The abandonment of the Decapolis region in Northern Jordan—forced by environmental change?

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Abstract

The Decapolis region in Northern Jordan flourished during the Roman, Byzantine and Umayyad period, leading to the construction of great monuments. They are very well preserved, because the region was abandoned in the 10th century AD and no significant resettlement took place. Earthquakes, diseases and political reasons are in general thought to be responsible for this development. However, rain-fed agriculture was the economic basis of the Decapolis cities, and only a surplus in production made their wealth possible. Thus environmental change, caused by mismanagement or climate change, could have been responsible for the abandonment of the area. Historical land use reconstruction and soil analysis are well-suited to prove environmental changes. Mismanagement should have left erosion on the plateau and colluvial substrates in the valleys, while a change of climate should be detectable in a differentiated soil genesis and indirectly by assessment of agricultural productivity of land use change. The analysis of the land use pattern and the study of soils at the Decapolis city of Abila indicate that a climate change had great influence in the abandonment of the site. In this context land use, soil development and local climate are important interrelated site factors.

1. Introduction

The ruins of the Decapolis cities in Northern Jordan are very famous and important places for cultural tourism. Their fame is due largely to the fact that much of the ancient building substance from the Roman, Byzantine and Umayyad periods has been preserved, as it has not been reused in later construction activities (Hoffmann and Kerner, 2002). This is due to the nearly complete abandonment of the region in the 10th century AD (Fuller, 1987; Geraty and Herr, 1989). Rain-fed agriculture in the vicinity formed the economic basis of the Decapolis cities (Fuller, 1987). Agriculture in this region must have exceeded subsistence economy and produced a considerable surplus, able to supply food to huge cities (up to 12,000 individuals in Abila) and also the construction of impressive buildings (Fuller, 1987; Fahlbusch, 2002).

The causes of the abandonment are still unknown. However, various authors suggested environmental reasons for this process (Huntington, 1911, 1915; Lowdermilk, 1944; Butzer, 1961; Fuller, 1987; Brentjes, 1994; Brown, 1998; Issar, 1990, 1998; van der Steel 2002; al-Shorman, 2002a). From this, three theories can be generalized: The first theory suggests a combination of political reasons, earthquakes and human diseases to be responsible (Walmsley, 1992). The second theory argues that mismanagement caused the exodus (Lowdermilk, 1944; Butzer, 1955, 1961), while the third theory postulates a medieval climate change (Huntington, 1911; Issar, 1990, 1998, 2003).

If there was an environmental change, this should be detectable in changes of the land use pattern and in soil development. The combination of land use and soil analysis provides relevant insight into environmental history. This methodology has indeed been successfully
applied in Middle European Archaeology (Born, 1980; Steensberg, 1980; Willerding, 1980; Fries, 1995a,b; Beran and Hensel, 2000), but not in the Mediterranean and Near East (al-Saad and Sari, 2003). The present investigation is one of the first attempts to apply the methods of land use and soil analysis in these regions (Pustovoytov, 1999; Lucke, 2002), with a particular focus on the site of Abila and the theatre of Capitolias (today Beit Ras). The methodology had to be adapted to the prevailing site conditions of the Mediterranean. However, this methodological approach was utilised for the Decapolis region by Lucke (2002). The Decapolis region is an important area for the reconstruction of environmental history, as the close vicinity of the desert causes climatic fluctuations with large impact. A better understanding of the past will allow the development of strategies for future sustainable land use and help to improve knowledge about climate and its impacts.

2. Study sites and methods

2.1. The site of Abila and the theatre of Beit Ras

Research was carried out at the site of Abila and the theatre of Beit Ras. Abila was chosen because of its minimal disturbance with regard to building activities. The closest modern settlement, the village of Hartha, lies ca. 2.5 km to the northwest and modern activities at the site are restricted to agriculture and excavations. Additionally, the specific settlement history is fairly well known (Table 1), and archaeobotanical and ethnoarchaeological findings are available (Fuller, 1985, 1987; Fuller and Fuller, 1992). The site is situated in Northern Jordan (Fig. 1) approximately 16 km north of the modern city of Irbid and ca. 5 km south of the Yarmouk River (which is today the border with Syria) on a gently sloping plateau of limestone formations, at the crossing point of two small wadis (Fig. 2). The highland around Abila gives the impression of a vast, gently undulating plain, dissected by several wadis with steep slopes (Fig. 3). The wadis are cut deeply into the soft rock, predominantly dry during the summer and too deep and narrow to be used by agriculture to a significant extent. Many wadi slopes are very steep with an angle of 40–80° and nearly bare of vegetation, while a grey and white substratum, mixed with gravel and stones, is present in the valley’s bed. Essentially all wadis are very narrow, allowing cultivation only at limited places where the valley floors widen. There, usually non-irrigated orchards are grown. These are supplied with abundant water during floods after the winter rains. The spring water of a once-perennial stream in one of the wadis at the site of Abila is pumped for the supply of nearby villages, leaving the wadi dry in summer. In contrast, the plateaux are under intense cultivation. Due to gentle slope degrees, there are no terraces. The plateaux are characterised by the intense red colour of soil, and look like a vast red-coloured plain that extends to the horizon. Except for large olive tree plantations, no other trees or forests are present. On the fields, rainfed cereals and vegetables are grown.

Capitolias/Beit Ras lies 10 km south of Abila, situated on a hill overlooking the plateaux of the highland. Its

![Fig. 1. Location of the investigation area in Jordan.](image-url)
recently discovered huge Roman theatre was used as cistern in the Byzantine period, and hence was filled with alluvial layers of sedimentation after the abandonment of the site. These are paired layers of dark and bright greyish colour, seemingly representing winter and summer seasons. The theatre lies at the bottom of the hill’s northern slope (Fig. 4), providing an obstacle for sediments carried down from the ruins of the ancient city.

2.2. Methodology: land use examination and soil analysis

Historic land use patterns allow for the reconstruction of the relevant agricultural technology and practice as well as for an assessment of the site productivity. Changes in the pattern of land use may provide insight into changes of the environment. To some detail the historic land use pattern was reconstructed according to air photos, maps and field visits. However, with regard to site productivity of the region only the present agriculture was evaluated.

Soil samples were collected both in the vicinity and inside the ruins of Abila. The aim was to gain an overview of the general soil properties and to identify relict surfaces. In the theatre of Capitolias/Beit Ras, only selected substrates were sampled. For collection of the samples, small plastic containers were filled with soil from a ca. 5 cm thick band in the middle of a defined layer/substrate. On the plateaux and in the wadis, holes were dug and the samples collected from freshly opened profiles. In existing excavation trenches, the covering 5 cm of substrate were removed to exclude influence from material washed down from above. As it was occasionally impossible to determine the exact depth in the excavation trenches, these sampling layers were numbered and their thickness was measured. Determining the correct depth of an excavation trench is sometimes difficult due to the excavation practice of digging several holes with different depths. The samples were analysed for texture, pH-value, as well as for nitrogen, calcium, carbonate, sulphur and phosphorus content. The phosphorus content was analysed in those soil samples for which an agricultural land use seemed likely. As the agricultural test areas were examined after heavy rains, the water content was also analysed by weighing the samples before and after 72 h of drying at 105 °C. The pH-value was measured potentiometrically with a glass electrode in distilled water. The calcium content was determined using a Scheibler-Apparatus according to Schlichting et al. (1995), while the content of carbon (C), nitrogen (N) and sulphur (S) was measured with the elemental analysis apparatus Vario El, which allows full automatic gas-chromatographic measuring. For analysis of the phosphorus (P) content
the samples experienced pressure decomposition according to Loftfield (Bock, 1972), allowing photometric measurement with the molybden-blue method according to Murphy and Riley (Schlichting et al., 1995). The texture was determined using wet sieving according to DIN 19683 (1973), while the smaller particles were measured with a laser diffraction device (HRLD Mode Sympatec) according to ISO 13320-1 (1999). Before sieving, the samples were treated with abundant hydrochloric acid (HCl) to eliminate carbonates. The hydrochloric acid was evaporated again and the sample was dispersed with natrium pyrophosphate solution (Na₄P₂O₇) to eliminate organic matter. Before measuring with the laser diffraction device, the samples were additionally exposed to 60 s of ultrasound to destroy any agglomerations.

3. Results and discussion

3.1. Land use

This study revealed that the present intensive land use prevented the preservation of relict patterns, for example under former forest cover. Also in literature, only little is known about the ancient land use in the Decapolis region. Here the most valuable sources are travel reports written in the 19th century (Seetzen, 1854; Schumacher, 1890). These authors indicate that the area was densely forested with the stone-oak (Quercus petraea) and tabor-oak (Q. itharburensis), but as the population grew quickly after reforms in the Ottoman Empire, the wood was cut for heating purposes (Schumacher, 1890). Also archaeological excavation reports allow insight into former land use. Carbonised seeds from ancient graves recovered by flotation during the 1982 and 1984 excavations at Abila consisted of olive, barley, wheat, grape, lentil, pea, bitter vetch, wild plum, hackberry and date palms (Fuller, 1987). In comparison, today olive trees, sunflowers, tomatoes, okra, eggplant, melons, barley, cucumber, tobacco, black mustard and wheat are cultivated on the fields (Lucke, 2002). This indicates a land use very similar to antiquity, as plants like eggplant were not available before the Arab conquest reached India. In ancient times Abila was famous for its wine grapes, as coins and grave paintings show (Wineland, 1992). There may have been a complex network of cisterns and small irrigation dams produced from local cores on the plains near Madaba (Geraty and Herr, 1989), but this cannot yet be confirmed for Abila, although there are ancient cisterns on the fields (Lucke, 2002; Fig. 5). However, overall only little is known about the land use system and technology in the Decapolis region. For example, the ancient ploughing technique is not known. Field visits and the study of air photos revealed long fields at Abila, which could be inherited from the ancient pattern; these observations point to the use of a medieval heavy plough (Fig. 6). This would be surprising for the Near East, because the heavy plough was usually used primarily under moist site conditions. Nevertheless, the use of heavy ploughs is also indicated by other findings in the Carmel Mountains in Israel (Kuhnen, 1989). The present information does not allow for any conclusions on how environmental history might have been influenced by land use or for an assessment of the productivity of ancient agriculture.

Analysis of the present land use of the region found that crops are highly dependent on rainfall patterns. Therefore, farmers do not usually decide before the first rainfalls which crops to sow (Lanzendorfer, 1985). If there are no well-distributed rains at the beginning of the rainy season a hard drought crust is likely to form in the summer heat, impeding germination of most crop seeds. Additionally, harvest is endangered if there are no late rains with regard to the growing season. As well, excessive rains are reported to be of disadvantage, since the soil becomes elastic and hence the field work difficult (personal communication, farmers in the village of Hartha close to Abila, December 2001). Similar problems of ancient agriculture are reported from Old Testament sources (Borowski, 1987). If there is sufficient and well-distributed rain, productivity is quite good (Lanzendorfer, 1985). There are a small number of perennial streams, all fed by rainwater, and thus irrigation is theoretically possible at some locations. However, the only spring close to the site of Abila is pumped to supply drinking water to the nearby villages, leaving no water for irrigation in the wadi. The next perennial water sources are located in the Wadi Ain Ghazal approximately 3 km south-east of Abila, and in the Yarmouk valley in the north. This water is not used for irrigation, as height differences of 240–300 m to the...
plateau, very steep slopes and the narrow valley floors make irrigation difficult, if not impossible.

The water of the spring Ain Queilby located approximately 1.2 km south of the site of Abila was channelled in antiquity by two underground aqueducts. The water was conducted to a nymphaeum in the centre of the city, close to a bath. Another underground aqueduct extended ca. 5 km south up to a spring at the modern village Khureiba (which is today also pumped). There are indicators that a fourth aqueduct brought water from the west (Fuller, 1987; Wineland, 2001). According to Wineland (2001), the Khureiba and upper Ain Queilby aqueducts were cut through the soft rock during the Late Roman period, while the lower Ain Queilby aqueduct was probably build already in the Iron Age or Hellenistic period. Fuller (1987) calculated the water transporting capacity of the Ain Queilby aqueducts and found it to be 100 times greater than the present flow of the spring. This could mean more water was available in the past, but the size of the tunnels could also be related to construction requirements. In any case, it can be assumed that the spring water was completely channelled for the supply of the city, and more water was brought from distant springs, supporting up to 20,000 people (Fuller, 1987). The aqueducts carried the water in underground tunnels directly to the centre of the city, so it was not available for irrigation.

Before construction of the aqueducts, the population of the city had to carry the water up from the perennial stream in the wadi or to rely on rainwater collected in cisterns. There is also evidence for numerous cisterns on the plateaux, which seem to be related to ancient farmsteads. It is possible that cisterns were also used to collect water for irrigation, but we assume their primary purpose was to supply drinking water as there is no other water source on the plateaux. Although the exact density of cisterns on the fields is as yet unknown, it seems that irrigation from cisterns was only possible for horticulture related to farmsteads (Geraty and Herr, 1989). Water channels observed close to cisterns are usually understood to carry water from roofs, etc. to the cistern and not to distribute it from there (Fuller, 1987). Additionally, both spring water recharge and the filling of cisterns at Abila fully depend on rainfall. Thus it is assumed that irrigation in ancient times was similar to today and played no major role for agriculture.

As irrigation is minimal and strong winter rains are common, salinization is not a problem for agriculture in
the highlands of Northern Jordan (Lanzendorfer, 1985). Thus, crop production in this area is fully rain-fed, and the shallowness of soils results in a high vulnerability to droughts.

Rostovtzeff (1932) argued that the Decapolis cities depended strongly on caravan trade. While there is no doubt that important trade lines went through the region, it is questionable whether they had important influence in the settlement history. The region depended economically on local agriculture as is indicated by archaeological evidence from the tombs. Only a small elite may have been involved in caravan trade, but the evidence from the graves is not conclusive (Fuller, 1987). The majority of artefacts and artistic styles at Abila shows influence from the west in contrast to eastern or oriental influences that would have resulted from caravan trade (Fuller, 1987). Additionally, Abila was famous for its grapes and olives, while a highly developed industry for pottery required considerable amounts of wood (Wineland, 2001).

A major earthquake in 747/748 AD was often considered to be responsible for the abandonment of the region (Hoffmann and Kerner, 2002). However, fallen columns in Gerasa/Jerash rest on a layer of debris which was accumulated before the earthquake (Walmsley, 1997). The same was reported from the Decapolis city of Gadara/Umm Queis, indicating that these parts of the cities were already abandoned when the earthquake took place (personal communication with J. Telfah, excavation supervisor in Umm Queis). Additionally, resettlement took place after the earthquakes, but the small reconstructed towns were gradually abandoned and vanished until the beginning of the Fatimid period (Walmsley, 1992). From this we conclude that the earthquake alone did not enforce the abandonment of the region. Indeed, it seems that agricultural productivity was most relevant for the settlement history.

3.2. The plateau

On the one hand, the soil on the agricultural plateau around the old city is too shallow to allow an unadapted transfer of the Middle European soil analysis methodology as no relict surfaces were preserved. On the other hand, the substrate is derived from calcareous rocks, allowing analysis using a pedogenetic approach. Soil and rock openings along streets at Hartha show different depths of soil on seemingly the same source rock. Partially, these differences seem to be related to the position in the relief, but variations in soil depth are also visible at similar relief positions. The street openings show profile depths of 40 cm–1 m, but most profiles reveal a mean soil depth of ca. 60 cm (Fig. 7). This proved also true for the sampling pits on fields 1A (Fig. 8) and 2A (Fig. 9), which were dug in the middle of a
plateau west of Abila (Fig. 10). The distance between the sampling pits is ca. 200 m. They are separated by a small agricultural road and lie on the same terrain unit. On field 1A young olive trees had been planted. On the slightly brighter field 2A, vegetables were grown. On this field, ca. 300 m north of the sampling pit, an ancient cistern was visible, investigated by Fuller (1985). In difference to field 1A, some rock outcrops were visible on field 2A. Neutral to slightly alkaline pH-values, the soil’s stoniness, the high calcium and low clay content (Tables 2 and 3), give the soil substrate the characteristics of a Rendzina (Rendzic Leptosol), whereas its red colour would lead to expect Terra rossa (Rhodochromic Cambisol). As the weathering of calcareous rocks produces only minimal remains, the development of a Terra rossa (Rhodochromic Cambisol) occurs very slowly. The red colour usually arises due to the clay mineral of haematite, which emerges after long and intensive weathering processes of the silicates (Horowitz, 1979). Therefore Terrae rossae (Rhodochromic Cambisols) are in general counted as old soils, dating from the Tertiary or the Pluvials of the Ice Ages (Horowitz, 1979; Scheffer and Schachtschabel, 1998). According to Scheffer and Schachtschabel (1998), an undegraded Terra rossa (Rhodochromic Cambisol) should be at least 1 m deep.

Assuming the virgin soils at Abila reached a depth of 1 m until they developed the red colour, it can be concluded that at least ca. 40 cm of soil depth were lost since cultivation of the fields which are now ca. 60 cm deep. However, no tracks of intensive mismanagement forcing the abandonment of the site could be detected. Today agriculture is applied on this ancient landsurface (Horowitz, 1979; Lanzendörfer, 1985). This matches the natural reforestation observed by Seetzen (1854) and Schumacher (1890), and is in disagreement with the Lovdermilk (1944) theory of insufficient land use, which assumed that Arab mismanagement produced barren lands and malaria-infested swamps in the wadis. Newer historical investigations also mediate against the theory

![Fig. 10. Map showing the distribution of soil sampling places (marked with a “x”). The map was copied from the “Samar” map sheet of the Royal Geographic Centre of Jordan with a scale of 1:25,000, drawn in 1984. Note that the names of the ancient site are wrong: The name of the main settlement hill is not “Khirbat Umm al’Amad”, but “Tell Abil”. The name of the southern settlement hill of Abila is not “Khirbat al Quwayliba”, but “Tell Umm el-Amad”.]

### Table 2
Soil properties of sampling place 1A

<table>
<thead>
<tr>
<th>Sample depth (cm)</th>
<th>No.</th>
<th>H$_2$O (%)</th>
<th>pH</th>
<th>Ca (%)</th>
<th>Ct (%)</th>
<th>N (%)</th>
<th>S (%)</th>
<th>P (mg/g)</th>
<th>Gravel (%)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>A1</td>
<td>14.4</td>
<td>7.7</td>
<td>22.5</td>
<td>1.7</td>
<td>0.06</td>
<td>0.03</td>
<td>0.94</td>
<td>1.2</td>
<td>Ploughed</td>
</tr>
<tr>
<td>15</td>
<td>A2</td>
<td>8.5</td>
<td>7.9</td>
<td>20</td>
<td>3.5</td>
<td>0.11</td>
<td>0.04</td>
<td>0.92</td>
<td>17.2</td>
<td>Crust</td>
</tr>
<tr>
<td>25</td>
<td>A3</td>
<td>8.1</td>
<td>7.8</td>
<td>25</td>
<td>4</td>
<td>0.10</td>
<td>0.03</td>
<td>0.73</td>
<td>57.4</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>A4</td>
<td>29.2</td>
<td>7.9</td>
<td>21</td>
<td>3.6</td>
<td>0.11</td>
<td>0.03</td>
<td>0.75</td>
<td>15.9</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample depth (cm)</th>
<th>No.</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Coarse sand (%)</th>
<th>Middle sand (%)</th>
<th>Fine sand (%)</th>
<th>Coarse silt (%)</th>
<th>Middle silt (%)</th>
<th>Fine silt (%)</th>
</tr>
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<tbody>
<tr>
<td>5</td>
<td>A1</td>
<td>3.7</td>
<td>87.9</td>
<td>6.6</td>
<td>0.3</td>
<td>0.4</td>
<td>3</td>
<td>37.8</td>
<td>32.4</td>
<td>18.6</td>
</tr>
<tr>
<td>15</td>
<td>A2</td>
<td>3.8</td>
<td>90.5</td>
<td>5.6</td>
<td>0.2</td>
<td>0.1</td>
<td>3</td>
<td>49.3</td>
<td>27.5</td>
<td>13.7</td>
</tr>
<tr>
<td>25</td>
<td>A3</td>
<td>10</td>
<td>84.4</td>
<td>5.4</td>
<td>0</td>
<td>0.7</td>
<td>9.3</td>
<td>43.2</td>
<td>27.2</td>
<td>14</td>
</tr>
<tr>
<td>40</td>
<td>A4</td>
<td>5</td>
<td>89.6</td>
<td>5.4</td>
<td>0.3</td>
<td>0.2</td>
<td>4.5</td>
<td>40.2</td>
<td>32.3</td>
<td>17.2</td>
</tr>
</tbody>
</table>

The sand- and silt-fractions are shown in total and divided in coarse, middle and fine material. The carbon content represents the total carbon (Ct).
of insufficient land use, because they demonstrate how Islamic Conquerors were not uncultivated Bedouins, destroying the agricultural systems, but indeed highly developed agriculturists (Watson, 1981).

The sampling plot on field 2A was characterised by enrichment of nutrients, very high calcium content and stronger weathering of bedrock (Table 3). Sampling plot 2A lies about 200 m next to plot 1A on the same terrain unit, differences due to the parent rock or relief can be excluded for this area. Although Schumacher reported in 1888 the fields close to Abila to be forested (Schumacher, 1890), field 2A apparently did not experience reforestation, or if it did this was for a shorter time than the surrounding area. Both field 1A and 2A revealed many ancient sherds, mostly from the Late Roman and Byzantine–Umayyad period. From the cistern on field 2A, Ayyubid–Mamluk sherds are reported by Fuller (1985), indicating a medieval farmstead which matches well to the stronger weathering and nutrient enrichment of the soil of field 2A.

Land use changed the character of the landscape. The high calcium contents indicate that the soils were considerably eroded, as the upper layers of a Terra Rossa (Rhodochromic Cambisol) should be leached of calcium, while the clay content should number ca. 40–60% clay (Scheffer and Schachtschabel, 1998). The comparison of the sampling places on fields 1A and 2A shows differences which can only be explained with different land use intensities and periods, as changes in parent material, relief and climate can be excluded. The soil on field 2A is characterised by a higher calcium content, brighter colour, and enrichment in carbon, nitrogen and phosphorus. Although the texture is not much different from plot 1A, it is slightly finer, indicating stronger weathering. All these indicators point to longer and more intensive land use than on the neighbouring plot 1A, which is further supported by the reported Ayyubid–Mamluk sherds and more numerous rock outcrops.

The red colour of the soils does not necessarily mean that this land surface dates from the Tertiary or from the Pluvials of the Pleistocene. According to Bronger (1976) and Bronger and Sedov (1998, 2003), the red colour can be caused by other weathering remains of the limestone, and haematite can emerge under today’s climatic conditions, if the mean annual temperature reaches 7°C and above. The limestone then weathers into a coarse and well-ventilated substrate, often becoming dry, and the parent rock contains a high proportion of FeCO₃ (Meyer, 1979; Schwertmann et al., 1982; Cornell and Schwertmann, 2003). The possibility that the soils around Abila are very young cannot be ruled out at present. The low clay contents point into this direction.

Yaalon and Ganor (1973) postulate that aeolian deposition during rainstorms plays an important role in the formation of soils in the Near East. Dry aeolian deposition from the desert would bring sand, which should accumulate in the wind-shadow of the valleys (Smalley and Krinsley, 1978). This could not be observed, and the main winds come from the west, but Yaalon and Ganor (1973) characterise the aeolian input as loess material derived from the Sahara and transported with the winter depressions and rainstorms to the area. According to them, it can be measured in soils derived from basalt according to the quartz content which is strange to the bedrock. Since no marker minerals give evidence on limestone soils, aeolian contribution can be assessed according to the clay-to-silt ratio. Yaalon and Ganor (1973) emphasise that the aeolian deposition is a process too slow and steady to be observed in the soil profile. Other authors found aeolian deposition mainly to be restricted to the last glacial period from 100,000 to 10,000 years BC (Issar and Bruins, 1983; Frumkin and Stein, 2003). It is still discussed whether and where aeolian deposition is a dominating factor of soil formation, and whether it is restricted to the areas close to the desert and the pleistocene period (Smalley and Krinsley, 1978; Jahn,
According to Reifenberg (1947), soil development is dependent on the source rock. The clay-to-silt ratio is also affected by land use and erosion. However, for the soils close to the ancient city Abila it can be concluded that the observed differences in soil development at fields 1A and 2A are even more striking if a great part of the parent material is of aeolian origin, as the deposition should be identical on two plots in a distance of ca. 200 m and should not vary according to field borders. From the examination of soils on fields 1A and 2A it can be concluded that ancient land use can be traced according to the soil’s development and that the thesis of a catastrophic erosion has to be rejected. The observed differences in soil development at fields 1A and 2A can only result from long periods of land use with different intensities. It is a hint that many of the present field borders on the plateaux around Abila refer to ancient ones, as variations of soil depth and colour are visible on many fields on the apparently same source rock and relief position. However, this has to be investigated further.

3.3. The wadis

A wadi soil was sampled in the wadi Queilby (plot 5W), a small valley passing by the site of Abila, in which a perennial stream flowed until pumping at the spring Ain Queilby started. This wadi was selected as it widens at the crossing point with another small wadi, where the ancient site is situated (Fig. 10). Here, the wadi floor is quite broad and the western slopes are gentle, providing good opportunities for irrigation (Fig. 11). Close to the old riverbed, a 60 cm deep pit was dug on a gentle slope, which had been ploughed by a Bedouin family living close by. The soil material in the wadi was found to be a mixture of eroded material from probably both the slopes and the plateau (Table 4). As its colour is grey and the calcium content very high, it seems that only the substrate of the steep slopes and not the red soil of the plateau feeds the wadi. The mixture process of the soil was illustrated by the discovery of sherds from various epochs throughout the wadi profile. As excavation trenches show, in the depressions bed rock is reached in depths of about 12 m.

In comparison with the soils on the plateau, the wadi substrate is characterised by variations of calcium content and texture. Some dry aeolian deposition may be indicated by the higher sand content recorded in the surface layer. The wadi substrate has not undergone long genesis, as is indicated by the high calcium content and grey colour. Indeed, it has the characteristics of mixed material enriched with organic garbage, as indicated by high phosphorus contents, and is probably moved again with every winter flood.

A massive Roman bridge in the main wadi at Abila is gathering point for eroded soil (Fig. 12). As Schumacher measured this bridge during his visit in 1888, it was possible to conclude that in the past 113 years 2.50 m

![Fig. 11. Sampling place 5W. Note the Tell Abil to the right and the theatre cavea behind the orchard.](image)

<table>
<thead>
<tr>
<th>Table 4: Soil properties of sampling place 5W</th>
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<tr>
<td>Sample depth (cm)</td>
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<tr>
<td>-------------------</td>
</tr>
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<td>10</td>
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<th>Sample depth (cm)</th>
<th>No.</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Coarse sand (%)</th>
<th>Middle sand (%)</th>
<th>Fine sand (%)</th>
<th>Coarse silt (%)</th>
<th>Middle silt (%)</th>
<th>Fine silt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>A17</td>
<td>14.4</td>
<td>79.4</td>
<td>6.2</td>
<td>0.3</td>
<td>11.7</td>
<td>2.4</td>
<td>27.8</td>
<td>33</td>
<td>18.5</td>
</tr>
<tr>
<td>30</td>
<td>A18</td>
<td>4.5</td>
<td>90.2</td>
<td>5.3</td>
<td>0.1</td>
<td>0.4</td>
<td>4</td>
<td>43.3</td>
<td>31.8</td>
<td>15</td>
</tr>
<tr>
<td>60</td>
<td>A19</td>
<td>2.7</td>
<td>90.7</td>
<td>6.6</td>
<td>0.2</td>
<td>0.7</td>
<td>1.8</td>
<td>26.5</td>
<td>42.5</td>
<td>21.7</td>
</tr>
</tbody>
</table>
substrate accumulated at the bridge, nearly filling its arch completely (Schumacher, 1889; Lucke, 2002). If the Roman bridge would be excavated up to its fundament, interesting results about the erosion regime can indeed be expected because the obstacle in form of the bridge should have prevented continued mixing of the accumulated substrate.

The weathering of rock, landslides and erosion processes can also be illustrated by ancient graves at the wadi slopes located in opposition of the ancient site. Here, excavations between 1980 and 1986 uncovered tombs which were conserved and protected against grave robbers with iron doors. Many of these doors are now partially covered with huge masses of greyish soil material (Fig. 13), demonstrating well the erosion at the soft wadi slopes. As the texture and calcium content of the substrate in the wadi is very similar to the soils on the plateau, but not coloured or ordered, it is assumed that both the wadi substrate and soils on the plateau are products of the same soft rocks.

Landslides and erosion are a major threat for Jordanian water reservoirs, but the exact composition and weathering behaviour of the rocks is not known yet (Sven-Oliver Lorenz, University of Würzburg, working near the Wadi el-Arab dam, personal communication). Based on the publications of Lowdermilk (1944) and Butzer (1961), erosion on the plateaux was estimated to be a threat for agriculture and to be responsible for the silting of the dams. However, the results of our wadi sampling indicate that the plateaux are not the main source of silt. This is supported by erosion measuring in the framework of the Zarqa-River Basin Project of the Ministry of Agriculture (MoA) and German Agency for Technical Cooperation (GTZ), which proved to be most difficult, ranging from zero to catastrophic scenarios (Hashemite Kingdom of Jordan, 1986). As an eroded, but old land surface is present on the plateaux, it is possible that not the plateaux, but the soft rocks exposed at the wadi slopes are the main sources for silt in the water reservoirs (Fig. 14).
3.4. The ruins of Abila

At the site of Abila, existing excavation trenches were sampled on the top of Tell Abil (sampling plot 11R; Fig. 10). Here, the oldest settlement remains of the site, dating from Early Bronze Age, were found at the bottom of the profile, being ca. 7.50 m deep. Remains of walls prevented the Tell from being eroded and led to the accumulation of substrate on the hill. The city was constructed with stones from quarries in the vicinity, the same stone as the parent rock of the probably degraded Terra rossa (Rhodochromic Cambisol) on the plateau (Fuller, 1987). Geologically, the upper stratigraphical section exposed at Abila belongs to the B.1 unit of the Belqua group calcareous sediments (Bender, 1974). This section is 15–30 m thick and contains a calcareous conglomerate with well-cemented clasts of chert and limestone. It was used as building stone at the site, specifically columns made from this stone were used in a large basilica (Fuller, 1987). A quarry with an unfinished column could be observed north of the site (Fig. 15).

Beneath this conglomerate, at least 60 m of chalky limestone appear, which seem to be several hundred metres thick as can be deduced from their exposure in the Yarmouk valley (Belqua group B.2; Bender, 1974). Many buildings in Abila were built from this stone (Fuller, 1987). When the buildings of an ancient city collapse, soil starts to develop from the relevant debris (Krause, 1992; Dohmann-Pfaelzner and Pfaelzner, 1999; Pustovoytov, 2003). The soil which developed out of the debris of Abila was compared with the soil on the plateaux. The substrate covering the ruins of Abila is grey, meaning that ca. 1000 years of weathering were not sufficient to let the red colour develop. Without a careful analysis of parent material, it is of course difficult to draw a direct comparison between the soils derived from mixed debris and the soils derived from the B.1 Belqua group limestone of the Plateaux. On the other hand, haematite and thus the red colour is due to the prevailing influence of climate, long weathering of clay minerals and silicates, or solution products of the bedrock. The latter should be present in the debris, as stones from the B.1 limestone group were used for the construction of the city. However, the red colour could not be observed except in a relict Bronze Age surface. It was preserved in an animal burrow (plot 11R, sample no. A52) and had developed from Early Bronze Age debris during a settlement gap (Fig. 16; Table 5). It seems that a Middle or Late Bronze Age floor removed and built over a surface of red soil developed out of Early Bronze Age debris. As the burrow was dug quite deeply into the debris (at minimum 30 cm, although the exact depth cannot be determined), the soil which fell into the cave after its abandonment was kept out of the range of the substrate-mixing activities of animals, roots and the Middle or Late Bronze Age construction activities. To develop the red colouring, it would either have needed a longer weathering period than the modern surface of debris or had to undergo more intensive weathering due to increased rainfall. Comparing the various sampled substrates, there is a strong similarity of the substrate in the burrow with the soil sampled on the plateau. Calcium content, total carbon

Fig. 15. Ancient quarry close to the site of Abila.

Fig. 16. Burrow under Bronze Age settlement with relict soil. Each mark on the measuring staff represents 10 cm.
content, texture and nutrients are very similar, only the phosphorous content is increased which is interpreted as influence of organic waste and leachate in the debris profile. As the Early Bronze Age lasted from 3300 to 1950 BC, and the Late Bronze Age from 1550 to 1200 BC, the substrate could have experienced 500–1500 years of weathering, dependant on the time when the Early Bronze Age debris was abandoned. The exact time of weathering cannot be determined, but these results point to increased rainfall during the Bronze Age compared to today, matching the results of Bar-Matthews et al. (1998; Fig. 19). Other debris surfaces did not develop red colouring and the emergence of the red colour is in general thought to be related to higher precipitation (Horowitz, 1979).

This also matches the results of Khresat et al. (1998) and Khresat (2001), who concluded that soils in Jordan developed in a humid climate that shifted gradually towards a more arid climate. Further, remains of mudbrick stones (Sample No. A51; Fig. 17) from Middle or Late Bronze Age could be observed in the upper part of the profile. They were seemingly quickly covered with debris and thus kept out of the range of animals, roots or other soil-mixing activities. The mudbrick remains are nearly identical with the present agricultural surface on the plateau. If this similarity can be proven for more mudbrick stone remains, it could mean that the Bronze Age agricultural conditions were already similar to the ones present today, because the inhabitants usually used local mudbrick for construction of their houses. This would mean that already the Bronze Age soils were considerably eroded, and either re-weathering of bedrock or aeolian deposition prevented the landscape to transform into a plateau of barren rock. The other sampled debris substrates show merely the characteristics of the wadi samples, pointing to a mixed substrate that did not undergo a genesis process but was deposited and mixed during construction activities.

It is theoretically possible that the soil observed in the burrow (Sample No. A52) represents remains of old mudbrick stones. This is not assumed as there are no other remains of mudbrick preserved at this part of the profile, and the area where once the entrance of the cave was sealed with remains of a Middle or Late Bronze Age plaster floor. However, if sample A52 represents preserved mudbrick (in this case from the Early Bronze

<table>
<thead>
<tr>
<th>Sample/thickness</th>
<th>No.</th>
<th>pH</th>
<th>Ca (%)</th>
<th>Ct (%)</th>
<th>N (%)</th>
<th>S (%)</th>
<th>P (mg/g)</th>
<th>Gravel (%)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>11R 8/60cm</td>
<td>A46</td>
<td>8.5</td>
<td>64.4</td>
<td>7.8</td>
<td>0.08</td>
<td>0.04</td>
<td>5.86</td>
<td>12.4</td>
<td>Surface today</td>
</tr>
<tr>
<td>11R 7/25cm</td>
<td>A47</td>
<td>8.3</td>
<td>39</td>
<td>5.1</td>
<td>0.08</td>
<td>0.03</td>
<td>5.59</td>
<td>4.9</td>
<td>Brownish substrate</td>
</tr>
<tr>
<td>11R 6/1.75m</td>
<td>A48</td>
<td>8.4</td>
<td>39</td>
<td>5</td>
<td>0.07</td>
<td>0.06</td>
<td>5.13</td>
<td>6</td>
<td>Grey debris</td>
</tr>
<tr>
<td>11R 3/15cm</td>
<td>A51</td>
<td>9.1</td>
<td>24</td>
<td>1.9</td>
<td>0.04</td>
<td>0.03</td>
<td>2.69</td>
<td>4.5</td>
<td>Mudbrick stone</td>
</tr>
<tr>
<td>11R 2/5cm</td>
<td>A52</td>
<td>8.6</td>
<td>20</td>
<td>1.9</td>
<td>0.05</td>
<td>0.04</td>
<td>1.30</td>
<td>15.7</td>
<td>Burrow</td>
</tr>
<tr>
<td>11R 1/2m</td>
<td>A53</td>
<td>8.6</td>
<td>53</td>
<td>7</td>
<td>0.08</td>
<td>0.06</td>
<td>6.38</td>
<td>13</td>
<td>Grey debris</td>
</tr>
<tr>
<td>11R 0/30cm</td>
<td>A54</td>
<td>8.4</td>
<td>48.8</td>
<td>6</td>
<td>0.08</td>
<td>0.8</td>
<td>5.56</td>
<td>11</td>
<td>Soil over bedrock</td>
</tr>
</tbody>
</table>

The samples were numbered and their thickness added, because it was not possible to measure their exact depth. The trench is in total 7.50 m deep, but the sampling had to avoid remains of walls, etc. The samples are listed as they are positioned in the trench.

The samples were numbered and their thickness added, because it was not possible to measure their exact depth. The trench is in total 7.50 m deep, but the sampling had to avoid remains of walls, etc. The samples are listed as they are positioned in the trench.
Age) and not a relict surface, it would support the assumption that the land surfaces on the plateaux are very old, as in this case no red colour of soil was developed in historical time. Careful analysis of parent material will allow us to understand the age and development process of soils.

3.5. The theatre of Capitolias/Beit Ras

A huge theatre was constructed in the Roman period and later used as cistern, indicated by the weathering of the inner stones (personal communication, K. al-Rousan and J. Telfah, excavation supervisors, December 2001). Like Abila, Capitolias/Beit Ras and its theatre was constructed with limestone from the vicinity (Lenzen and Knauf, 1987; Karasneh et al., 2002). When an earthquake destroyed the old city, the inner walls of the theatre in direction to the city collapsed. Rubble rolled down and filled the space up to the top of the remaining inner walls, creating a ramp and allowing alluvial sediments to enter. These sediments accumulated at the outer wall of the theatre, which was still standing. The excavation trenches clearly show this debris accumulating in yearly paired layers fading out towards the blocking backstage wall and finally moving over it (Fig. 18). This pattern of dark and light grey substrate in thin, paired layers is sometimes disturbed by ash and brownish-red soil deposits.

The fill of the theatre seems to be a mixture of substrates carried there by rainwater or humans (Table 6). The brownish substrate did not develop in place, but was carried there by humans (personal communication, K. al-Rousan and J. Telfah, excavation supervisors, December 2001). During the archaeological excavations, the mixture and abundance of sherds indicated that the theatre was used as a disposal pit, supported by the soil analysis (Lucke, 2002). The high phosphorus and nitrogen contents make it very probable that the brownish substrates resemble garbage. The distribution of the layers in the profile indicates that the grey substrates were carried there by rainwater: Sometimes thin bands fade out soon, while sometimes considerable amounts of substrate accumulate at the backstage wall. The texture of the substrates is very similar, while the differences in calcium content seem to be distributed randomly. These substrates look like the wadi samples and the debris in the ruins of Abila, pointing to a similar source: Weakly weathered limestone products.

This indicates that the limestone groups present at the sites seemingly weather into similar substrates, although this has to be investigated further. Analyses of full profiles of the alluvial sediments in the theatre are needed to demonstrate the sedimentation history of Beit Ras. Here, interesting results can be expected as the ash deposits will allow dating. It is evident from the archaeological findings that the theatre filled with sediments and material culture from the

![Fig. 18. Alluvial sedimented fill in the theatre of Capitolias/Beit Ras.](image)

Table 6
Soil properties of sampling place 7R

<table>
<thead>
<tr>
<th>Sample/thickness</th>
<th>No.</th>
<th>pH</th>
<th>Ca (%)</th>
<th>Cn (%)</th>
<th>N (%)</th>
<th>S (%)</th>
<th>P (mg/g)</th>
<th>Gravel (%)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>7R + 2/5 cm</td>
<td>A30</td>
<td>7.7</td>
<td>53</td>
<td>7.5</td>
<td>0.31</td>
<td>0.18</td>
<td>n.a.</td>
<td>14.4</td>
<td>Light grey band</td>
</tr>
<tr>
<td>7R + 1/20 cm</td>
<td>A29</td>
<td>8</td>
<td>48</td>
<td>7.4</td>
<td>0.44</td>
<td>0.12</td>
<td>n.a.</td>
<td>8.5</td>
<td>Dark grey band</td>
</tr>
<tr>
<td>7R -1/35 cm</td>
<td>A27</td>
<td>7.7</td>
<td>38.2</td>
<td>9</td>
<td>0.83</td>
<td>0.24</td>
<td>7.60</td>
<td>9.5</td>
<td>Brownish substrate</td>
</tr>
<tr>
<td>7R -2/5 cm</td>
<td>A26</td>
<td>7.7</td>
<td>58.8</td>
<td>9.9</td>
<td>0.23</td>
<td>0.55</td>
<td>n.a.</td>
<td>40.7</td>
<td>Light grey band</td>
</tr>
<tr>
<td>7R -3/1 m</td>
<td>A25</td>
<td>7.7</td>
<td>53.1</td>
<td>7.8</td>
<td>0.25</td>
<td>0.26</td>
<td>n.a.</td>
<td>9.7</td>
<td>Mixed debris</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample/thickness</th>
<th>No.</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Coarse sand (%)</th>
<th>Middle sand (%)</th>
<th>Fine sand (%)</th>
<th>Coarse silt (%)</th>
<th>Middle silt (%)</th>
<th>Fine silt (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7R + 2/5 cm</td>
<td>A30</td>
<td>5.8</td>
<td>85.5</td>
<td>8.6</td>
<td>0.06</td>
<td>1.2</td>
<td>4.6</td>
<td>30.8</td>
<td>33.6</td>
<td>21</td>
</tr>
<tr>
<td>7R + 1/20 cm</td>
<td>A29</td>
<td>6.7</td>
<td>85.6</td>
<td>7.7</td>
<td>0.3</td>
<td>1.4</td>
<td>5</td>
<td>30.8</td>
<td>35</td>
<td>19.8</td>
</tr>
<tr>
<td>7R -1/35 cm</td>
<td>A27</td>
<td>6.9</td>
<td>85.2</td>
<td>7.9</td>
<td>0.1</td>
<td>1.5</td>
<td>5.3</td>
<td>33</td>
<td>34.3</td>
<td>18</td>
</tr>
<tr>
<td>7R -2/5 cm</td>
<td>A26</td>
<td>8.5</td>
<td>86.5</td>
<td>5</td>
<td>0.5</td>
<td>2.4</td>
<td>5.6</td>
<td>61.6</td>
<td>15.9</td>
<td>9</td>
</tr>
<tr>
<td>7R -3/1 m</td>
<td>A25</td>
<td>5.2</td>
<td>84</td>
<td>10.7</td>
<td>0.1</td>
<td>1.3</td>
<td>3.8</td>
<td>22.5</td>
<td>36</td>
<td>25.4</td>
</tr>
</tbody>
</table>
Byzantine–Umayyad and earlier periods, carried down with the debris from the destroyed city and deposited during domestic re-use of the theatre. The vaults leading to the seats were used for housing and as domestic areas after the theatre was already partially covered with sediments (personal communication, K. al-Rousan and J. Telfah, excavation supervisors, December 2001). It is possible that the major earthquake in 747/748 AD destroyed the city and allowed the sediments to enter. Clarification of the sedimentary processes in the theatre would give evidence for the sedimentation regime since this event and about the domestic resettlement of the partially destroyed theatre.

3.6. Land use, soil genesis and local climate

In the recent years, important progress has been achieved in climate research in the Near East (Issar, 1990, 1995, 1998, 2003; Issar et al., 1992; Issar and Angelakis, 1996; Issar and Yakir, 1997; Weiss et al., 1993; Brentjes, 1994; Bar-Matthews et al., 1997, 1998; Brown, 1998; Netser, 1998; Crowley, 2000; DeMenocal, 2001, Griffiths et al., 2001; al-Shorman, 2002b). Newest investigation results based on speleothem stalagmites and lake sediments found short, but intensive drought periods matching to the time of abandonment of the Decapolis region (Bar-Matthews et al., 1998; Issar, 1998). The results of Bar-Matthews et al. (1998) indicate that annual rainfall was reduced by ca. 50 mm for about 100 years during the Abbasid period (Fig. 19). A minor resettlement during the Ayyubid–Mamluk era is contemporary with an increase of rainfall, while the following abandonment in the Ottoman period coincides with another precipitation reduction. Butzer also found precipitation changes in his investigations (although not delivering a rainfall calculation), but estimated the economic effects of fluctuations since the Roman period to be negligible (Butzer, 1955, 1961; Figs. 20 and 21). His dating differs from that of Bar-Matthews et al. (1998). According to Butzer, the decay of the Decapolis region took place in a moister period, while it was abandoned during a following dry period.

As not only the annual precipitation, but also the distribution of rainfall during the year is most important for agricultural practices, it is difficult to correctly assess the impact of the proposed scenarios. The Decapolis region is geographically very heterogeneous (including the Jordan valley, the mountains east of the Jordan River and the highlands merging with the desert in the east), so the climatic influence may vary locally. Additionally, it seems very probable that the land use, especially forest coverage, has important influence on local climate. This context was already considered in the 19th century (Anderlind, 1885). Forest coverage is not only advantageous due to moisture retention, soil development and core fertility, and protecting against wind, but also because it increases the amount of precipitation and improves the distribution of rainfall (Anderlind, 1885; Seth, 1978). Land use, local climate and soil development are interrelated.

Fig. 19. Rainfall calculation from speleothem stalagmites (for cave water temperatures of 18 and 20 °C) by Bar-Matthews et al. (1998).
However, the investigations in past climate show an increase of rainfall for the Bronze Age period, which matches well to the relict s oil found on Tell Abil. Unfortunately, Butzer gives only relative changes of rainfall and does not explain what “dry” or “very moist” means. Butzer assesses the climate fluctuations for the time since the Roman period to be negligible, while he thinks that earlier variations had important influence on the settlement history (Butzer, 1961). He assumes that not climate, but soil erosion governed the settlement history since the Roman period, but on the basis of his data, it cannot be assessed how the impact of precipitation changes on agriculture or soil development looked like. Additionally, the catastrophic erosion after the Arab conquest as suggested by Lowdermilk (1944) and Butzer (1961) could not be observed by our investigation. Taking into consideration that the Islamic Empire enjoyed a peaceful and prosperous time during the Early Abbasid period (Watson, 1981), it seems most likely the rainfall variations measured by Bar-Matthews et al. (1998) influenced the abandonment of the Decapolis region, because agriculture cultivated soils on an old land surface. As the mudbrick remains indicate, these soils were probably already shallow. Due to a lack of irrigation possibilities, dependence on precipitation for the supply of drinking water, and shallow soils with high contents of calcium carbonate, it can be assumed that agriculture was very vulnerable to drought and thus it seems likely that climate variation had important influence on the abandonment of the region. However, to clarify this exactly more data is needed to assess ancient agriculture, to analyse the age and genesis process of soils and to evaluate a possible impact of land use on local climate.

5. Conclusion and synopsis

Our results show that land use and soil analysis are well-suited methods for reconstructing the environmental history of Jordan. From our preliminary investigation it might be concluded, that climate could have played a decisive role in the abandonment of the Decapolis region. Shallow soils rich in calcium carbonate are vulnerable to drought, and agriculture is today highly dependent on sufficient and well-distributed rainfall. Also erosion is prevailing to some degree. The land surface on the plateaux around Abila seems to be old, having experienced natural forest regeneration until the 19th century. Variation of soil depth and properties seems not only to be related to parent material or the position in the relief, but also to historical land use. Further investigation in the soil patterns of the Decapolis should therefore not only provide important information about the age of soil, erosion and weathering processes, but also about the historical land use pattern and intensity. For now it an be said that the agricultural productivity of the ancient fields seems not to differ significantly from the one of the fields present today. A relict Bronze Age surface recovered from Tell Abil points to higher precipitation during that period than today and matches well to the climate reconstructions of Butzer (1961) and Bar-Matthews et al. (1998).

As land use, local climate and soil genesis are interrelated, further research should be carried out, clarifying the impact of the proposed precipitation reductions and assessing the role of land use with regard to the environmental history and its influence in local climate. The Decapolis region provides good research opportunities for these questions.

Acknowledgements

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