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The nature of the Pleistocene-Holocene palaeosols in the Gaza Strip, Palestine

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Abstract

The Pleistocene to Holocene succession in the Gaza Strip, Palestine, consists of an alternation of calcareous sandstones and reddish fine-grained deposits (palaeosols). The palaeosols can be subdivided into two main groups based on the sand-sized versus clay- to silt-sized grains: (1) the sandy hamra palaeosols, and (2) the loess and loess-derived palaeosols. The hamra palaeosols can, in turn, also be subdivided into two main types according to their colour and grain size: (1) light brown loamy to sandy hamra palaeosols, and (2) dark brown sandy clay hamra palaeosols. The hamra palaeosols are polygenetic and originated in humid environments. Their red colour results from ferric oxides coating the sand grains, but also by illuviation. The various pedogenitic units and their gradual transition to loess palaeosols are due to different phases of dust accretion. Both groups of palaeosols developed during the last glacial. They are considered to represent different climate environments: hamra palaeosols represent humid climates, whereas the loess and loess-derived palaeosols represent dry and semi-dry climates.

Keywords: hamra, palaeosols, palaeoclimate, Quaternary, Gaza

1. Introduction

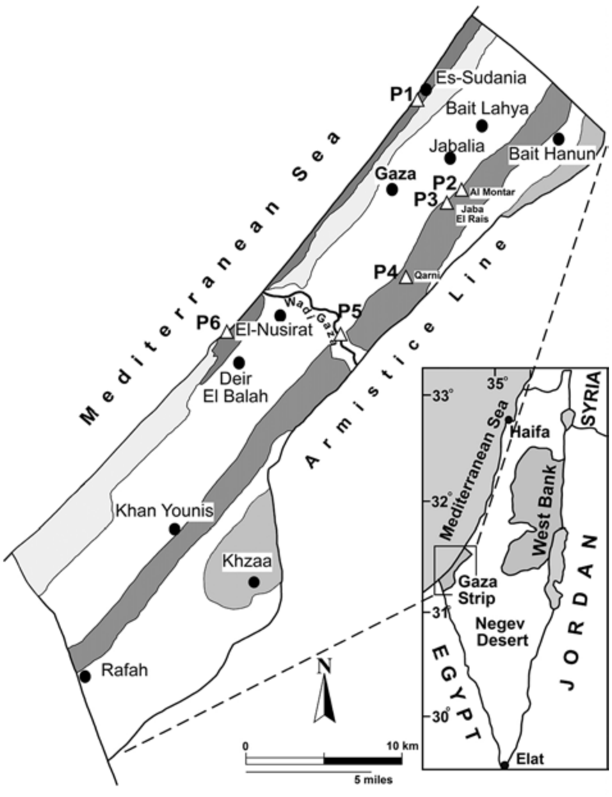
The central Palestinian coastal plain along the Mediterranean Sea is characterised by three ridges, known locally as ’kurkar ridges’; they run parallel to the coastline (Issar, 1968; Neev et al., 1987; Frechen et al., 2001, 2002, 2004). The ages of these ridges increase from the coast landwards. The ridges consist of Pleistocene-Holocene calcareous sandstones (locally termed ’kurkar’) intercalated by red-brown palaeosols (locally termed ‘hamra’) (Gvirtzman, et al., 1984; Frechen et al., 2001, 2002, 2004; Ubeid, 2010).

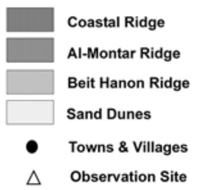
A palaeosol complex occurs in the southern coastal plain of Palestine. The palaeosols are derived from either sandy or loess-like parent material, or from a mixture of these materials, in varying ratios. In the western part of the southern coastal plain, soils derived from sandy parent material prevail, whereas loess and loess-derived soils cover the landscape in the eastern part (Yaalon & Dan, 1974; Bruins & Yaalon, 1979; Wieder & Gvirtzman, 1999; Gvirtzman & Wieder, 2001). The hamra palaeosols which crop out in the Gaza Strip are developed on sand or calcareous sand mixed with silty aeolian dust. These palaeosols occur within Pleistocene-Holocene strata along the coastal and Al Montar ridges, whereas the loess and loess-derived soils occur around Wadi Gaza.

1.1. Geographical setting

The Gaza Strip constitutes the south-western part of the Palestinian coastal plain, between 34°2′ and 34°25′ East and 31°16′ and 31°45′ North. The Gaza Strip is confined between the Mediterranean Sea in the West, the Sinai desert of Egypt in the South and the Negev desert in the East (Fig. 1). It covers an area of approx. 365 km^2 and has a length of 45 km between Beit Hanoun in the North to Rafah in the South. Its width ranges from 5 to 8 km in the central and northern regions to a maximum of 12 km in the South. The climate is characterised by mild winters, and dry, warm to hot summers. The average mean daily temperature ranges from 26 °C in summer to 12 °C in winter. The average annual rainfall is 335 mm per year; and the average annual evaporation amounts to 1300 mm.

The topography of the Gaza Strip is defined by the kurkar ridges, which are known (in the Gaza Strip) as the Coastal, the Al Montar, and the Biet Hanon ridges (Fig. 1). The surface elevations range from mean sea level to about 110 m above mean sea level. The ridges are separated by deep depressions (20–40 m above mean sea level), which contain alluvial deposits. Stratigraphically, these ridges belong to the Kurkar Group (Bartov et al., 1981) (Fig. 2).





Site	Coordinates	
P1	31° 33.600'N	34° 28.200'E
P2	31° 30.769'N	34° 29.517'E
P3	31° 29.409'N	34° 28.370'E
P4	31° 28.612'N	34° 27.782'E
P5	31° 26.058'N	34° 24.953'E
P6	31° 25.058'N	34° 19.753'E

Fig. 1. Location map showing the study sites (after Ubeid, 2010). The table below the map shows the coordinates of these sites.

1.2. Geology of the Kurkar Group

The Kurkar Group has a Pliocene-Pleistocene age and consists of marine and continental deposits (Bartov et al., 1981; Frechen et al., 2004; Al-Agha & El-Nakhal, 2004; Galili et al., 2007; Ubeid, 2010). Three formations are distinguished (Fig. 2A): (1) the Ahuzam Formation (0–15 m thick), which consists of conglomerates of limestone and chalk, (2) the Pleshet Formation (0–80 m thick), which consists of calcareous sandstones with a marine fauna, indicating a marine origin, and (3) the Gaza Formation, which consists mainly of alternating kurkar and hamra deposits with either gradational or sharp contacts, and which is 50–60 m thick (Figs 2B, 3).

This thickness of the Gaza Formation varies considerably, and a complete section is nowhere exposed (Horowitz, 1975; Abed & Al Weshahy, 1999; Ubeid, 2010). Lithologically, the Kurkar Member is composed of marine and continental calcareous sandstones (Horowitz, 1975; Frechen et al., 2004; Ubeid, 2010). The Hamra Member is built by red or brown palaeosols, which occasionally grade into blackish, clay-rich marsh deposits. The loess deposits form the Ruhama Loess Member (Horowitz, 1975). The Hamra Member forms lenses of several metres thick that extend laterally for some hundreds of metres.

The objective of the present study is to classify the palaeosols and to reconstruct the palaeoclimate during their development.

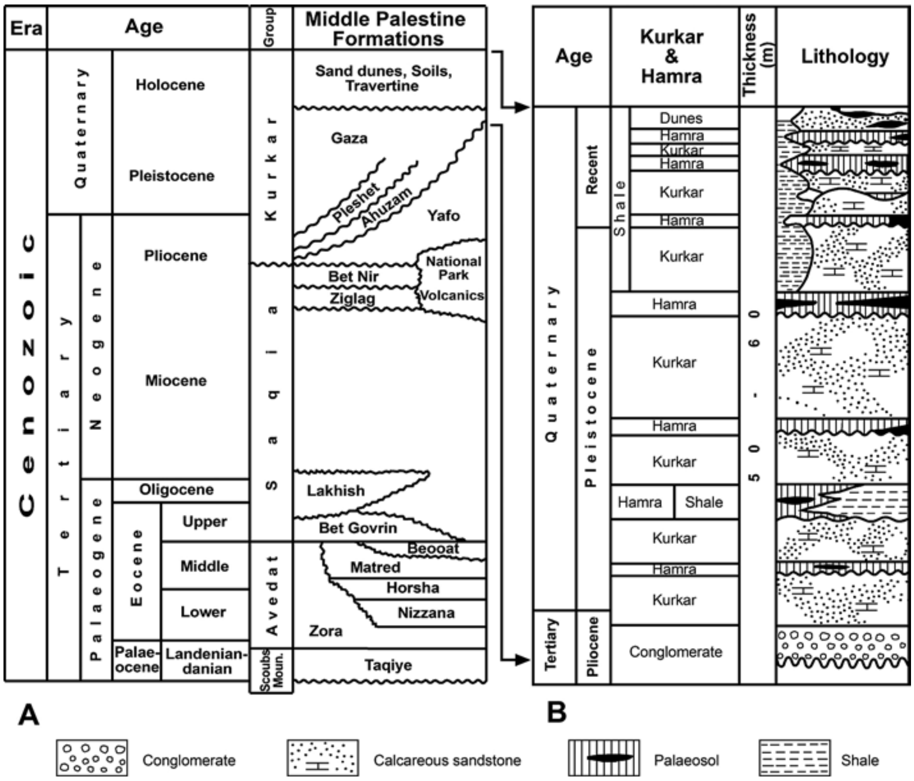


Fig. 2. Stratigraphy and lithology.
A – Stratigraphic succession of the Tertiary and Quaternary in the central coastal plain of Palestine (after Bartove et al., 1981);
B – Lithology of the Plio-Pleistocene Gaza Formation (after Abed & Al Weshahy, 1999).

2. Methods

The soils along the Coastal and Al Montar ridges were investigated for their colour, thickness, and grain size, as well as for their vertical relationships with the under- and overlying deposits. It should be noted that the Biet Hanon Ridge was inaccessible due to security measures, as it is located along the armistice line (Fig. 1). In the two other ridges, six sites with outcrops of palaeosols were studied: Es-Sudania, El Rais, Al Montar, Qarni, Wadi Gaza, and Dier El-Balah (Fig. 1).

The total calcium-carbonate content was measured by volumetric calcimetry. The grain-size distribution was determined by sieve analysis for the coarse articles, and by hydrometry after dispersion in calgon. The data were processed using GRADISTAT software following Blott & Pye (2001). The palaeosols were classified on the basis of their colour and grain-size composition.

3. Results and discussion

Two distinct groups of palaeosols were identified in the Coastal and Al Montar ridges. The first group, consisting of hamra palaeosols, has two distinct colour classes: light brown and dark brown. The light brown hamra palaeosols, which occur between two kurkar units (Fig. 5), can have a lateral extent of several hundreds of metres. Sill-like deposits of several centimetres thick are also present (Fig. 4B). This type of palaeosol mainly crops out at Es-Sudania, Deir El Balah, and Jabal E- Rais (Fig. 1). The dark brown hamra palaeosols are reddish-brown to dark brown (Fig. 6; Table 1) and consist of fine-grained sand to clay, representing a Bt horizon. The calcium-carbonate content in the soil matrix is around 12% (Tables 2 and 3). They have a blocky to massive structure, and their upper part is rich in carbonate nodules of pebble to cobble size. Yellow mottles and root traces are also present. The thickness of these palaeosols reaches 3 m. They show a sharp boundary with the overlying kurkar unit (Fig. 6).

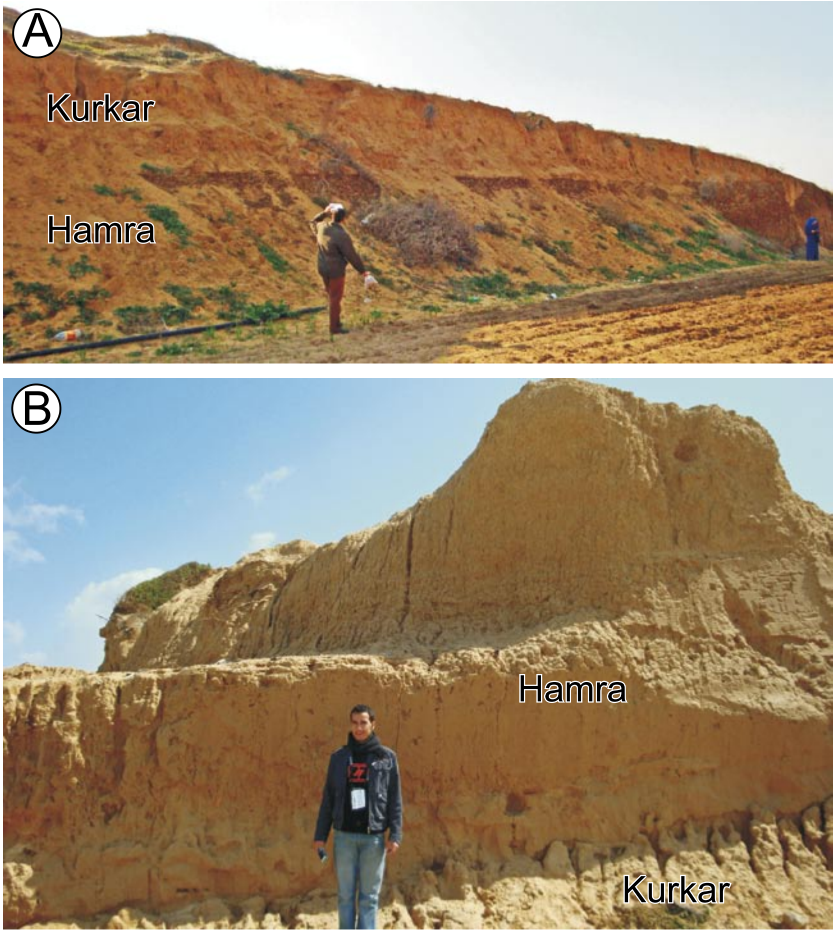


Fig. 3. Character of the boundary between the hamra and kurkar deposits.
A – Sharp boundary between the dark brown hamra palaeosols and the kurkar deposits at Qarni (north-eastern Gaza Strip); **B –** Gradational boundary between the light brown hamra palaeosols and the kurkar deposits at Deir El Balah (central Gaza Strip).

The second group of palaeosols identified in the Al Montar ridge consists of the light brown loess palaeosols.

3.1. Hamra palaeosols

The hamra soils have commonly a reddish colour and they are coarser than the loess soils. The light brown hamra palaeosols are developed in loamy sand to sand, which represent the A and B horizons. They consist of fine- to very fine-grained sand, and the calcium-carbonate content in the soil matrix ranges from 3% to 13% (Tables 1 and 2). The grains are well-sorted, they show a normal distribution, and they consist of quartz with subordinate feldspars. Massive structures with elongated car-

Table 1. Grain-size distribution from sieve analysis of coarse-grained samples from Al Montar (P3) and Deir El Balah (P6).

Observation site	Sample no.	Silt-clay %	VF sand %	F sand %	M sand %	C sand %	VC sand %	F gravel %
P6	DB-1	6.2	7.8	45.0	29.8	7.9	3.2	0.5
P6	DB-2	5.2	5.5	73.7	14.3	1.4	0.2	0.1
P6	DB-6	2.2	2.2	41.1	44.2	6.2	1.9	1.4
P6	DB-7	10.6	11.5	42.1	21.9	8.1	4.9	1.0
P6	DB-8	12.2	13.3	40.4	11.7	16.0	6.0	1.0
P6	DB-9	9.7	21.9	39.4	11.7	11.4	5.0	1.1
P3	MR-4	1.8	2.2	31.0	52.1	10.0	2.5	0.0

Table 2. Calcium-carbonate percentages of the samples from Al Montar, (P3), Qarni (P4), Wadi Gaza (P5), and Deir El Balah (P6).

Observation site	Sample no.	Lithology	$CaCO_3$ %
P6	DB-1	hamra	3.36
P6	DB-2	hamra	6.60
P6	DB-6	hamra	7.48
P6	DB-7	hamra	9.60
P6	DB-8	hamra	13.60
P6	DB-9	hamra	13.70
P3	MR-4	hamra	12.90
P5	WG-1	loess	15.65
P5	WG-2	loess	15.91
P4	Q-1	hamra	11.65

bonate nodules are also present, just like shells and fragments of land snails (Fig. 4A). This soil usually has a mottled appearance and shows occasionally by root traces.

The grain size of the hamra palaeosols indicates that they developed in a sandy parent material. This is supported by the sorting of the sand, which reflects typically transport by saltation (Gvirtzman & Wieder, 2001). The red coating on the quartz and feldspars grains sug-

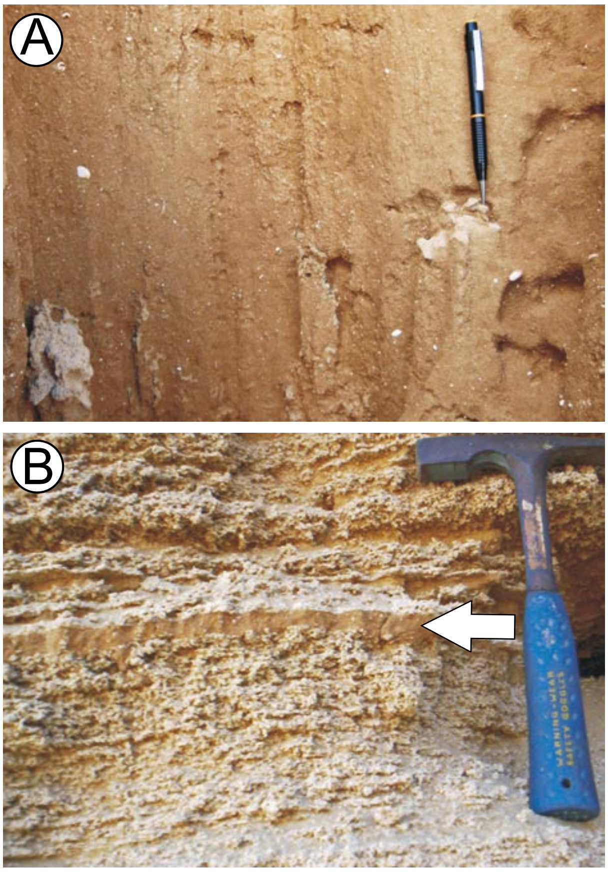


Fig. 4. The light brown hamra palaeosols. **A –** Shells and bioclasts of terrestrial snails (white colour) at Deir El Balah (central Gaza Strip); **B –** Sill-like palaeosols in kurkar deposits at Qarni (northeastern Gaza Strip).

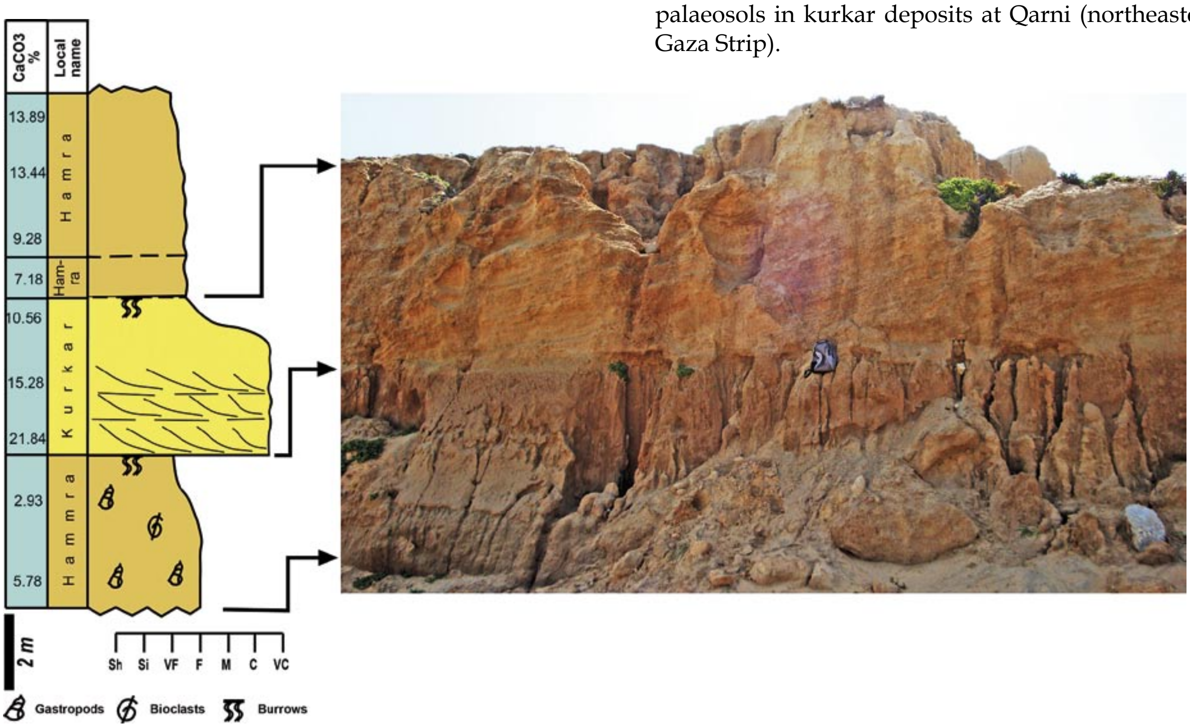


Fig. 5. Light brown palaeosols overlain (sharp contact) by kurkar deposits, at Dier El Balah (central Gaza Strip). Note the grain size and calcium-carbonate concentrations of the soils in the stratigraphic log.

Fig. 6. Dark brown palaeosols at Qarni (north-eastern Gaza Strip). Note that the kurkar deposits overlie the hamra palaeosols through a sharp contact, and that the frequency of carbonate nodules increases upwards.

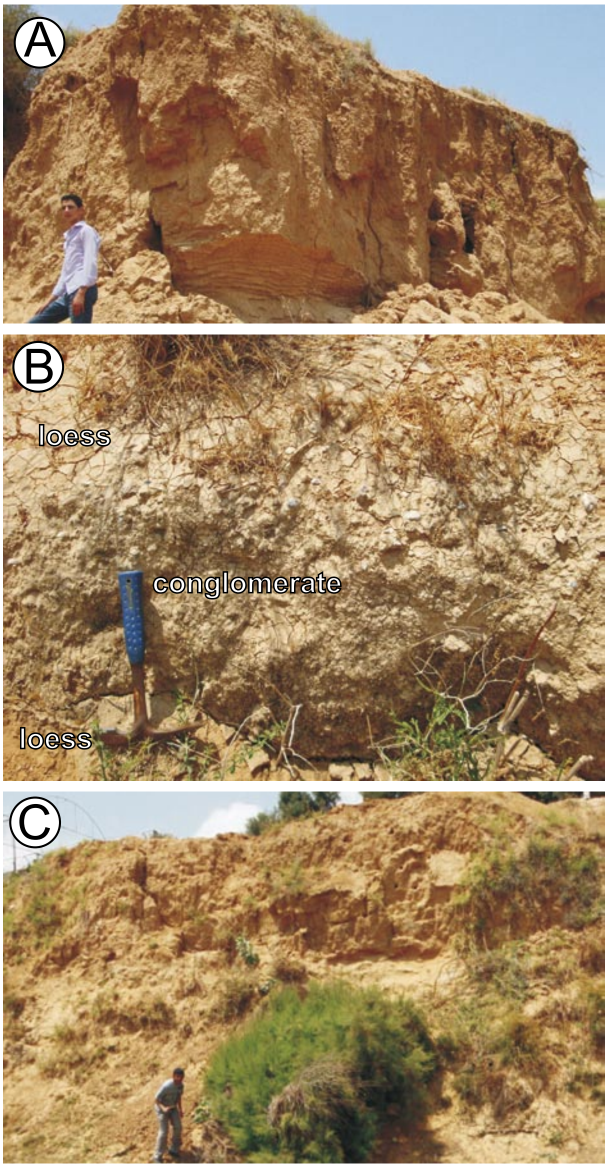


Fig. 7. Loess palaeosols in Wadi Gaza (central Gaza Strip).
A – Vertical collapse due to erosion of the palaeosols; **B –** Fluvial conglomerate between two loess palaeosols; **C –** The complex of loess palaeosols with a total thickness of some 10 m.

gests that the soils are well-drained and formed under oxidizing conditions (Wieder & Yaalon, 1978; Tsatskin & Ronen, 1999). The mottling is ascribed to iron reduction in places rich in organic matter, probably plant roots.

The sandy soils developed on sand or calcareous sand mixed with silty aeolian dust. They formed in the humid environments that prevail in the central coastal plain of Palestine.

The hamra soils are considered to be polygenetic (Wieder & Gvirtzman, 1999). The first pedogenic phase occurred in well-sorted sands and included strong leaching of carbonates and reddening of the soil material. Within these initial soils, the carbonate leached through the permeable sand and became concentrated in the form of carbonate nodules. These nodules form a pedogenic calcic horizon. Reddening (rubification) of the soil can be ascribed to the release of large amounts of iron oxides, which crystallized as finely dispersed, red-coloured hematite upon drying, as established by Bresson (1974) for the western Mediterranean area. Horowitz (1979) suggested that the reddening of the hamra soils occurred during earlier, more humid intervals with summer rains, when the climatic belts were situated south of their present-day position. Ferric oxides, closely associated with clay in these soils, are found in

Table 3. Grain-size distribution from hydrometer analysis of fine-grained samples from Wadi Gaza (P5) and Qarni (P4).

Sample no.	Lithology	Sand %	Silt %	Clay %
WG-1	loess	0	45.50	54.50
WG-2	loess	51.48	24	24.52
Q-1	hamra	47.48	8	44.52

birefringent streaks around sand grains, suggesting that they formed through illuviation (Wieder & Gvirtzman, 1999).

The next developmental stage was characterised by accumulation of fine-grained material and vertisol formation on a more clayey substrata (approx. 45% clay). Eventually the leaching of carbonate, which was strong during the earlier developmental pedogenic stage, stopped. Most likely, the calcium carbonate formed in situ by local dissolution of land snail shells and subsequent precipitation, replaced the illuviation of carbonates at the end of this stage.

3.2. Light brown loess palaeosols

These palaeosols consist of sandy clay loam, more specifically very fine- to fine-grained sand (51%), silt (24%) and clay (25%) (Table 3), and they contain about 16% of calcium carbonate (Table 2). These massive palaeosols are represented by a thick B horizon which gradually overlies a calcic horizon. They show vertical collapse due to erosion (Fig. 7A).

The palaeosols consist of two units separated by a conglomerate of about a decimetre thick (Fig. 7B), and form a succession of up to 10 m thick (Fig. 7C). The conglomerate is moderately to poorly sorted, clast-supported and consists of pebbles and small cobbles of quartzite and carbonates, with a matrix consisting of coarse sand to fine pebbles.

The upper palaeosol unit contains clayey loess-derived dark brown layers consisting of approx. 55% clay and 45% silt, apart from the calcium–carbonate content of some 16%. The lower unit is poorly exposed and has not been analysed. Both the light brown loess soils and the dark brown loess-derived soils occur at Wadi Gaza (Fig. 1), where they form substantial outcrops at the surface; here, they overly the continental kurkar deposits. More to the North, these palaeosols are also present under the (mostly continental) kurkar deposits.

Loess-derived soils are loess soils from which the carbonates were leached out to a large extent (10–35%) so that the material became more clayey (Dan et al., 1976; Wieder & Givitzman, 1999). The grain-size distribution in these soils reflects atmospheric dust that was supplied from the Sinai and the Negev deserts (Yaalon & Dan, 1974; Yaalon & Ganor, 1979; Dan et al., 1981; Ganor et al., 1991; Emzel et al., 2008; Crouvi et al., 2008; 2009; 2010). Aeolian dust from these deserts is still involved in the formation of all soils in Palestine (Dan & Yaalon, 1969). The high clay and silt content in the lower part of these palaeosols, compared with the upper part, is noteworthy (Table 2). The concentration of aeolian dust in the lower part is also higher than in the upper part.

It seems appropriate to compare here briefly the buried soils with the present-day soils in the area. In the southern part of the semi-arid belt, with its mean annual rainfall of 320–420 mm, mainly loess-derived dark brown soils (Dan et al., 1972), whereas light brown loess soils occur in the mildly arid climate with a mean annual rainfall of 220–320 mm.

The pedogenic interpretation of the loess-derived palaeosols has implications for the stratigraphy of the late Quaternary deposits in the area and for the reconstruction of the past environmental conditions. The transition from one pedogenic unit to the other within the main upper unit is gradual. Earlier studies therefore considered the clayey palaeosols as developed during ongoing sedimentation, thus representing uninterrupted soil formation (Dan & Yaalon, 1971; Yaalon & Ganor, 1973). Dust deposition was estimated to be 50–200 $g{\cdot}m^{-3}$, as this value is the rate of present-day dust deposition (Yaalon & Dan, 1974), but aeolian dust can, obviously, have taken place at different rates in the past.

Two phases might, indeed, be distinguished. One phase may have been characterized by rapid dust accumulation so that pedogenesis could not keep pace, whereas the other phase was characterized by slow dust accumulation so that soils could develop in full. This would explain not only the occurrence of the different pedogenetic units but also the gradual transition between both palaeo-pedogenetic units. Since the intensity of soil differentiation increases with decreasing intensity of soil erosion and/or sedimentation (Wieder & Yaalon, 1985; Wieder & Gvirtzman, 1999), the phase of dust accumulation was probably short, whereas the pedogenetic phase was long-lived and stable.

The conglomerate represents an intermediate interval with fluvial activity during the humid phase in the area between the El-Khalil mountains (part of the West Bank in the north-eastern part of the Gaza Strip) and Wadi Gaza.

3.3. Sedimentation and the boundary between the soils and the kurkar

The sedimentation of sand and desert dust took – and still takes – place simultaneously with pedogenesis in the coastal belt of Palestine. The intensity of both processes depends on the climate: if the intensity of pedogenesis exceeds the rate of sand and dust accumulation, sand and dust become incorporated into the soil, thus becoming part of the soil material. If, on the other hand, the rate of sand and dust accumulation exceeds that of soil formation, the soil material becomes buried by sediment, resulting in a relatively sharp boundary with the underlying soil. The soil then becomes a palaeosol and a new soil cycle starts (Kukla et al., 1988; Kukla & An, 1989). If the rate of sand and dust accumulation equals the rate of soil formation, the soil material becomes buried by sediment, but their mutual boundary will be gradational (Figs 3 and 8). Such a boundary is known as a 'soil-sequence boundary', and it separates the palaeosols from the calcareous sandstone 'kurkar deposits'.

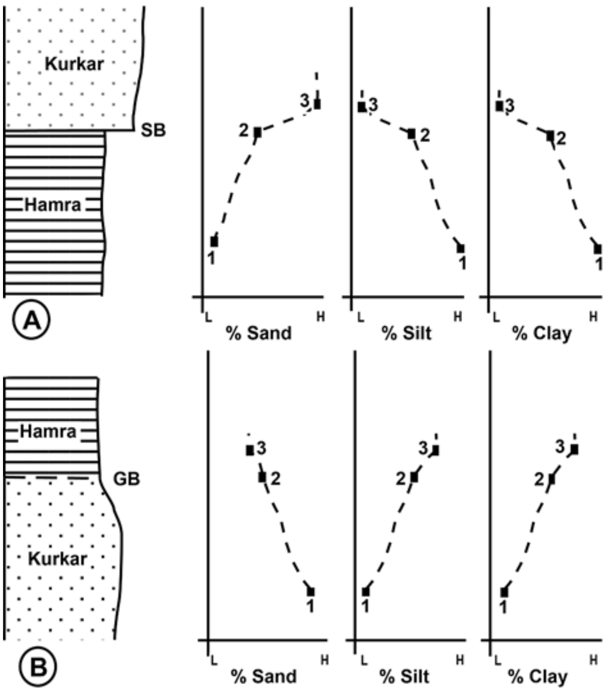


Fig. 8. Different boundaries between the palaeosols and the kurkar deposits.
A – Sharp boundary (SB) between points 2 and 3, indicating that the sand accumulation exceeded the rate of soil formation; **B –** Gradational boundary (GB) between points 2 and 3, indicating that the sand accumulation was in balance with the rate of soil formation. L and H indicate low and high percentages, respectively, of sand, silt and clay in the soil.

4. Palaeoclimate and age

The dark brown hamra palaeosols are polygenetic. They formed during a historically humid and warm Mediterranean climate. This climate was present during the last glacial. The light brown hamra palaeosols are also polygenetic, but they developed during a humid, less warm climate. The warm conditions gave rise to the relatively strong rubification of the dark brown hamra palaeosols, whereas the somewhat colder climate resulted in the light brown hamra palaeosols. The secondary carbonates accumulated later, during the drier conditions that prevailed before the last glacial.

The loess palaeosols indicate a dry climate, whereas the loess-derived palaeosols indicate a semi-arid climate; the mean annual rainfalls amounted to 220–320 mm and 320–420 mm, respectively. This indicates that the loess and loess-derived soils in the study area were formed under climatic conditions that passed from arid to semi-arid, interrupted by a short period of increased humidity.

Previous studies have interpreted the palaeosoil units as formed during the last glacial, 70,000–10,000 years B.P. (cf. Yaalon & Dan, 1974; Issar & Bruins, 1986; Wieder & Gvirtzman, 1999; Crouvi et al., 2008). Most of the loess deposits formed then as well. In the central Negev desert, evidence has been found that the deposits that accumulated during this time-span were due to a dust-laden regime (Bowman et al., 1986). A palaeoclimatic model has also been proposed to explain the then dust deposition (Issar et al., 1987). The just-mentioned authors

Table 4. The various types of the palaeosols in the Gaza Strip.

Palaeosol		Lithologic description	Interpretation of pedogenic processes	Climatic conditions	Age
Hamra palaeosols	Light brown hamra palaeosol	Loamy sand to sand; 3% to 13% $CaCO_3$; massive structures; shells of land snails	Polygenetic: leaching of carbonate, rubification and accumulation of fine-grained materials	Humid climate	Last glacial period
	Dark brown hamra palaeosol	Fine-grained sands to clay; 12% $CaCO_3$; blocky to massive structures; root traces		Humid and warm climate	
Loess palaeosol		Sandy clay loam; 16% $CaCO_3$; massive structures	Occurred due to different phases of dust accretions	Arid and semiarid climate	Pre-last glacial period

suggested that a strong anticyclonic regime prevailed, that shifted the westerlies more to the South, including a cyclonic depression over the Lybian desert that, in turn, generated dust-loaded storms in the central and northern Negev.

The hamra deposits in the Gaza Strip are older than the loess deposits. The dark brown hamra palaeosols are present in the Al Montar ridge at Qarni, and these palaeosols are situated between the underlying light brown hamra palaeosols and the overlying loess palaeosols. This stratigraphic position, in combination with the grain-size distribution in the various palaeosols leads to the conclusion that the dark brown hamra palaeosols formed before the last glacial. The light brown hamra palaeosols are found in the Coastal ridge, which is considered the oldest ridge.

5. Conclusions

Three types of palaeosols occur in the Gaza Strip in the south-western central coastal plain of Palestine (Table 4):

(1) light brown hamra palaeosols, which mainly consist of fine- to very fine-grained sand, with a calcium-carbonate content of up to 13%; these soils developed ring a humid climate;

(2) dark brown hamra palaeosols which mainly consist of fine-grain sands to clay, with calcium carbonate contents around 12%; these soils also developed in a humid climate;

(3) light brown loess (and loess-derived) palaeosols, which consist of fine-grained deposits (very fine sand, silt, and clay).

The palaeosol types (1) and (2) developed on sand and their carbonate content was leached out completely in a humid climate. Secondary carbonate nodules were formed later. The carbonate nodules in the clayey dark brown hamra soils represent the pedogenic calcic horizon. The colour of these palaeosols, which ranges from light brown to reddish brown, is due to iron-oxide segregation and/or coatings, reflecting oxidising conditions. The loess palaeosols (type 3) were formed in a arid and semiarid climates. The palaeosol units and their gradual boundaries formed during a relative short time-span with a high accumulation rate and a long phase of pedogenesis with a lower rate of dust accumulation. These loess palaeosols formed during the last glacial, whereas the hamra palaeosols seem to have formed before the last glacial.

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