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ABSTRACT

A 15 m thick sequence of calcic sandy paleosols was exposed in a trench excavated in the western Negev flat sand sheet that extends between the Agur dune field in the south and the kurkar ridge of the Gaza Strip in the northwest.

Seven calcic paleosols, separated by erosion contacts, were identified in the sequence. Most of the paleosols developed to stage III-IV and they are intensely bioturbated, with abundant burrows and rhyzolites traces.

We used the optically stimulated luminescence (OSL) method to date the time of sand deposition and soil formation. By separately dating the medium-sand fraction and the very-fine-sand fractions, we could distinguish for some units between the event of sand incursion and the subsequent dust accumulation, which contributed to the formation of the calcic soils. The ages of the sand units range from more than 400 ka at the base of the section (Units 1, 2) to about 13 ka at its uppermost part (Unit 7), with large time gaps between the units. However, the major Late Pleistocene phase of sand incursion into the Negev, which formed the Agur and Haluza dune fields, is missing from this sequence.

Since the source area of the sand in the western Negev is the Mediterranean coast, each unit of sand sheets in the western Negev reflects an event of sand incursion to the coastal plain of Israel and formation of Kurkar ridges. Each break in sand supply is represented in the western Negev by calcic soil and in the Sharon coast by Hamra soil.

The western Negev sand sheets sequence reflects the Pleistocene history of sand incursions to the coastal plain of Israel and as such it can be used to reconstruct climatic fluctuations in the eastern Mediterranean. The calcic soils developed under a climatic regime not much different from the present, with annual precipitation of at least 200-250 mm. The time span between each sand accumulation event indicates that in this region, where the only source for carbonate and silt is in dust, the development of mature calcic soil takes several ten thousands years.

1. INTRODUCTION

Massive sand incursions and formation of coastal dunes started along the shoreline of Israel in the latest Pliocene (Lewy, Z. in: Menashe, 2003), and since then it continued intermittently until the late Holocene. The source of quartzose sand is the Nile delta, and it is transported to the western coast of the eastern Mediterranean basin by alongshore currents induced mainly by southwestern and western winds and by the Coriolis Effect (Almagor, 2005 and references therein). During its movement along the coast the Nilotic sand is mixed with biogenic fragments originating from marine fauna that live on the continental shelf and washed by the waves onto the coast as calcareous sand. Streams draining the limestone hinterland also contribute carbonate grains, however, that is minor compared to the biogenic marine component.

Several coastal dune ridges comprising lithified aeolianite rich in bioclastic fragments (locally termed kurkar) are aligned sub-parallel to the coast of Israel. The mode of formation of these kurkar ridges was interpreted in several ways, each mode inherently indicating a different environment: transverse coastal dunes (Yaalon and Laronne, 1971) suggesting that kurkar formed during high sea stand; longitudinal dunes, formed simultaneously along the coast line by winds that blew parallel to the coast line during periods of low precipitation (Gvirtzman et al., 1998; Sivan, 1999) and fore-dunes formed by vegetation that trapped the blown sand near the coast (Tsoar and Moller, 1986; Tsoar, 2000), also indicating proximity to the coast.

Further inland, periods of sand invasion are represented by formation of sand sheet or dune fields, forming the Rehovot Formation in the central coastal plain (Gvirtzman et al., 1984) and the Gaza Formation in the western Negev (Horowitz, 1979). This sand is dominated by quartz grains and because of the lack of carbonate clasts it generally remained unlithified. In the eastern Sharon it forms a continuous sandy sequence, which contains reddish paleosols known locally as "Hamra". In the western Negev, the Middle Pleistocene sequence is composed of a series of tabular sandy units most of them contain calcic paleosol (Menashe, 2003).

The youngest kurkar units exposed along the Sharon coast were dated to the early last glacial period (65-50 ka; Frechen et al., 2002; Porat et al., 2004). Submerged kurkar ridges are located west of the coast, on the continental shelf, attesting to the migration of the coastline during the last glacial regression. During the entire glacial period ubiquitous Hamra soils formed over the stabilized kurkar ridges and sand sheets of the coastal plain (35-13 ka; Frechen et al., 2002; Porat et al., 2004).

During the Late Pleistocene, massive dunes movement started from northern Sinai into the western Negev. The first sand incursion is dated to 60 Ka (Ben David, 2003), however the main phase of extensive dune fields formation in the western Negev (Agur, Nizzana and Halutza dune fields) occurred during the peak of the cold and dry last glacial (25-16 Ka) (Goldberg, 1986; Goring-Morris and Goldberg, 1990; Zilberman, 1992; Ben David, 2003; Goodfriend and Magaritz, 1988; Bar Matthews et al., 1997; 1999; Robinson et al., 2006).

During the main period of sand incursion into the western Negev, well-developed soils (Netanya Hamra) formed throughout the coastal plain (Porat and Wintel, 1995; Ritte, 1998), indicating stability of the eolian landscape due to decrease in wind erosion and increase in vegetation cover on the dunes (Tzoar and Blumberg, 2002).

The study area is located on the boundary between the two major sand sources, one from the continental shelf, represented by the kurkar ridges of the Gaza strip to the west, and the other from northern Sinai, represented by the Haluza-Agur dune field in the south east (Fig 1). Identifying episodes of sand incursion or soil formation at the site, and comparing them to the two different sand provinces, can assist in elucidating when each of the sand sources was active and how climate and sea level influenced sand mobilization during the Late Pleistocene and the Holocene in the eastern Mediterranean.

2. SITE MORPHOLOGY

Sand sheets are area of eolian sand with very subdued dune forms. Most sand sheets appear to be virtually featureless, level plains, underlain by near horizontal bedded sands only a few meters thick. Many of the sand sheets border sand seas, and some of them act as a stable bases on which other dunes migrates (Cook et al., p.394).

The western Negev sand sheet is bounded by the coastal Kurkar ridges in the north, Nahal (ephemeral stream) Besor in the northeast, the Agur-Haluza sand field in the south and south east (Fig 1) and it extends westward to northern Sinai. It forms a flat or undulating terrain underlain by a sandy sequence up to a few tens meters thick.

Kerem Shalom settlement is located near the border of Israel with both Egypt and the Gaza Strip; 14 km southeast of the Mediterranean coast (Fig. 1). Average rainfall is 200-300 mm/y and the average temperatures ranges between 26-28º in the summer to 14-16º in the winter. It is situated in the middle of a flat terrain (Fig. 2), several km wide that extends between Gaza Strip kurkar ridge in the northwest and the Agur dune field in the southeast. The dune fields of the Negev are the eastern part of the regional sandy body that extends from the Nile Delta in the west through northern Sinai to Nahal Besor in the east. The north-west oriented N. Besor valley formed a topographic barrier to the sand invasion from the west during the Late Pleistocene and especially during the Holocene, and therefore it separates between a western sandy domain and an eastern loessy domain.

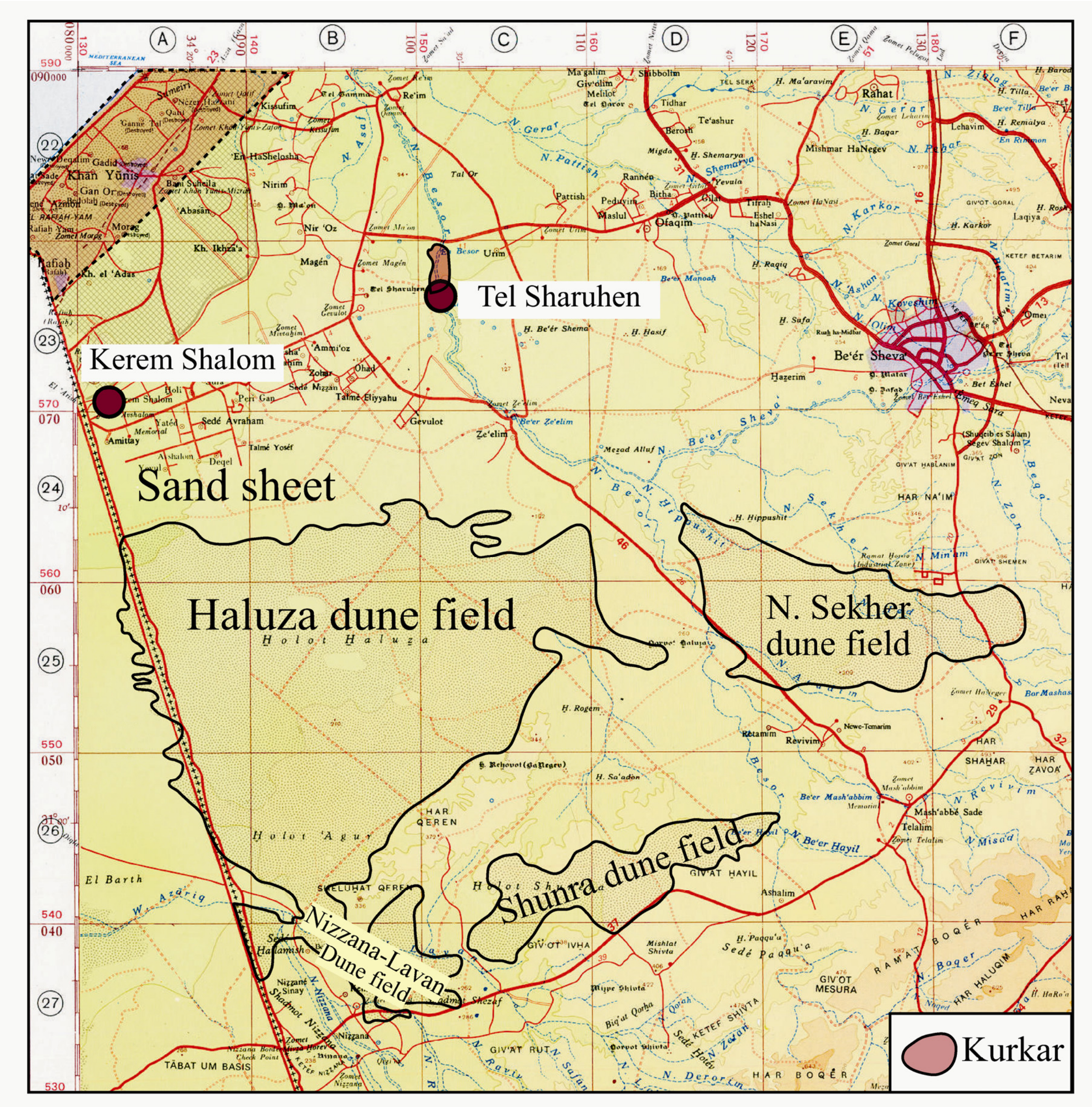

Fig. 1: Location map

Sand was mobile in this area until recent time because of overgrazing. However, in the last 30-40 y, this was a fire zone and grass community was recovered and stabilized the sand.

There is no substantial drainage network in the entire sandy terrain extending from N. Besor to N. El-Arish in northern Sinai (about 70 km), therefore no outcrops are available for stratigraphic study. The nearest exposed sequence is located about 20 km to the northeast, along N. Besor near Tel Sharuhen (Zilberman et al.,1994 ;Menashe, 2003). However, a deep pit excavated near Kerem Shalom (Fig. 3) exposed the sandy sequence buried under this flat terrain, enabling for the first time to study the history of sand accumulation in this area.

Fig. 2: The landscape at Kerem Shalom-view to the south. An extensive flat terrain of a sand sheet. The Agur sand dunes is on the horizon.

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Fig. 3: The pit - view to the east.

3. FIELD AND LABORATORY METHODS

The sequence was exposed in a large pit about 15 m deep (Figs. 3, 4), excavated south of Kerem Shalom. A small trench, about 50 m west on the main pit, was also described and sampled. Field work included detailed measurements and description of the section. Soil profiles were described according to Birkland (1984). The determination of the development stage of the Bk horizons was based on field observations. The boundaries between the main sedimentary units were determined according to unconformity contacts.

Samples for luminescence dating and for further sedimentological analyses were collected from each of the units at intervals of 0.5-1 m.

Seventeen samples were collected for luminescence dating; 15 from the main pit and 2 from the small trench. Holes were drilled into the section to a depth of ~0.3 m, and after discarding the sediment from the outer 0.1 m, a sample for chemical analyses of the radionuclides was collected from between 0.1 and 0.2 m depth. The sample for luminescence dating was collected from the deep end of the hole directly into opaque black bags.

Gamma and cosmic dose rates were measured in the field in the same holes from which the sediment was collected. Alpha and beta dose rates were calculated from the concentrations of the radionuclides U, Th and K, measured by ICP-MS. Time-averaged moisture content was estimated at 5±2%, in accord with the sandy nature of the sediments and the general aridity in the region.

Fine sand size quartz, in the range of 88-125 μm or 125-150 μm, was extracted and purified using routine laboratory procedures. The sample was first sieved to the selected grain size, carbonates were dissolved with 8% HCl, and after rinsing and drying, heavy minerals and most feldspars were removed by magnetic separation. Subsequent etching with concentrated (42%) HF was used to dissolve any remaining feldspars and remove the outer rim of the quartz grains.

In the paleosols of the upper units, two size fractions were dated in an attempt to differentiate between the timing of sand deposition and that of subsequent dust accumulation and soil formation. For samples KR-7 and KR-10 from Unit 6 and Unit 5, respectively, two fractions were separated and analyzed. The coarser medium-sand fraction, 150-177 μm, is the modal grain size of the sand and its age is the time of sand deposition. The very-fine-sand fraction, 74-105 μm, forms about 1-5 % of the present dust and loess in the area and the dust deposited today in the Negev (Ganor, 1975).

Equivalent doses (De) were measured using the single aliquot regenerative dose (SAR) protocol (Murray and Wintle, 2003). Nine to eighteen aliquots were measured for each sample. A range of preheats between 200° and 260°C was used before measuring the optically stimulated luminescence (OSL) signal, and a brief preheat at 180°C was used before measuring the test dose.

Data reduction was carried out using the Analyst software (By G.A.T. Duller, University of Wales, Aberystwyth) and an exponential fit with a linear component was used to fit the dose response curve.

3.1 . Sediment Analysis

Grain size distribution was measured on 23 samples, each of 20 gr in the GSI sedimentology laboratory. Each sample was separated to 14 fractions ranging in size from 0.5 mm (coarse sand) to 0.062 mm (coarse silt).

4. RESULTS

4.1 Luminescence dating

The age of the Kerem Shalom samples range from sub-recent (130 years) to close to 500,000 years, well beyond saturation of the OSL signal and the limit of quartz OSL dating (Table 1). Overall the samples display good preheat plateaus between 220° and 260°C, and there is no consistent change of De values as a function of preheat temperatures. Recycling ratios are mostly within 10% of 1.0, and IR presence, measured as a second recycling point after IRSL exposure, is minimal (less than 10%).

In the upper half of the sequence, up to a depth of 8 m, the ages are mostly in stratigraphic order (Fig. 5). Below that, as the OSL signal of the sample is close to saturation, the errors are very large and the ages are scattered. These ages should be considered as minimum ages. The ages for individual units will be given and discussed below in stratigraphic context.

4.2 Stratigraphy

The Kerem Shalom section is composed of a series of seven eolian sandy units separated by sharp contacts. Each of these units contains at least one calcic paleosol, (Fig. 4), and some of them contain complex pedogenic profiles with several B horizons. The uppermost unit is capped by sand containing pottery fragments.

The units and the paleosols are described below, together with their respective OSL age (see also Fig. 9):

4.2.1 Unit 1 (Fig. 5) - The lower unit consists of four amalgamated Bk horizons separated by erosion contacts formed by slight truncation of the upper part of the soil profile.

Pal 1a –The base of the profile is composed of compact sand with organic material remains and calcic nodules (5-10%), mostly orthic. The amount of nodules increases upward to form a stage III-IV Bk horizon, 20-30 cm thick. It also contains patches of carbonate disseminated in the sandy matrix (5-10 cm). The Bk horizon is penetrated by rhyzolites and burrows, which are filled by younger sand. The top is eroded, showing a relief of a few cm. The nodules near the top are orthic. The age of the lower part of unit 1 is beyond the range of the OSL method.

Pal 1b – The lower part (C1) consists of friable sand with burrows and rhyzolites with few calcic nodules eroded from the underlying B horizon of Pal 1a. It also contains undeveloped (stage I) nodules. The overlying Bk horizon contains orthic nodules (5-10 cm), scattered in clusters near the upper contact.

Pal 1c – The lower part (C1) consists of compact sand with remnants of organic material and a few calcic nodules. The upper Bk horizon, 15 cm thick, contains ~10% nodules (1-3 cm).

Pal 1d –The matrix of the lower part is rich in organic matter and contains 5-10% calcic nodules (1-5 cm). The size of the nodules increases upward to form a Bk horizon, composed of 20-30% calcic nodules (3-4 cm), and roots remains. The upper 2-3 cm contains mainly disorthic nodules and burrows penetrating from the overlying unit. The upper contact is sharp. The OSL age of unit 1 is older than 422±91 ka.

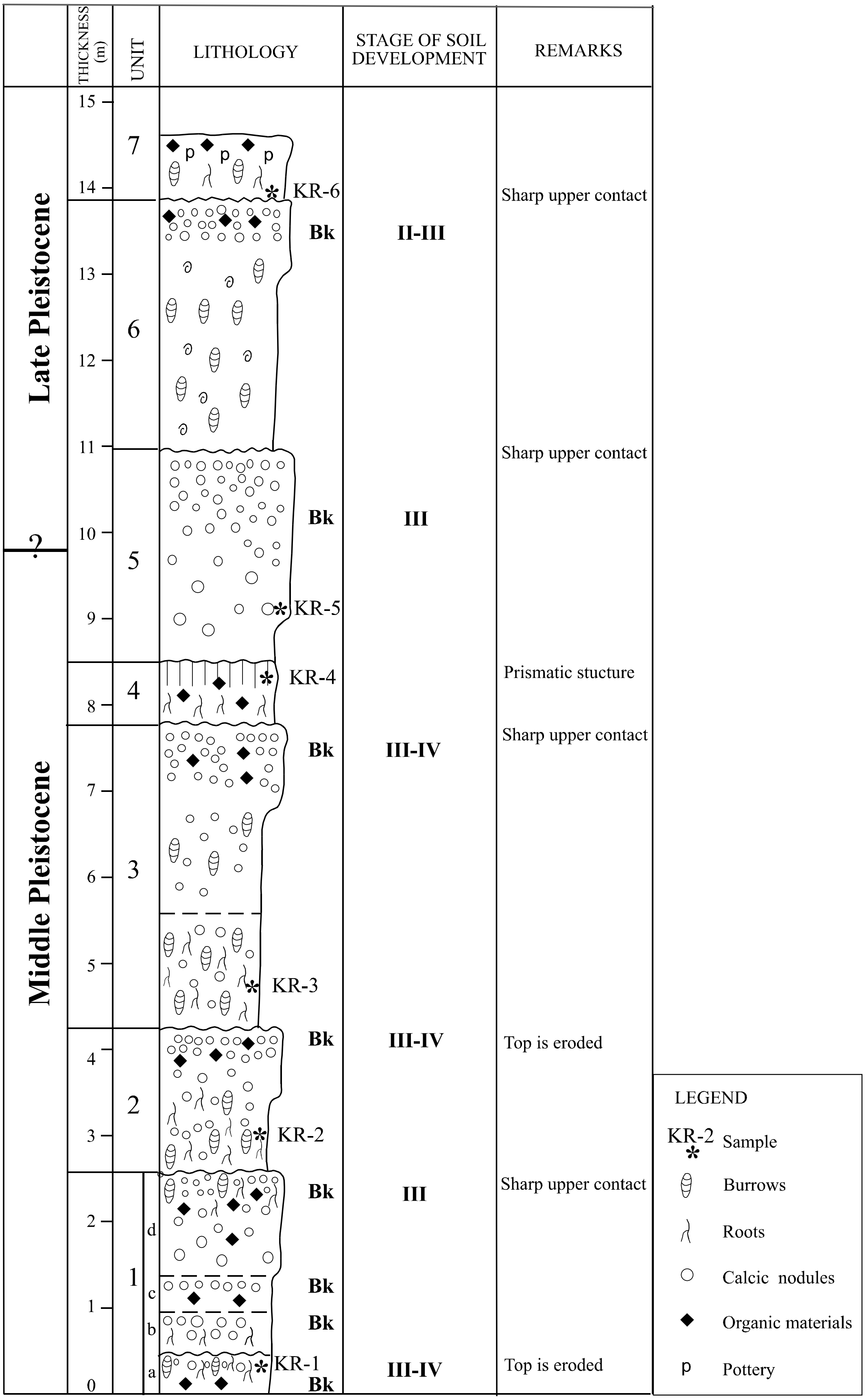

Fig 4: Columnar section of the Kerem Shalom sand sheet sequence.

<u>4.2.2 Unit 2</u> (Fig. 5)- Contains a Bk horizon. Its lower part is friable sand with burrows, root remains, and small (1-0.5 cm) calcic nodules, which compose 5-15% of the unit. Upward, the sand becomes compact and it is densely penetrated by root remains. It contains orthic nodules (up to 5 cm), which compose about 50% of the upper 40 cm of the profile, forming stage III-IV calcic horizon. This part also contains organic materials that forms dark patches. The upper contact is sharp with a relief of few tens of cm. The OSL age of unit 2 ranges between 364±108 ka and 478±91 ka. These are minimum ages and effectively this unit is well beyond the range of the OSL method.

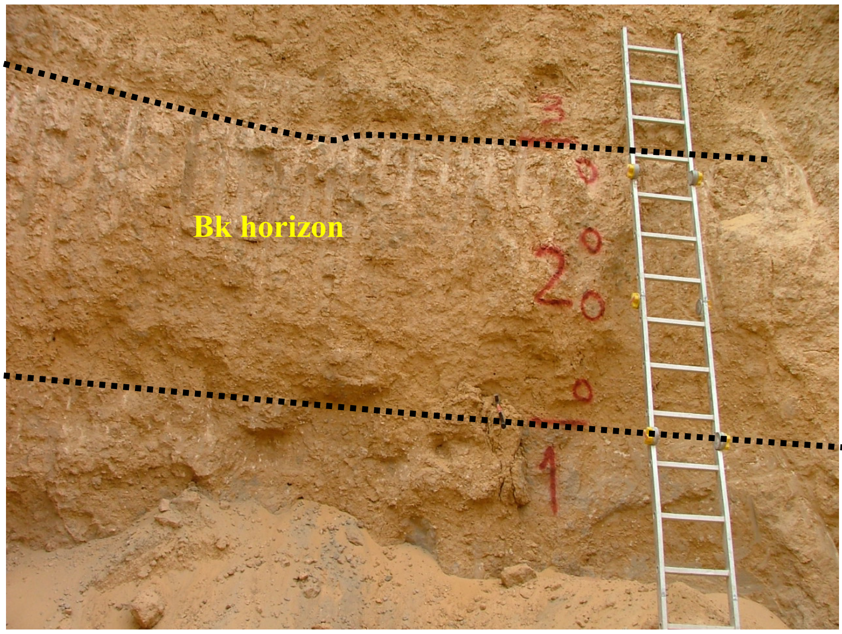

Fig. 5: Units 1-3. Note dense carbonate horizon at the top of Unit 2.

<u>4.2.3 Unit 3</u> (Fig. 6) **-** This unit contains two soil profiles:

Pal 3a – consists of friable sand with disorthic nodules, burrows and root remains. The contact with paleosol 3b is clear. This unit was dated to 234±25 ka and this age should be regarded as a minimum age.

Pal 3b – consists of more compact sand with many burrows. It lower part contains less nodules and more clay and carbonate in the matrix than Pal 3a. The amount of nodules and clay increase in its upper part, forming a brown stage III-IV Bk horizon, containing dark patches of organic material (mainly in the upper 50 cm) and orthic nodules (1-5 cm), which comprise 70-80% of the sequence. The upper contact is sharp. The OSL ages for Unit 3b are 293±85 and 326±68 ka. The large errors and their overlap with the age of Unit 3a suggest that this unit is beyond reliable OSL dating.

4.2.4 Unit 4 (Fig. 6) – is only 60 cm thick. It consists of silty sand, with abundant organic material and root remains. The lower 30 cm are sandy-silty with a few nodules. The upper 20-30 cm is a Bt horizon with a prismatic structure, with light patches of carbonate disseminated in the matrix (stage I). The OSL age of unit 4 is 183±25 ka.

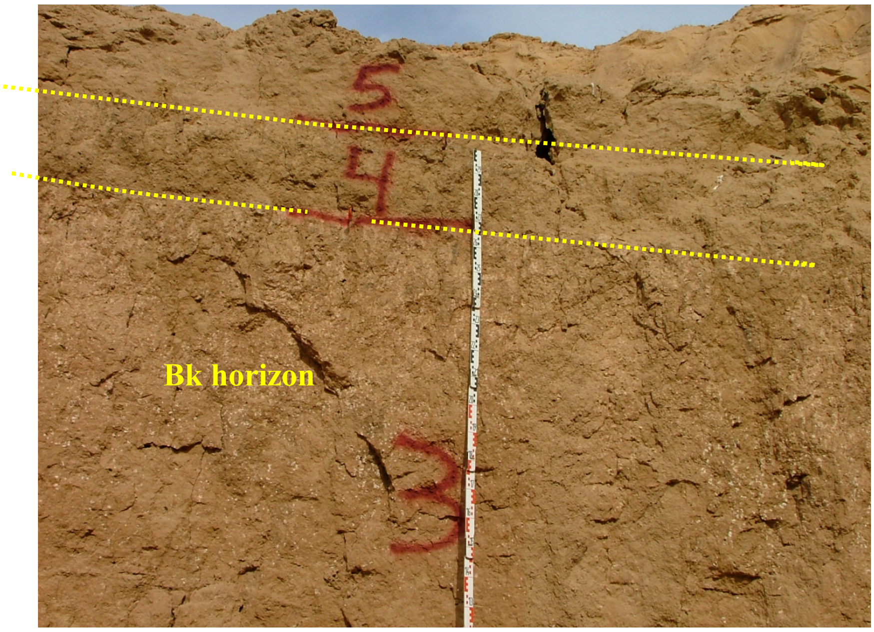

Fig. 6. Units 3-5. Note distinct carbonate nodules in the upper part of Unit 3.

4.2.5 Unit 5 (Figs. 6, 8) – is sandy to silty with a few orthic nodules at the base. Upwards it passes to Stage III Bk horizon, which contains 30% of calcic nodules (1-2 cm) in the lower part and 40-50% in the upper part. The upper contact is sharp. The OSL ages obtained for this unit, from its base to its top are 154±24 ka, 196±23 ka, 150±44 ka and 149±35 ka (KR 4, KR 11 and KR-10a&b, respectively). Although within errors, the middle sample is out of stratigraphic order, especially when compared to the age of Unit 4.

4.2.6 Unit 6 (Figs. 7, 8) – its lower 2 m consists of friable, intensively burrowed, light sand, resembling fresh dune sand and containing abundant land snails fragments, root remains and no calcic nodules. At the upper part, a stage II-III Bk horizon, 30-50 cm thick, is developed. It contains up to 50 % orthic nodules, mostly 0.5-1 cm, but some are 2 cm. The amount of nodules changes laterally. At places it is dark due to abundant organic material. There is no clear relation between the amount of organic material and the amount of calcic nodules. The upper contact is sharp.

Two OSL ages of the lower part of this unit average 90±7 ka while the age of the middle part is 75±14 ka. The medium-sand of sample KR-7, collected from the middle of the calcic horizon 0.25 m below the unconformity with Unit 7, was deposited at about 55±13 ka, representing the time of sand deposition. The very-fine-sand fraction was dated to 42±5 ka, giving the time of dust input. Although the ages overlap within errors, the age difference gives and indication for the difference between sand incursion and soil formation processes.

Fig. 7: The contact between the truncated Bk of units 6 and the unconsolidated sand of unit 7

4.2.7 Unit 7 (Fig. 8)**-** forms the top of the sequence. Its thickness varies laterally between 60-70 cm and 1.5 m. The upper 20 cm are grayish, rich in organic materials and contain a few immature calcic nodules developed especially along burrows. In the upper 30-40 cm there are some pieces of pottery presumably from the Early Bronze period. The lower part of this unit was dated to 13.6±1.7 ka and 14.5±2.3 ka at the pit and trench, respectively (~50m apart).

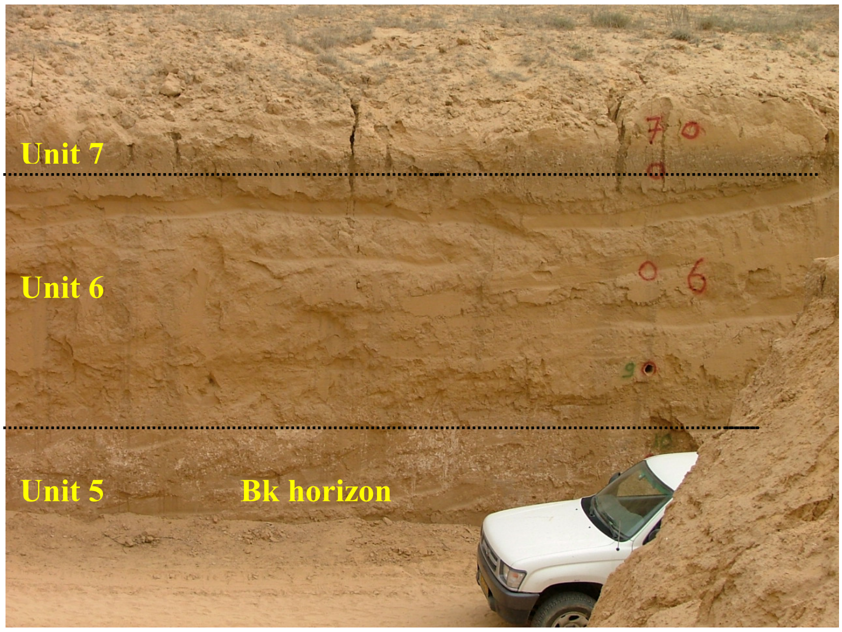

Fig.8 Units 5-7. The dark upper part of unit 6 is a calcic paleosol rich in organic materials.

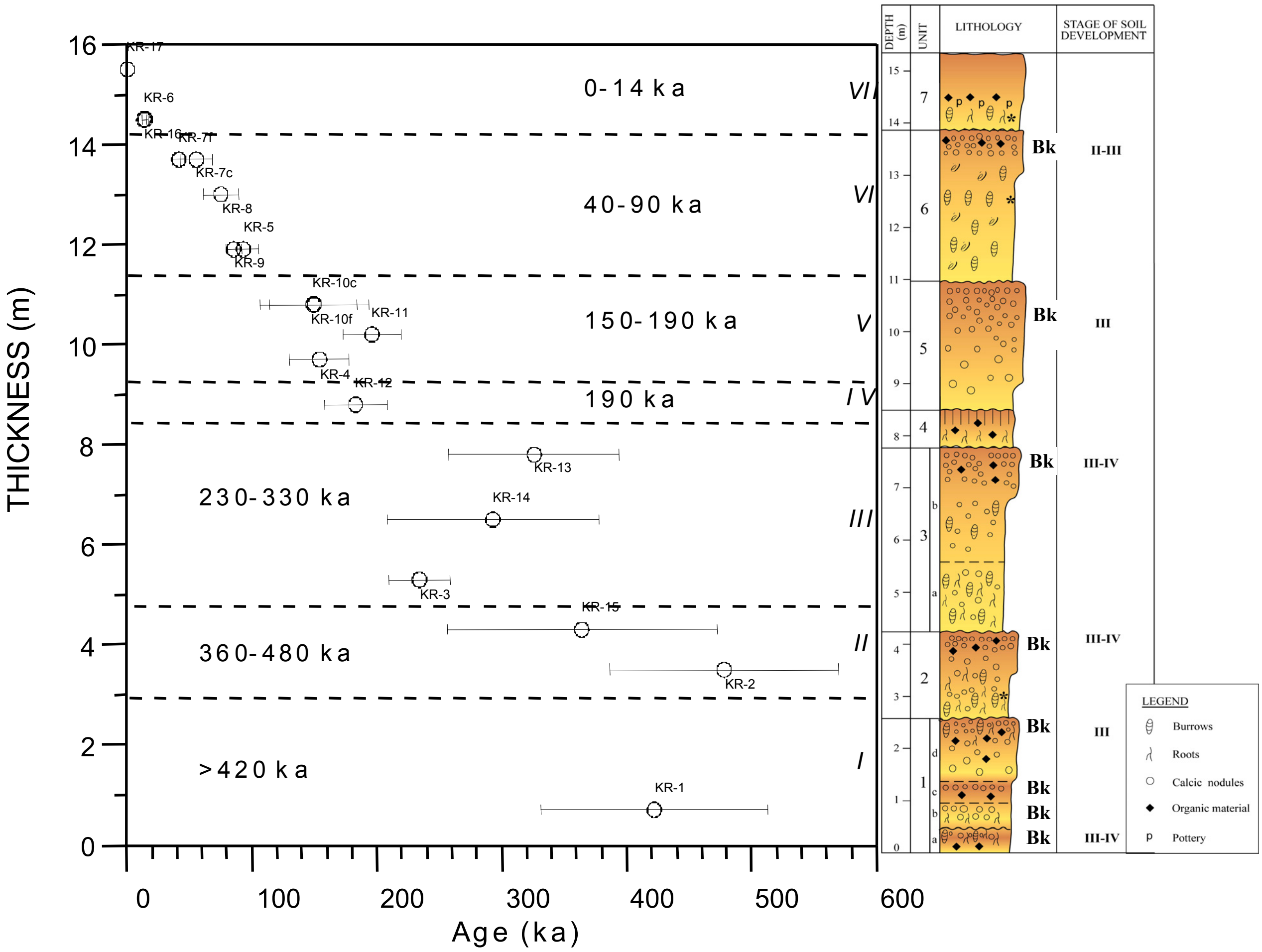

Fig. 9: OSL ages plotted against depth, and the deposition time-range of the upper four units. Note that the ages increase systematically up to a depth of ~ 8 m. Below that ages should be considered as minimum.

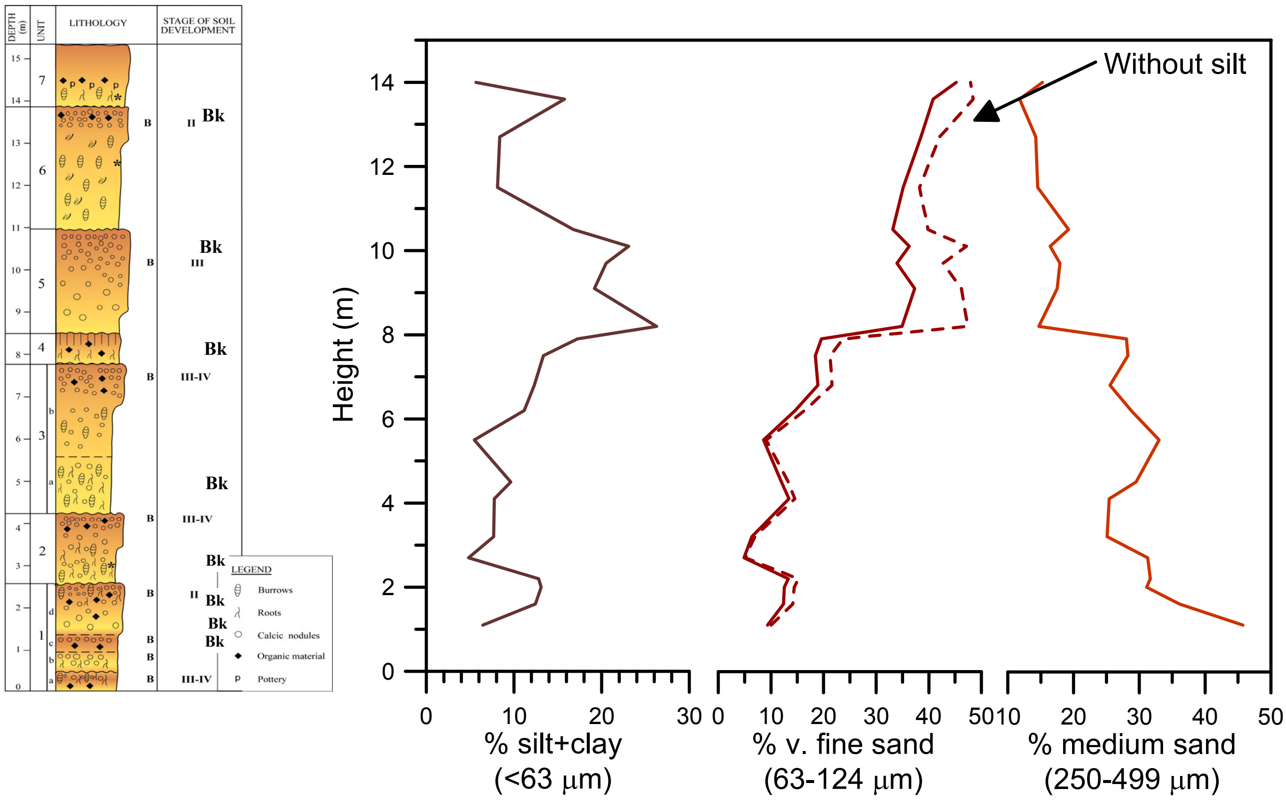

Fig 10: The composite section and grain size analyses. All units are bimodal and contain silt+clay. Note the decrease in the proportion of medium sand (right curve) and the abrupt increase in silt and silt contents in unit 4 in the middle of the sequence (middle curve).

4.3 Granulometry

The granulometry analyses (Fig 10) show that in most profiles, the Bk horizon contains more silt and clay than the C1 and C horizons, reflecting the contribution of dust to the pedogenesis processes. On top of these variations, there is an abrupt decrease in the grain size in the transition from the lower part of the sequence (units 1-4) to its upper part (units 5-7). The amount of the medium size sand decrease above unit 4 while the amount of fine and very fine sand increase. This change might reflect a westward migrating of the coast line, a change in the wind regime, or the establishment of the coastal kurkar ridge that forms a topographic barrier to the eastward movement of the sand.

5. DISCUSSION

The sandy section exposed in the Kerem Shalom pit is the only geological window to the Middle-Late Pleistocene sequences in the western Negev and northern Sinai area west of Nahal Besor.

The section is relatively complete; it lacks major erosion unconformities as evident by the relative completeness of the soil profiles. The lower-most units (1 and 2) are too old to be dated by OSL methods, and the ages of Unit 3 have large scatter. However, considering the time span represented by the younger units and the continuity of the sequence, we estimate that the lower units are no older than the Middle Pleistocene. The studied sequence resembles the Tel Sharuhen section (Menashe, 2003), located 20 km to the northeast. There, a thick sequence of sandy calcic paleosols, dated by IRSL of alkali feldspar to 530 ka-330 ka, unconformably overlies a latest Pliocene kurkar unit. However, in Tel Sharuhen area the younger sequence (between 325 ka and 60 ka) is missing and it was probably eroded prior to ~60 ka due to a major incision period of Nahal Besor (Menashe, 2003). This missing sequence is now found in Kerem Shalom pit, and the sequence we present here complements that of Tel Sharuhen. Together they span the Middle to Late Pleistocene.

The Kerem Shalom sequence reflects several cycles of aeolian activity, each starting with sand accumulation as a sand sheet, continues with a period of stability characterized by calcic soil formation and terminates with the erosion of the upper part of the soil (A and upper B horizons) by deflation.

The study site is located 5-6 km north of the extensive Agur-Haluza dune field, which was built by a major Late Pleistocene phase of dune incursion to the western Negev, a process that started during the peak of the last glacial period and was time transgressive. These dunes overly fluvial sediments, with Upper Paleolithic sites that rang in age from ca. 35ka to 25ka and contain Upper Paleolithic and Epipaleolithic sites, which ranges in age between ca. 20 ka to 14ka (Goring-Morris and Goldberg, 1990). Therefore, most of the dunes were emplaced within a time span of some 5000 years, but were locally mobilized during Neolithic, Chalcolithic and Byzantine periods (Goring-Morris and Goldberg, 1990).

This sand migration is not represented in the Kerem Shalom sand sheet, which was stable at this period and exposed to pedological processes that formed the calcic soil at the top of Unit 6. Therefore, in this sense it is similar to the Coastal Plain eolian sequence, where a period of about 30 ky of stability (between 35ka and 5ky) led to the development of the extensive soil complex of the Netanya Hamra (Porat and Wintel, 1995; Ritte, 1998). The reason for this sharp environments boundary between the coastal and the inland eolian provinces is not clear yet.

5.1 Timing of accumulation and pedogenesis

There are several conditions favorable for the formation of warm-climate aeolian sand sheets: high water table, surface cementation, periodic flooding, significant coarse grained sediment population that prevents dune formation, and vegetation (Kocurek and Nielseon, 1986). In the study area there are no evidences for the existence of the first four conditions. The sand is typical dune sand and there is no drainage system that can produce neither floods nor evidences to high water table or any stabilizing crusts. On the other hand, all the sand units in the Kerem shalom sequence are intensively bioturbated, reflecting long surface exposure due to low accumulation rates. This suggests that vegetation did play a major role in the formation and stabilization of the sand sheet, indicating that vegetation was usually present in this area sustained by sufficient rainfall, even during periods of strong winds and prevented substantial sand movement.

Bioturbation mixes the sediment, bringing up and re-exposing buried grains and moving downward into the section exposed and bleached grains. Luminescence ages of bioturbated deposits therefore reflect this mixture and in fact the time when the burial of a unit was deep enough to be outside the range of burrowing animals (mostly less than 1 m deep).

During times of sand movement caused by strong winds, only sand grains, which move by saltation, accumulate and form dunes and sand sheets (Pye and Tsoar, 1990). Silt and clay, which are transported in suspension, can not be deposited at the same time and place as sand, since subsequent strong wind will remove any fines, which may have accumulated. When wind power decreases and vegetation recovers and stabilizes the sand, only then silt and clay, transported by dust storms, are trapped by the vegetation. Rain leaches the carbonates and mobilizes the clay and silt particles down the sand to form the paleosol profile (Birkland, 1984 and references therein).

Since the sandy sediment in Kerem Shalom is dominated by quartz, the predominant source of carbonate in the Bk horizons is wind blown dust, which in this area contains roughly 30% carbonates and 30% clay minerals (Ganor, 1975). In such environment the formation of a well developed Bk horizon (Stage III-IV) might last thousands or even a few ten thousands years (Gile, 1966,1981; Birkland, 1984; Machette, 1985; Wells et al., 1985; McFadden et al., 1987; Wells et al., 1995), depending mainly on the dust influx and the amount of rainfall (Machette, 1985).

A rough estimate of deposition rates can be arrived at from the detailed dating of Unit 6, which is 2.9 m thick. Its base and top were dated to 90 ka and 55 ka, respectively, giving a deposition rate of approximately 8 cm/ky. The contemporaneous kurkar on the coastal plain was deposited much more rapidly, with accumulation rates of several meters per thousand years. On the other hand the low deposition rate at Kerem Shalom is comparable to that of the Late Pleistocene Hamra along the coastal plain, of 10 cm/ky (Porat et al., 2004).

The scatter and large errors of the ages of the lower units do not allow reliable estimates of their rate of deposition, however the sedimentological evidence suggests that all accumulated slowly.

The time difference between sand deposition and dust input can be evaluated from sample KR-7, for which the coarse-sand and very-fine-sand were dated to 55 ka and 42 ka, respectively. This demonstrates that indeed the silt was introduced into the section after the accumulation of the sand ceased. The pedogenic processes could be active until the profile was buried beneath unit 7 some time before 14 ka. This leaves ~40 ky between the two events of sand accumulation, during which a Stage II-III calcic soil developed.

The Stage III paleosol of Unit 5 developed in the interval between the youngest age for Unit 5 and oldest age for Unit 6, ~150 ka and ~90 ka respectively, thus extending over 60 ky. The incipient soil in Unit 4 developed between 183 and 154 ka (~ 30 ky), and the Stage III-IV calcic soil of Unit 3 perhaps took more than 100 ky to develop. Below that the ages are too scattered to give reliable times for soil forming intervals. Overall, the ages imply that at least during the last 300 ka calcic soil formation in the western Negev was a slow process, and the development of stage III-IV Bk horizon lasted several tens thousands years.

5.2 Climate

The well developed calcic soils of Kerem Shalom reflect a semi arid climate with annual precipitation of at least 200-250 mm/y (Eisenberg et al., 1982; Birkland, 1984), similar to the present. The transition from mobile to stable sand and vice versa is not necessarily the result of major changes in precipitation but it could also reflect changes in the wind regime (Tsoar, 2000). Frequent strong winds, which move the sand and prevent germination of seeds on the dunes, are the most effective factor in sand mobility, even more than the amount of rainfall (Tsoar and Illenbereger, 1998, Tsoar, 2000; Tzoar and Blumberg, 2002). In the present arid climate of the western Negev southeast of the study area, with 90-150 mm/y of rainfall, most of the sand dunes are partly or fully stabilized. Moreover, incipient precipitation of carbonate was found around roots in the Nizzana Dune fields, where rainfall is only 90 mm/y (Amit and Harrison, 1995).

During the Middle and Late Pleistocene the Eastern Mediterranean underwent several climatic fluctuations, in sync with global climate changes (Bar- Matthews et al., 1997, 1999; Bar-Matthews and Ayalon, 2001, Robinson et al., 2006). These fluctuations are reflected in the Kerem Shalom sandy sequence by the transitions from periods of sand migration and formation of sand

sheets to periods when the sandy terrain was stabilized, covered by vegetation and calcic paleosols developed in the upper part of the sand units.
Unit 7 started to accumulate at 13-15 ka. However, it is most likely that sand accumulation was most intensive during the Younger Dryas (~12.7-11.5 ka), which was extremely dry and cold period and was associated in the Negev desert with intensive stream incision (Magaritz, 1986; Magaritz and Goodfriend, 1987: Goldberg , 1986, Zilberman, 1992), and reactivation of dunes (Goring-Morris and Neigel, 1990).

The deposition of Unit 6 started at ~ 90 ka during marine oxygen isotope stage (MIS) 5 and sand continued to accumulate until ~55 ka during MIS 4; subsequently soil formed during the colder Last Glacial periods of MIS 3 and 2. The time of sand deposition in the upper part of Unit 6 is similar to the time of dune formation along the Sharon coast. These dunes, dated to between 65 and 50 ka, are now cemented into the kurkar units Ramat Gan and Dor, which form the coastal ridge (Porat et al., 2004). The time span of paleosol formation in Unit 6 corresponds to the formation of Hamra in the Coastal Plain, which developed between ~50 ka and ~13 ka (Engelmann et al., 2001; Frechen et al., 2001, 2002; Porat et al, 2003).

Unit 5 was deposited mainly during the glacial MIS 6 and its paleosol developed during the interglacial MIS 5. This paleosol may be correlated with the coastal plain Kefar Vitkin Hamra (Gvirtzman et al., 1984), dated at the Holon prehistoric site to 90-100 ka (Porat et al., 1999; Porat, 2001). Continuing with this line, the paleosol of Unit 4 formed later than 183 ka and can probably be related to the glacial MIS 6. The ages of Unit 3 to1 have very large errors, and they cannot be correlated reliably to any specific climate episode.

5.3 Summary

The sequence of Kerem Shalom forms part of the Coastal Plain dune province, which is intermittently accumulating along the Mediterranean coast since the Late Pliocene. Although it is closer to the inland Agur dune field, for unknown reason it is not influenced by this late Pleistocene sand incursion. There are no clear relations between periods of sand mobilization and soil formation with specific climatic regime. This is attributed to the long term memory of soils, which usually do not record short time climatic changes. Time transgressive pedogenesis and polygenetic nature of the calcic paleosols must also be considered in evaluation of the reconstruction of their development history.

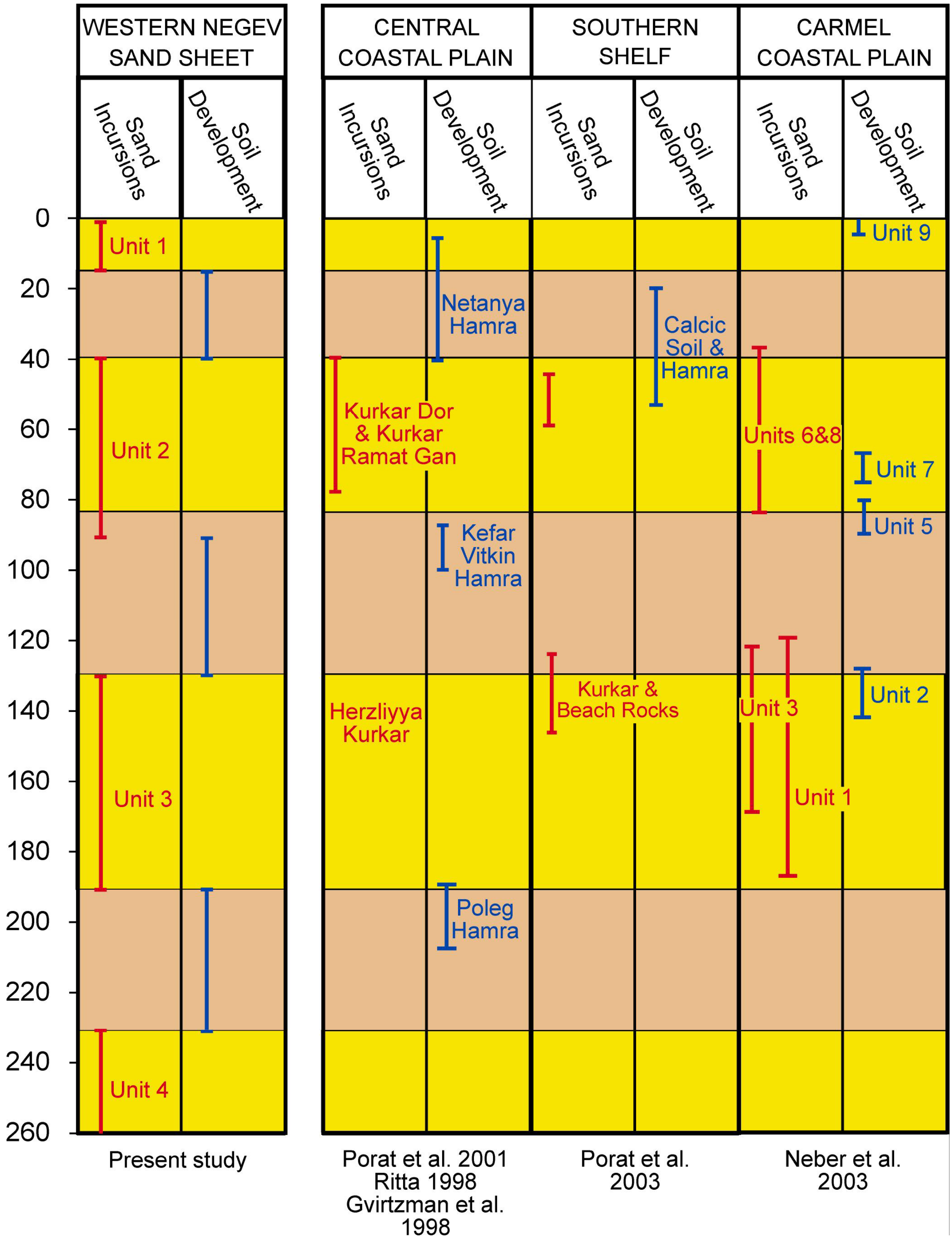

Fig. 11: Schematic correlation between the sandy sequence of Kerem Shalom (left) and the aeolianite sequence of the coastal plain. In the Late Pleistocene episodes of sand accumulation or soil formation are synchronous in both areas. The yellow color corresponds for periods dominated by sand incursion while the brown color represents periods when soil developed along the entire coastal plain of Israel.

Table 1: Kerem Shalom section - luminescence dating results

Sample	Unit	Depth (m)	Field γ (μGy/a)	Grain size	K %	U (ppm)	Th (ppm)	Ext. α (μGy/a)	Ext. β (μGy/a)	Total dose (μGy/a)	No. of discs	De (Gy)	Age (ka)
Main section													
KR-6	7	1.5	604	125-150	0.73	0.68	2.2	3	611	1218±65	10/12	16.3±1.9	**13.4±1.7**
KR-7b KR7a	6	2.3	709	74-105 150-177	0.83	1.8	4.2	9 5	880 851	1598±77 1565±76	7/9 8/9	66.3±6.4 86.7±20.4	**41.5±4.5** **55.4±13.3**
KR-8	6	3	690	88-125	0.77	2.3	2.6	8	858	1556±75	6/18	117±21	**75±14**
KR-5	6	4.1	684	125-150	0.73	0.88	2.0	3	632	1319±73	12/12	123±15	**93±13**
KR-9	6	4.1	606	88-125	0.68	0.9	2.5	4	622	1232±66	6/18	105±6	**86±6**
KR-10a KR-10b	5	5.2	690	74-105 150-177	0.59	1.5	3.5	8 4	655 643	1363±74 1337±73	14/17 17/18	203±46 201±57	**149±35** **150±44**
KR-11	5	5.8	739	88-125	0.70	1.8	4.4	8	791	1538±79	10/12	301±32	**196±23**
KR-4	5	6.3	753	125-150	0.76	1.73	4.0	6	801	1560±80	12/12	240±36	**154±24**
KR-12	4	7.2	826	88-125	0.73	2.2	4.5	9	863	1698±88	12/12	311±39	**183±25**
KR-13	3	8.2	395+89	88-125	0.38	1.7	2.8	7	529	1020±51	12/12	333±67	**326±68**
KR-14	3	9.5	739	88-125	0.45	1.4	2.4	5	529	1273±78	12/12	373±106	**293±85**
KR-3	3	10.7	579	125-150	0.38	1.3	2.6	4	469	1052±62	12/12	246±21	**234±25**
KR-15	2	11.7	382	88-125	0.29	0.90	1.7	4	344	730±44	10/11	266±77	**364±108**
KR-2	2	12.5	383	125-150	0.29	0.62	1.3	2	295	680±44	12/12	325±58	**478±91**
KR-1	1	15.3	398	125-150	0.27	0.56	1.5	2	280	680±45	8/10	287±58	**422±91**
X trench													
KR-17	7	0.5	597	88-125	0.73	0.8	2.4	4	641	1241±64	5/6	0.16±0.03	**0.13±0.02**
KR-16	7	1.5	560	88-125	0.75	0.70	2.2	3	637	1200±62	11/12	17.4±2.5	**14.5±2.3**

Quartz samples, water contents estimated at 5 ± 2%. All samples were etched by concentrated HF for 40 minutes. De was obtained using the single aliquot regeneration (SAR), using preheats of 10s @ 220-260°C. All samples show good preheat plateaus, recycling ratios within 5% of 1.0 and very low IR signals. No. of discs is the number from those measured that was used for calculating the De. The ages are calculated from the mean and error of the De.

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