Sedimentation and soil formation phases in the Ghardimaou Basin (northern Tunisia) during the Holocene

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Abstract

Chronological and stratigraphical interpretations as well as 14C-dates and geoarchaeological investigations of detailed profiles from the mid-Medjerda valley (northern Tunisia) allow us to reconstruct one late Pleistocene and four Holocene sedimentation cycles within the floodplain area. Initial results from pedological examinations, including thin sections, indicate a latest Pleistocene and three Holocene soil formation periods. Our observations from the Medjerda valley are discussed in relation to current research in the southwestern Mediterranean region. The Crise Romaine—shown in the headwaters of the Medjerda river system by thick cobble accumulations—is exhibited in the basin region by a clear accentuation of the water level amplitude. Catastrophic flooding can be observed for the first time in the late Roman period. After soil formation during Middle Ages, ending at about 450 BP, flooding again increased. © 2002 Elsevier Science Ltd and INQUA. All rights reserved.

1. Introduction

During the DFG-Project, “Reconstruction of Holocene environmental conditions in North-Tunisia based on sedimentological analysis and pedogenetic findings from the mid-Medjerda valley”, detailed profiles of outer bank positions of the Oued Medjerda were carried out. From chronological and stratigraphical interpretations we are able to reconstruct the water level amplitude of the river during the Holocene. Mineralogical, palaeomagnetic, pedological and geoarchaeological examinations, as well as 14C-dates, allow derivation of soil formation and sedimentation cycles. The initial results of the ongoing project broaden knowledge of morphodynamics during the Holocene in northern Tunisia and allow us, to some extent, to draw parallels to comparable work in the West-Mediterranean region.

2. Area of investigation

The Oued Medjerda is the main water course in North-Tunisia. The northern catchment area includes the subhumid to Mediterranean-humid south facing slope of the Tunisian Tell region, whose hills in the Kroumir Mountains reach to over 1200 m. A much greater catchment area lies in the south, drained by the main tributaries Oued Melleque, Oued Tessa and Oued Siliana (Fig. 1). They drain the north-facing slopes and piedmonts of the semiarid Dorsal Mountains. The Oued Medjerda itself rises in the semiarid Atlas Mountains of eastern Algeria. In the area of the upper middle course, before the river is joined by the main southern tributaries, it passes through the Ghardimaou Basin (Fig. 2), a tectonic depression with 8–10 m thick Holocene floodplain sediments. The Ghardimaou Basin has been settled since at least the latest Paleolithic, as shown by many artifacts found within the sediment layers.

3. Methods

The profiles we have introduced are limited to the Ghardimaou Basin (Fig. 3) and are the result of a 6-week stay in the project area itself. Profiles taken from the eastern linked Jendouba Basin (Fig. 3) remain at this point unexamined, as the complex fluvial dynamics of the tributaries hinder the recognition of sedimentation series during the Holocene.
Previous stratigraphical and chronological analysis of sedimentation in the Ghardimaou Basin is based on the dating of many artifacts and pottery fragments, \(^{14}\)C-dating (AMS) of charcoal (calibrated after Stuiver et al., 1998), pedological and sedimentological field observations (color, soil texture, soil structure, bioturbation, humic content, rubefaction, calcareous concretions, etc.), as well as comparison of individual profiles. Fortunately, the charcoal samples consisted almost entirely of in situ fire-sites, so that we can assume that we dated reliable material. Palaeomagnetic analysis of the samples is still ongoing.

4. Key profiles in the Ghardimaou Basin

The most important profiles for the Ghardimaou Basin are those of (OM) Chemtou (CH) and Sidi Abdallah (SA) (Fig. 3). After the initial observations of the outer bank positions within the basin, these profiles were chosen for detailed soil sampling and analysis. These three exposures allowed observation of the sedimentation and soil formation spectrum during the Holocene in a somewhat representative and compressed form.

4.1. Oued Mliz Profile (OM)

This site lies approx. 500 m northeast of the village of OM. The village takes its name from the small, southern tributary, which enters the Ghardimaou Basin in this area. Thus the exposure lies in the interlocking area of Oued Medjerda as well as that of OM. The actual location is an outer bank position of the OM directly before it joins the Oued Medjerda (Fig. 3).

In the OM, 16 sediment layers were defined according to field observations and laboratory analysis (Fig. 4), grouped into five main sedimentation series (Fig. 7). With the exception of the first incomplete series (S1), the basal sequences of series S2–S4 mainly show sandy to silty soil texture, with the upper parts of the individual series fining upwards to clayey sediments.

Series S1 (980–620 cm) consists of, from base to top:

- OM1: silty clay, very calcareous, hydromorphic features (weak staining of slightly developed aggregate surfaces);
- In situ fire-site, 11,440 ± 50 BP (13,790–13,160 Cal BP; Beta-135718);
- OM2: silty clay, very calcareous, slightly aggregated, hydromorphic features.

Series S2 begins with rhythmic lamination of silty–clayey to medium-sandy sediments (OM3). In some places gravel layers (OM4; loamy sand, very calcareous) are embedded. The overlying OM5 layer is clay loam, extreme calcareous, subangular blocky (7.5 to 10 YR 6/4, light brown to light yellowish-brown). This unit is transitional along a diffuse contact to clearly aggregated, subangular blocky, calcareous, humic, silty clay (OM6). S2 closes with sediment (OM5 to 6) indicating soil formation beyond the degree of simple humic enrichment. The light reddish-brown color and the subangular blocky structure of the clay loam (OM5) show slight rubefaction. Bean-sized calcareous concretions in the lower part of S2 indicate calcareous precipitation during soil formation.

Series S3 (440–250 cm) consists of (Fig. 4):

- OM7: silty clay, very calcareous, prismatic structure, hydromorphic features (2.5 Y 5/4, light olive-brown), 30–160 cm thickness;
Fig. 3. Area of investigation and key profiles.
OM8: loam, very calcareous;
OM9: silty clay, very calcareous;
OM10: silty clay, humic, very calcareous, angular blocky; soil sediment.

Thin section analysis, conducted by N. Günster, Physical Geography, Bonn University, confirms the hydromorphic character of OM7. Soil texture, color, hydromorphic features and prismatic structure indicate slow accumulation under lagoonal conditions. This accumulation covers a great part of the floodplain, mostly situated away from the main riverbed. The humic, silty clay (OM10) is solely a re-deposited soil, as in situ soil formation processes cannot be confirmed from the micromorphology.

The transition to series S4 is indicated by a marked change in the soil texture to fine-sandy (OM11) as well as by the presence of numerous Roman pottery.

Fig. 4. (a) OM Profile: mainly composed of fine sediments, shows a flat and even bedding of the layers. The black horizon (OM6) is seen as a humic in situ soil formation. According to our results obtained in southern Spain we would suppose this soil to having been formed during Neolithics. Below the dark humic horizon we observed a slight reddening (OM5) and some calcareous concretions (OM3). In the upper part of the sequence three colored horizons can be distinguished. The upper dark one (OM14) and the brown layer (OM12) seem to be a redeposition of eroded soils. The sequence ends with laminated latest sedimentation (OM15) that happened during the last 400 years. (b) OM Profile (photo).
fragments (<1900 BP). Series S4 (250–120 cm) consists of
- OM11: fine sandy loam, very calcareous;
- OM12: clay loam, very calcareous, reddish; Roman ceramics;
- OM13: sandy clay loam, very calcareous;
- OM14: silty clay, humic, subangular blocky, extreme calcareous; soil sediment, as indicated by thin section analysis. The micromorphology shows clearly stratified accumulation.

The youngest floodplain sediment (S5; 120–0 cm) represents finely banded deposits of loam (OM15) to silty loam (OM16). The inhomogeneous matrix distinctly borders S5 from the underlying series. Soil formation characteristics are not present.

4.2. Chemtou Profile (CH)

The CH lies close to the ancient Roman city Chemtou (see Fig. 3). Due to the North-African Atlas orogenesis, an outcrop of Jurassic marble is located here. The yellowish Chemtou-Marble has been quarried and exported since Antiquity. Similar to the OM Profile, the CH does not lie directly in the meandering belt of the Oued Medjerda, but on an outer bank position of the small northern tributary Oued Melah, shortly after it enters the northern edge of the Ghardimaou Basin. The profile represents the interlocking sedimentation area of both rivers.

Fig. 5 shows the CH containing exposures from inner bank to outer bank positions. Altogether 23 layers, including some which are only fluvial facies, are divided into—similar to the OM Profile—five main sedimentation series (Fig. 7: S1–S5).

Series S1 (850–510 cm) consists of
- CH1: silty clay loam, calcareous, angular blocky; calcareous concretions;
- CH2: silty clay loam, noncalcareous aggregate surfaces, angular blocky;
- CH3: clay, noncalcareous, angular blocky, clay films; B-horizon (5–7.5 YR 4/6, yellowish-red to strong brown);
- CH4: silty clay, calcareous;
- CH5: in situ cultural layer (Ibéromaurisien); 11,160 ± 50 BP (13,360–12,990 Cal BP; Beta-135726).

In the lowermost part of series S1, a reddish soil has developed (CH1–CH3), whose humic horizon has been eroded. The clay-rich B-horizon (CH3) is fully decalcified, has a markedly angular blocky structure and displays clay films on aggregate faces. The subsoil (CH1) exhibits bean-sized calcareous concretions in a calcic, grayish-brown soil matrix.

Series S1 concludes with an in situ cultural layer (CH5) with a thickness of between 50 and 70 cm. The cultural layer, in Tunisian literature known as escargotières (Bourgou, 1993), shows numerous charcoal remains, snail shells, bones, and many angular, chipped-off gravels and cobbles. Despite an intense search, however, a datable industry could not be found. The 14C dating of the in situ charcoal samples resulted in a calibrated 14C-age of 13,360–12,990 BP (Ibéromaurisian culture). Therefore, the development of the underlying, red soil must have been completed somewhere around 14,000 BP. The compaction of the hematitic (5–7.5 YR 4/6) B-horizon (CH3) has hindered secondary calcification.

Series S2 (810–600 cm) consists of, from base to top:
- CH–N0: gravel layer, calcareous;
- CH–N1: clay loam, extreme calcareous, calcareous concretions;
- CH–N2: clay, subangular blocky, very calcareous; B-horizon (10 YR 5/6, yellowish brown);
- CH–N3: clay, subangular blocky, calcareous; A-horizon.

In an outer bank position lying approx. 200 m down river (see Fig. 5a) the almost completely eroded, Pleistocene layer is covered by a thin gravel layer
Fig. 5. (a) CH: The CH profile is in our point of view the most complete in the whole Ghardimaou Basin. It shows nearly the complete Holocene sequence beginning after a soil formation phase of the latest Pleistocene. Rubefacted features point to latest Pleistocene climatic conditions that enabled the reddening (sharp contrast of seasons). Above the red soil charcoal and lots of snail shells witness in situ remnants of an ancient settlement. $^{14}$C-analysis of the charcoal indicate an age of 13,360–12,990 Cal BP. (b) Late Pleistocene soil in the CH (photo).
(CH–N0) as well as an approx. 180 cm thick, silty–clayey floodplain sediment, in which a yellowish-brown soil has developed (CH–N1 to CH–N3). The calcic (secondary?) B-horizon (CH–N2) exhibits a subangular blocky structure with slightly hydromorphic features. Clay films are not present. In the subsoil a horizon with bean-sized calcareous concretions has developed.

From the intensity of their soil-forming characteristics, these horizons are similar to those of the OM Profile (OM3–OM6). The calcareous concretions also are similar in size and intensity to those in the OM profile. Comparable soil-forming characteristics and chronological information suggests that the sedimentation and soil formation phases from CH–N1 to CH–N3 and OM3–OM6 occurred at the same time (S2).

The palaeosol (CH–N3) is overlain along a distinct contact by a clay loam deposit (CH9), which is in turn covered by a thick cobble layer (CH11; see Fig. 5). The cobble layer is rich in Roman artifacts and broken stone remains from the nearby marble quarry. CH11 is the beginning of the historical sedimentation.

Between series S1 and the historical sedimentation (series S4), the CH demonstrates a facies differentiation within series S2–S3. In some of the outer bank positions, sedimentation from CH–N1 to CH–N3 is associated with connecting soil formation, which we correlate to OM. The floodplain sediments in the upper part of the cultural layer (CH5) indicate a wider depositional milieu, however.

Series S2–S3 (850–430 cm) consists of

- CH6: cultural layer, re-deposited;
- CH7: silty clay, calcareous, prismatic structure, hydromorphic features (10 YR 5/3, brown);
- CH8: silty clay, slightly humic, aggregated, calcareous, hydromorphic features; A-horizon?;
- CH9: clay loam, calcareous;
- CH10: silty clay, aggregated, calcareous, humic features at the top; A-horizon? (10 YR 6/4, light yellowish-brown).

Similar to the sedimentation conditions represented by OM7, clayey to silty sediment accumulated in a wide palaeochannel (CH7 and CH10), suggesting a lagoonal still-water milieu. Slight aggregation, prismatic structure, hydromorphic features and calcified plant remains in the thin section point to a flat water area with slightly terrestrial conditions. The still water sedimentation is only broken by the clay loam deposit (CH9), which also covers the yellowish-brown soil (CH–N1 to CH–N3).

Series S4 (430–120 cm) consists of

- CH11: cobble layer (fine-soil: loamy sand, calcareous), numerous Roman artifacts;
- CH12: clay loam, calcareous;
- CH13: clay, aggregated, strongly calcareous;
- CH14: clay loam, calcareous;
- CH15: silty clay, aggregated, calcareous.

The historical sedimentation (S4) begins with the cobble layer CH11. This layer is unequivocally to be categorized with the Oued Melah fluvial system. Connected to the upper part of the cobble layer is a succession of clay and clay loam, which ends with a clearly darker, lightly aggregated, silty clay (CH15). The youngest calcareous clay loam layer...
4.3. S:d: Abdallah Profile (SA)

The SA Profile (Fig. 6) is taken from an outer bank position of the Oued Medjerda and is located approx. 7 km down river from the location of the CH. The Ghardimaou Basin gradually narrows in this region and at Jendouba passes into the Jendouba Basin (Fig. 3). The fortified Roman city of Borj Hellal lies in the vicinity of the SA Profile, so that, as at Chemtou, the historical sedimentation is easily recorded through the numerous Roman pottery findings. The location of the SA lies exclusively in the fluvial sedimentation area of the Oued Medjerda.

Series S3 (790–250 cm) consists of:
- SA1: clay loam, very calcareous;
- SA2: clay loam, very calcareous;
- SA3: silty loam, prismatic structure, calcareous, hydromorphic features (2.5 Y 7/4 to 10 YR 7/3, pale yellow to very pale brown); in situ fire-site, 3000 ± 25 BP (3209–3170 Cal BP; KIA-12408);
- SA4: sand layer, banded;
- SA5: sandy loam, strongly calcareous, including SA5a (basal gravel layer), and SA5b (loam, slightly humic, very calcareous);
- SA6: silty clay, prismatic structure, calcareous, hydromorphic features (10 YR 7/3, very pale brown).

Of special interest in the SA Profile are the pre-Roman still-water sediments SA3 and SA6 (see Fig. 6). Silty clays with pale tongues and large prismatic structure resemble the hydromorphic layers OM7 from OM, and CH7 and CH10 from the CH. During surveys in September 2000 an in situ fire-site was found in the upper part of SA3 (3209–3170 Cal BP). Series S4 (250–100 cm) includes SA7: calcareous sandy loam, containing numerous Roman artifacts. The historical sedimentation begins with coarser material. Stratigraphically and chronologically, SA7 is categorized with sedimentation series S4 (see Fig. 7). Series S5 (100–0 cm) includes SA8: silty clay, calcareous; and SA9: silty clay, calcareous; ploughed.

5. Discussion

The profile locations provide an insight into the sedimentation process during the Holocene in the Ghardimaou Basin. Sedimentation and soil formation phases within each profile position allow correlation with other profile positions (Fig. 7). Some sedimentation series (S) and soil formation phases (P) can be chronologically more narrowly defined by field results and numerical dating, particularly series S1, S4, and S5. Where complete chronological categorization is not yet possible, our project results can at this point be discussed with the help of literature reflecting the current state of knowledge. For a clear chronological classification all secondary 14C-ages (radiocarbon ages) mentioned in literature are converted into approximate calendar years (Cal BP), according to the calibration curve (Fig. 8) of Stuiver et al. (1998).

5.1. >13,000 Cal BP—Pleistocene sedimentation series (S1) and the late Pleistocene soil (P1)

Stratigraphically, the Pleistocene ends with a well-developed, rubefied soil (CH1–CH3). In the CH the late Pleistocene red soil (5–7.5 YR 4/6) is exposed (see Figs. 5a and b).

The chronological categorization of the red soil is not definitively clarified by earlier research. Sabelberg (1977) postulates that the uppermost, and simultaneously the most strongly developed, red soil in the cliff profiles of Southwest-Morocco is a key horizon for the beginning of the early Rharbian and therefore places it in the latest Pleistocene. He refers thereby to the extensive 14C-findings from Geyh and Jäkel (1974) from the central Saharan region, which assert that at around 16,000 Cal BP, at the latest approx. 14,500 Cal BP an abrupt cross-regional humid phase set in. Rohdenburg (1977) also, in his observations in Southwest-Morocco, on the Balearic Islands, and in Southeast-Spain, set the beginning of an intense rubefaction phase at approx. 16,000 Cal BP. From the papers of Borja Barrera and Diaz del Olmo (1994) as well as Faust (1995), B-horizon formation began 2000–3000 yr earlier, at least in Southwest-Spain. For the Tunisian region, no field results were known which could clarify a beginning of the rubefaction in the latest Pleistocene until now. Steinmann and Bartels (1982) date the youngest red soil found at the Oued Djeraba (southern catchment area of the Oued Medjerda) from 14C-samples of mollusc shells at approx. 22,000 BP (uncalibrated). Although Steinmann and Bartels do not fundamentally rule out a younger rubefaction phase for the Tunisian region, they could not confirm Sabelberg’s (1977) key horizon from Morocco. Molle (1979) had similar results in the northern and central Tunisian regions. Dating of calcareous crusts and snail shells confirm a multi-phased rubefaction between 30,000 and 20,000 BP (uncalibrated). Although Steinmann and Bartels do not fundamentally rule out a younger rubefaction phase for the Tunisian region, they could not confirm Sabelberg’s (1977) key horizon from Morocco. Molle (1979) had similar results in the northern and central Tunisian regions. Dating of calcareous crusts and snail shells confirm a multi-phased rubefaction between 30,000 and 20,000 BP (uncalibrated). Although Steinmann and Bartels do not fundamentally rule out a younger rubefaction phase for the Tunisian region, they could not confirm Sabelberg’s (1977) key horizon from Morocco. Molle (1979) had similar results in the northern and central Tunisian regions.
Figs. 5a and b). The dating of in situ charcoal provided a $^{14}$C age of $11,160 \pm 50$ BP (13,360–12,990 Cal BP). Although the A-horizon of the soil is eroded, the findings are at least evidence of the end of a strong soil formation phase (P1) in the earliest Rharbian and thereby, possibly provide proof for Sabelberg’s (1977) key horizon for the Tunisian region. If future OSL-dating of the sediment series (S1) is successful,

Fig. 6. (a) SA Profile: Of special interest is the pre-Roman sedimentation of the layers 3 and 6. We assume slow accumulation conditions proved by fine silty and clayey deposits. They are characterized by grayish to light greenish coloring, by slight humic contents and by clear prismatic structure. Layers 3 and 6 can be recognized also in CH Profile (7 and 10) as pre-Roman sedimentation. (b) SA Profile—noticable are two thick still-water deposits with distinct prismatic structures (photo).
Fig. 7. (a,b) Stratigraphic correlation of the OM, CH and SA Profiles.
Fig. 7b: Stratigraphic correlation of the Oued Mliz, Chemtou and Sidi Abdallah Profiles

- **Sidi Abdallah Profile**
- **Chemtou (I) Profile**
- **Chemtou (II) Profile**
- **Profile “Oued Mliz”**

**Key**
- Loam, banded
- Clay
- Sand
- Loam, redeposited
- Clayey to silty layer, humic content
- Cultural layer a) redeposited
- Fire-site
- Plough horizon
- Hydromorphic features
- Humic enrichment, A-horizon (?)
- Calcareous concretions
- Rubefaction, B-horizon (?)

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Fig. 7 (continued).
5.2. From approx. 13,000 Cal BP—beginning of sedimentation S2 (transition to the Holocene)

In the Ghardimaou Basin the late Pleistocene/early Holocene transition is characterized by the beginning of a thick sedimentation phase (S2). The laminated sediment alternates between medium-sandy and silty–clayey deposits (Fig. 4a: OM3). The beginning of series S2 can be quite easily chronologically placed by dating the Epipalaeolithic layer (11,160 ± 50 BP [13,360–12,990 Cal BP]) covering the red soil found in Chemtou. In addition a fire-site within the uppermost late Pleistocene floodplain sediments (series S1) in OM (Fig. 4a) dates to 11,440 ± 50 BP (13,790–13,160 Cal BP). These dates are somewhat earlier than the observations of Steinmann and Bartels (1982), which indicate a substantial, early Rharbian sedimentation phase between 12,500 and 10,500 Cal BP at Oued Siliana (southern catchment area of the Oued Medjerda). Rohdenburg (1977) and Sabelberg (1977) describe the transition to the Holocene in the western Mediterranean region through substantial sedimentation phases. Rohdenburg (1977) sets the beginning of the mighty sediment accumulation at same time as the completion of the youngest red soil formation (approx. 13,200 Cal BP; Profile of Cala Tarida, Ibiza), which is close to our own results. According to detailed studies of lacustrine deposits in central Italy (Ramrath et al., 2000) the late Pleistocene/early Holocene period indicates a colder and drier phases from 12,650 to 11,400 Cal BP (Younger Dryas). Probably an aridification of the climate also induced active morphodynamics in the mid-Medjerda meander system marked by the beginning of series S2.

5.3. To approx. 5500 Cal BP—ending of sedimentation S2 and Neolithic soil formation P2

In the Ghardimaou Basin the sedimentation series S2, which begins in the latest Pleistocene/early Holocene, ends with a humic, brown soil (P2). This oldest Holocene soil is exposed in the OM Profile (see Fig. 4a and b) as in the CH (see Fig. 5a). These soil formation phases (P2) are linked to the incision of the Oued Medjerda and the first Holocene terrace (T1; Fig. 9). We can see a sign of this incision in the subsequent gravel deposits of the Oued Melah at CH (lowermost layer of series S3: CH–N4), which had accumulated at a similar riverbed level to the current one. In contrast to the younger gravel deposits, containing numerous historic artifacts (CH11), CH–N4 contains no man-made relics, with the exception of a spinning wheel weight, whose use was already known in the Neolithic period (personal communication: H. Baklouti, Tunis). The soil formation phase P2 can be limited insofar as that the Neolithic pottery fragments are first found in the subsequent sedimentation series S3. The completion of the series S2 more or less forms the Neolithic land surface.

Within the Ghardimaou Basin, the mid-Holocene soil from OM and Chemtou shows soil-forming characteristics whose intensity has never been replicated by later Holocene soil formation phases. Correlative to observations from the western Mediterranean region (Faust and Diaz del Olmo, 1997) the brown soil from the OM and CH can be paralleled with the Neolithic Pluvial, i.e. with the climatic optimum during the Holocene from a hygric and thermal perspective. A more exact chronological classification of the soil is difficult, as numerical dating is not yet available.

All earlier research of Holocene morphodynamics in the North-African region indicate that from approx. 5500 Cal BP a stark and abrupt change to markedly drier climate conditions occurred (Geyh and Jäkel, 1974; Sabelberg, 1977; Molle, 1979; Macklin et al., 1995), ending the formation of substantial, dark humic soils. Sabelberg (1977) for Southwest-Morocco and Molle (1979) for the northern and central Tunisian region describe a more or less single-phased soil formation, which ends around 5500 Cal BP. Molle (1979) places the Neolithic soil formation period in a time frame from between 6800 and 5500 Cal BP, when more moist climate conditions could have reached relatively far south. He supports this with the investigations of Conrad (1969), which verify the existence of a dark swampy soil in the area from Beni-Abbès (northern edge of Algerian Sahara). The humus dating of the swampy soil falls within a time frame of 7400–4500 Cal BP.

Scharpenseel and Zakosek (1979) describe a wider, early Holocene humic layer in the Medjerda floodplain.
at Bou Salem (Jendouba Basin; Fig. 3), the humus dating of which is approx. 9500 Cal BP. The age of the humic layer correlates to the assumptions of Molle and Brosche (1976) as well as Molle (1979). Each sees in the phase of predominately fine-sedimentation between 11,000 and 7800 Cal BP in the southern Tunisian region evidence of moister climate conditions, as in the present. Similar fluvial silty sediments are to be found in the south of the Aures Mountains. The layers include Capsien industries, placed in a time frame from 11,000 to 8000 Cal BP (Coque, 1962). The author concur with the assumption that in this time period moist climate conditions existed.

Steinmann and Bartels (1982) assume there was a multi-phased soil formation period in the early to mid-Holocene in Tunisia. The dating of the uppermost humic layer in the Oued El M’Dou Profile (at Gabes, South-Tunisia) gave a result of approx. 6000 Cal BP, and the humic layer (or soil?) at Hammam Lif (Northeast-Tunisia) produced a similar result of around 5800 Cal BP. These dates match the corresponding postulated Neolithic soil formation period between 6800 and 5500 Cal BP by Molle (1979). From the swampy palaeosol near Gabes, Steinmann and Bartels (1982) conclude that another moisture maximum in the climate existed. The humic content of the swampy soil is dated at approx. 8000 Cal BP. Taking into account the retarded behaviour of water tables in correlation to climatic alternation, the moisture maximum throughout the southern Tunisia region, according to our interpretation, could have begun a few hundred years earlier. In this case the result would be temporally more in accordance with the calculations of Molle and Brosche (1976) as well as those of Scharpenseel and Zakosek (1979), which for the sub-Saharan region would assume moister conditions between 11,000 and 7800 Cal BP and a soil formation phase of around 9500 Cal BP for the central Tunisian region. In a chronological overview of geomorphodynamics during Holocene in northern Tunisia, Faust (1993) also divided the soil formation period during the early to mid-Holocene into two phases. These previous researchers did not clearly differentiate between in situ palaeosols and soil sediments.

Supported by our stratigraphical investigations we place the soil from OM and CH at a time before 5500 Cal BP. For a more exact chronological classification, reliable dating results are still necessary.

5.4. Ca. 5500–1800 Cal BP—Mid-Holocene sedimentation S3 and Roman soil P3

The Neolithic soil follows a phase of increased sedimentation with slightly humic, clayey still-water accumulation. The lagoon-like sedimentation within series S3 can be observed and correlated in several profiles from the Ghardimaou Basin (OM7, CH7, CH10, SA3, SA6). The sedimentation series S3 ends with a soil (P3) that was formed before the Roman cultivation. Such a pre-Roman soil is to be found in the CH (CH10), where thin section analysis clearly indicates in situ formation. Pre-Roman soil formation is evident in the Ghardimaou I Profile (Fig. 3), whereas the thin section from OM10 indicated strictly re-deposited soil sediment.

The beginning of the mid-Holocene aridification and the associated sedimentation phase covered a substantial area in Mediterranean North Africa as well as in the western, central and eastern Saharan regions. From palaeolimnological observations in the western Saharan region, Petit-Maire (1994) concluded that the lake levels had dropped substantially until the final drying out, which occurred at 5300 Cal BP at the latest. Geyh and Jäkel (1974) describe the abrupt onset of an arid phase for the central Saharan region at 5400 Cal BP. With aridification, one can also observe a distinct decrease in the Neolithic population a couple of hundred years later (Geyh and Jäkel, 1974). Following palaeolimnological studies in Nubian, Pachur (1999) argued for aridification also in the eastern Saharan region from 5300 Cal BP at the latest. In the West-Mediterranean region the mid-Holocene soil formation was superseded approx. 5500 BP by a phase of geomorphodynamic instability (Rohdenburg, 1977). We interpret the sedimentation from OM7 as an accumulation indicating a more arid climate with accentuated rainfall events.

Since the mid-Holocene, we must speculate on an increasing human influence on the landscape of the Tunisian region. The beginning of the Neolithic cultivation is here relatively late, around 5000 Cal BP (Faust, 1993). For Southwest Spain, Diaz del Olmo et al. (1993) assume that from 4500 Cal BP one of the first anthropogenic clearing phases occurred, characterized by a population increase in the region, resulting in dune accumulation and colluvial re-deposition. The colluvial re-deposition in the Rio Fraja Profile in Andalusia in the transition time between the Neolithic and the Bronze Age (charcoal dating at 3800 Cal BP) allows us to temporally correlate this as well with an increasing population and land-cultivation (Faust et al., 2000). For Tunisia, there are indications of increased geomorphodynamic activity from approx. 5500 Cal BP, which, with some interruptions, continues into the present. To what extent sedimentation phases are accentuated by climatic or anthropogenic factors, can only be established with any certainty in a few examples. The reconstruction of the Holocene Oued Medjerda water level amplitude should provide clarification (Chapter 6).

The mid-Holocene sedimentation series S3 ends in the Ghardimaou Basin with a soil formation phase (P3). In
the Ghardimaou I Profile, a pre-Roman humic soil has developed, charcoal dating of which gives the age of the sediment (S3) at <2,785 Cal BP (Faust and Zielhofer, i.p.). According to Rohdenburg (1977), a phase of geomorphodynamic stability is indicated on the Balearic Islands and in Morocco from around 2100 to 2000 Cal BP. On several profiles he was able to confirm Calcareic Ranker formations from this time frame with the help of humus and mollusk dating. In the Ghardimaou Basin, the pre-Roman to Roman soil formation occurs simultaneously with the incision of the Oued Medjerda.

The formation of the second terrace occurred during the Holocene along the Oued Medjerda (Fig. 9: T2). Along Oued Siliana, a southern tributary of the Oued Medjerda, a terrace could been formed. Steinmann and Bartels (1982) dated snail shells in the terrace at approx. 2400 Cal BP. According to Geyh and Jäkel (1974) one must assume there was a period of moister conditions in the central Saharan region in the time around 2600–2000 Cal BP. This conclusion corresponds with our observations at Oued Medjerda. However, Geyh and Jäkel observed an intervening moist phase after the mid-Holocene onset of the arid phase around 5500 Cal BP from approx. 4000 to 3300 Cal BP, which also corresponds with the observations of Rohdenburg (1977) in Morocco. Holocene soil formation in Tunisia in this time period cannot be confirmed.

The records from the marine pollen profile from Brun and Rouvillois-Brigol (1985) from the isle of Kneiss (Gulf of Gabes) confirm a pre-Roman/early Roman moisture phase through a rise in oak pollen from 2500 to 2100 Cal BP. Interestingly, the pollen profile shows neither the Geyh and Jäkel (1974) postulated moist phase around 3600 Cal BP nor the onset of an arid phase in approx. 5500 Cal BP, which is otherwise documented in most scientific papers. Rather, Brun and Rouvillois-Brigol (1985) assume the ongoing state of moister conditions than today throughout until around 3100 Cal BP. Herein arises in our opinion the need for further scientific clarification.

5.5. 1800–1000 Cal BP—late Roman to post-Roman sediments S4

Morphodynamically, the end of the Roman Age can be recognized by a filling of the ancient river bed with a cobble layer (see Fig. 5). Substantial flooding across the entire floodplain led to sedimentation outside of the Holocene meander belt. Floodplain sediments covered the level of the originally flood-free Roman settlement area. The post-Roman sedimentation S4 is the key series for almost all the profiles and due to the numerous Roman artifacts, easy to correlate. A distinct increase in morphodynamic activity at the close of the Roman Age is also known to have occurred in other regions of the Mediterranean (van Zuidam, 1975; Rohdenburg, 1977; May, 1991; May et al., 1992; Schulte, 1995; Faust, 1997). The cause of this increase corresponds to the intensity of land use toward the end of the Roman Age. According to Geyh and Jäkel (1974), however, at least for the central Saharan region, one must also calculate on an accentuated aridification of the climate.

5.6. Ca. 1000–400 Cal BP—Middle Ages soil formation P4

The youngest A-horizons in the CH and Ghardimaou I Profiles (Fig. 3) indicate a mediaeval soil formation phase from approx. 1000 to 440 BP. \(^{14}C\)-dating of a
fire-site underlying the youngest layer (S5) yielded an age of 390 Cal BP (Faust and Zielhofer, i.p.). The Middle Ages soil formation ended no earlier than this time. Faust et al. (2000) have likewise observed a soil formation phase in Southwest-Spain around 1000 Cal BP. They correlate the time of geomorphodynamic stability with the corresponding sustainable land use system during the Moorish epoch, more or less as resulting from a phase of socio-political stability. Likewise, soil formation for the Tunisian region from the time around 1000 to 500 Cal BP was predicted. Scharpenseel and Zakosek (1979) have dated humic layers on Cape Bon and in the Medjerda valley at Bou Salem at approx. 1000 and 600 Cal BP, respectively, although these produced no evidence of in situ soil formation. The Middle Ages soil formation phase P4 in the Ghardimaou Basin again corresponds to an incision in the valley. The deepening of the river bed had resulted in a third (T3) Holocene terrace (see Fig. 9).

5.7. Approx. 400 Cal BP to recent—series S5: Ottoman, Protectorate Time and Independent Tunisia

At the earliest 400 Cal BP renewed catastrophic flooding began, which led to creation of the final “Youngest Layer” (S5) in the whole Ghardimaou Basin. The Youngest Layer is characterized by a fine lamination from silty-clayey to sandy-loamy sediments without recognizable soil-forming features. Within the Holocene meander belt the lateral shifting of the Oued Medjerda continues, with its resulting inner bank terraces (see Fig. 9). The present river bed shows slight accumulation.

6. Reconstruction of the Holocene water level amplitude of the Oued Medjerda

Gravel layers indicate the original bottom contour line of the river bed. From there we can temporally reconstruct the level of the riverbed during the Holocene of the Oued Medjerda (see Fig. 10). The different soil horizons imbedded in the sedimentation series indicate phases in which the river only seldom overflowed into the floodplain. From the difference in level between soil and chronologically corresponding gravel layer, we can reconstruct changes in the flow regime during the Holocene of the Oued Medjerda. Catastrophic flooding can be observed for the first time in the late Roman Age, associated with a high water level of over 8 m (Zielhofer and Faust, i.p.). After the Middle Ages soil formation phase, flooding again increased. High water levels have been reconstructed which reached, at least, over the 10 m mark.

7. Future research

Further clarification of the genesis of the late Pleistocene soil in the Southwest-Mediterranean region is required. The current status of research, above all in

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Fig. 10. Water level amplitude of the Oued Medjerda in the Ghardimaou Basin during the Holocene.
regard to questions about the development intensity and time frame, remains at this point incomplete and in parts contradictory. Especially, the question of a multi-phased soil formation during the early to mid-Holocene is not yet sufficiently clarified. From the $^{14}$C-dates currently under analysis, we hope that a clearer chronological clarification of the early to mid-Holocene will emerge.

The post-Neolithic sedimentation phase S3 is defined by numerous, lagoon-like still-water sediment layers. These layers are mostly unsuitable for the reconstruction of palaeoclimatic conditions. From the determination of in situ palygorskite content within the still-water deposition, we hope to find proof of an increase in the aridification of the climate in this phase. For final clarification of questions regarding the morphodynamically stable phases and the consequential soil formations within the Ghardimaou Basin, further analysis of thin sections is required.

From excursions with our Tunisian colleagues (work group Bourgou, University of Tunis) we know that morphodynamic activity and soil formation during the Holocene in the catchment area of the Medjerda has developed differently as in the basin itself. The Crise Romaine is exhibited in the catchment area through thick cobble accumulations, whereas in the basin region no thick sediment layers are to be observed, although there is a clear accentuation of the water level amplitude. Thus it would make sense to widen the research area to include the catchment area of the Oued Medjerda.

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References


