Geomorphological Landscapes in the Konya Plain and Surroundings

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17 Geomorphological Landscapes in the Konya Plain and Surroundings

Catherine Kuzucuoğlu

Abstract

Like other large plains of Central Anatolia, the Konya Plain is occupied by deposits and land features recording the past presence of a large lake. Sand beaches and bars, gravel sand lake and coastal fans, fringe the base of low cliffs developed in (i) Neogene lake limestone forming a wide plateau to the north (ca. 1050–1200 m a.s.l.), (ii) Quaternary volcanics in the centre and (iii) Palaeozoic limestone in the south and west. The plain is flat at ca. 980–1000 m a.s.l. and corresponds to the bottom clay of a 4200 km^2 large palaeolake. ^{14}C dating performed on *Dreissena* and mollusc shells collected in quarries exploiting the coastal sand and clay, and also in stream sections and in cores, date the lake to the coldest period of the Last Glacial, the LGM. Together with other formations (e.g. palaeosol, volcanics, alluvial fans), and geomorphological features (e.g. karstic, volcanic, tectonic), these deposits allow understanding today's landscapes, as well as to reconstruct past landscapes and climates, and their evolution during the late Pleistocene. Tectonically controlled (subsidence), the plain and surroundings are subject to karstic processes. Karstic features are mainly represented by sinkhole (called *obruk* in Turkish) concentrations in the Obruk Plateau that separates the Konya Plain from the Tuz Gölü Plain. Starting two decades ago in relation to groundwater overuse, the occurrence of new sinkholes, wider and deeper with time, is a matter of great concern in the agricultural areas where they occur, on roads and villages too. Other threats to the environment (e.g. biological diversity, wetlands, soil, water) are linked to resource overuse and sustainability in the context of drying trend since the 1990s.

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Keywords

Central Anatolia • Konya Plain • Karst • Late Pleistocene • Water management Palaeoenvironment • Volcanoes

17.1 The Geomorphological Records in the Konya Plain

The Konya Plain (Fig. 17.1a) is located in the innermost centre of the closed lake basin region in Central Anatolia. The plain opens within the Central Anatolian plateaus, which are here mainly formed by Neogene lacustrine sediments. It is both artificially (Beyşehir Lake) and naturally (Tuz Gölü) linked to its neighbouring basins (Fig. 17.1b). Residual hills and massifs are formed by Palaeozoic (e.g. metamorphosed carbonates, dolomites) or Mesozoic (e.g. ophiolites) substratum and, at places, by Quaternary volcanics.

17.1.1 Climate

The Konya Plain is located in the rain shadow of the Taurus range, where precipitation originating from the Mediterranean cyclonic circulation reaches 900–800 mm/yr. Its neighbouring basins closer to the range (Beyşehir) or higher in altitude (Cappadocian plateaus) receive 500–600 mm/yr of precipitation. With its low altitude and surrounding topographic obstacles, the Konya Plain is the driest region of Turkey. Rainfall varies between 280 mm/yr (Karapınar) and 320 mm/yr (Konya). The continentality of climate is also expressed by the annual variability of precipitation, both on inter-annual (max/min precipitation = 550–150 mm/yr) and multi-annual (30–34 yrs wet/dry cycles between 1925 and 1998) scales. High annual potential evapotranspiration of ca. 1200 mm/yr causes an important annual humidity deficit, which also causes high sensitivity of vegetation and soils to overuse. These climatic conditions favour extensive steppe

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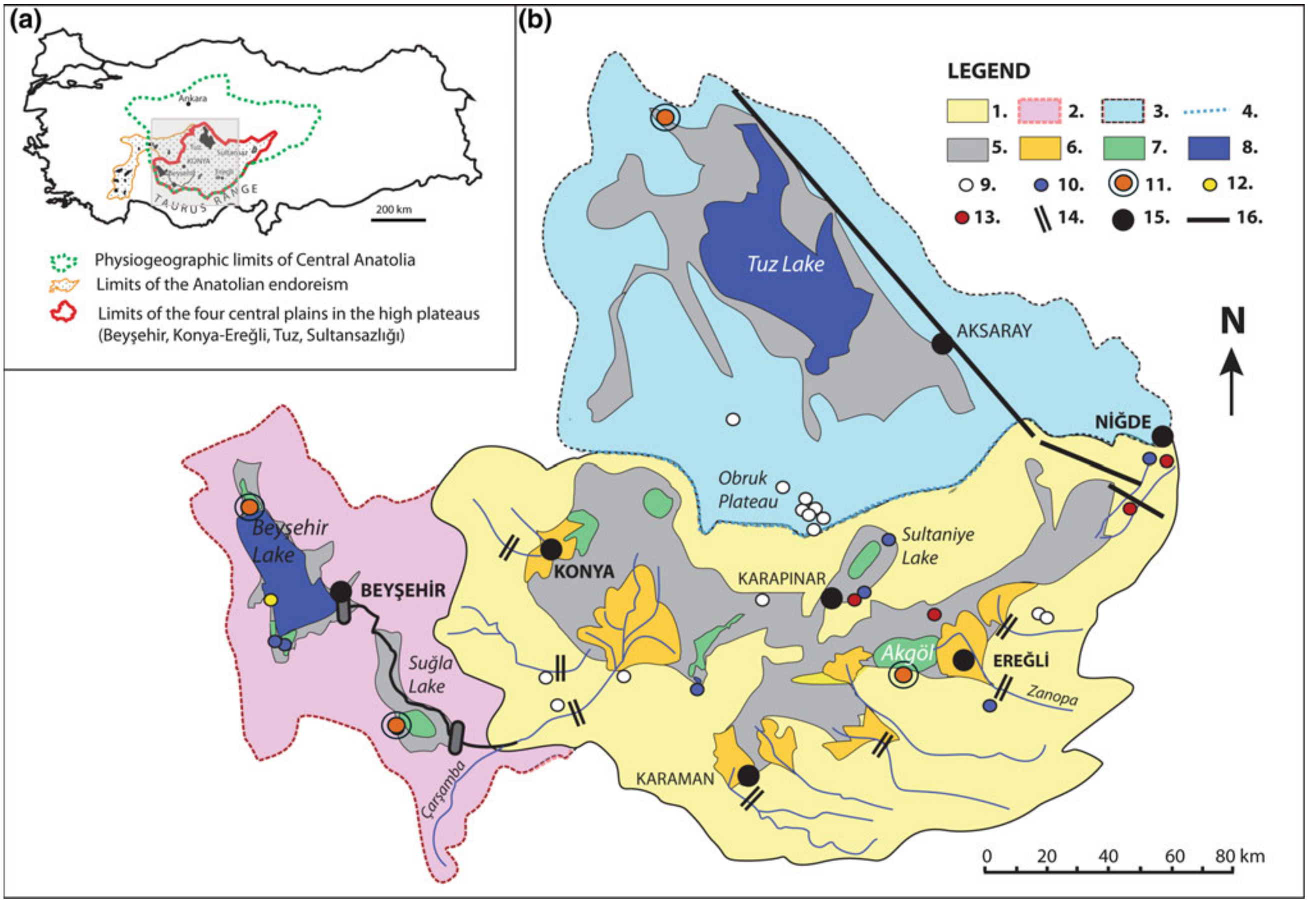


Fig. 17.1 Presentation of the Konya Plain: **a** The Konya Plain, at the heart of the Central Anatolian endorheism. **b** Closed basins connected to the Konya Basin. 1. Konya Plain Basin; 2. Beyşehir Lake Basin; 3. Tuz Gölü Basin; 4. Approximate limit between Konya Plain and Tuz Gölü basins (Obruk Plateau); 5. Late Quaternary lake sediments; 6. Holocene alluvial fans; 7. Wetlands; 8. Lake; 9. Sinkhole; 10. Karstic spring and emergence; 11. Swallow hole; 12. Estavelle (inversac); 13. CO_2 outflux in the Konya Plain; 14. Dam; 15. Town; 16. Tuz Gölü Fault. Modified from Kuzucuoğlu et al. (1998b), Kuzucuoğlu (2007), Gramond (2002), Boyer et al. (2006), Bayarı et al. (2009). *Note* The Beyşehir Basin impacts the surface run-off of the Konya Basin through its artificial connection with the Suğla Basin and the Çarşamba River gorge since 1908. The Tuz Gölü Basin is impacted by the underground water flowing from the Taurus range below the Geomorphological sketch of the Konya Plain, and its surface connections with the Beyşehir and Tuz Gölü closed basins

vegetation in the areas which are not watered by rivers or springs. Volcanic mountains of Karacadağ and Karadağ are covered with oak forests, which were still dense 80 years ago.

17.1.2 Land Use

Lake marls form wide areas of the Konya Plain. Poor for agricultural production, they are covered with an *Artemisia*-rich steppe in natural conditions. In the almost semi-arid context, the traditional land use of the Konya Plain involved the production of rain-fed crops of cereals, vegetables and pulses. This activity has long been accompanied by semi-nomadism devoted to sheep husbandry, whose seasonal rhythm was the foundation of lifestyle, economics, social structures and landscapes (Fig. 17.2b, d).

This system, based on the combination of rain-fed agriculture and short-range sheep husbandry for milk and meat products, disappeared after the mid-1990s because of the development of irrigated agriculture for the production of incentive-supported industrial crops.

17.1.3 Surface Hydrology

The southern part of the Konya Plain receives rivers fed by the northern heights of the Taurus range (e.g. mainly the Çarşamba River, and the Zanopa River in Ereğli) and by the highlands separating the Konya Plain from the Beyşehir Basin (Apa and May rivers) (Fig. 17.3). The Karacadağ volcano to the north provides running water to low local areas (e.g. Sultaniye). Elsewhere, the water divide is too close to the plain for providing any consistent run-off to the plain.

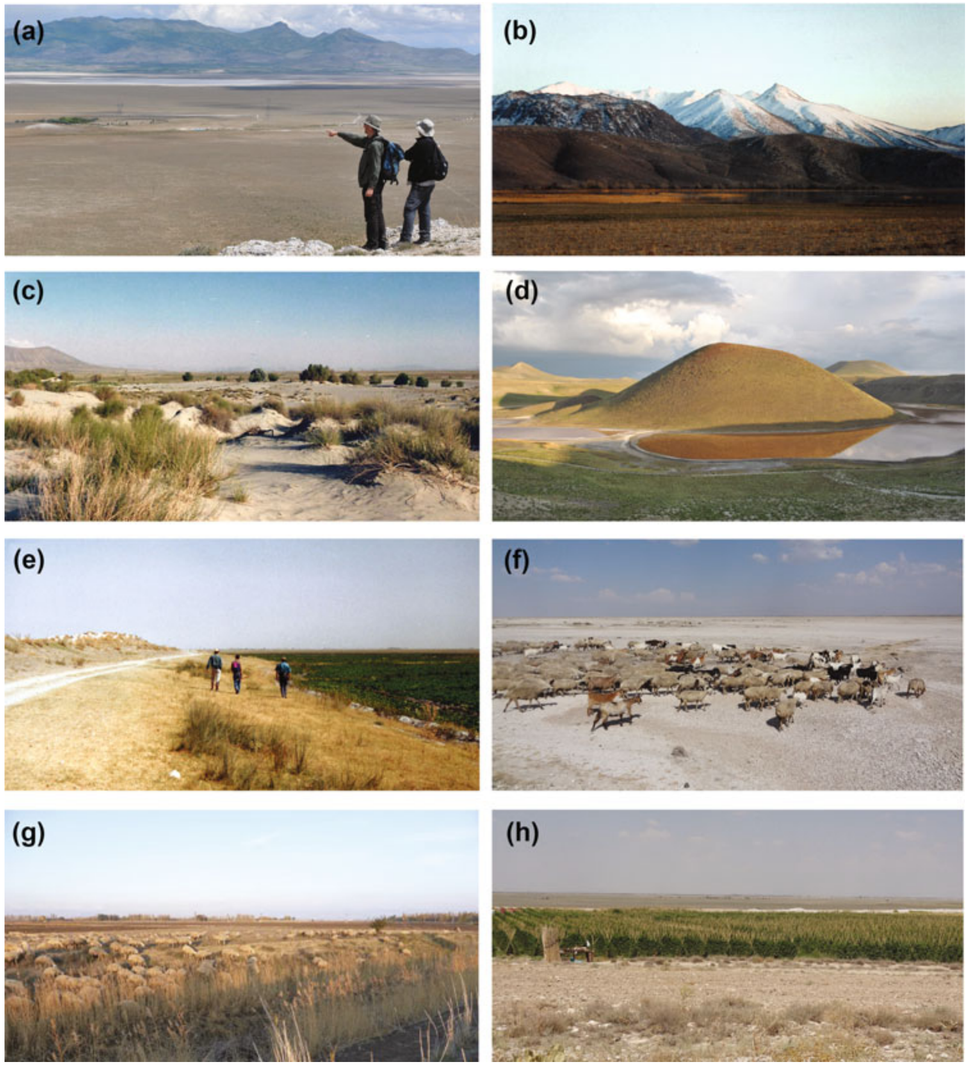


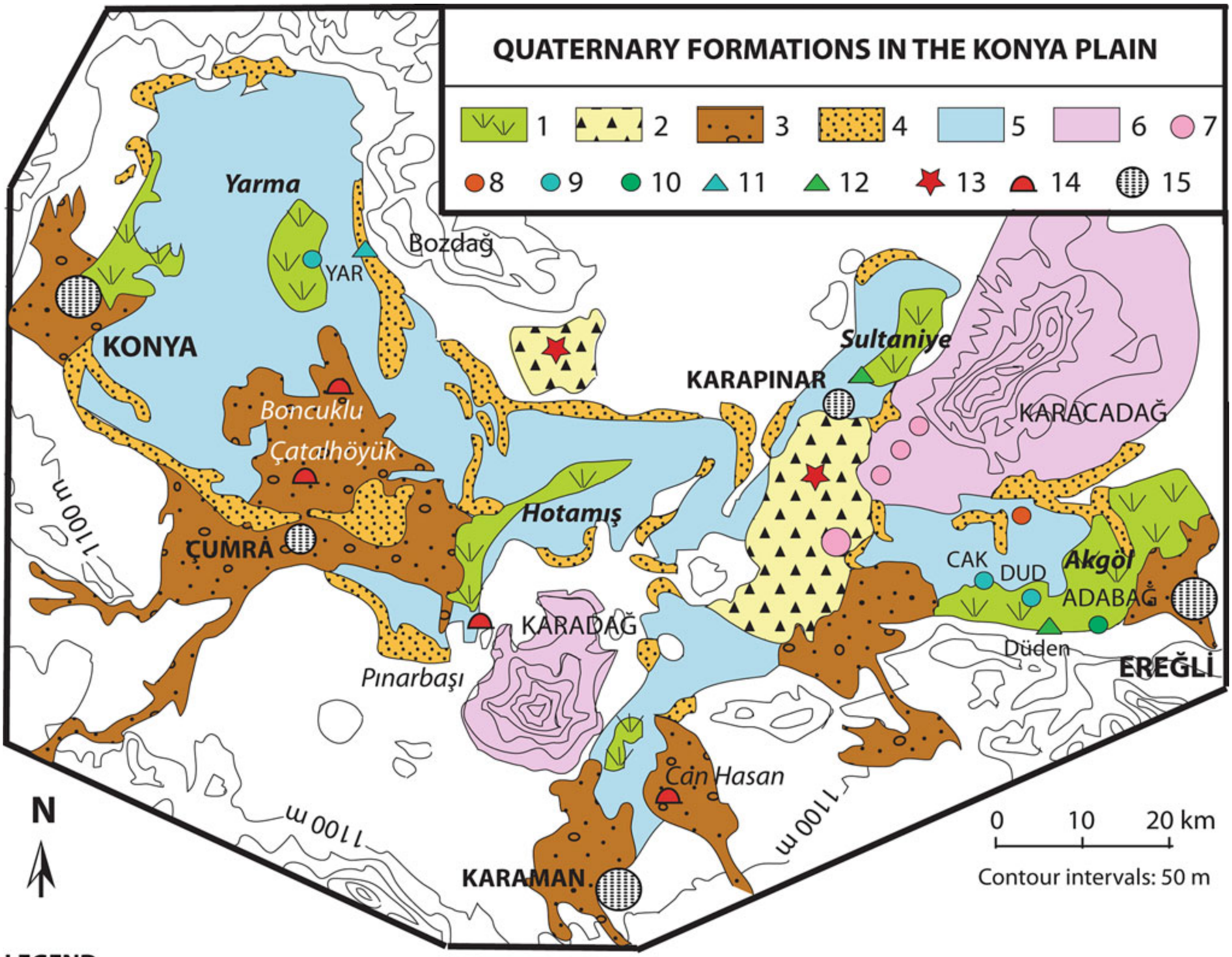
Fig. 17.2 Landscapes in the Konya Plain: **a** Sultaniye summer sebkha; in the background, the Karacadağ Volcano rises over the Konya plain to the north; **b** The Süleymanhacı Lake at the foot of the Karadağ composite volcano in the south of the plain; today, the lake is totally dry because of irrigation water withdrawals; **c** South of Karapinar town volcanics, a moving sand field is composed of several lines of barchan dunes as high as 12 m; **d** Meke Tuzlası Volcano: a Strombolian cone nested in an initial maar filled with a lake; the lake vanished at the end of the 2000's, in relation to steady drop of the underground water table; **e** LGM coastal sandy bars fringe the clay floor of the Palaeolake Konya. While sand quarries deplete heavily the past fans, coastal beaches and bars (left of the photograph), irrigation development transforms the lake floor landscapes into green grounds (right of the picture); **f** In the midst of summer, sheep flocks head in the afternoon toward pastures still covered with *Artemisia* steppe; **g** Wheat fields in August, pastured by sheep flocks after harvest; **h** Irrigated tree fields (mid-ground) over palaeolake floor, limited by sand coastal deposits landforms (foreground) fringing the palaeolake bottom (background). Photographs **a** and **d** by A. Ciner; Photographs (**b**, **c**, **e**–**h**) by C. Kuzucuoğlu

The sub-surface water flowing in the alluvial fans distributed along the plain edges used to generate a sub-surface fresh to brackish water at 4–5 m below the ground level. This flow was also feeding marshes and lakes in the lowest areas (Mera, Yarma, Hotamış, Akgöl, Sultaniye) (Figs. 17.1b and 17.3). After 1995, this resource disappeared rapidly because of dams retaining stream water (Fig. 17.1b) and of the climatic drying trend. This context contributed to the desiccation of springs (e.g. Pınarbaşı near Karaman), marshes (Yarma, Mera, Sultaniye) and lakes (Hotamış, Akgöl).

17.1.4 Groundwater

The Taurus recharges two aquifer systems in carbonate rocks, which flow north to the Tuz Gölü terminal salt lake (Fig. 17.4) (Bayarı et al. 2009). The aquifers flow beneath both the Konya Plain and the Obruk Plateau, which separates topographically the Konya Plain from the Tuz Gölü Plain.

The deepest aquifer is confined. Its saline water is of thermal origin. It emerges at travertine and thermal springs



LEGEND:

1. Wetlands; **2.** Dune fields; **3.** Alluvial fans and valley fills; **4.** Coastal ridges, fan deltas and beaches; **5.** Marl floor of the Upper Pleistocene Konya Palaeolake; **6.** Upper Pleistocene (and Holocene?) strombolian cones and basaltic maars; **7.** Quaternary volcanic massifs; **8.** thermal water-fed travertine; **9.** Deep cores in palaeolake deposits (presented in text); **10.** Core in Holocene deposits (Bottema *et al.*, 1984); **11.** Göçü LGM section; **12.** Late Glacial and Holocene sections; **13.** OSL dates in dunes; **14.** Excavated Pre-Pottery Neolithic and Neolithic sites; **15.** Town.

Fig. 17.3 Quaternary deposits of the Konya Plain. Modified from de Meester (1970), Roberts (1983) and Kuzucuoğlu et al. (1999)

in the Tuz Gölü Basin, and at Akkuyu in the northern part of the Ereğli sub-basin in the Konya Plain (Fig. 17.3). The shallow top aquifer is freshwater. Flowing through Neogene carbonate rocks (limestone, dolomite and gypsum), it is confined below the Konya Plain lake sediments and unconfined in the heights around (Fig. 17.4). Its geochemical characteristics are good indicators of the origin and direction of the flow, with total dissolved solids content increasing from the main recharge area (Taurus flanks) to the main discharge area (south of the Tuz Gölü Plain) (Bayarı et al. 2009). Meanwhile, the ^{14}C age of the water also increases from 0 to 40 ka along the same route. The water pumped today by thousands of deep wells in the Konya Plain is thus several thousand years old.

17.2 Volcanic Landscapes

Volcanoes of the Konya Plain form the SW extension of the Central Anatolian Volcanic Province, which contains also Cappadocia to the NE. In the plain, volcanoes are distributed along a SW–NE line joining the Karadağ to the Karacadağ, through the Karapınar volcanic field (Figs. 17.3 and 17.5).

Between Karaman and Çumra in the south of the Konya Plain, the Karadağ is a composite and solitary volcano covering a 220 km^2 area. It emitted calc-alkaline series products (basalt, andesite, dacite). In the volcano, domes and *domes-coulées* are accompanied by ash falls, pumice fall-outs, *nuées ardentes* and lava flows. At its top, a beautiful

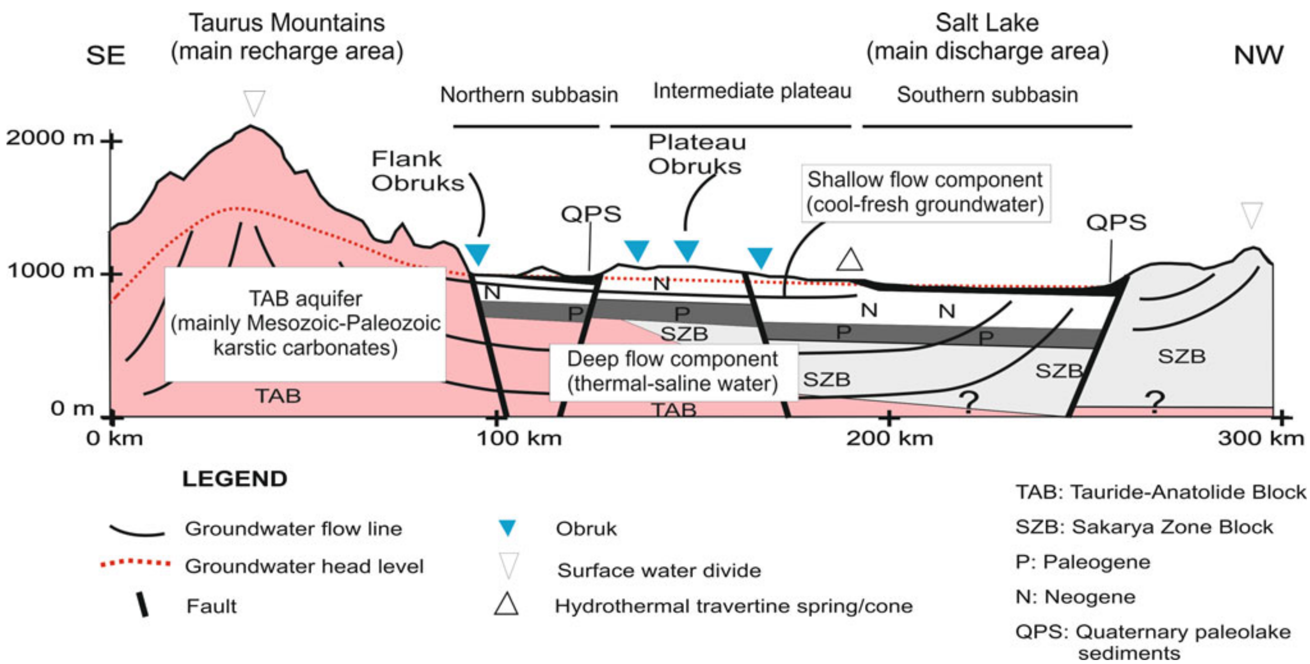


Fig. 17.4 Schematic representation of groundwater flow system in the Konya Closed Basin (Bayarı et al. 2009)

round, 200 m deep, crater is preserved. In spite of the survival of its original morphology, the crater is aged between 3.2–3.3 and 1.2–1.3 Ma (the youngest ages come from the crater rim) (Besang et al. 1977). According to Kasapoğlu et al. (1997), the volcano had four activity phases, the last one being represented by the formation of domes and deposition of *nuées ardentes*.

South of the town of Karapınar, a flat basaltic relief is composed of fractured lava flows. K-Ar dated 450 ka ago (Ercan et al. 1992), they form today a mesa partly destroyed by erosion and also partly covered by sand dunes (Erinç 1962) (Figs. 17.2f and 17.5).

On top of the mesa and distributed along a SW–NE line, several basaltic Strombolian volcanoes have grown over more or less hidden maars formed during the initial phase of the eruptions. Cones and maars are aligned towards the Karacadağ. The line possibly reflects an age order, from the oldest volcano in the SW (Büyük Meke) to the youngest (Acıgöl maar) in the NE (Fig. 17.3).

The *Büyük Meke* ("Large Cone") is the biggest cone. Surges from its initial maar phase are visible in a quarry at its foot. On the walls of a well north of the volcano (VAH sequence), three scoriae layers are interstratified with marsh and lake deposits (Kuzucuoğlu et al. 1998b). Geochemical analyses of the scoriae point to a source in the Büyük Meke. The lake-marsh environmental evolution, as well as the date obtained on the VAH marshy layer (mean age: 26.5 cal ka BP), suggest the age of the eruption ca. 27–26 cal ka BP. If the assumption that the Büyük Meke is the oldest cone at the SW end of the Karapınar line is correct, the age from the marshes means that the other volcanoes are younger than the Last Glacial Maximum (LGM). Northwestward, other Strombolian cones are the *Küçük Meke* ("Small Cone"), on the flank of which a diatreme is visible (*Yılan Obruk*), and the *Meke Tuzlası* ("Salina Cone"). Meke Tuzlası is composed of a small Strombolian cone and flows nested in a wider initial maar. Olanca (1994) dated the basaltic lava flow emitted by the Meke Tuzlası to 20 ka. In the maar, a hypersaline shallow lake transforms the cone in an impressive island. Because of its exceptional landscape (Fig. 17.2c, d), the site is today a protected monument. The *Acıgöl* basaltic maar is most probably the youngest of this series. Its 50-m-high cliffs truncate both the Karacadağ volcanics and the LGM lake deposits. Its crater contains a 70-m-deep lake in which gas is still emitted.

On the northern border of the Konya Plain between Karapınar and Ereğli, the Karacadağ (highest point: 1995 m) is the largest volcanic system in the area. The rocks are mainly andesite, trachyandesite, dacite and basaltic andesite. The series is potassium-rich calc-alkaline. According to Ercan et al. (1992), its age is Pliocene.

17.3 An Exceptional Record of Late Pleistocene Climatic Changes

After de Meester's team (1970) studied in detail and mapped the soils of the Konya Plain, researches in the 1980s and 1990s went on, defining the climate, environmental evolution and the geomorphological records in and around the plain. They were initiated by Erol (1978) and continued by Roberts (1983). In 1979, Roberts et al. evidenced the LGM

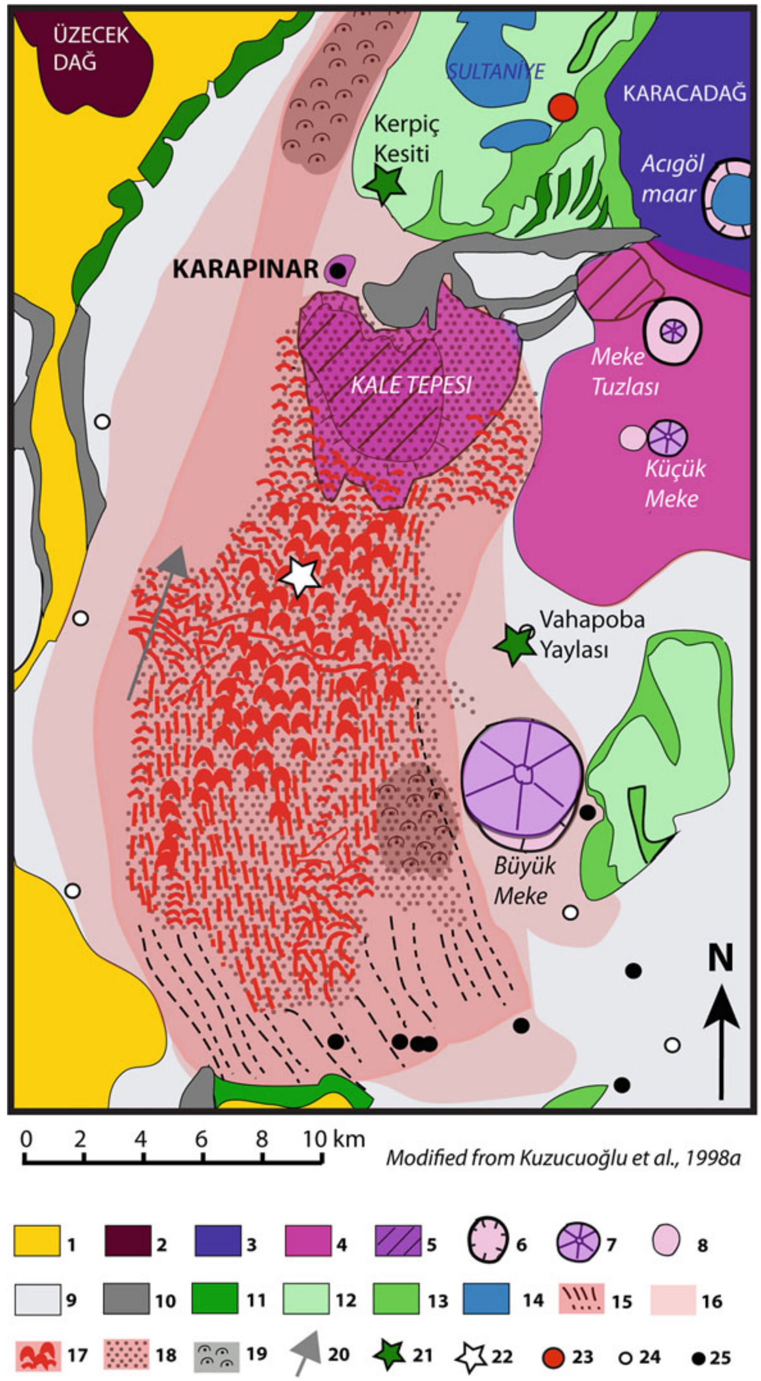


Fig. 17.5 Holocene sand dune system of Karapınar in its morphological context. 1. Pliocene limestone plateau; 2. Tertiary volcanics; 3. Karacadağ volcanics (Late Pliocene); 4. Middle Pleistocene volcanics (basalts ca. 450 ka old); 5. Mesa; 6. Late Pleistocene basaltic maar; 7. Late Pleistocene Strombolian cone; 8. Diatreme; 9. LGM marls (lake floor, ca. 980 m a.s.l.); 10. LGM sand beach; 11. Late Glacial coastal deposit; 12. Holocene lake floor; 13. Holocene sand beach; 14. Present lake (sebkha) and marshes; 15. Wind deflated area; 16. Lateral extension of wind deflation; 17. Dune field; 18. Sand accumulation area; 19. Hummocky-like sub-recent, downwind dune field; 20. Direction of dominant wind at present; 21. Published LGM to Holocene sections in lake sediments, with climatic and volcanic records; 22. OSL dated dune; 23. CO_2 emission; 24. Archaeological site (non-excavated); 25. Summer hamlet. Modified from Kuzucuoğlu et al. (1998a) (mapping partly based on SPOT 1, 110-274r1, copyright CNES and Spot-Image, 1987)

LEGEND: 1. Pliocene limestone plateau; **2.** Tertiary volcanics; **3.** Karacadağ volcanics (Late Pliocene?); **4.** Middle Pleistocene volcanics (basalts ca 450 ka old); **5.** Mesa; **6.** Upper Pleistocene basaltic maar; **7.** Upper Pleistocene strombolian cone; **8.** Diatreme; **9.** LGM marls (lake floor, ca 980 m a.s.l.); **10.** LGM sand beach; **11.** Late Glacial coastal deposit; **12.** Holocene lake floor; **13.** Holocene sand beach; **14.** Present lake (sebkha) and marshes; **15.** Wind deflated area; **16.** Lateral extension of wind deflation; **17.** Dune field; **18.** Sand accumulation area; **19.** Hummocky-like sub-recent, down-wind dune field; **20.** Direction of dominant wind at present; **21.** Published LGM to Holocene sections in lake sediments, with climatic and volcanic records; **22.** OSL dated dune; **23.** CO_2 emission; **24.** Archaeological site (non excavated); **25.** Summer hamlet.

age of coastal lake sediments fringing the plain. In the late 1990s, Inoue and Saito (1997), Naruse et al. (1997), Kuzucuoğlu et al. (1998a, b, 1999), Fontugne et al. (1999), Karabıyıkoğlu et al. (1999), Roberts et al. (1999) and Melnick et al. (2017) published further dates and various types of records out of sediment sequences. Methods applied are stratigraphy and chronology, as well as the mineral, geochemical and biological contents of the sediments. Consecutive reconstructions are based on ^{14}C, OSL and U-Th dates. Records from these studies extend from the Last Interglacial to the mid-Holocene. As a result, the Konya Plain delivered the first detailed record of climate in Central Anatolia during the Last Interglacial and the Last Glacial, detailing climatic changes within the LGM, during the Late Glacial and the Holocene.

17.3.1 The Last Interglacial (MIS 5e, Eemian)

In three cores, Kuzucuoğlu et al. (1999) studied periods previous to the LGM (Fig. 17.6). Two were retrieved in the Akgöl Lake and a third one in the Yarma marshes (locations in Fig. 17.3). In the Akgöl cores, a peat layer at a ca. −20 m depth is aged MIS 6 (end of Middle Pleistocene) and MIS 5e (Last Interglacial). During MIS 6, vegetation was a steppe (AP < 15%) rich in *Artemisia* and Chenopodiaceae. During MIS 5e, run-off records (characterized by mineralogy and grain size of sediments) and biotic indicators (pollen, molluscs) record a humid and temperate climate apparently colder than today.

17.3.2 The Last Glacial

In 1997, Inoue and Saito published mineral records from the Last Glacial clay, unfortunately with no date. Their data are comparable to those obtained in the Akgöl Lake (CAK and DUD cores: Kuzucuoğlu et al. 1999) where results (Fig. 17.6) illustrate the response to evaporation stress recorded by the authigenic calcite-aragonite-dolomite-gypsum/palygorskite series content of the lake mud. Other minerals allow identifying the input of (i) run-off from the slopes and streams (semi-arid climate) and (ii) long-distance wind erosion (semi-arid to arid climate). According to U-Th dates performed on authigenic gypsum and carbonates, the Last Glacial was mostly dry or extremely dry. Three periods with sebkha-like landscapes occurred in highly evaporative environments ca. 115–85, 70–60 and 40–30 ka ago. These episodes ended in total desiccation of the plain, evidenced by gypsum crusts. In between the semi-arid and arid episodes, the sedimentary hiatuses may have lasted long, except for the last one that was interrupted abruptly ca. 30 ka ago by a pre-LGM humid period recorded by marshes. Peat from these marshes is ^{14}C aged 27.3 ± 0.9 cal ka BP (VAH sequence: Kuzucuoğlu et al. 1998b), 30.9 ± 0.9 cal ka BP (GÖÇÜ sequence: Karabıyıkoğlu et al. 1999), and U-Th dated 29.6 ± 3.1 ka ago (DUD sequence: Kuzucuoğlu et al. 1999) (Fig. 17.6). Covered by younger LGM near-shore sediments, the peat layer structure records periglacial processes (ice coin) and is blanketed by in situ products of volcanic fall containing rhyolitic glass and obsidian lithics (Kuzucuoğlu et al. 1998b; Karabıyıkoğlu et al. 1999). The obsidian content points to a source in the Acıgöl area near Nevşehir where domes were active in a similar time.

17.3.3 The LGM: Several Phases of High Lake Levels

Records from around the plain indicate that a substantial lake filled it during the LGM, the coldest episode of the late Pleistocene. The lake was brackish to freshwater and 20 m deep over a 4200 km^2 surface (Roberts 1983). After drying, its emerged floor was surrounded by thick coastal deposits where successive facies allow reconstructing variations in the lake level. These are prograding coastal fans, sandbars, shore/near-shore/off-shore deposits, lagunas, dunes, etc. (Karabıyıkoğlu et al. 1999). At places, cliffs and notches are the only still visible evidence of older lakes. After calibration (using http://calib.qub.ac.ku/calib, see Steiner et al. 2013) of ^{14}C dates published in Roberts et al. (1979), Roberts (1983), Naruse et al. (1997), Fontugne et al. (1999), Kuzucuoğlu et al. (1999), one can suggest that there may have been several lake rise pulses during the LGM. After a first rise occurred 28 cal ka BP, five further pulses, some of which 1500 years long, some others 800–600 years long, occurred between 26.5 and 17.3 cal ka BP. Several causes have been suggested to explain such huge lake water bodies in Central Anatolia during the LGM: low evaporation due to cloud cover, extreme snowfall and/or temperature instability on the Taurus highlands, modifications of water exchanges in the underground network, etc.

17.3.4 After the LGM

After the LGM, there was no more such large lake as the "Palaeolake Konya". However, marshes and shallow lakes developed several times during humid phases, and sand dunes extended or were reworked during dry phases. Indeed, since the surface of the LGM muds is impermeable, the lowest parts of the plain concentrate excess of rainfall and run-off water and are thus good recording sites for humidity variations (Fig. 17.3).

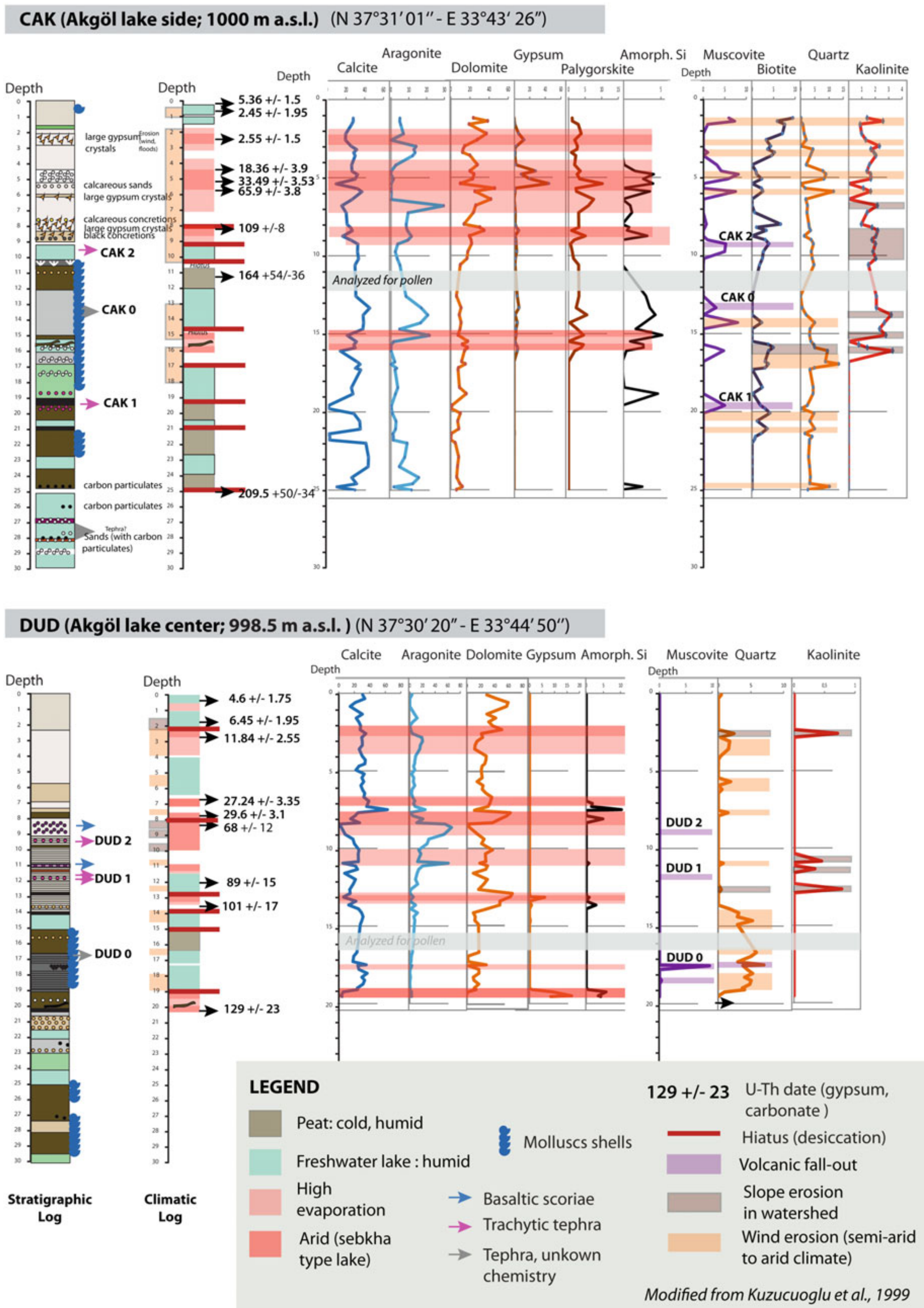


Fig. 17.6 Late Pleistocene climatic and environmental records from the CAK and DUD Akgöl Lake cores. Modified from Kuzucuoğlu et al. (1999)

17.3.4.1 The Late Glacial

In the north of the Konya Plain near İsmil, S–N-oriented barchan dunes cover an erosion surface truncating the Neogene limestone (Fig. 17.3). Today, this eroded dune field overlooks the LGM lake floor by a 30 to 50-m-high cliff OSL dated 14,328 ± 3220 yrs ago (Kuzucuoğlu et al. 1998a). The medium age corresponds to the beginning of the Late Glacial warming, but the uncertainty spans from the end of LGM to the onset of the Holocene.

The end of LGM and Late Glacial marshes has also been dated in the sub-basins of the Konya Plain (Roberts 1983; Bottema and Woldring 1984; Naruse et al. 1997; Kuzucuoğlu et al. 1997, 1999; Fontugne et al. 1999). Dates evidence local wet environments at the end of the LGM (ca. 16.5–16.0 cal ka BP), and during the Late Glacial (14.5–13.5 and 13.0–12.5 cal ka BP). According to Bottema and Woldring (1984), vegetation at ca. 13.0–12.8 cal ka BP was steppic. Alternating dry phases occurred 16–14.5 cal ka BP, 13.5–13 cal ka BP and during the Younger Dryas. The age of the İsmil dune field fits any of these three phases.

17.3.4.2 The Holocene

The onset of the Holocene ca. 11.4 cal ka BP is recorded by a marsh developing at Sultaniye (Kuzucuoğlu et al. 1997). The marsh evolved into a wetland decreasing back to a swampy area ca. 10.3 cal ka BP. Ca. 9.5 cal ka BP, alluvial fans started to expand at the mouths of the Taurus rivers entering the south of the Konya Plain (Boyer et al. 2006). At the front of these alluvial fans, water flowing inside the alluvium fed marshes and lakes such as Hotamış. At 9.1–8.7 cal ka BP, the Akgöl sub-basin dried; humidity was high enough to support the formation of soil over the floor of the dried lake (Bottema and Woldring 1984). There is no environmental record of the following 1000 years during which the "8.2 cal ka BP" dry event occurred. Ca. 7.8 cal ka BP, marshes reappeared on the floor of low-lying sub-basins (Sultaniye, Yarma, Akgöl) where they lasted until ca. 6.5 cal ka BP (Fontugne et al. 1999). Their disappearance marks the boundary between the humid Early Holocene, and the mid-Holocene transition preceding the dry late Holocene.

During this transition, a wet signal is produced by (i) a soil dated 5.5–5.3 cal ka BP followed by (ii) the development of marshes in the Akgöl wetland, dated 4.85–4.65 cal ka BP.

South of Karapınar, a dune field was built by strong winds shaping >12-m-high barchans (Figs. 17.2f and 17.5) (Kuzucuoğlu et al. 1998a). A sand sequence cored in the highest dunes delivered an OSL age of 5674 ± 988 yrs. The interval of uncertainty (6.7–4.7 ka ago) fits a dry period evidenced by marsh absence in the plain (6.5–5.5 cal ka BP).

The late Holocene started after a dry period dated 4.5–3.7 ka cal BP. Soils developed ca. 3.5 cal ka BP and marshes in the low areas from 3.4 to 3.16 ka cal BP. This latter date corresponds to the start of the 3.2 cal ka BP "event", a drought occurring during the transition between the Late Bronze and Early Iron Ages in the Near East (Kuzucuoğlu et al. 2011; Roberts et al. 2011; Kuzucuoğlu 2012).

17.4 The Impact of Tectonic and Karstic Processes on the Landscapes

17.4.1 Morphological Imprint of Tectonic Activity

The Konya Plain is a faulted subsidence basin, tilted towards its NW edge where the Quaternary sediments reach 400 m in thickness (De Meester 1970). Elsewhere in the plain, the mean thickness is 100 m, declining to 30–40 m near the northern extension of the Hotamış Plain (Doğan and Yılmaz 2011). The LGM coastal deposits on the NW edge of the lake reach an unusual thickness above the ground. According to Karabıyıkoğlu et al. (1999), they were uplifted while depositing. Nevertheless, active tectonic impact on the Konya Plain morphology is less evident than in some other lake depressions of Central Anatolia.

17.4.2 Karstic and Hydrothermal Features

17.4.2.1 Swallow Holes ("Ponor")

In Turkish, the common word for a swallow hole is "*Düden*". The sole swallow hole in the Konya Plain is located south of the Akgöl Lake (Fig. 17.3). Lower than the base of the lake floor, it is today separated from it by the Kilbasan-Ereğli road. Positioned on a fault zone between the Quaternary lake deposits and the Palaeozoic limestone forming the southern highlands, it used to be filled by a lake fed by underground water emerging from a karstic network during high humidity periods (such as between the 1970s and the 1980s). The lake contracted strongly after the 1990s. It is now dry, as are also the Akgöl marshes and shallow lakes, which used to be connected.

17.4.2.2 Emergences (Resurgences)

Several emergences of karst groundwater occur in the region of Ereğli, where they give birth to green spots (oasis) and streams ultimately feeding alluvial fans and wetlands on the piedmont. At İvriz, south of Ereğli, a very famous emergence reaches the surface and produces a pond at the foot of an important Hittite wall sculpture. From there, the flowing water becomes the Zanopa River, which builds an alluvial fan where the Hittite town of *Hupišna* (the Roman *Heraclea Cybistra*, today Ereğli) was founded.

17.4.2.3 Travertines

In the northern part of the Ereğli sub-basin at some distance from the foot of Karacadağ, the Akhöyük elongated travertine mound is formed by hydrothermal processes with sulphur- and carbonate-rich underground water outflowing along an open fissure (Figs. 17.1b and 17.3).

17.4.2.4 Sinkholes

Obruk is the Turkish word applying to a "round-shaped hole in the ground". In very rare cases, the term is misused when naming a "round-shaped hole" of volcanic origin, e.g. "Yılan Obruk", a *diatreme* near Karapınar (Fig. 17.5), and "Obruk *maar*" east of the Karacadağ.

Most commonly, obruks apply to dolines and collapse dolines. A doline deepens and widens with water accumulating on its bottom and its floor. It is filled with reddish gravelly clay remaining after carbonate dissolution. The collapse doline (sinkhole) results from collapse of a buried karstic cavity. The evolution of a sinkhole is determined by dissolution and suffusion processes deep at the bottom of the feature. In the Konya region, obruks are typical collapse dolines in the karstic Neogene carbonate environment. During the last two decades, occurrences of such collapses have increased, preferably in karstified limestone masked by old alluvium fill (caprock sinkholes).

17.4.3 The Obruk Plateau

The Obruk Plateau is an exceptional area hosting today 67 obruks extending along a 50-km-long and ca. 8-km-wide rectilinear zone (Figs. 17.1, 17.7 and 17.8). This distribution follows a SE–NW fault line disrupting the Neogene limestone plateau at the SW margin of the Tuz Gölü Basin, in the threshold area between the Tuz Gölü and Konya plains.

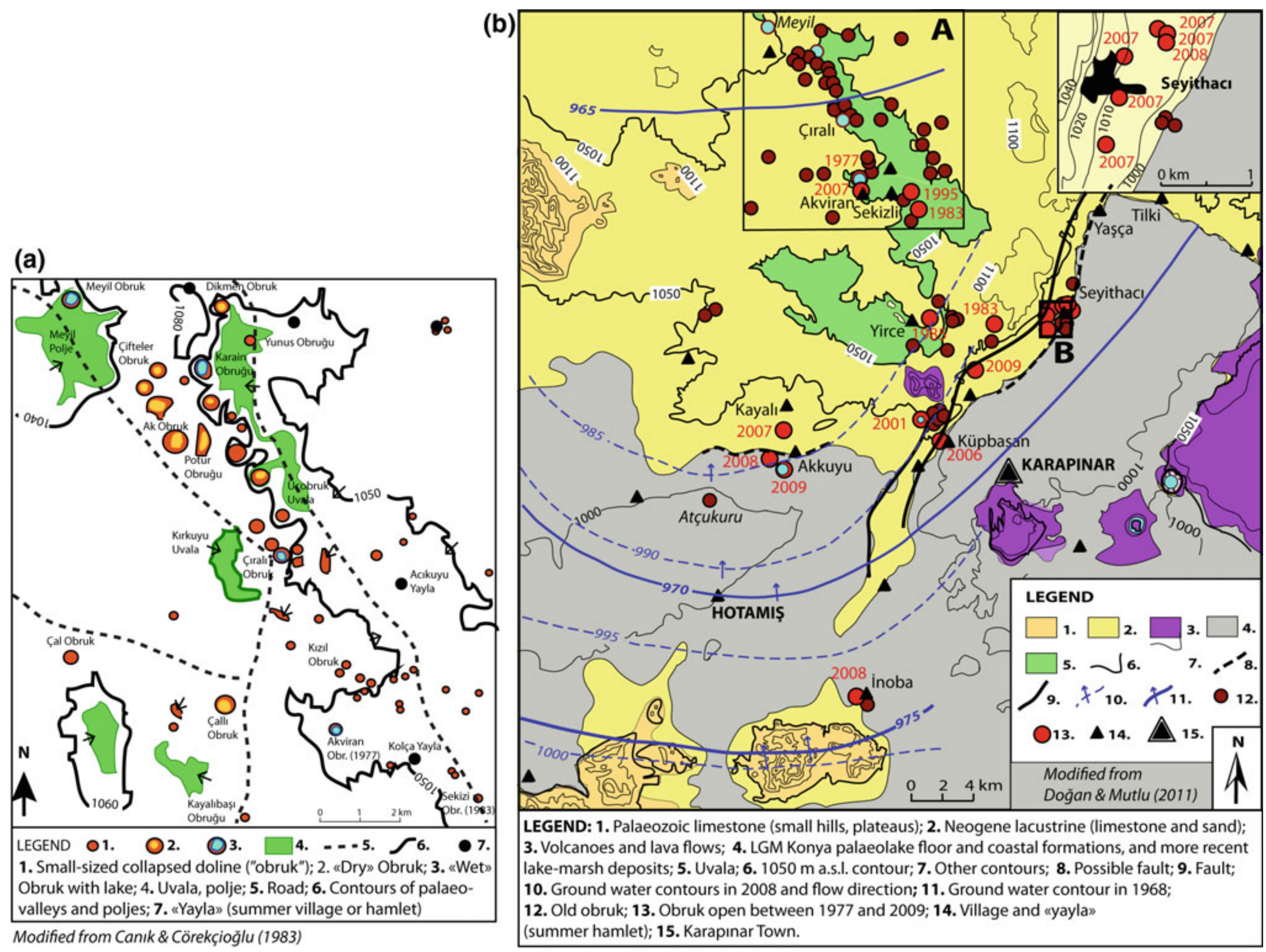


Fig. 17.7 Obruk Plateau between the Konya Basin and the Tuz Gölü Basin. **a** Alignment of collapse dolines in the Obruk Plateau and Dikmen-Sekizi Uvala. Modified from Canik and Çörekçioğlu (1986). **b** The Şeyithacı village where six sinkholes opened in 2007 and 2008. Modified from Doğan and Yılmaz (2011)

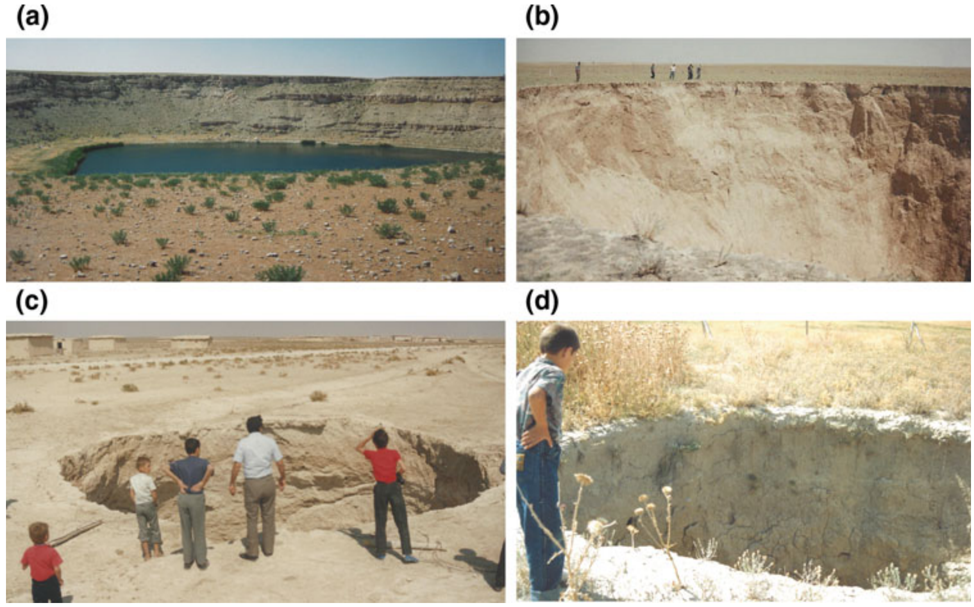


Fig. 17.8 Photographs of sinkholes in the Konya Closed Basin. **a** Wet obruk, **b–d** Newly collapsed obruks in the sandy silts covering the Neogene limestones. West of Sultaniye depression (NW Karapınar). Photographs by C. Kuzucuoğlu

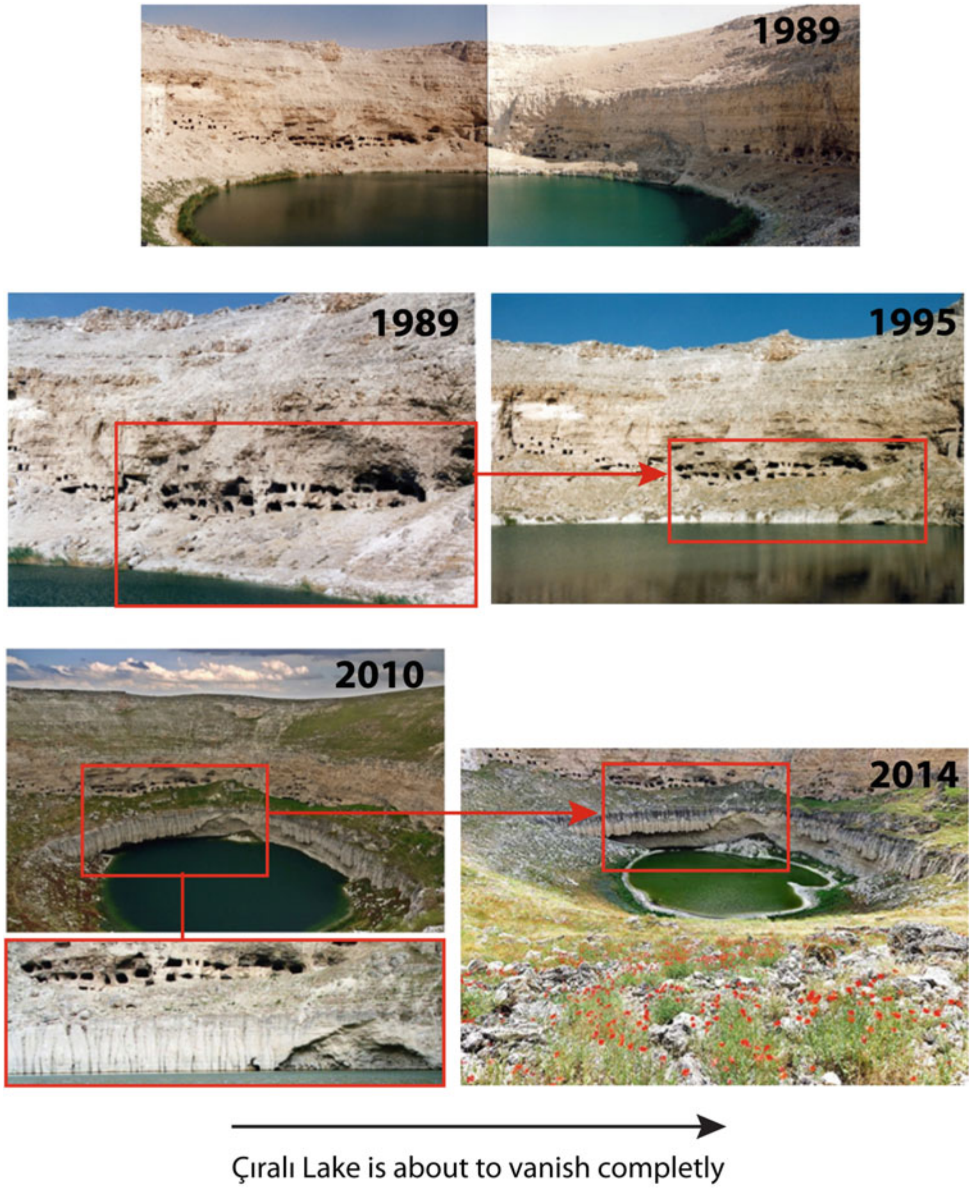
In the Konya Plain Basin, the total number of sinkholes is however much higher (182), with concentration in the vicinity of Karapınar. Their distribution in the basin indicates that favourable locations are (i) the edges of the plain and (ii) the Obruk Plateau. Their base levels are controlled by underground water circulation routes connecting the Taurus limestone range (recharge area) to the Tuz Gölü Plain at north (discharge area) (Fig. 17.4). In some of the largest and deepest ones, a lake occupies the sinkhole when it intersects the local water table (Bayarı et al. 2009) (Fig. 17.8a). Outside the plateau, other spectacular obruks are located at Kızören in the Tuz Gölü Basin, at the northern edge (e.g. Atçukuru) as well as the southern one (Timras, May ve Arpa obruks) of the Konya Plain (Figs. 17.1 and 17.8a).

Studying air photographs, Erol (1986) mapped these features, characterizing their shapes and classifying them on the basis of the freshness, depth, width and bottom shapes (conical/flat). He identified two generations of obruks and interpreted their formation processes and their chronology. According to him, the oldest obruks are found in the limestones of Bozdağ (Permian) and Sarnıç (Mesozoic) residual relief. They originated during the Miocene and the Pliocene, below the level of an old denudational surface. Later covered by Neogene lacustrine limestone, this palaeokarstic system partly controlled later karstification processes in the Neogene carbonates. The Pliocene ended with a fluvial phase and erosion of the Neogene limestone surfaces. During the Quaternary, the uplift of the plateau and subsidence of its south and north plains forced the fluvial water network and the karst system to sink into the Neogene plateau.

The Quaternary climatic fluctuations led lake levels in the plains to rise and drop, forcing the second generation of obruks to appear, directed by edges of former valleys and uvalas (Fig. 17.7). These obruks sunk into the 1070–1080 m a.s.l. level (Figs. 17.8 and 17.9). Some of them intersect the local water table and are filled by a lake (Fig. 17.8a). Erol (1986) proposed an LGM age for the dissolution preceding their collapse, when deep lakes filled the Tuz and Konya plains, i.e. when the head of the aquifer was significantly higher than before the LGM. According to this interpretation, the collapse occurred after the lakes disappeared ca. 17 cal ka BP. Consequently, the formation of most obruks on the plateau has been controlled by both (i) climatic fluctuations and (ii) the continuous subsidence of the Konya and Tuz Gölü plains *vs* the uplift of the plateau.

Canık and Çörekçioğlu (1986) and Bayarı et al. (2009) have shown that the regional magmatic activity at depth is the driving force in the evolution of hypogenic fluids causing the formation of obruks, through the influx of strong carbon dioxide-rich gas discharges. This underground magmatic activity produced the now-dormant volcanoes, cinder cones, maars, as well as hydrothermal springs scattered in the basin. Its activity produced CO_2 discharges common in the plains of Konya (Karapınar), Tuz Gölü (SW of Aksaray) and Bor, which are connected to tectonic lineaments mirrored by the rectilinear distribution of obruks. In addition, the location of obruks on both sides of the Konya Plain (its SW flank and the northern plateau) suggests that the route of the CO_2 flux into the atmosphere is constrained by the low permeability of Quaternary lake marls and the high-permeability zones formed by faults bordering the plain (Fig. 17.4).

Fig. 17.9 Fall of the Çıralı Obruk Lake level between 1989 and 2014. Photographs by C. Kuzucuoğlu, except for that of 2014 which is from internet



17.5 Archaeological Sites and Cultures

17.5.1 Is the Konya Plain One of the Source Areas of the Neolithic Spread ca. 9.5–9.0 cal ka BP?

At the beginning of the Holocene, Epipalaeolithic cultures existed in the Konya Plain where a site dated 9100–7900 BC has been excavated at Pınarbaşı near Karaman (Baird 2012a). Later on, the Konya Plain hosted some of the earliest Neolithic populations of Turkey (Özdoğan et al. 2012), e.g. the Pre-Pottery Neolithic site of Boncuklu (8500–7500 BC: Baird et al. 2012b); Early to Middle Pottery Neolithic sites of Çatalhöyük (7400–5500 BC: Mellaart 1967; Hodder 2006) and Canhasan III (7500–6500 BC: French et al. 1972) (locations in Fig. 17.3). Archaeological researches in the area are fundamental for understanding and reconstructing the history of plant and animal domestication (e.g. Asouti and Fairbairn 2002) and cultural development (technology, rituals, urbanization, etc.) in Central Anatolia (e.g. Özbaşaran 2011).

17.5.2 At the Heart of Several Empires During History

All later cultures from Chalcolithic to the Middle Ages are present in the Konya Plain. Not only Hittite remains are numerous (especially around Ereğli), but the last 2000 years are particularly rich in remains from famous historical kingdoms and cultures such as the Roman Province of which Iconium (Konya) was the capital, Byzantine troglodyte villages, the Seldjuk, capital of Karaman (which still preserves some impressive Seldjuk buildings), Konya, the capital of the Soufis with Mevlâna's mausoleum, remains (hans) of the Silk Road which used to go from Konya to Aksaray (north road) and from Konya to Ereğli and Bor (south road), famous Ottoman mosques (Konya, Karapınar, Karaman).

17.6 Threats

17.6.1 The Climate Change

Recent climatic trends between 1975 and 2007 have been studied by Altın et al. (2012). In the whole Central Anatolian Region, the increase in mean annual temperatures is +0.4 °C (2.6%). Increases are higher in the south and southeastern parts of the region. In Konya, it reaches 1% and in Karaman 7%. Mean rainfall intensity (MRI) is a good indicator of vulnerability regarding desertification processes, because it affects the recharge of groundwater level in winter and spring, i.e. the sustainability of agricultural yields and, consequently, the needs for irrigation during summertime. MRI is decreasing everywhere in Central Anatolia since the late 1970s and the early 1980s, and the trend is stronger since 1990. Generally, it affects more strongly the southern and eastern parts of Central Anatolia. In Konya, MRI decreased by 14.7%, in Karaman by 5% and in Ereğli by 1.9%. In Konya, this decrease is recorded in all seasons, a result evidencing high risk for the economic, social and political situation of the agricultural future of the region.

Differences in mean annual precipitation between 1975–1990 and 1991–2007 periods confirm this worrying situation, as all stations of Central Anatolia recorded a decrease. In the Konya Plain, the decrease was -2.46% in Konya itself, –3.02% in Karaman, –1.95% in Karapınar, -1.88% in Çumra and -2.46% in Ereğli.

17.6.2 The Depletion of the Neogene Aquifer

According to DSI (State Water Office), in the 1970s the head level of the Neogene aquifer was sloping from 1100 m at the flank of the Taurus Mountains to 905 m around Tuz Gölü. By 2008, the head level of the Neogene aquifer has declined about 25 m in the Konya Plain (DSI) (Fig. 17.7). When extending the period to 1970–2010, differences in depths are up to 64 m in certain places (Özdemir 2015) (Fig. 17.9).

In DSI-controlled wells, the decrease rate at the Karapınar Plain border (DSI, stated by Doğan and Yılmaz 2011) accelerated in 1990 and 1996, finally reaching a total of 23.5 m in 2008 after a rapid 8 m decline between 2005 and 2008 (ie. 2 m/yr!). In the Hotamış area, the decline between 1991 and 2000 reached 1 m/yr, with a maximum of 2 m/yr (Kuzucuoğlu and Gramond 2006). In parallel, seasonal differences in the groundwater levels have also increased (8 m between April and October) (Özdemir 2015). The lowering of the groundwater table parallels the occurrences and characteristics (locations, widths, depths) of the new obruks and fissures, an illustration of a direct relationship between the two.

17.6.3 Geomorphological Hazards

The recent increase of sudden occurrences of sinkhole collapses in the area has become one of the most challenging geological hazards in the area, as it is dangerous for engineering structures, settlements, agricultural areas and humans. Since the mid-1980s in the NW of Karapınar, the number and size of new collapse dolines have increased. They occur both along the faulted edges of the Sultaniye flats (Fig. 17.7b) and in the silty–sandy sediment of alluvial and lake origin over the Obruk Plateau. Between 1970 and 2012, approximately 20 large sinkholes (>10 m in diameter) formed in the Obruk Plateau, and between 2012 and 2014, twelve more sinkholes occurred (Fig. 17.8b–d). Sometimes, the collapse is preceded by the appearance of impressive cracks in the soil. Between March and June 2015, nine more sinkholes (some reaching 70 m depth) formed by collapse near the town of Karapınar (source: *Turkish Daily news*) (Fig. 17.7).

These newly born obruks are caused by the recent water table decrease due to excess water pumping for irrigation (Fig. 17.9). Further foreseen decline in the water table increases the probability of new sinkholes in the area of Karapınar and Obruk plateaus.

17.6.4 Loss of Wetlands and Soils

Another hazard, which does not seem to be an official priority, is the complete loss of all natural wetlands in the plain, with their wildlife and capacities to generate biodiversity and primary production (Gramond 2002). The conservation of the remaining ones cannot be efficient for the reason that no water is discharged anymore into them and that the underground water does not reach the plain floor anymore (Figs. 17.2, 17.9 and 17.10). This concerns particularly the Akgöl wetlands near Ereğli, which are still a natural protected area for birds and waterfowl, today absent (Fig. 17.10). The Meke Tuzlası (dry since the 2010s) and the Kızören Obruk are both Ramsar sites, but the quality of the sites is threatened by the lake level drop. Finally, an increasing surface of agricultural land in the Çumra area is being sterilized by salt concentration in the upper soil layers,

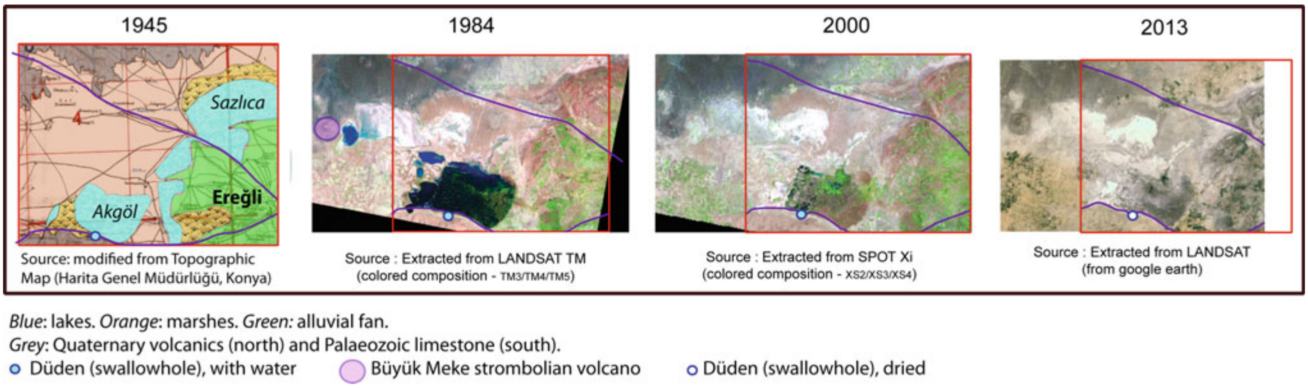


Fig. 17.10 Contraction and desiccation of the Akgöl wetlands between 1945 and 2013. Modified from Gramond (2002) and completed by the author in 2015 with image extraction from Google Earth imagery dated 2013

because of agricultural practices not adapted to soil characteristics and evaporation pressure on irrigated land.

17.6.5 Environmental Degradation

The closed nature of the basin (absence of surface outflow capable of renewing the water, a process favouring chemical concentrations in soil) has made the degradation of the environment extremely rapid.

17.6.5.1 Overuse of Groundwater for Irrigation

The rapid depletion of the underground water is related to the development of irrigation in the plain. As much as 88% of water available in the Konya Closed Basin is used for agriculture, and of this amount 61% is provided by underground water pumping. This development is financed by State incentives for producing speculative crops (sugar beets, corn, sunflower, potatoes, alfalfa, etc.) which have very high water requirements in summer, when the deficit between rainfall (7.5–11.4 mm/month from June to September in Konya) and potential evapotranspiration (ca. 1200 mm/yr) is the highest (mean T = 20–23 °C; mean max T = 26–30 °C in Konya). Apart for wheat and pulses fields, agriculture in the Konya Plain during these warm and dry 4 months relies only on dammed reservoirs and pumping of underground water reserves. According to Göçmez et al. (2008), the aquifer in the Konya Closed Basin can provide only 77% of the water used for irrigation. The difference is the depletion causing the underground water level drop.

There are three main reasons of this excessive use of water resource for irrigation (Topak and Acar 2010). The first one is related to the recent and spectacular increase of irrigation needs due to the addition of: (i) high water-demanding speculative (industrial) crops to the previous, more traditional ones; (ii) increase in irrigated surfaces; (iii) land surface devoted to high water-demanding crops has increased twofold after the State incentive started to support industrial crop production. The second reason is linked to the technical aspects of irrigation: (i) the amount of sprinklers used (46,600) is insufficient; (ii) the number of deep wells is too high (ca. 90,000 authorized wells); there are also at least 50,000 unauthorized wells which are never taken into account in official development plans and production accounts; (iii) the lackof farmers' taining induces evaporation losses that are still high, even when using sprinkler systems. Finally, the society does not seem much concerned about either the risks related to water resources depletion (whether due to climate or to resource overuse) or to water management priorities that would generate or reduce these risks.

17.6.5.2 The Implementation of Two Great Water Management Plans for Developing Irrigation

The Capture of the Beyşehir Lake (1903–1908)

Before the area between Lake Suğla polje and the Konya Plain was uplifted, the Suğla polje used to have an outflow (karstic? surficial? both?) heading towards Çumra/Hotamış. This outflow used to flow at the bottom of the gorges also used by the Çarşamba River which flows from the Taurus (Fig. 17.1b). North of Suğla Plain, gorges also continue from Lake Suğla to Lake Beyşehir. The whole set of gorges from Beyşehir to Konya plains are antecedent to the uplift, as shown by its meanders incising the erosional surface truncating the substratum between Konya and Suğla. At some time, the Suğla outlet stopped to carry water, probably because of lowering of karstic circulation in the Suğla Lake plain and, regionally, in the limestone bedrock. The Çarşamba River remained the sole headwater of the river running toward the Konya plain. Today the threshold of a few metres in alluvial material forms the natural "water divide" between the Konya Plain and the Suğla polje.

Until a few years ago, in summertime and/or dry years, the Lake Suğla used to escape into swallow holes (Fig. 17.1b). During humid years, the lake water would flow back again into the Çarşamba River and to the Konya Plain where floodwaters generated drainage problems.

Out-passing this small threshold was the initial step of the first modern irrigation project in Turkey (1903–1908). Open earth conveyance canals of a 217-km total length were associated with several regulators. The continuity of the flow was established by-passing Lake Suğla, from Beyşehir to Çumra in the Konya Plain where three main irrigation canals ensured the agricultural development of the area.

The "Blue Project" (2010–2016)

The Konya Plain Project (KOP) or "Blue Project" aims at transferring water from the Mediterranean Göksu River to the endoreic Konya Plain. It consists of: (1) the derivation of the Göksu River to (2) three dams (Bozkır, Afşar, Bağbaşı); (3) a 17-km-long "Blue Tunnel" directing the dammed water to a "Blue Regulator" in the Çarşamba basin; (4) a 127-km artificial channel discharging the water into (5) a huge open-air storage equipment to be yet built at the location of the now-dried Hotamış Lake. The latter will be Turkey's biggest artificial lake.

After launching the "Blue Project" in 2010, DSI announced that the completion of the project was expected at the end of 2015. According to DSI, the project will provide the Konya Plain with 414 mm^3/yr of water *"in order to maintain agriculture and save wildlife*", adding *"with this project, the climate of Konya will be changed, the product range will be increased and 700 million cubic meters of water will feed Konya Plain instead of emptying into Mediterranean Sea"* (Konya Anadolu Agency, 21 May 2015). In 2018, the Project is not yet implemented.

The KOP is the second largest irrigation scheme in Turkey after the Southeastern Anatolia Project (GAP), sought to enable 235.000 ha of agricultural land to be irrigated for increasing production. The project does not say whether the present depletion of the aquifer will continue with the present irrigation networks and practices, and in the present drying of the climate.

The Göksu River flows to the Mediterranean where it forms a delta used for intensive agricultural (greenhouses) production and touristic activities. The water flow redirection to the closed Central Anatolia will generate geomorphological, ecologic (land/marine biodiversity), human and economic problems in the Silifke area, e.g. interruption of water and sediment contribution to the delta.

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