Plecotus auritus*, *R. meheyli*, *Rhinolophus euryale*, *Rhinolophus ferrumequinum*, *Rhinolophus hipposideros*, *Tadarida teniotis* (Albayrak, 2003 gathered from the studies: Albayrak, 1990; Aşan, Baydemir & Albayrak, 2006; Aşan & Albayrak, 2011; Benda & Horacek, 1998; Helversen, 1989; Steiner & Gaisler, 1994). One of the most extensive studies on cave-dwelling bats in Turkey was conducted by Furman and Özgül (2002, 2004) in Eastern Thrace in 1999–2000 and in Western Thrace in 2001. From eight underground sites in Eastern Thrace, 17,000 bat records representing eight species were covered, while there were approximately 76,000 bat records, representing 13 species from 32 underground sites covered from the western extension. Koyunbaba and Dupnisa Caves were reported to be the most important caves for bat dwelling, hibernaculum and nursery. The authors also raised their concern about the touristic activity that may harm the bat population in the Dupnisa Cave System (Kırklareli, the Thrace region of northwest Turkey).

Within this context, another study that investigated the seasonal population dynamics following the opening of Dupnisa Cave for tourism to understand the impact of visitors and show cave arrangements by a total of 53 surveys, reported no negative consequences observed (Paksuz & Özkan, 2012). The seasonal variations of bat fauna and the effect of microclimate on bat population were also studied in Dupnisa Cave System (Paksuz, Özkan, & Postawa, 2008). The study revealed that the different parts of the Dupnisa Cave System (Sulu Cave, Kuru Cave, Kız Cave) serve the purposes of dwelling, hibernaculum and nursery differently. While the particular temperature of each part was found to be in correlation with the species composition, no correlation with humidity was observed. The caves with bat populations in Northwest of Central Anatolia were investigated to survey the distribution of bat species and the characteristics of these caves (Barlas & Yamaç, 2016). In different studies conducted between 2016 and 2010 about bat diversity in Turkey, different protection unit approaches (evolutionarily important unit, protection management unit and population grouping analysis) were examined for the protection of genetic diversity of *Rhinolophus ferrumequinum*, *Miniopterus schreibersii* and *Myotis capaccinii* and cave based protection strategies were suggested as a result of analyses applied for the first time for species living in Turkey (Bilgin, 2012). Giant Wings of the Underground Project is an exemplary work among the studies that aim for the detection of bat groups, preparation of cave protection plans for the

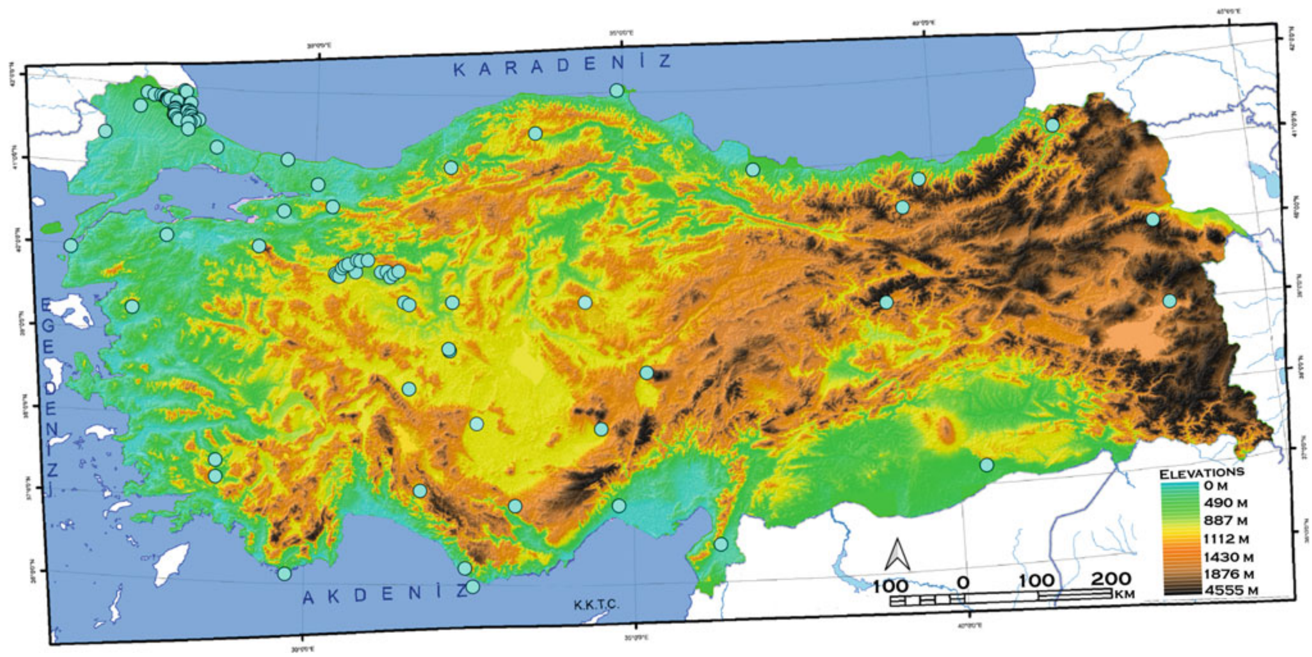

Fig. 3.6 Map of Turkey with the locations of the caves that investigated during the given cave-dwelling bat researches: Barlas and Yamaç (2016); Bilgin (2012); Furman and Özgül (2002). The relief basemap with the locations marked with blue dots was prepared by E. Tok with QGIS v.3.12.0 software set the reference coordinate system to wgs84/UTM zone 36. The colors are representing the elevations from sea level

protection of cave ecosystems and ensuring that protective legal precautions are taken. Studies are still being conducted to detect the population size and protection needs of the Egyptian fruit bat (*Rousettus aegyptiacus*), which can only be observed in Turkey in caves found in the East Mediterranean and the Mid-Mediterranean regions.

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