The Kula–Salihli UNESCO Geopark: spectacular records of Quaternary volcanism, fluvial and landscape evolution and Quaternary environmental change

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Abstract

The Kula–Salihli UNESCO Geopark, western Turkey, is a tectonically and volcanically active region in which the most recent eruptions of basaltic lava, associated with scoria cone formation, were during the latest Pleistocene and the Holocene. Much older volcanism within the same volcanic province is also in evidence, with some of the older lavas capping mesa-style uplands, such that they have preserved underlying poorly consolidated sediments that would otherwise have been lost to erosion. Beneath these hill-capping lavas, above the Neogene sediments representing endorheic basin-fill, are the early gravels of the River Gediz system, forming narrowly separated terraces (separation by a few metres) thought to have been formed in response to the ~41 kyrs obliquity-driven climate cycles of the Early Pleistocene. The rarity of terrace preservation from this early part of the Quaternary makes this a very valuable part of the geopark, in which there is also evidence for the progressive incision into the landscape, and for periodic damming of the river system by lava eruptions, bringing about lacustrine phases that can be recognized from lake sediments and deltas that were built into the former lakes. The combination of volcanic and drainage evolutionary evidence has few if any parallels elsewhere. The geopark, which also contains sites of archaeological and historical importance, is managed sustainably in order to maximize its educational, economic, touristic and heritage value.

Keywords:

Kula–Salihli UNESCO Geopark, Geoheritage, Gediz River, Gediz Graben, Western Anatolia, Turkey,

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1. Introduction

Geoparks combine a sustainable development strategy with the conservation of geoheritage and its use in educational and geotourism activities, in conjunction with other natural and cultural resources of the territory. Geoheritage, which is part of natural heritage, is constituted by aspects of particular geological or geodiversity value deemed worthy of safeguard for the benefit of present and future generations. This can include elements that are in situ (geosites) or ex situ (collections of geological specimens), with combinations of palaeontological, geomorphological, mineralogical, petrological or stratigraphical significance, among others. Geoheritage is a non-renewable natural resource that is affected by natural and anthropogenic impacts, including weathering, erosion, climate change, quarrying and infrastructure development (Moufti et al., 2013; Crofts et al., 2015); impacts range from active harm to damage resulting from negligence and ignorance.

Geoparks and geotourism offer means for integrating the natural and cultural components of a landscape, enabling people to reconnect through memorable aesthetic and emotional experiences (Brilha, 2018a). Although geoparks are concentrated in Europe and Asia, in recent years the initiative has been spreading in Latin America and Africa, taking advantage of ethnic, cultural, geographical, climatic and, above all, geological diversity **(**Quesada-Román and Pérez-Umaña, 2020). The geopark concept has thus gained worldwide recognition in less than 20 years, its growth reflected in the number of sites now officially designated as ‘UNESCO Global Geoparks’, an international label of distinction initiated in 2015 for unique areas where geoheritage is protected (Brilha, 2018a-b).

The remarkable recent growth of geoparks has helped to promote wider awareness of geoheritage and its scientific and cultural value beyond the immediate geoscience community (Crofts et al., 2015; Brilha, 2018a). In this context, Turkey, which hosts unique landscapes and outstanding morphologies of international importance, showed a strong commitment to the protection and promotion of its geoheritage with the establishment of the Kula–Salihli UNESCO Global Geopark in 2013. This is the first and so far the only UNESCO registered geopark in Turkey and the Turkish-speaking countries of Asia. This paper will recount the establishment of the geopark and outline its current and future management strategy in relation to geoheritage conservation and geotourism. In the context of the present special issue ‘'Valuing the Quaternary’, it will also review the evidence for Quaternary landscape evolution of global and regional significance in the Kula–Salihli Geopark.

2. Location and geological setting

The Kula–Salihli UNESCO Geopark is located in the eastern part of the Aegean extensional (tectonic) province, covering the northern–central part of the Gediz graben and extending across the administrative borders of the Kula and Salihli districts of Manisa Province in Western Turkey (Fig 1).

There are 73 separate geosites incorporated within the 2320 km^2 of the geopark (Fig 2), which has two clear geographical divisions: the Kula Volcanic Province, located on the northern uplifted shoulder of the graben, and the graben itself.

In this region, the continental lithosphere has been extended in a N–S direction following crustal thickening due to previous orogenic contraction (Bozkurt and Sözbilir, 2004; Ersoy et al., 2010). This extension dates from the latest Oligocene – Early Miocene and was influenced by the subduction of the African Plate beneath the southern margin of the Anatolian Plate along the Aegean–Cyprean subduction zone and the dextral slip on the North Anatolian Fault System (Seyitoğlu, 1997; Bozkurt, 2001; Ersoy, et al., 2010; Fig. 3A). This tectonic activity has given rise to a series of E–W-trending grabens (e.g., the Gediz and Büyük Menderes grabens; Bozkurt and Sözbilir, 2004; Ersoy et al., 2010; Fig. 3B).

There has been significant research on the Late Cenozoic tectonic evolution of Western Anatolia over the past two decades. The extensional tectonic activity here has resulted in magmatism and the formation of volcano-sedimentary basins (Seyitoğlu, 1997; Bozkurt, 2001; Ersoy, et al., 2010). There are Neogene extensional shear zones that accompanied the collapse of the Palaeogene over-thickened Anatolian crust. In the north of the region, these shear zones generally juxtapose the Paleozoic–Mesozoic Menderes Massif, consisting of metamorphic rocks, with overlying late Mesozoic Neo-Tethyan ophiolitic mélange material (comprising the rocks of the İzmir–Ankara zone), the Lycian Nappes, and Neogene volcano-sedimentary units. The dating of this activity along low-angle detachment faults to the late Oligocene – Pliocene interval is based upon radiometric ages (Ersoy et al., 2010).

A series of NE–SW-trending basins with Neogene volcano-sedimentary infill form major structural elements of the region (Ersoy et al., 2010; Fig. 3). From west to east, these are the Gördes, Demirci, Selendi and Uşak–Güre basins. They are dissected by still-active Pliocene–Quaternary E–W-trending grabens, such as the Edremit, Simav, Gediz, Küçük Menderes and Büyük Menderes grabens (Ersoy et al., 2010; Fig. 3).

2.1 The Selendi basin

The NE–SW trending Selendi basin, covering an area of 65 × 35 km, is located between the Gediz graben to the southwest, the Simav graben to the north, the Demirci basin to the west, and the Uşak–Güre basin to the east (Fig. 4). Limited by metamorphic highs to the east and west, the basin has developed on the Paleozoic–Mesozoic metamorphic rocks of the Menderes Massif, on Late Mesozoic ophiolitic mélange rocks of the İzmir–Ankara zone and on Neogene granitoids (Ersoy et al., 2010; Figs

4 and 5). Its fill comprises the middle–late Miocene fluviatile Hacıbekir group, overlain unconformably by the Pliocene İnay group, which is composed of the predominantly fluviatile Ahmetler and lacustrine Ulubey formations (Fig. 10), with intercalated Beydağ volcanics. The Pliocene–Quaternary Kula volcanism represents the youngest such activity in the region (Seyitoğlu, 1997; Ersoy et al., 2010).

2.2 The Gediz Graben

Another name for the middle part of the Alaşehir Graben (Fig. 3B), this is one of the most active such structures in the world, reflecting major crustal extension in a N–S direction since the Late Oligocene (Bozkurt, 2001). This region forms the eastern part of the Aegean extensional province, which has been experiencing N–S extension related to subduction of the African Plate beneath the southern margin of the Anatolian Plate (along the Aegean–Cyprean subduction zone) and to dextral slip on the North Anatolian Fault System (Bozkurt, 2001; Fig. 3). E–W-trending grabens of this type, which also include the Büyük Menderes Graben, are prominent features of western Turkey. The Gediz and Büyük Menderes grabens dissect the Menderes Massif, globally one of the largest core complexes, into northern, central and southern submassifs (Bozkurt and Sözbilir, 2004; Ersoy et al., 2010; Figs 4 and 5).

3. Earth-science interests

In terms of the Earth Sciences, the Kula–Salihli Geopark encompasses evidence of more than 200 million years of geological history, from Paleozoic metamorphic rocks to late prehistoric volcanic eruptions. As such, it represents a field laboratory for the Earth sciences, hosting various types of fault and graben structures, examples of fluvial, volcanic and karstic landforms, evidence of erosional processes and topographic inversions due to differential erosion, as well as rocks from several different geological periods. A physical record of Earth history is provided here, revealing evidence of significant active geological, geomorphological and biological evolutionary processes. Due to its geoheritage value, which will be shown to be of international scientific, educational and aesthetic importance, the geopark is developing as a place for scientific research, education and the exploration of natural phenomena.

The geopark exists because of the spectacular volcanic geology in the Kula area, which dates back to at least the Early Pleistocene and remains active, with the most recent eruptions being of Holocene age, 2.7 ka (Westaway et al., 2006; van Gorp et al., 2013; Fig. 6). In addition, and in association with the Quaternary volcanism, there is a remarkable sedimentary (Early Pleistocene river terrace deposits) and geomorphological record of landscape and drainage evolution, aspects of which have been strongly influenced by volcanic events and much of which has only been preserved due to the emplacement of resistant lavas and tuffs, which have protected the softer fluvial sediments from erosion.

3.1 The Kula Volcanic Province

Covering ∼300 km^2, the Kula volcanic province coincides with an area of continental crust, ~15 km N–S by 40 km E–W, that is extending in response to forces exerted on it by subduction of the African plate beneath its southern margin (e.g., Meijer and Wortel, 1997). The volcanic rocks here comprise lavas, tephras and tuffs associated with ~80 small cinder (scoria) cones (Richardson-Bunbury 1996). The volcanism at Kula, documented∼2000 years ago by Strabo (e.g., Jones, 1954), has also been described periodically since the early 19th century (e.g., Hamilton and Strickland, 1841, Philippson, 1913, Ercan and Öztunalı, 1982). The geochemistry of the volcanism, first established at the end of that century (Washington, 1894, 1900), has led to the classification of the lavas as alkali olivine basalt, phonotephrite, and basanite (Güleç, 1991). The oldest published dates suggest that the volcanic activity began at ~1.7 Ma (Richardson-Bunbury, 1996), in close association with the crustal rifting that has produced the graben structure (Ercan et al., 1982; Ercan, 1993). The basalt flows that have arisen are classified according to their relative age into four categories, from β1, the oldest, to β4, the youngest (Erinç, 1970). Understanding of the earliest β1 volanicity is problematic, with the β2 basalts recognizable as the oldest within the familiar landscape of the geopark. With an estimated total volume of ∼0.5 km^3, these are sometimes termed the 'Burgaz volcanics', since they cap the highest elements of the modern fluvial landscape, typically plateaux, including the Burgaz Plateau, ∼150–200 m above the present level of the River Gediz (Maddy et. al., 2005; Fig. 7).

By forming resistant plateaux cap-rocks, these lavas have preserved important evidence of the landscape and fluvial evolution in the region, already noted as an important element of the geological record of the geopark. This includes Lower Pleistocene river-terrace deposits that represent the early incision by the palaeo-Gediz into the unconsolidated Miocene infill of the Selendi Basin (e.g., Ercan and Öztunalı, 1982; Richardson-Bunbury, 1996; Westaway et al., 2004; Maddy et al., 2005), the higher elements of which are also preserved beneath these plateaux due to the resistant cap-rock. The underlying terrace gravels show that the basalts flowed onto the contemporaneous Gediz floodplain and that they erupted before the incision of the modern Gediz Valley.

The β3 basalts, or 'Elekçitepe volcanics', erupted during the Middle Pleistocene, after the start of this phase of incision, and crop out within the Gediz gorge, albeit above the present river level. In contrast, the considerably more recent and less weathered β4 basalts, or 'Divlit Tepe volcanics', are preserved on the modern floor of the gorge, having flowed into the main gorge along the valleys of tributary streams. The β3 and β4 basalts together total ∼2 km^3, with β3 more widespread. There are also geographical variations between these phases of volcanism, related to their association with different eruption centres. Those furthest north, now on or around the basalt plateaux, are the oldest, with highly degraded volcanic cones or exposed volcanic necks. The eruption centres that produced the lower-level Middle Pleistocene lava flows lay further south, while the most recent eruptions are from centres even further south, closer to the Alaşehir (Gediz) graben, as is evidenced by large well-preserved cones and lava flows with relatively fresh, irregular surfaces, some reaching the current River Gediz to the north of Kula (Ersoy et al., 2010; Fig. 4).

3.2 Landscape evolution: basin sedimentation to incision and river-terrace formation

The transition between the Cenozoic sedimentary basin infill and deep valley incision is one that has been repeated in numerous locations globally and in particular on the relatively young and dynamic crust of the Mediterranean region (Stokes and Mather, 2000; Demir et al., 2018; Bridgland et al., 2020). It is uncertain whether basin filling persisted in the Gediz Graben into the Pliocene (cf. Westaway et al., 2004) but inversion had certainly occurred by the Late Pliocene – Early Pleistocene, given that this interval is represented by closely-spaced gravel terraces, preserved beneath basalt plateau cap-rock (Fig. 8). The latter is dated by Ar–Ar to ~1.32 Ma, leading to the attribution of the river terraces to Marine Isotope Stages (MIS) 52–42, implying a date range of ~1.5–1.3 Ma and terrace formation in response to 41 ka (obliquity-driven) climate cycles (Maddy et al., 2017). Bridgland and Westaway (2014) suggested that this and similar occurrences of Late Cenozoic basin inversion were an indirect result of global cooling, related to the acceleration of surface processes that this caused and the resultant enhancement of erosional isostatic uplift. Preservation of river-terrace evidence for the early Quaternary part of this trend in landscape evolution is extremely rare and has occurred at Kula only because of the protective lava capping (Fig. 8).

The full range of evidence for the Quaternary evolution of the Gediz valley around Kula has been recognized thanks to the programme of research undertaken by a multi-national team led by Darrel Maddy (Maddy et al., 2005, 2008, 2012a, b, 2015, 2017; Veldkamp et al., 2015). Interaction between the volcanism and the evolution of the Gediz valley was already apparent from the pre-existing literature. Westaway et al. (2004) had noted several occurrences of basalt-capped terrace gravels and evidence for breaches of lava dams that had clearly caused ponding and diversion of the river at various times during the Pleistocene. They also reported outcrops of gravels beneath the lavas capping the high plateaux: both limestone gravels, their clasts reworked from the uppermost (Ulubey Formation) part of the basin fill, and polymict gravels comparable to those forming the terraces and the modern bedload of the Gediz. Detailed study by Maddy et al. (2005, 2012a, 2017) subsequently revealed that these latter deposits represented a staircase of eleven closely spaced terraces, buried and preserved beneath the basalt plateaux cap-rocks; all eleven terraces are preserved on the Burgaz Plateau, with parts of the sequence recorded from the other basalt-capped mesas (Fig. 7 and 8). The preservation of river terraces of so great an age is extremely rare and can be directly attributed to the protective properties of the basalt capping, although the post-Early Pleistocene incision has played an important role in exhuming and exposing the buried gravels (Fig. 7 and 8). Their recognition adds markedly to the international significance of the geopark. Formed at intervals during the incision was a staircase of mostly Middle Pleistocene terraces, catalogued by Westaway et al. (2004, 2006), who also dated the younger basalts emplaced above examples of these. The steeply incised and terraced valley of the Gediz and those of its various tributaries form a classic fluvially sculpted landscape (Fig. 7 and 8). Veldkamp et al. (2015) have also recorded, within the sequence capping the Burgaz Plateau, a suite of fluvial and colluvial sediments in which two laminar calcretes alternating with three reddened palaeosols occur, yielding detailed information (from analyses of micromorphology and stable isotopes) about Early Pleistocene climate and vegetation, and their fluctuation. This last example underlines the value of the Kula–Salihli geopark for detailed study of environmental changes that occurred on a global scale but for which evidence is preserved very rarely.

The record of Early Pleistocene fluvial evolution from the plateau-capping sequences is of sufficient resolution for Maddy et al. (2012b) to have reconstructed palaeochannel abandonment and diversion as a result of lava and tephra blockages, not just for the Gediz but also for its tributary, the River Hudut. They also observed lacustrine sediments associated with the ponding of the river system, further alluding to comparable sediments and evidence for deltaic deposition into palaeo-lakes later in the Pleistocene from the lower-level records in the area. Van Gorp et al. (2013) subsequently reported on the well-preserved evidence for volcanic damming of, and lava-dam breaching by, the Gediz and its tributary, the River Geren, during the Holocene. Van Gorp et al. (2015) subsequently extended consideration of the Geren catchment to report on multiple phases of lava damming during the Quaternary, using Palaeo-DEM reconstruction and computer modelling of landscape evolution (incorporating aqueous erosion and deposition) as a means for interrogating the response of this tributary system to volcanic disruption.

3.3 The Gediz Graben

This graben, formed as a result of extensional tectonic activity that has been occurring in the Aegean region since the Early Miocene (see above; Figs 3–4), forms an important part of the Earth-science interest of the geopark. It is an actively growing asymmetric graben (actually a WNW–ESE-trending half graben), with the active normal faults mainly located on its southern margin, which has a distinctive topography reflective of the major bounding fault system located there, while to the north a younger normal fault system has controlled the morphological development of the graben since the Miocene. These geological processes have not only created the fertile Salihli and Alaşehir plains, with hot springs and gold deposits that have attracted human settlement, but have also caused natural disasters such as earthquakes. These geological issues, which can be followed in the history of the ancient city of Sardis, continue to be relevant at the present day (Seyitoğlu et al., 2019). The youngest graben fill is the sediment of the Salihli–Alaşehir plain. The initation of the Gediz graben started with the activity of the Karadut fault, which is the youngest detachment fault in the region. The footwall section of the Karadut fault consists of schists and marbles of the Menderes Massif, whereas the hanging-wall section consists of rocks of the Menderes Massif and a Neogene sedimentary succession (Bozkurt and Oberhänsli, 2001; Bozkurt and Sözbilir, 2004).

3.4 Other interests: geological and archaeological

The geopark incorporates several travertine accumulations of different sizes, many clearly associated with past/present hot springs related to the tectonism and volcanism (Maddy et al., 2020). In the wider region of western Turkey, there are larger and better-known travertines, in particular the cascade at Pamukkale, a celebrated geosite (Şimşek et al., 2000), and at Kocabas, where a ~80 m thick Lower Pleistocene sequence has yielded a *Homo erectus* cranium (Lebatard et al., 2014). Those in the Kula–Salihli Geopark are less well known, although some have been observed to contain fossils (e.g., Mollusca). The Kurşunlu hot spring, near Salihli, provides domestic heating and has potential for geothermal energy (Başokur et al., 2017). Maddy et al. (2020) noted that travertines have formed in the area as mounds and sheets, often extending onto the contemporaneous valley floor, thus connecting with the fluvial archives in the geopark and providing linkage between surface and subsurface hydrological change. They reported on stable-isotope analyses, which confirmed that most of the travertines in the area were probably formed from hot springs, and are therefore to be associated with tectonic and/or volcanic activity (Fig. 9).

As well as being deeply incised by the River Gediz and its tributaries cutting into the Late Cenozoic basin sediments, the landscape in parts of the geopark provides examples of classic 'badlands' geomorphology, arising from the rapid erosion of poorly consolidated strata, particularly the Ahmetler Formation, during high-rainfall events (Maddy et al., 2007, 2008; Fig. 10).

The geopark is rich in terms of its historical and cultural heritage, this having been an important area of human activity since prehistoric times. Thus there are many archaeological and historical sites within the geopark. For example, a Lower Palaeolithic artefact (a struck flake made from a quartzitic rock) was found, reputedly the oldest from western Anatolia and attributed to Early Pleistocene *Homo erectus* (Maddy et al., 2015). It was found in the uppermost part of a fluvial deposit in an abandoned meader loop of the palaeo-Gediz, beneath the final filling of this abandoned valley segment with slope-derived material (Fig. 11). Correlation of the sediments at this location with the sequence of the Early Pleistocene terraces capping the nearby Kale Tepe and Burgaz plateau suggests an age for the indicated hominin occupation of between ~1.24 and ~1.17 Ma, perhaps indicative of presence during the lengthy interglacial that correlates with MIS 35 (Maddy et al., 2015). This is comparable with the revised age range (1.3–1.1 Ma) estimated, on the basis of magnetic polarity measurements and modelled $26^{Al}/10^{Be}$ cosmogenic isotope burial ages, for the hominin-bearing Upper Travertine at Kocabas (Lebatard et al., 2014; see above).

There are further geo-archaeological sites in the western part of the geopark area, consisting of formations or sites that are associated directly with geological processes or archaeological elements that contain evidence of a number of geological events in the past, or places where human activities have markedly changed the topography. Some examples of these are the Çakallar prehistoric fossil human footprints, the ancient city of Sardis and the Temple of Artemis, the Bintepeler (Thousand Hills) burial mounds (Yükçü and Gönen, 2013), and the Kanlıkaya (Bloody Stone) prehistoric rock paintings (Ulusoy et al., 2019; Figs 12–14). The Çakallar footprints were discovered on a thin tuff layer covering metamorphic bedrock during the construction of the Demirköprü Dam in 1954–1960 (Gümüş, 2014; Türe, 2018; Fig 11). They are interpreted as formed by three Bronze Age people, two walking uphill and the third moving in the opposite direction, during or immediately after a volcanic ash-fall from Çakallar Cone (Gümüş, 2014). According to recent research, they date from 4700–4000 BP (Ulusoy et al., 2019) and are the oldest evidence of human–volcano interaction in Turkey (Gümüş, 2014). They invite comparison, therefore, with late Pleistocene footprints in tuffs in the Ngorongoro Geopark in Tanzania (Hatala et al., 2020) and lacustrine examples such as in White Sands National Park (USA), where footprints occur in playa subsoil (Bennett et al., 2020), and Gampung Lake (Australia), where they are in hardpans at the edge of the lake (Webb et al., 2006).

The Çakallar footprints were discovered during road construction in 1969; construction was interrupted so that they could be examined by experts. Initial investigation revealed the footprints of a woman, a man, a child and even a dog, amongst 200 complete or nearly complete examples. At least 60 of these were taken to the museum of the General Directorate of Mineral Exploration and Research (MTA) for preservation (MTA., 1976). The anticipated designation of a conservation site at the footprint locality is still awaited.

The footprints occur in tuffs that are extremely fragile, so an open-air geosite would leave them susceptible to damage. Indeed, their conservation in situ will require measures to maintain stable environmental conditions (e.g., humiditiy and temperature). Thus the inauguration of a specific geoste for the footprints awaits development of an environmentally compatible conservation strategy and inclusion of special articles regarding the protection of the footprints in the geopark activation plan. While protection of the footprints remains unresolved, the location of the site is not widely revealed. However, for scientific purposes, access to the location can be obtained from the geopark office.

The geopark area was also of great importance in the history of Christianity and is rich in examples of traditional residential architecture, with a range of mosques/churches and other religious sites. This cultural and architectural diversity cannot be considered independent of the geology of the area; the houses were built using local stone and the different building materials and the cisterns transformed from the karstic water sources are examples of geological influence on cultural heritage in the area.

4. Initiation, management and development of the geopark

4.1 Establishment of the geopark

The process of establishing the Kula region as a geopark has a 10-year history (Aytaç and Demir, 2019), having been initiated within a European Union (EU) project under the 2007–2008 framework grant programme. Working to UNESCO criteria, it took several years to organize the area as a geopark and in November 2012 the first official application was made to the Global Geoparks Network (GGN). In March 2013, the Kula Volcanic Geopark officially became Turkey's first Global Geopark candidate. It was inspected by the experts of the Global Geoparks Network in June 2013 and was accepted as Turkey's first geopark, registered by that network from September 2013. Its title ‘Kula Global Geopark’ was changed to ‘Kula UNESCO Global Geopark’ after all such geoparks were taken under the umbrella of UNESCO in 2015. Evaluation in 2017 revealed that the Kula geopark did not meet the standards required under some of the UNESCO criteria. As a result, the geopark management unit was changed and a new structure was initiated to comply with the UNESCO criteria. In this context, all geosites and geopark boundaries were re-evaluated and the territory included within the geopark was increased from 300 km to 2320 km, its name was changed to Kula–Salihli Geopark and a full extension application was made to UNESCO. As a result, the geopark was revalidated in July 2019, and re-registered by UNESCO in 2020.

4.2 Management and development of the geopark

Following acceptance, in 2013, of the Kula Geopark as a member of the Global Geoparks Network by UNESCO, it came under the obligation to adhere to the UNESCO approach towards the development and operation of Global Geoparks (https://kulasalihligeopark.com/en/). Its extension, in 2018, to form the Kula–Salihli Geopark (see above) was to ensure sustainable development of the whole area and thus achieve its more effective management and to protect those areas that also have geological, historical and cultural importance in Salihli District, complementary to those in the original Kula Geopark,.

In order to provide better protection, promotion and management of the natural heritage of the Kula–Salihli Geopark following the European Geoparks Network and UNESCO Global Geopark regulations, three municipalities (Manisa Metropolitan Municipality and the Kula and Salihli municipalities) established an official but semi-independent body to manage the geopark, based on the national code. The Geopark Municipalities Union (GMU) was established by the Turkish Parliament and the approval of the Ministry of the Interior. Thus the GMU is recognized as an official institution of the Republic of Turkey, with statutory powers. Decisions regarding the park are generally proposed by the geopark coordinating office and approved by the Assembly of the Union, with opinions from an academic board and external stakeholders sought when necessary (Fig. 15).

The development approach of the Kula–Salihli Geopark can be summarized as follows:

- Full consideration of UNESCO philosophy concerning geopark development
- Consideration of the geopark as a process, not a project (the sustainable development approach)
- Development and marketing of the geopark as a geotourism destination
- Significant contribution to regional development in the Kula and Salihli Districts.
- Protection of the outstanding geology of the area (protection measures have clear priority over both site development and presentation)
- Development of a best-practice institution for both geotourism and regional development
- Intensive cooperation with local communities and local small enterprises
- Full consideration of the local culture and customs and of existing sensitivities within the implementation of geopark infrastructure and programs, the preservation and enhancement of cultural identity
- Full consideration of the sensitivity of the landscape and scenery within the realization of the geopark infrastructure
- Full consideration of environmental and social issues
- Raising awareness of the population towards the recognition and protection of both the natural and cultural environment
- Establishment of geo-education in local schools
- Cooperation and networking with relevant stakeholders in Manisa, Kula and Salihli
- Development of regional marketing linkages (tourist-industry stakeholders)
- Participation in the UNESCO Global Geoparks Network

There are also strategic objectives within the general framework for design and implementation of geopark development, established according to the philosophy of the Global Geoparks Network, with reference to the general development approach of the Kula–Salihli Geopark, the overall goal being the sustainable development of the geopark area. These objectives are:

- Protection of geological heritage
- Creating visibility - development of a geopark infrastructure network

- Creating services - development of geopark visitor amenities and geopark information material
- Creating ownership - geopark cooperation with local communities
- Enhancing geo-education - communicating geology to the younger generation
- Continuous promotion and networking
- Development of regional marketing linkages
- Extension of the geopark territory

Since the geopark received the UNESCO label and became a member of the UNESCO-Global Geoparks Network, it has become an attractive tourist destination. Although, there are no definitive data, the total number of visitors to the geopark is estimated at 80,000 in 2018 and 92,000 in 2019. These figures are a measure of successful development of the geopark during the latter part of the 2010s, although the Covid pandemic is bound to have brought about a reverse in fortunes. The challenge for the third decade of the 21st Century will be to recover from this setback and continue the enhancement process.

5. Discussion

The Kula–Salihli Geopark has made significant contributions to the region in terms of education, scientific research, tourism, and sustainable local economic development since its establishment, in addition to its role as a geoheritage site. Volcanic geoheritage sites represent natural processes that have variously fascinated, terrified, destroyed and 'provisioned' societies with soil nutrients and other geological benefits (Erfurt-Cooper 2011; Aquino et al., 2019). Volcanism is of especially great public interest because of the human-scale timeframe of its activity and the highly visual effects of both its destructive and productive consequences. Thus, geoparks with active volcanoes and in areas dominated by recent volcanism are growing in popularity (Joyce, 2009, 2010a, b; Kazancı, 2012; Migon and Pijet-Migon, 2016a; Dóniz-Páez, 2020–1), with recent recognition of opportunities provided by such geosites for facilitating geotourism in regions not directly associated with active volcanism (Migon and Pijet-Migon, 2016b; Nemeth et al., 2017). The latest volcanism in the Kula region took place approximately 2.7 thousand years ago. Although there are no active volcanoes today, the volcanic landforms formed by the most recent volcanism retain freshness and majesty, making this a centre of great interest and attraction.

This discussion section will explore the context of the Kula–Salihli Geopark in relation to global representation of comparable geological interests as well as details of some of the initiatives listed in the previous section, as well as looking towards the future.

5.1. Global context

The Kula–Salihli Geopark is essentially a geoheritage site centred on volcanism, but with numerous supplementary interests, and in particular an excellent record of Quaternary fluvial and landscape evolution, as outlined above and which cements its credentials in relation to the theme of this special issue: 'Valuing the Quaternary: Nature Conservation and Geoheritage. The landscape evolution is closely related to the volcanism, with both disruption of the river system by lava eruptions and exceptional preservation of ancient (Early Pleistocene) fluvial archives by lava cap-rocks (Maddy et al., 2005, 2012a, 2017; Fig. 8). There are other examples of comparable records with such combined interests, including some from other parts of Turkey, although the combination of recent volcanic activity with ancient (early/pre Quaternary) records of volcanism and its interaction with other surface processes is an exceptional feature of the Kula locality. Thus the terrace sequence of the River Ceyhan, in the region of Düziçi, in the Amanos Mountains of central Turkey, shows interaction with Pleistocene basaltic lavas of the Ceyhan–Osmaniye volcanic field (Seyrek et al., 2008; Bridgland and Westaway, 2014). Similarly, the fluvial sequence of the Tigris around at Diyarbakır, SE Turkey, shows interaction with Lower Pleistocene lavas of the Karacadağ shield volcano (Bridgland et al., 2007; Westaway et al., 2009). Although a later phase of volcanism at Diyarbakır extended into the Late Pleistocene, neither of these examples includes Holocene eruptions and neither preserves evidence of multiple Early Pleistocene obliquity-driven terraces. There is a second Turkish example of river terraces related to obliquity cycles, in this case preserved by the early Quaternary Çakmaközü basalt of eastern Anatolia, which has been K–Ar dated to ~1.8 Ma (Demir et al., 2009). Located in the interior of the Anatolian plateau, these terraces represent the ancient River Murat, a tributary of the Euphrates, at around the Pliocene–Pleistocene transition. Although this is an exceptionally rare occurrence, it is not associated with later volcanism and study of the long-term fluvial record in the region is compromised by reservoir construction and resultant flooding of the valleys.

Looking further afield, Western Europe has two well-known centres of recently active volcanism, the Massif Central in France and the Eifel in Germany. In the former area, the most recent activity has given rise to the cones of the Chaîne des Puys, with the most recent eruption in the mid-Holocene. Part of the Auvergne Volcanos Regional Natural Park (IUCN Cat.V protected area), this is a World Heritage Site (https://whc.unesco.org/en/list/1434). Older volcanism in the Massif Central, associated with the Mont-Dore stratovolcano, is integral with recognition of a long Pliocene–Pleistocene fluvial record in the River Allier basin, constrained by reworked volcanic minerals and Ar–Ar dating of the interbedded in-situ tephras (Pastre, 2004). The Eifel enjoys UNESCO Global Geopark status (https://www.geopark-vulkaneifel.de/), with a significant geo-tourism component within its brief (Megerle, 2020). The record of Eifel volcanism extends from the Tertiary to the Holocene, with notable interaction with the River Rhine, including the provision of valuable geochronological markers in the form of interbedded tephra and reworked volcanic material within the extensive Rhine terrace sequence (Boenigk and Frechen, 2006; Cordier et al., 2009).

Long-timescale river-terrace sequences have been shown to be largely restricted to the temperate latitudes, where the interglacial–glacial climatic fluctuation that has driven their formation has been most profound (Bridgland and Westaway, 2008, 2014; cf. Büdel, 1977, 1982). This means that geosites sharing the combined interests seen at Kula will be rare elsewhere, although the preservational properties of resistant lavas have given rise to a notable example within the equatorial zone, in the case of the River Tana system in Kenya. Here Veldkamp et al. (2007) have reported on a long-timescale terrace system that can be dated with reference to Quaternary volcanic activity in the nearby Nyambeni Range, northeast of Mount Kenya. The Tana record includes volcani-clastic lahar deposits that preserve former valley floors of the Tana system, now perched high in the landscape, providing rare insights into former drainage patterns and armouring the landscape in a comparable way to the lava cap-rocks at Kula. The evidence is spread over a wide area, some of it within national parks and wildlife reserves, the principal rationale for which is the protection of biodiversity (www. http://www.kws.go.ke/national-parks).

An example from the temperate zone of the Southern Hemisphere is provided by Mount Ruapehu, the largest active volcano in New Zealand and the highest point in the North Island, which falls within the protection of Tongariro National Park, a UNESCO World heritage site. Its record of volcani-clastic deposition extends from Middle Pleistocene to Holocene and interacts with the fluvial archives of surrounding river systems (Tost and Cronin, 2016).

5.2. Geoconservation and sustainable development

The Kula–Salihli UNESCO Geopark underpins the effective awareness and development of geo-protection in the region. In this context, besides education and awareness-raising activities regarding the protection of geoheritage, geopark guards and security forces also contribute to the protection of some geosites. The Kula volcanoes constitute some of the most important sites of the geopark. These volcanoes are very young and fresh and so have attracted the attention of scientists and travellers since ancient times, constituting a highly notable landscape element for the Kula Region. However, these scoria cones were used as slag quarries before the geopark was established. Strict restrictions on the use of scoria cones were put in place following the establishment of the geopark, as a result of which the only local scoria quarry operations now being carried out are in non-geosite cones and within the scope of legal mining activities.

Before its establishment and in the early years of the geopark, another threat faced by the volcanic fields was the use of these areas as storage areas for solid waste. This was because local people perceived these areas as worthless, given that they could not use them for agriculture and animal husbandry. The benefits of these areas in terms of tourism, landscape and ecology were eventually acknowledged as a result of both the educational activities carried out by the geopark and the increasing tourism in the region. Indeed, the number of visitors to the Kula region was around 10,000 per year until 2014 but increased to 80,000 in 2018 and 92,000 in 2019 (from the Geopark Municipalities Union).

The region has become a main destination for professional tour operators, having been little known in terms of tourism previously. To this end, a number of educational activities and field trips focusing on the geological history of the geopark have been organized for tour operators. Field guidance training programmes have been organized within the scope of the cooperation of the geopark management and the Public Education Directorate and guided tours are organized by geopark staff for special-interest groups from universities or schools who require detailed academic information about the geology and history of the geopark area.

There are many information and interpretation panels promoting the geopark and particular geosites within it. İn addition, there are various types of digital displays in district centres that promote and advertise the geopark. All of these have contributed to the growth of tourism in the region and have increased local awareness of the importance of the geo-heritage enterprise.

Businesses such as restaurants, hotels and souvenir shops within the boundaries of the geopark are set up as certificated geopark partners, provided that certain criteria are met. Traditional Kula houses, previously belonging to the Kula Municipality, have been turned into private businesses offering special services such as hotels or cafeterias with the aim of developing tourism. Various sports and activities have been developed in the geopark area, such as nature watching, hiking, cycling and endurance events. All has been supported by numerous brochures and related documents that promote the geopark.

The Union of Geopark Municipalities aims to enhance the development and extension of rural tourism to the entire geopark area by means of infrastructure investment. In this context, as of 2021, construction of a Geopark Visitor Centre has commenced in the Kula Divlit Volcanic Park in Kula District and the restoration of two historical buildings in Adala is in progress. In addition, endeavours continue to achieve the protection of the Çakallar footprints in an on-site visitor centre at Salihli and the construction of a ‘tumulus demonstration exhibit’, in which all the features of a tumulus (similar to the Bintepeler tumuli) can be observed. These projects will contribute to the teaching of Quaternary geology and archaeology, to rural tourism in the region and to the sustainable economic development of the local economy.

5.3 Developments in Education

A number of initiatives exist under this heading. First, information is provided to local people and visitors about the goals and missions of the geopark through various information panels within the geopark area. Second, training is provided for people of different ages and interests on topics such as geotourism, geoprotection, geosites, geoparks and nature. Gender inclusivity is ensured, with training for women provided on subjects such as entrepreneurship, handicrafts and geotourism. In addition, women's cooperatives have been established in both Kula and the Salihli district, where various local products and items of handicraft are sold. Training on tourism and service quality are provided for tourism-related entrepreneurs, including proprietors of hotels, restaurants, etc. within the geopark area.

The establishment of the geopark has increased scientific interest in the region and a significant upturn in the number of related scientific research projects has been recorded. Summer schools associated with the geological features of the area have been established for children from primary to senior school age. These include introductury seminars on topics such as global climate change, earthquakes, floods, the importance of water and its economic use in the schools located in the geopark.

Within the framework of Geopark activation plan, the “Geopark education at school” programme has been initiated in 2021. In Turkey, which is an earthquake country, there has in recent years been an increase in the frequency of natural disasters such as forest fires and floods. Additionally, the effects of global climate change are being clearly felt. Of relevance to this, the terraces of the Gediz River within the Kula Salihli UNESCO Global Geopark provide an archive of Quaternary climate fluctuation and their study is of value in the understanding of global environmental change. Furthermore, in the Salihli part of the Geopark, the temples of Artemis and Sard provide data on tectonism, since they document the effects of past earthquakes.

5.4 Future management strategy

Long-term plans for the Geopark include the aim of opening a ‘Geoschool’ and research centre within the Geopark area. It is antcipated that future development of the geopark, with the support of the Union of Geopark Municipalities, will make important contributions to the popularization of Earth science and provide enhanced information about the Quaternary geology of the region for local people and visitors.

Currently, geotourism activities are actively carried out at 30 geosites within the geopark area. An aim over the medium and long term is to open up other geosites within the geopark to tourism as the geosciences become more popular. A significant proportion of the population formerly living in the region has migrated in recent years to the metropolitan cities in Turkey, leaving the local villages depleted of young people. It is hoped that the envisaged expansion of tourism within the geopark will initiate a reversed migrational trend, or at least stem further population exodus from the rural area. In fact, an effect of the Covid 19 pandemic has been a signficantly increased interest amongst Turkish urban dwellers in moving to rural areas, in parallel with many other parts of the world. It is anticipated that a parallel increase in the poularity of rural tourism, with geoparks playing an important role, will be part of the recovery from the pandemic. It is believed that the further development of geotourism in the Kula–Salihli Geopark will indeed contribute to the development within the region of other types of rural tourism.

5.5 Wider influence

Geoprotection is a relatively new development for Turkey, with the Kula–Salihli Geopark the first and the only UNESCO geopark in the Turkish World. Indeed, the situation in Central Asian Turkish States is significantly behind that in Turkey in terms of geoconservation and geotourism. A further goal for the Kula–Salihli Geopark is to support such development in these states, to which end representatives of the Kula–Salihli Geopark participate in an advisary role in meetings and field studies on geoprotection, geopark development and geotourism in Kyrgyzstan and Uzbekistan, where they share their knowledge and experience. An agreement to develop cooperation on geoprotection, geoparks and geotourism was signed in September 2021 between the Kula–Salihli UNESCO Global Geopark, Yangan Tau UNESCO Global Geopark (Russia) and other candidate geoparks in the Central Asian States (https://en.unesco.org/news/unesco-global-geoparks-events-central-asia). This took place at a meeting in Batken city, Kyrgyzstan, at which the instigation of Batken Geopark was agreed; this has varied geological strata as well as geomorphological features ranging from mountains to gorges and caves, with a high potential for geotourism. At a further meeting in Uzbekistan in November 2021 a candidate geopark at Kitap(Devonian / Lower Emsien) was visited. These recent developments illustrate the role of the pioneering Kula–Salihli UNESCO Global Geopark as an exemplar for comparable devlopments in the wider area.

6. Conclusion

The Kula–Salihli Geopark contains evidence of more than 200 million years of Earth history, from Paleozoic metamorphic rocks to prehistoric volcanic eruptions, and is therefore home to a very rich geodiversity. Included are structural geological history and Late Cenozoic landscape evolution, the latter exemplified by the incision history of the River Gediz and its tributaries, which has been strongly influenced by the volcanism that forms the primary geoheritage interest. The combination of Quaternary interests available is thus highly rare, if not unique. There is a significant overlap with archaeological interest in a region that has been occupied by humanity since early prehistory. Management of the geopark is undertaken in conjunction with socio-economic imperatives, including enhancement of the local economy, engagement with the younger generation, and environmental sustainability. There is a potential role for the geopark in the recovery of Turkey, and especially its rural regions, from the Covid pandemic, as well as in expanding geoconservation know how to adjacent regions in Central Asia.

Acknowledgement

The authors would like to thank the Geopark Municipalities Union and the Kula-Salihli Geopark staff for their contributions and supports in this study. The constructive comments of two referees and the special issue editors, which are gratefully acknowledged, have led to significant improvements in the paper.

Figures:

Figure 1. Location map of the Kula–Salihli UNESCO Global Geopark (Topographic data taken from SRTM)

Figure 2. Geosite map of the Kula-Salihli Geopark (Topographic data taken from SRTM, Geosite Map based on the Kula Salihli UGGp data).

Figure 3. A: Simplified tectonic map of Turkey showing major neotectonic structures (from Bozkurt, 2001) B: Tectonic structures of Western Anatolia (Aksu et al., 1987).

Figure 4. Simplified regional geology around the Kula–Salihli Geopark, based on the 1:500,000 scale Geological Map of Turkey (1973) and Seyitoğlu (1997).

Figure 5. Geology map of the geopark, showing its considerable geological diversity (Based upon the 1/100 000 Geological Map of Turkey).

Figure 6. An example of the most recent eruptions of Holocene volcanism at Kula: the Sandal scoria cone and associated lava flows (looking north) (Photo by Kula Salihli UGGp)

Figure 7. (A) general view from the current Gediz floodplain looking north-west to the Burgaz and Sarnıç- plateaux; (B) exposure of river deposits showing Early Pleistocene palaeo-Gediz terrace gravels beneath limestone-rich alluvial fan gravels, which are capped by Lower Pleistocene basalts (Burgaz Volcanics) (Photos By Darrel Maddy).

Figure 8. A Detailed map of the interpolated buried terraces of the Gediz (Adapted from Maddy et al., 2005). B. Schematic section showing the Burgaz Bagtepe flows capping the terrace and alluvial fan sediments along the transect A'–A across the Burgaz plateau, the end points being shown in part A (after Maddy et al., 2005). The base of the lava flow represents the contact of the volcaniclastic sequence with the underlying fan sediments. The stepped line represents the base of the terrace sediments, i.e. the contact between the Ahmetler Formation and the various palaeo-Gediz gravels.

Figure 9. A. Travertine promontory at Palankaya, looking due east. The positions of faults are indicated with red arrows. Clear scarps associated with faults are shown with offset direction indicated (after Maddy et al., 2020). B. Quarry exposure in one of the travertine mounds in the geopark; the travertine is quarried for the industrial aims (Photos By Darrel Maddy).

Figure 10. A and B: Examples of classic 'badlands' geomorphology, arising from the rapid erosion of the soft unconsolidated strata during high-rainfall events; this is particularly seen where the overlying lacustrine Ulubey limestone has been removed and erosion of the underlying sands and silts of the

Ahmetler Formation has formed classic landforms such as these ‘fairy chimneys’ (Maddy et al., 2007, 2008).

Figure 11. Outcrop of Gediz palaeomeander deposits in which a Lower Paleolithic artefact was discovered (a struck flake made from a quartzitic rock), beneath a final filling of slope-derived material. Approximate bounding surfaces delimit six Pleistocene units (1-6) overlying the Miocene Ahmetler Formation. The inset shows a close-up of the hard hammer flake, showing (in profile) classic features including the bulb of percussion and subdued Z-shape (from Maddy et al., 2015).

Figure 12. Holocene prehistoric human footprint, Çakallar volcanic area (Photo by Kula Salihli UGGp).

Figure 13. The ancient city of Sardis (Sart); Dating from ~1000 B.C., this was the capital of the Lydian kingdom, the Provincial Centre during the Roman Period and the Episcopal Centre in the Byzantine Period (Yükçü and Gönen, 2013). A. The remains of the city. B and C. The Temple of Artemis, which has been exhumed by archaeological excavation from beneath slope deposits at the southern edge of the Gediz Graben., having been completely buried beneath except for the upper parts of two columns (thus providing a measure of erosion and deposition over the past 1500 years (Ürer, 2009).

Figure 14. The Thousand-hills (Bintepe-in Turkish), the largest burial area in Turkey (~74 km2), comprises 119 tumuli of various dimensions, some of the largest linked to Lydian kings of ~1000 BC. (Photo by Kula Salihli UGGp)

Figure 15. Kula–Salihli Geopark Management Structure

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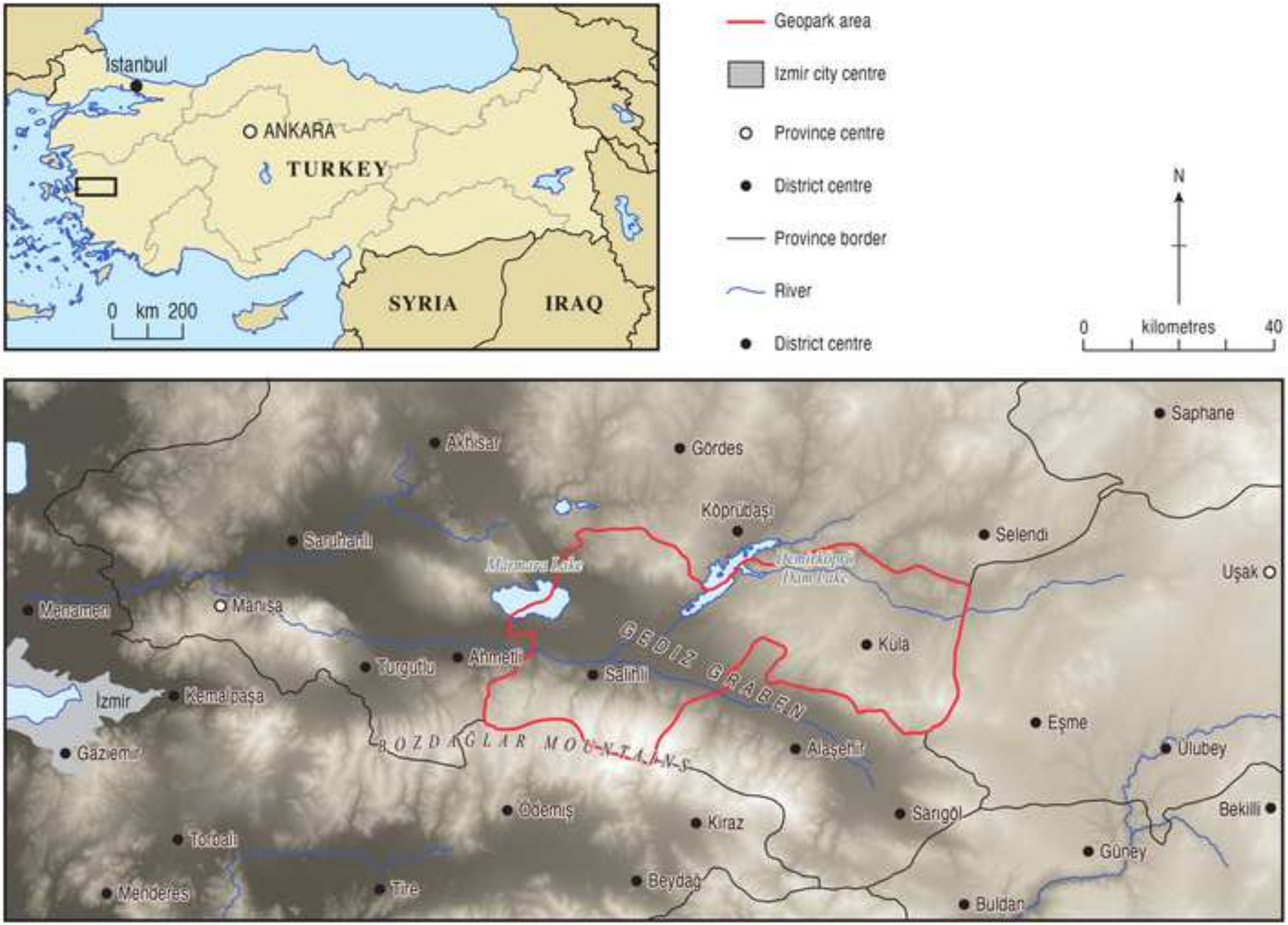

Istanbul
ANKARA
TURKEY
SYRIA
IRAQ
0 km 200
Geopark area
Izmir city centre
Province centre
District centre
Province border
River
District centre
N
0 kilometres 40
Saphane
Akhisar
Gördes
Köprübaşı
Selendi
Saruhanli
Marmara Lake
Demirköprü Dam Lake
Uşak
Menemen
Manisa
Kula
GEDIZ GRABEN
Turgutlu
Ahmetli
Salihli
Izmir
Kemalpaşa
Eşme
Ulubey
Gaziemir
BOZDAGLAR MOUNTAINS
Alaşehir
Ödemiş
Kiraz
Sarıgöl
Bekilli
Torbalı
Güney
Menderes
Tire
Beydağ
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N
Hacıhıdır
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Akoren
Taytan
Durasılı
Esenyazı
Kula
Evciler
Mersindere
Sart
Salihli
Hayallı
Hacıtufan
Tatlıçeşme
Başlıoğlu
Allahdiyen
Hacılı
Gökköy
Burhanköy
Çarıkballı
Yeniköy
Geopark area
Kula Geopark Museum
Kula Divlit Volcanic Park
Salihli Town Museum
Villages
Izmir-Ankara road
0 kilometres 10
1 Urban architecture of the Kula town
2 Kula Divlit Lava Cave
3 Kula Divlit Parasite Cones
4 Kula Divlit Lava Flow
5 Kula Divlit Spatter Cones
6 Kula Divlit Volcanic Cone
7 Yetik Schist Topography
8 Hacıtufan Quartzite Vein
9 Elekçitepe Rock Tombs
10 Evciler Schist Topography
11 Evciler Village Architecture
12 Evciler Badlands and Fairy Chimneys
13 Elekçitepe-Hacıhasan Lava Flow Platform
14 Evciler Volcanic Canyon
15 Dereköy Lava Cave
16 Tabala Castle Mesa Structure and Roman Castle
17 Kula Fairy Chimneys
18 Homo Erectus Valley
19 Burgaz Lava Plateaux and Terraces of the Paleo Gediz River
20 Şehitoğlu Badlands
21 Kav Tepe Volcanic Neck
22 Sarnıç Contact Metamorphism and Palaeozoic Layers
23 Karayar Dike
24 Thermal Theos Hot Springs and Rock Sculptures
25 Cakırca Columnar Basalts
26 Dereköy Volcanic Canyon
27 Dereköy Waterfall
28 Acısu Ofiolite
29 Acısu Hot Springs and Kaenolit
30 Hoca Seyfettin Bridge
31 Ancient Kollyda (Gölde) Village Architecture and Cisterns
32 Saraçlar Base Surge Structure
33 Saraçlar Horseshoe Volcanic Cone
34 Sandal Divlit Lava Cave
35 Bağtepe Divlit Volcanic Cone
36 Plant Succession on Volcanics
37 Sandal Divlit Volcanic Cone
38 Çukurada Maar
39 Sandal Divlit Lava Flow
40 Küçük Divlit Volcanic Cone
41 Sacred Tomb of Yunus Emre and Tabduk Emre Caruhan Bin Süleyman Mosque
42 Encekler Rock Tombs
43 Palankaya Roman Settlement
44 Harmanyeri Doline
45 Palankaya Columnar Basalts
46 Börtlüce Karstic Cave
47 Kaplan Divlit Volcanic Cone
48 Kaplan Divlit Lava Cave
49 Kaplan Divlit Lava Flow
50 Gediz Graben
51 Adala Volcanic Canyon
52 Suuçtu Waterfall
53 Kız Köprüsü Bridge
54 Çakallar Prehistoric Fossil Human Footprints
55 Çakallar Divlit Cinder Cone
56 Kanlıkaya (Bloody Stone) Prehistoric Rock Paingtngs
57 Gökeyüp Pottery
58 Viticulture
59 Damatlı Village
60 Karadut Fault
61 Tmolos Deposits
62 Kurşunlu Hot Springs
63 Kurşunlu Waterfall and Present Travertine Formation
64 Hydrothermal Alteration of Tmolos Deposits
65 Kurşunlu Valley
66 Urganlı Geothermal Resources
67 Tabak River Potholes
68 Çamurhamamı (Mud Bath) Hot Springs
69 Kışık River Ancient Quarry
70 Sardis and Temple of Artemis
71 Bintepeler (Thousand Hills)
72 Marmara Lake
73 Kemer Village

Figure

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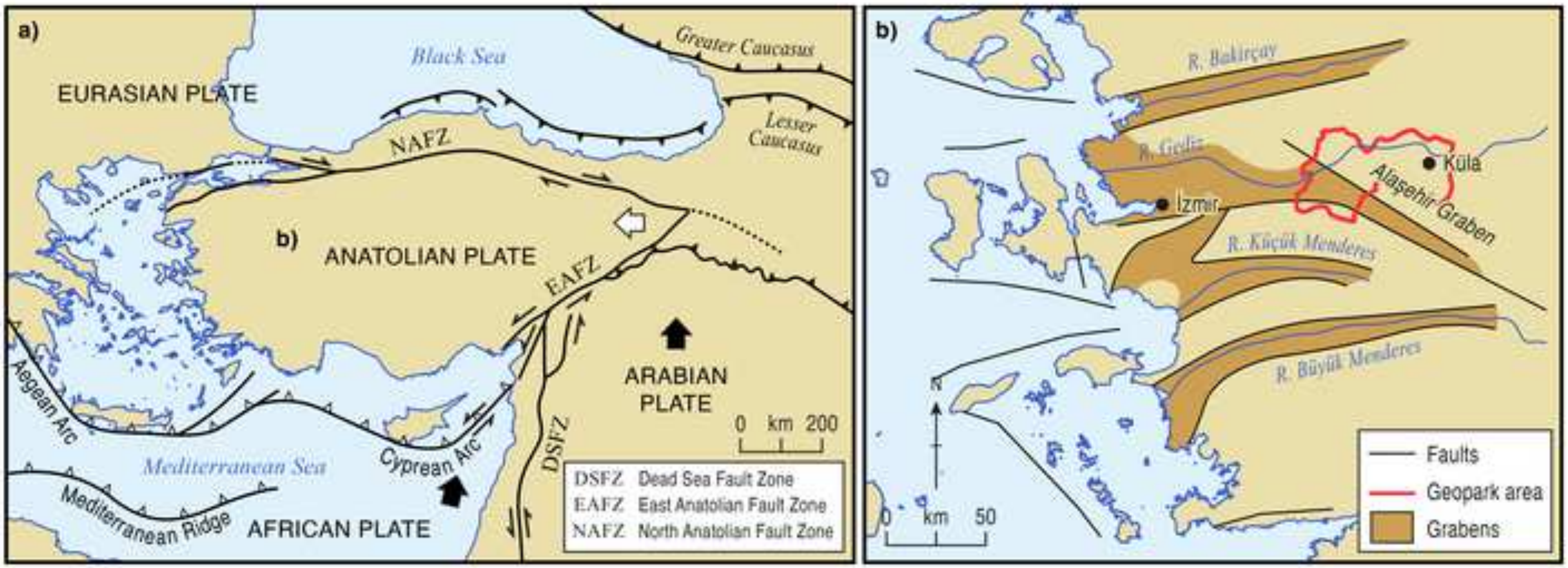

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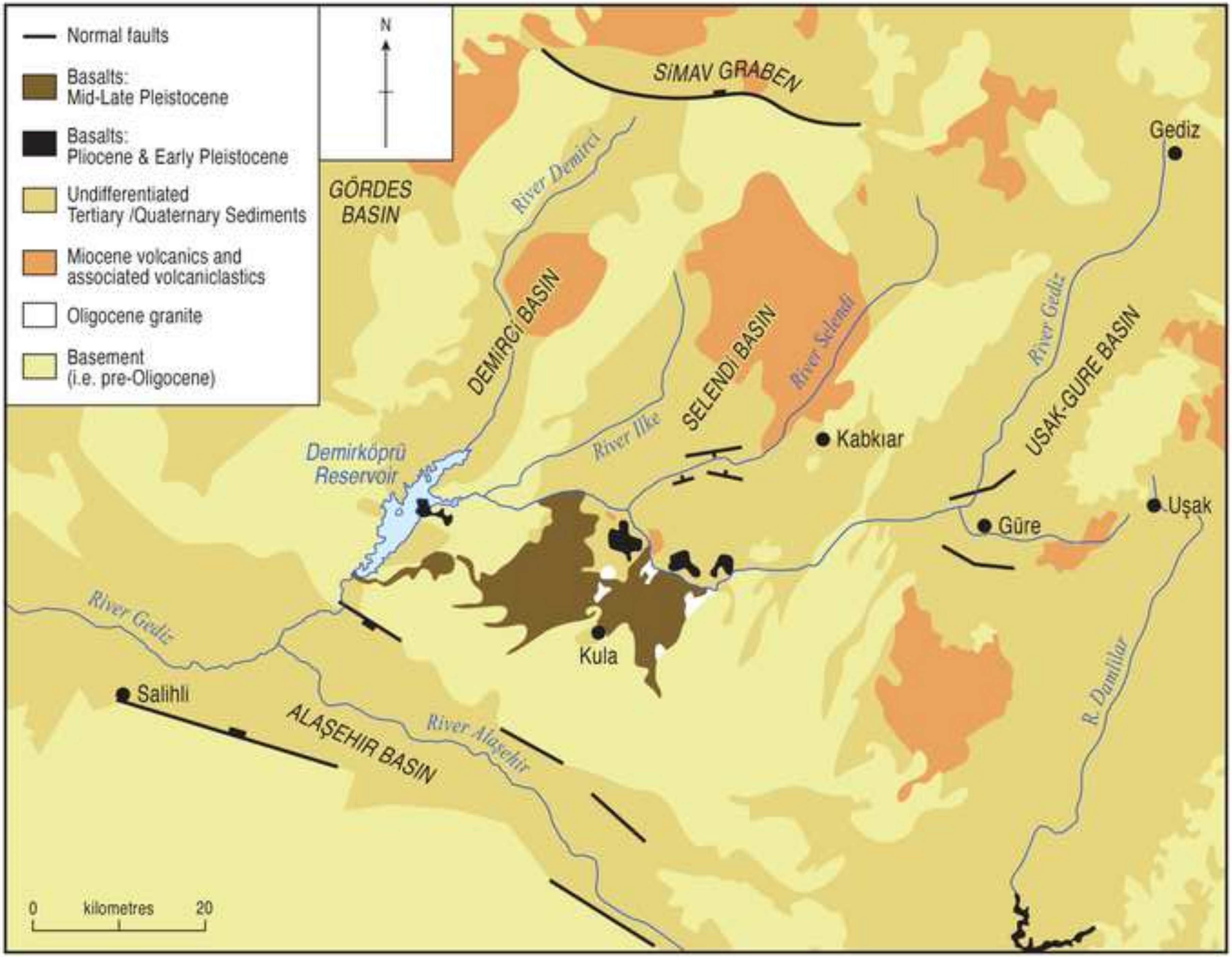

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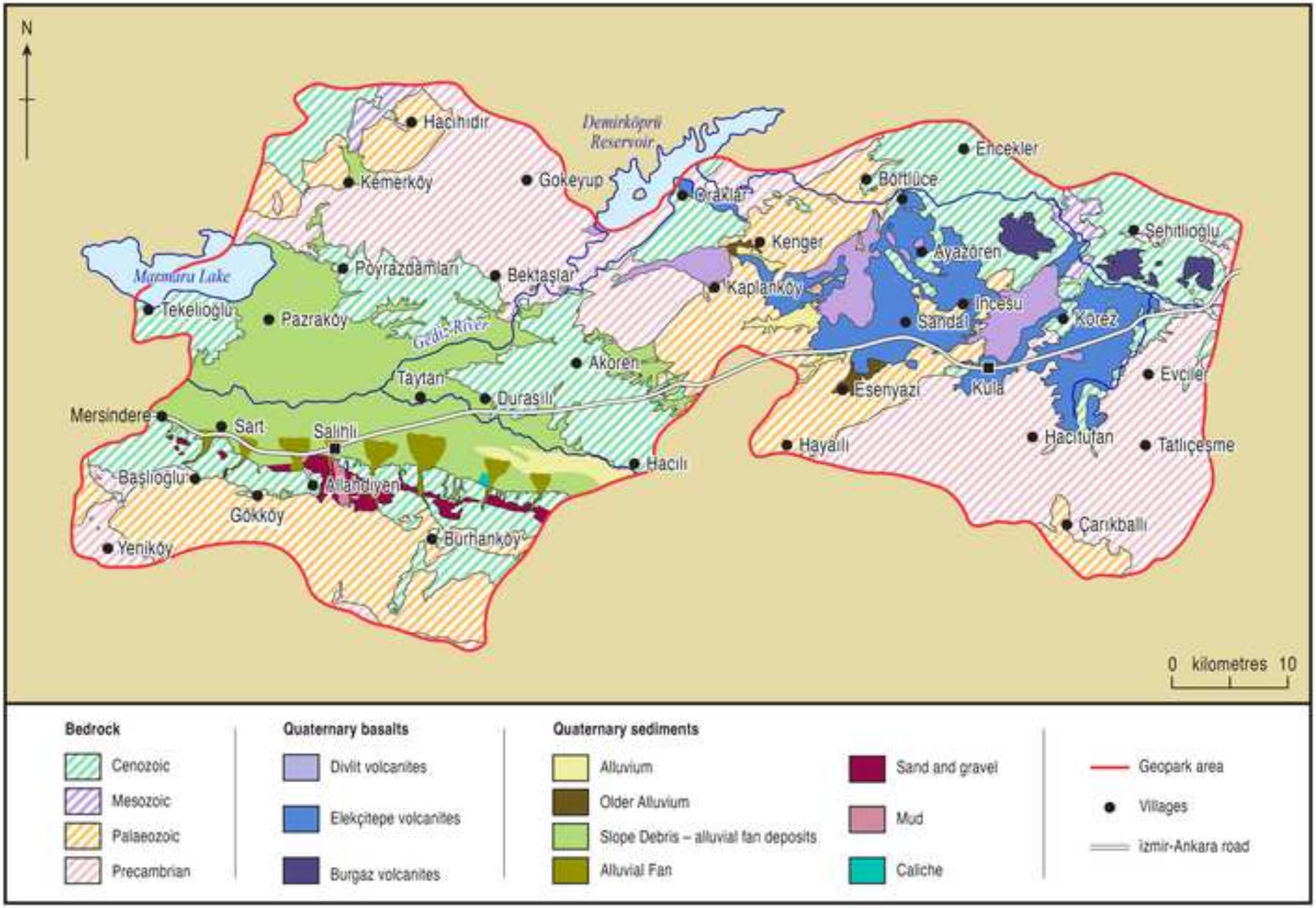

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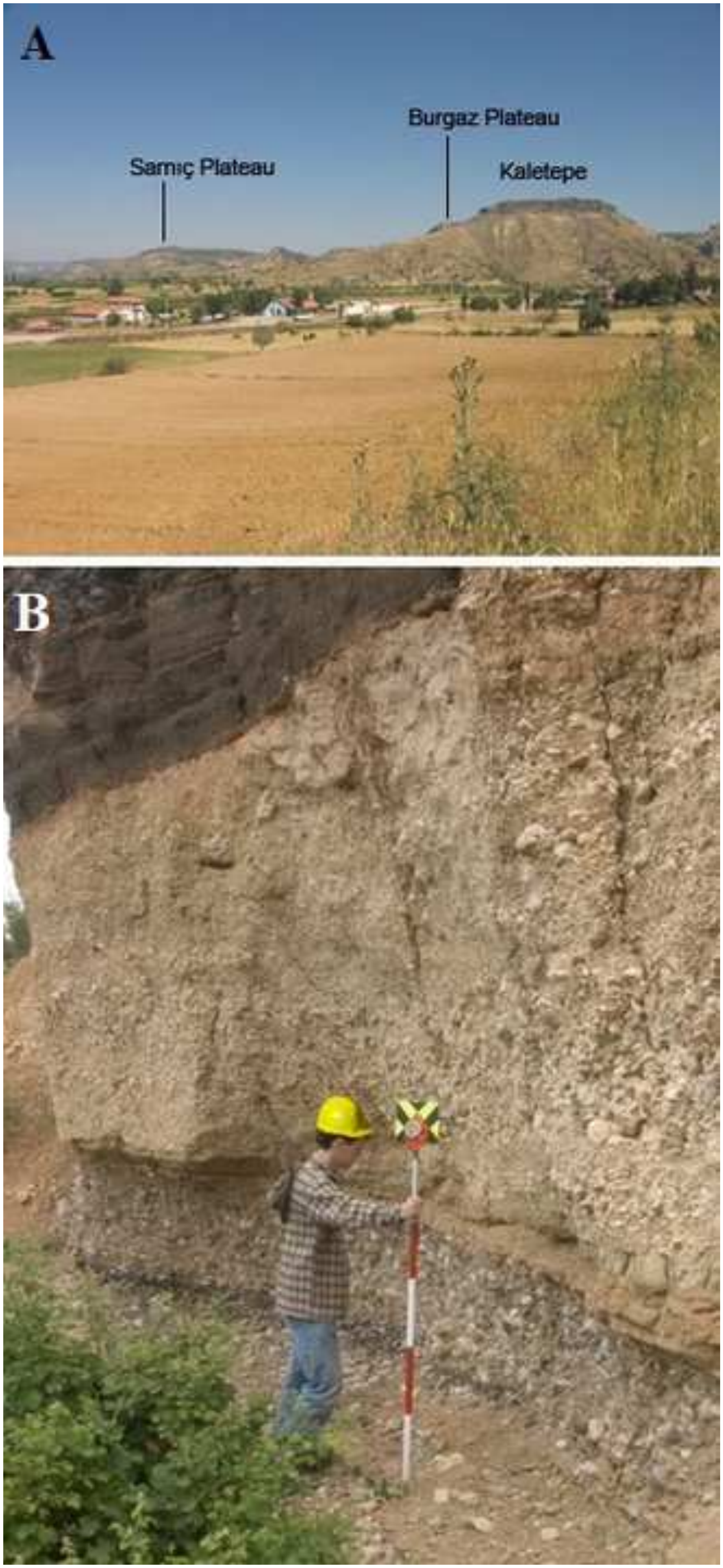

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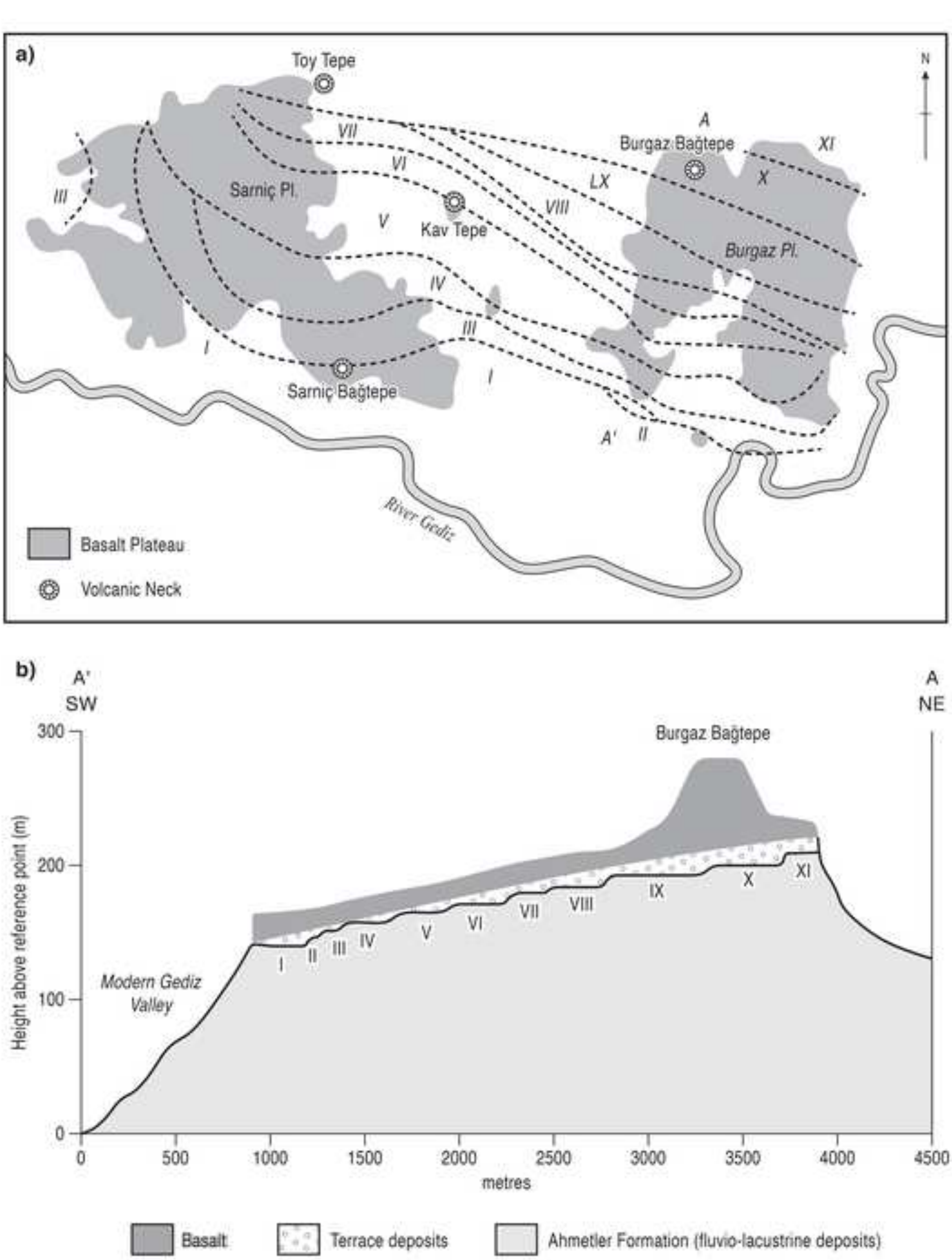

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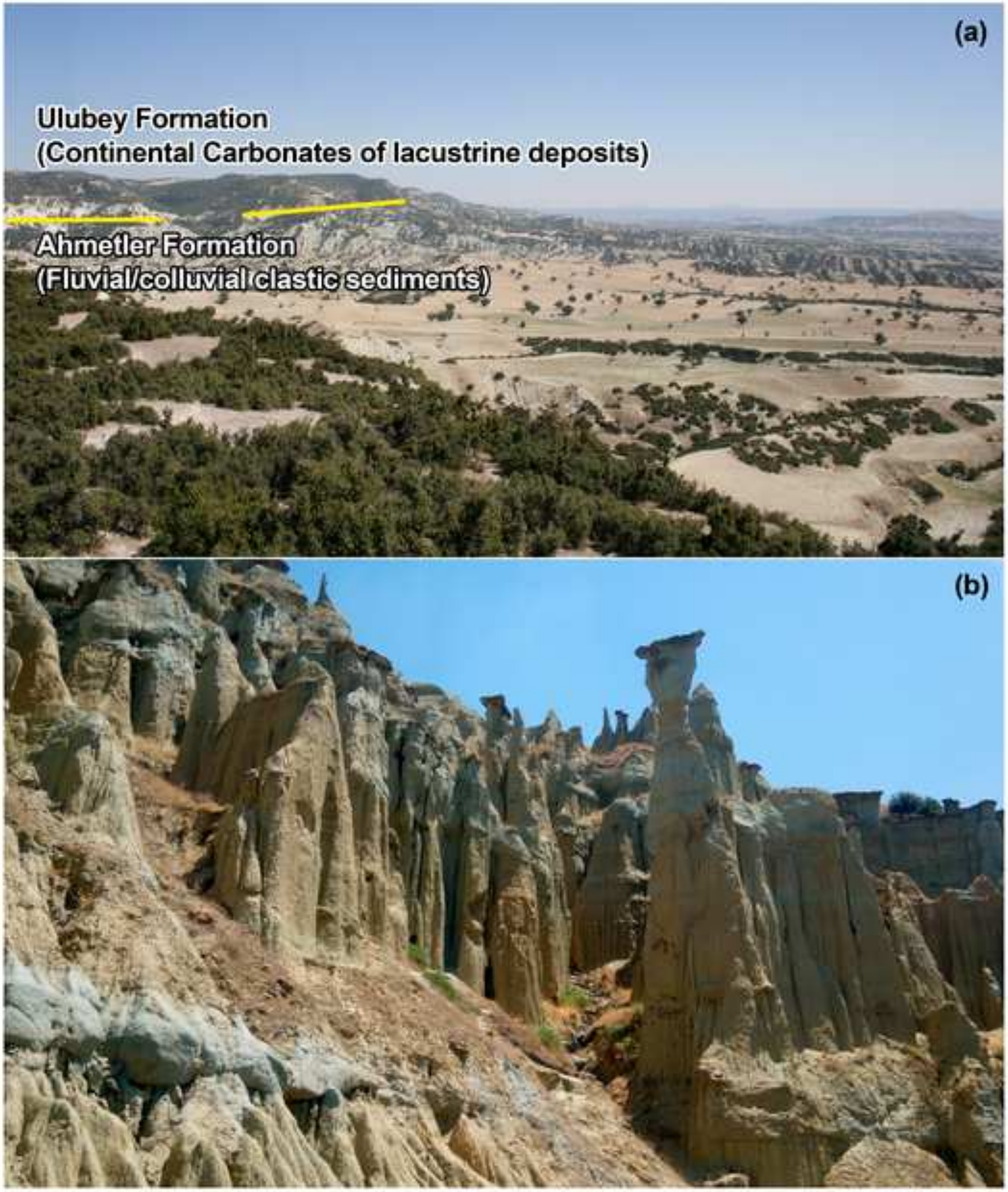

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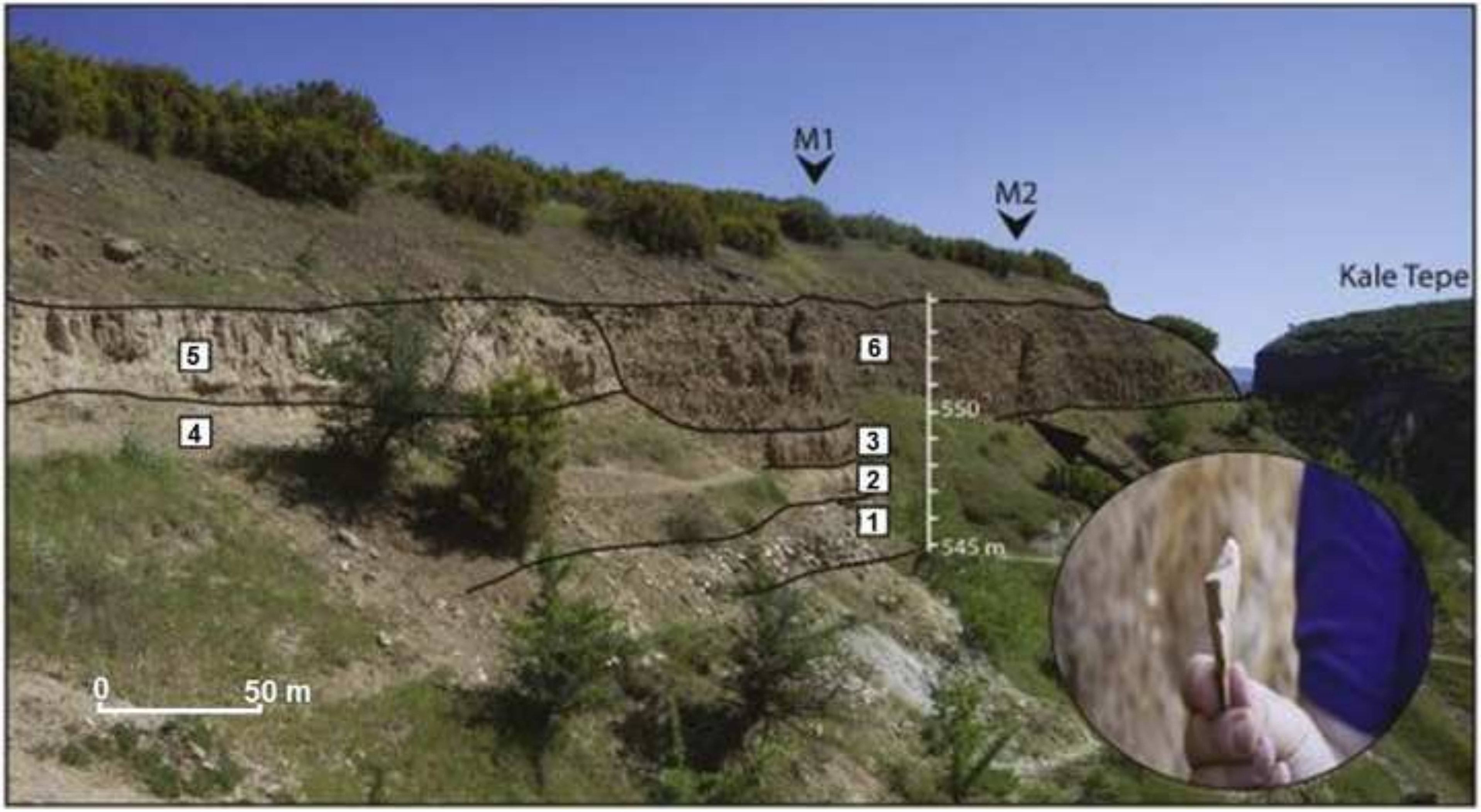

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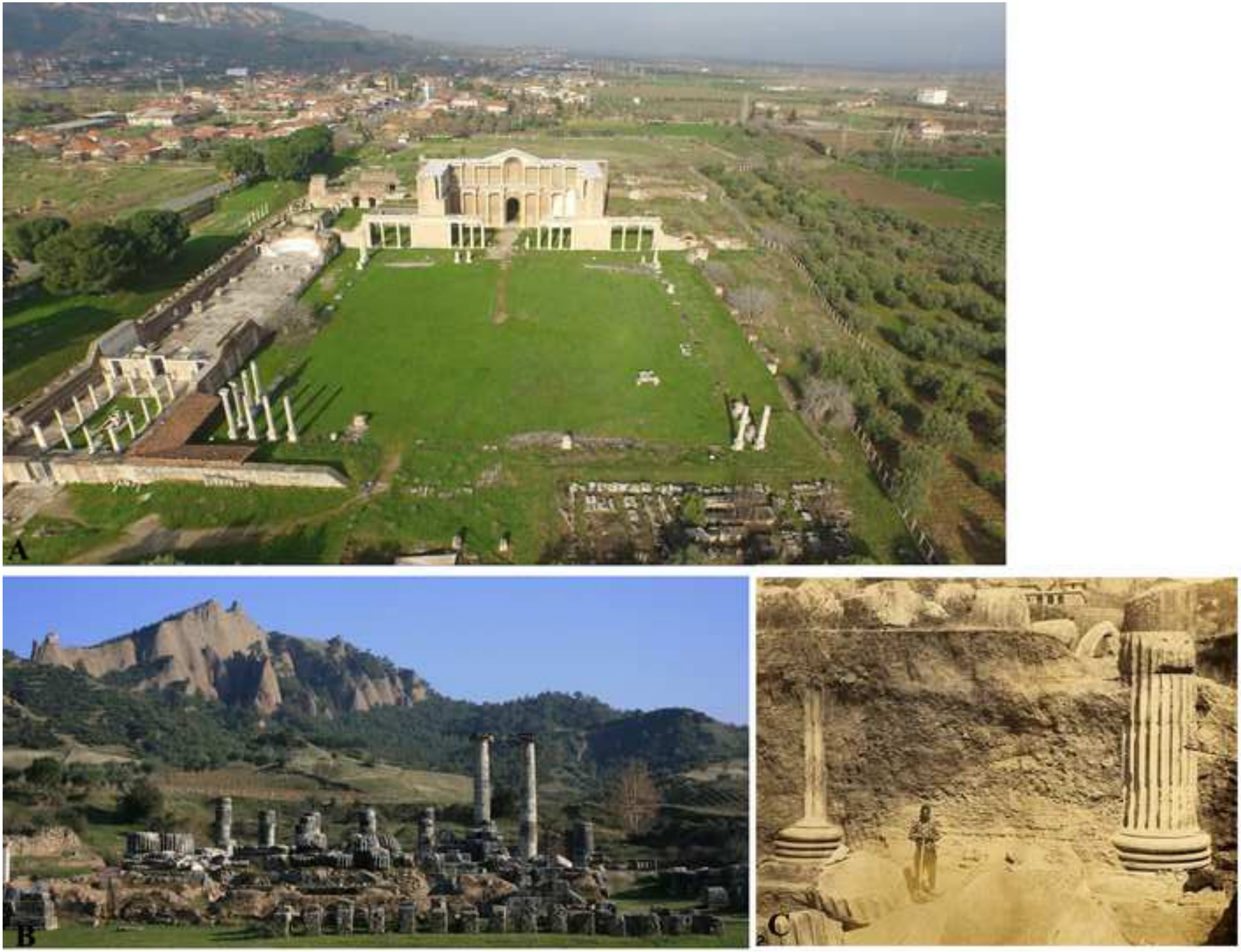
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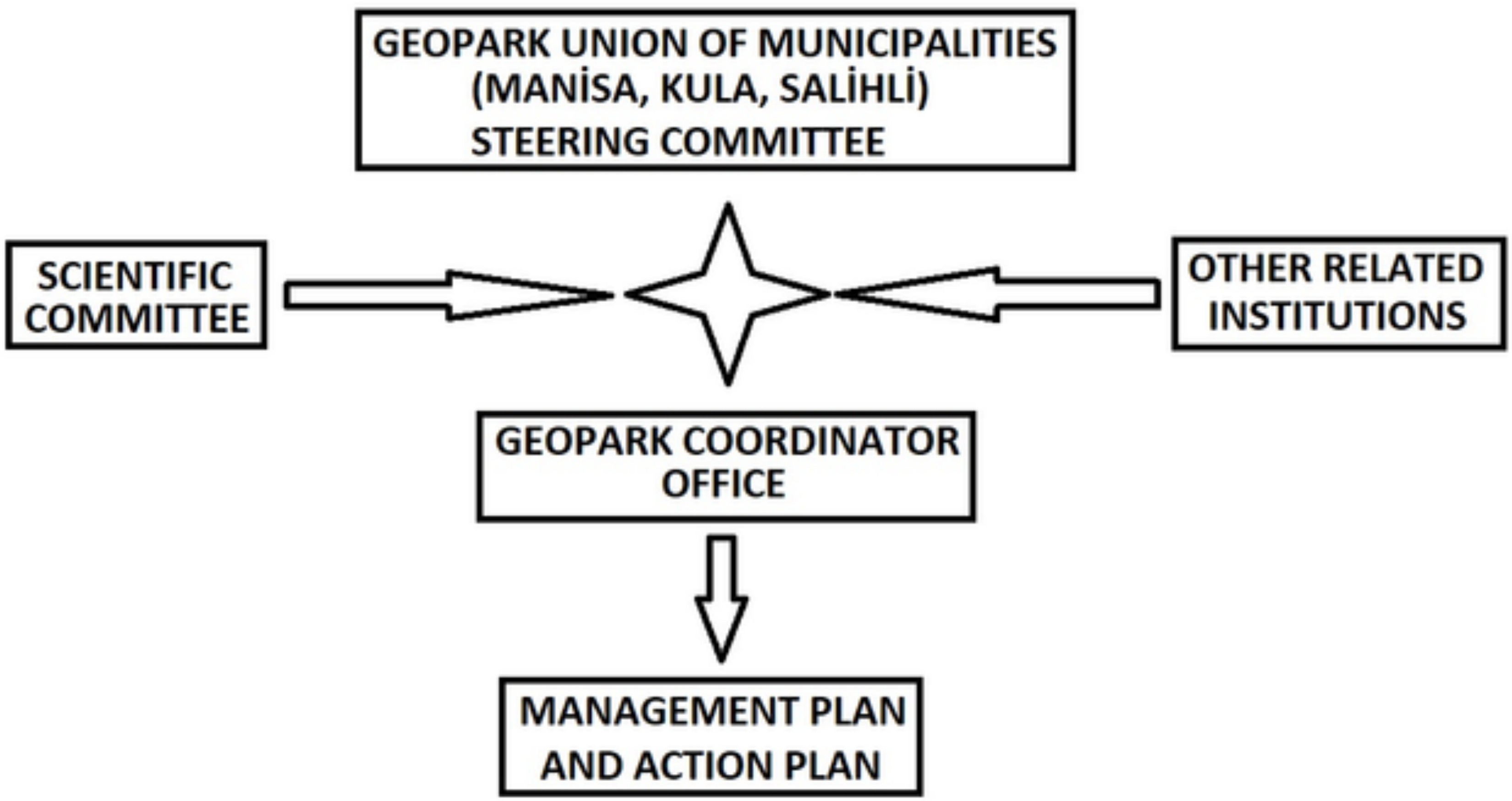
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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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