Quaternary Loess Deposits of Wadi Gaza in the Middle of the Gaza Strip, Palestine

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Abstract

The Gaza Strip constitutes the south-western part of Palestine. It is located between the Mediterranean Sea in the west, the Sinai Desert in the south, and the Negev Desert in the east. The loess deposits were observed in the Middle and Gaza Governorates in Gaza Strip. This study carried out in the Wadi Gaza where Quaternary loess well crops out. Twenty three samples were collected from nine observation sites in the study area, and performed a textural, calcium carbonate and organic matter content studies. The loess sequence which is in some locations intercalated by conglomerates overlies sand dunes. The exposed loess shows stable steep walls, easily eroded by water. It consists of sandy loam to loam, with light brown to dark reddish brown color. It composed of clay (1-20%), silt (28-49%), and very fine- to fine-grained sand (43-71%). The carbonate contents range from 6 to 20%, and organic matter contents range from 1 to 2%. The dominant coarse silt-to very fine-grained sands, and quartz-rich composition suggest that the sand dunes of the northern Sinai and western the Negev sands could be the most prominent reservoir of loess sediments in the study area. Other but not the main source of the silt- to very fine-grain sand could be direct contribution from exposed Mediterranean shelf during period of eustatically low sea levels in early MIS 4 (73-60 ka) or even earlier. The loess of coarse silt-to very fine-grained sand are mostly dry- or moist semi-arid-deposited. During the accumulation of the loess there were intensive periods of precipitation which indicated by the presence of conglomerates layers within the loess.

Keywords: *Gaza Strip, Wadi Gaza, Loess, Sand Dunes, Climate*

Introduction

The loess is entrained, transported and deposited by wind. It consists of clay, silt and very fine sand (<125 µm). It is composed of quartz, feldspar, mica, clay minerals and carbonate particles (Pye, 1987). To distinguish loess from fine-grained (aerosolic) dust that may have a subtle presence within soils or sediments, loess should be recognizable in the field as a distinctive sedimentary body. It commonly forms a mantle or cover on preexisting landscapes and can be anywhere from a few centimeters to several hundred meters in thickness.

Tracing the sources of the loess in Palestine especially in Gaza Strip and NW of the Negev desert has been a long-term target in the Eastern Mediterranean settings (e.g., Dan & Yaalon, 1980; Yaalon, 1987) with recent advances (e.g., Crouvi *et al*., 2008; 2009; Ubeid, 2011; Haliva-Cohen *et al*., 2012). The loess accumulation covered interval time includes global climatic cycles and drastically environmental changes conditions in the region (Torfstein *et al*., 2013).

A distinguish between coarse- and fine-grained (very fine sand to silt) of loess is important because coarse-grained are only transported short distance (<300 km) through saltation and short-term suspension, whereas fine-grained may be transported great distance (Dan & Yaalon, 1980;Yaalon & Ganor, 1973; Tsoar & Pye, 1987). Therefore, the coarse- and fine-grained may have different sources, and may differ in composition. In the Negev desert the loess of fine-grained may include Saharan dust, whereas coarse-grained loess was the dominant and its source was the adjacent Sinai-Negev and sea (Yaalon & Ganor, 1973; Crouvi *et al*., 2008).

The geology of Gaza Strip lacks studies about the detail of Quaternary loess deposits, especially their sources and palaeoclimate implications. Incidentally, these deposits generally studied as a part of Quaternary palaesols in Gaza Strip by Ubeid (2011), and suggested that the loess was occurred due to different phases of dust accretions.

The aims of present study are to identify the loess deposits of Wadi Gaza in the middle of Gaza Strip, focusing on the sedimentolgical characteristics, their sources and palaeoclimate implications.

Geographical and geological background

The Gaza Strip constitutes the southwestern part of the Palestinian coastal plain between 34° 2` and 34° 25` East, 31° 16` and 31° 45` North. It is located between the Mediterranean Sea in the west, the Sinai Desert in the south, and the Negev Desert in the east (Fig. 1A). It has an area of about 365 km². Its length is about 45 km, and the width ranges from

6 to 8 km in the central and northern regions to a maximum of 12 km in the south. It divided into five governorates, the Rafah and Khan Younis governorates in the south, the Middle governorate, and Gaza and North Governorates in the north of Gaza Strip (Fig. 1B).

Three elongated ridges generally extend parallel to coastline are defined the topography of Gaza Strip (Fig. 1B). The elevation and age of these ridges increase towards the east. At the west of Gaza Strip lays the Coastal Ridge with elevation up to 50 m above MSL (Mean Sea Level), in the middle Al-Montar Ridge with elevation up to 80 m above MSL, and Biet Hanoun Ridge lays at the east of Gaza strip with elevation up to 110 m above MSL. The ridges are separated by deep depressions (20-40 m above MSL) with alluvial deposits.

The Wadi Gaza dissects the middle Gaza Strip from east to west. The length of the wadi is about 109 km andthe last 9 km is located in the Gaza Strip from east to west. The wadi`s watershed covers about 3600 km² of northern Negev desert and El-Khalil mountains, as well as the small catchments in Gaza, which estimated to cover about 36.8 km² (Abdel Daim, 2012).

The stratigraphy of the Paleogene and Neogene age built by the following units: the Mt. Scopus, Avedat, Saqiye and Kurkar Groups (Fig. 2A). The Mt. Scopus Group (Gr.) made of limy chalk, chalk, and marly chalk. Whereas, the Avedat Gr. is represented by alternation of chalk and chalky limestones (Horowitz, 1975; 1979). The Saqiye Gr. unconformably overlies the Mt. Scopus and Avedat Groups, and is sharply overlain by Kurkar Gr. The lower Saqiye Gr. made of marly chalks, marls, and bioclastic limestones, while the upper Saqiye contained evaporates, sandstones and conglomerates. The Kurkar Gr. composed of marine and continental deposits (Bartov *et al.,* 1981; Frechen *et al*., 2004; Galili *et al*., 2007; Ubeid, 2010; 2011). It built by four units: Ahuzam, Pleshet, Rehovotand Gaza Formations (Fig.2B). The Ahuzam Fm. made of conglomerates, limestone, and chalk. The Pleshet Fm. which made of calcareous sandstones with a marine fauna, indicating a marine origin. The Rehovot Fm. consisted of alternations of unconsolidated dune sands and Hamra. Whereas the Gaza Fm. consisted of alternations of Kurkar and Hamra with either gradational or sharp contacts (Fig. 2B).

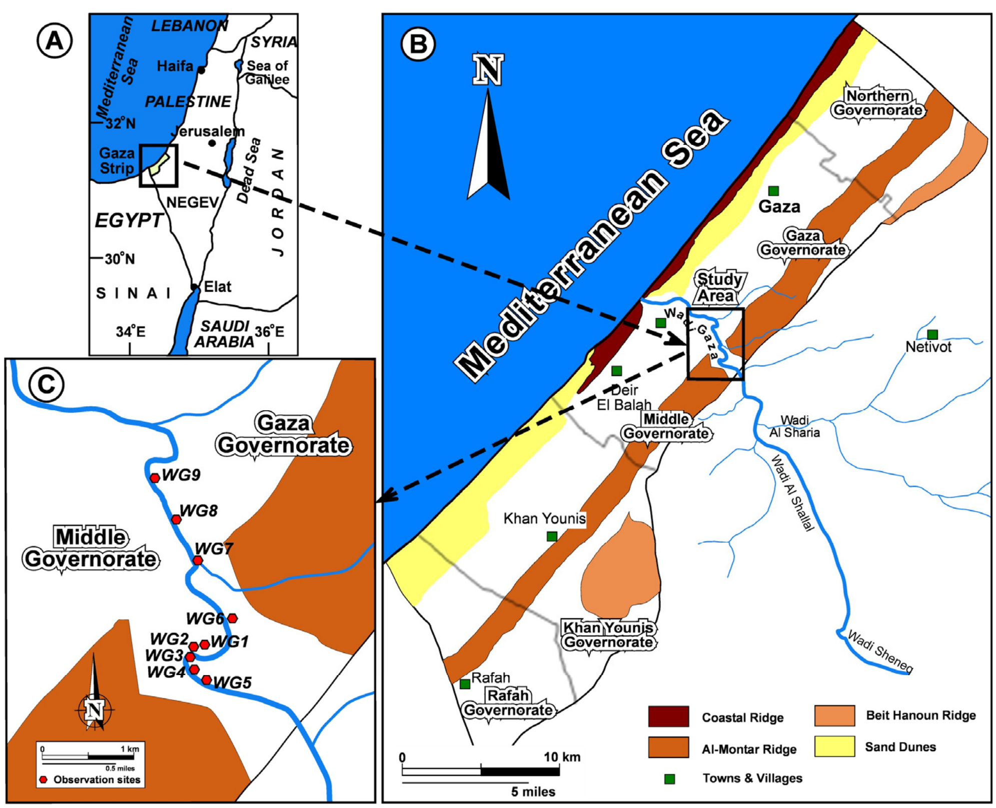

Figure 1. Location map of the study area.

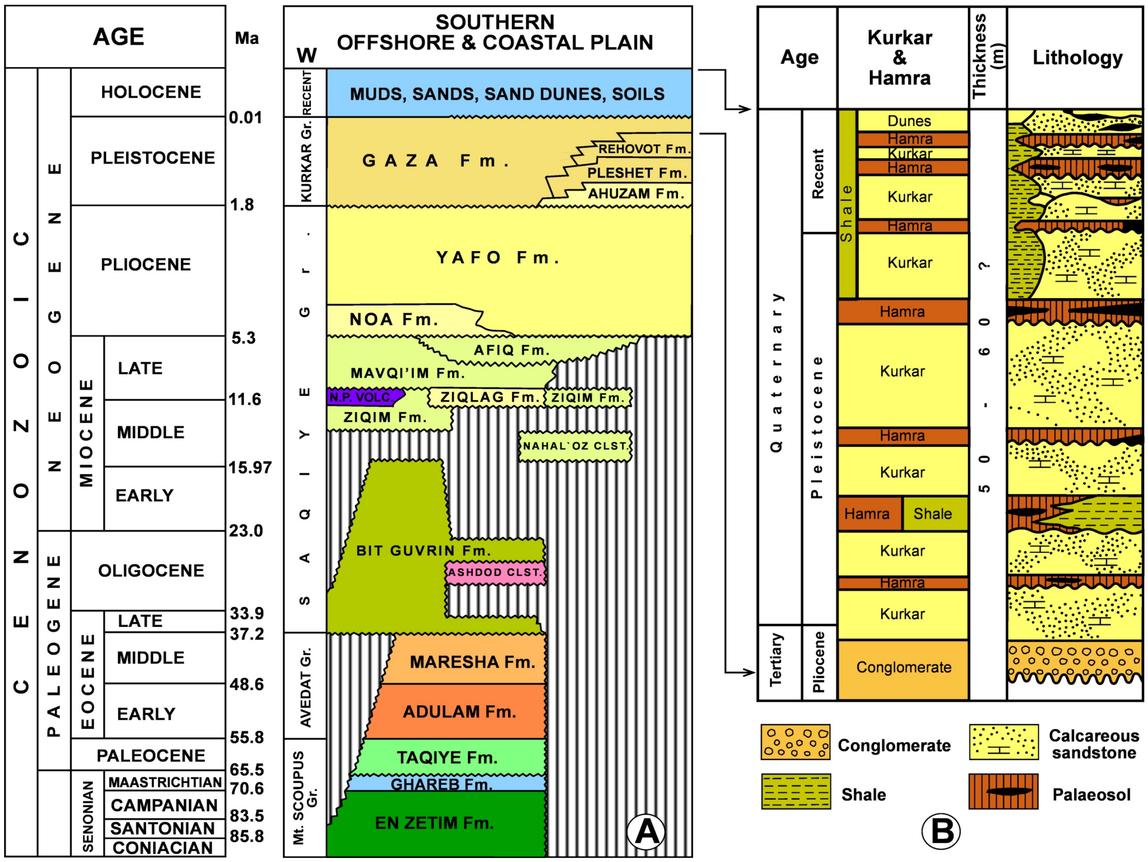

Figure 2. Stratigraphy and lithology. (A) Stratigraphic succession of the Paleogene and Neogene age of the southern and coastal plain of Palestine (after Gvirtzman *et al*., 2005). (B) Lithology of Pliocene-Pleistocene Gaza Formation (after Abed & Al Weshahy, 1999).

Lithologically, the Kurkar made of marine and continental calcareous sandstones (Horowitz, 1975; Frechen *et al*., 2004; Ubeid, 2010; 2011). The Hamra composed of brownish-to-reddish fine-grained marsh deposits (Ubeid, 2011). The loess deposits is represented by Ruhama Member in the succession (Horowitz, 1975). In Gaza Strip they characterized by brown-colored, and they are found in the Middle and Gaza governorates. Well outcrops of Quaternary loess are observed at Wadi Gaza in the Middle governorate. Whereas, a sandy loess which characterized by light brown- to yellow-colored are observed in the depressions between the Kurkar ridges of Deir El-Balah in the Middle governorate (Ubeid, 2010, 2011). Recent loessial soils can be found some 5 km inland in the Middle and Gaza governorates. A zone between the Khan Younis and Rafah which parallel to the coast forms a transitional zone between the sandy soils and the loess soils, usually with a calcareous loamy sandy texture and a deep uniform pale brown soil profile.

Materials and methods

Classical geological field work carried out along the course of Wadi Gaza in the middle of Gaza Strip. It started from southeast- to northwestwards of the wadi. Nine observation sites were selected where there well outcrops fine-grained deposits (Fig. 1C). These observation sites were located by GPS device (Table 1). At each site, description of lithology were noted down. Additional, twenty three fresh samples were collected. Samples were placed into polyethylene bags and transferred to the laboratory for further analyses. Other observation notes for further sedimentological analysis were collected for each of the lithologic units.

In order to clarify the field observations, laboratory analysis were done. Initially, the samples were dried at 110 °C in an oven for complete removal of moisture contents. Sedimentation analysis method by using hydrometer and dispersive calgon were done to separate the grain sizes for each fine-grained sample. Grain-size separation of sandy samples were done by using sieve analysis method. The calciometry method was used to determine the content of carbonate $(CO_3)^{-2}$ in the sediments. In this method, the amount of CO_2 released from the reaction is dependent on the amount of $CaCO_3$ in the sample. The total organic matter was determined by burring method at 450 °C.

The textural classes of the samples due to grain-size distribution results were defined by using USDA soil texture triangle chart (Table 2).

Results and discussion

The crop out of the stratigraphic succession inWadi Gaza mainly consists of three units, the lower unit composed of sand dunes, the middle made of alternations of sandstones and conglomerates and the upper unit made of fine-grained deposits with reddish brown color (Fig. 3; Fig. 4A, B, & C). In this study we will focus on the fine-grained deposits mainly on the loess part deposits. Table 2 details the results analysis of collected samples at the observation sites in the study area.

Sedimentological characteristics of loess sequence

On the whole, the Quaternary loess sequence in Wadi Gaza reaches an average thickness up to 25m (Fig. 4C).It built of units 20-40 cm thick. In some locations theloesses were intercalated by thin layers of conglomerates of about decimeters thick. These conglomerates consist of pebble- to cobble of quartzite and carbonates. They were moderately to poorly sorted, clast-supported, with sandy matrix(Ubeid, 2011; 2016).The loess sequence overlies sand dunes which in some locations alternated with conglomerates, with sharp and slightly inclined contact (Fig. 4A). In exposed sections the loess deposits easily differentiated from underlaings and dunes by darker color, stronger consistency, finer texture, orthic carbonate and organic contents. The exposed loess shows stable steep walls, easily eroded by water. It consists of sandy loam to loam, with light brown to dark reddish brown color (Table 2).

Table 1. Coordinates of observation sites in the study area.

Site no.	Sample No.	Coordinates	
		N	E
WG1	WG-1	31° 26` 01.7``	34° 24` 56.5``
WG2	WG-5	31° 26` 02.1``	34° 24` 59.8``
	WG-4		
	WG-3		
	WG-2		
WG3	Covered by solid waste	31° 25` 59.2``	34° 24` 55.7``
WG4	WG-6 (Sand dunes)	31° 25` 57.6``	34° 24` 55.7``
WG5	WG-8 WG-7	31° 25` 55.4``	34° 24` 56.1``
WG6	WG-12	31° 26` 09.5``	34° 25` 12.1``
	WG-11		
	WG-10		
	WG-9		
WG7	WG-16	31° 26` 28.6``	34° 24` 57.0``
	WG-15		
	WG-14		
	WG-13		
WG8	WG-17	31° 26` 41.9``	34° 24` 50.6``
WG9	WG-23	31° 26` 55.7``	34° 24` 42.6``
	WG-22		
	WG-21		
	WG-20		
	WG-19		
	WG-18		

Table 2. Grain size distribution, calcium carbonate (CC), and organic matter (OM) contents ofthe samples in the study area.

Site No.	Sample No.	Clay (%)	Silt (%)	Sand (VF-F) (%)	CC (%)	OM (%)	Main filed description features
WG1	WG-1	5.4	42	52.6	16.4	0.80	Sandy loam, light brown
WG2	WG-5	3.4	36	60.6	16.5	2.21	Sandy loam , light brown, with bands of very dark brown
	WG-4	15.4	34	50.6	15.8	1.07	Loam, dark brown
	WG-3	1.4	46	52.6	11.7	0.82	Sandy loam, light brown
	WG-2	19.4	32	48.6	15.7	1.25	Loam, very dark brown
Mean		9.9	37	53.1	14.9	1.33	
WG4	WG-6	20.0		80.0	13.6	0.13	Dune sand
WG5	WG-8	5.4	36	58.6	6.8	0.56	Moderate to very hard sandy loam , light brown
	WG-7	11.4	46	42.6	14.5	0.96	Moderate to very hard loam, light brown, with root traces
Mean		8.4	41	50.6	10.7	0.76	
WG6	WG-12	3.4	32	64.6	11.2	0.27	Sandy loam, light brown, upper part dark brown
	WG-11	1.4	44	54.6	16.4	0.51	Sandy loam, light brown
	WG-10	5.4	40	54.6	7.1	0.65	Sandy loam, light brown
	WG-9	1.4	28	70.6	10.7	0.37	Sandy loam, light brown
Mean		2.9	36	61.1	11.4	0.45	
WG7	WG-16	15.4	42	42.6	9.4	0.34	Loam, reddish brown, with cc stains
	WG-15	5.4	40	54.6	10.6	0.35	Sandy loam, light brown
	WG-14	9.4	32	58.6	11.7	0.70	Sandy loam, light brown
	WG-13	2.4	49	48.6	16.8	1.30	Loam, dark brown
Mean		8.15	40.75	51.1	12.1	0.67	
WG8	WG-17	7.4	34	58.6	8.3	0.31	Sandy loam, light brown
WG9	WG-23	11.4	32	56.6	17.2	0.87	Sandy loam, light brown
	WG-22	5.4	34	60.6	20.0	0.78	Sandy loam, light brown, with cc nodules
	WG-21	13.4	40	46.6	13.3	0.56	Loam, light brown
	WG-20	3.4	42	54.6	11.6	0.87	Sandy loam, light brown
	WG-19	3.4	40	56.6	13.0	0.70	Sandy loam, light brown
	WG-18	1.4	42	56.6	6.1	0.64	Sandy loam, light brown
Mean		6.4	38.3	55.3	13.5	0.67	

The reddish color of the loess suggests the ferric oxides that coating the grains.

According to the definition, the loess consists of fine-grained ranging in size from clay to very fine sand (<125 µm), but are dominated by coarse silt to the finest sand fraction ranging from 50 to 100 µm (Pecsi, 1990, Pye, 1995; Muhs, 2007; Crouvi *et al*., 2010). More specifically, the mechanical analysis of studied samples show that the grain-size distribution is made of clay (1-20%), silt (28-49%), and very fine- to fine-grained sands (43-71%) (Table 2, Fig. 5). It was observed that the fine-grained fraction (mud) increases down direction in studied sites (Table 2), forming B-horizons. This caused due to translocation of fine-grained by percolating water.

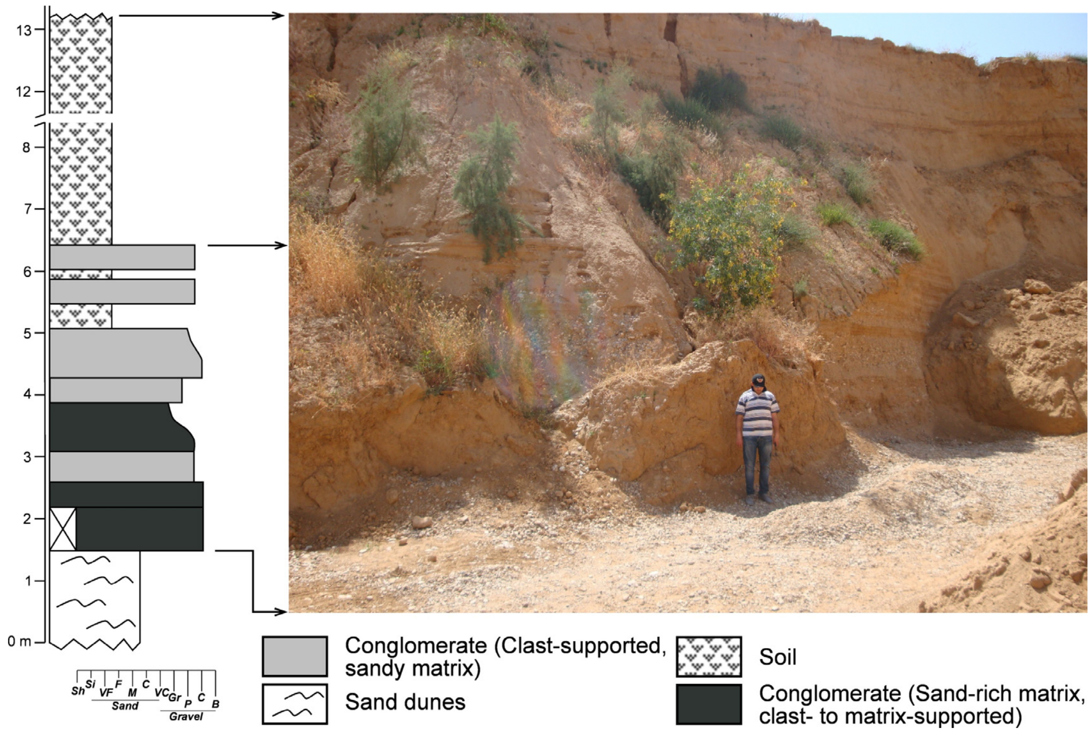

Figure 3. Shows the sedimentary succession in the study area.

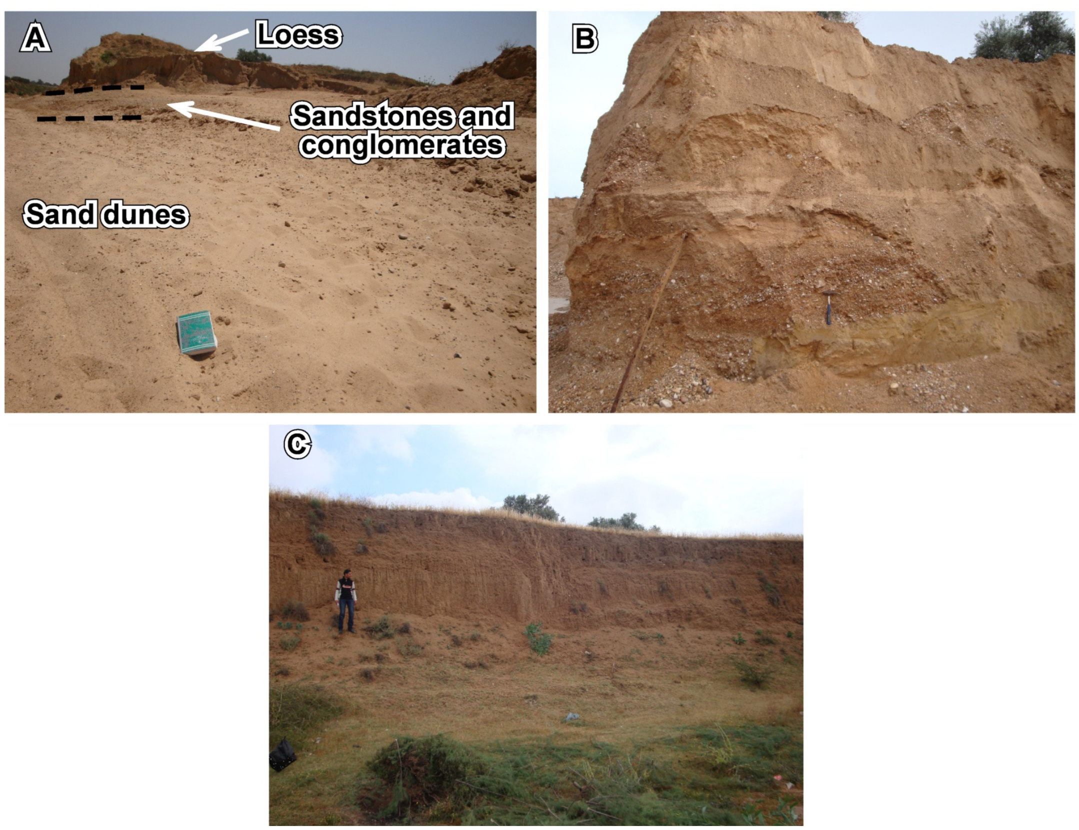

Figure 4. Fieldphotographsshow the stratigraphic units in the Wadi Gaza (note the sand dunes in the course of the wadi). (A) The stratigraphic succession (sand dunes, sandstones and conglomerates, and the loess deposits. (B) The sandstones and conglomerates alternations. (C) The loess unit in the wadi.

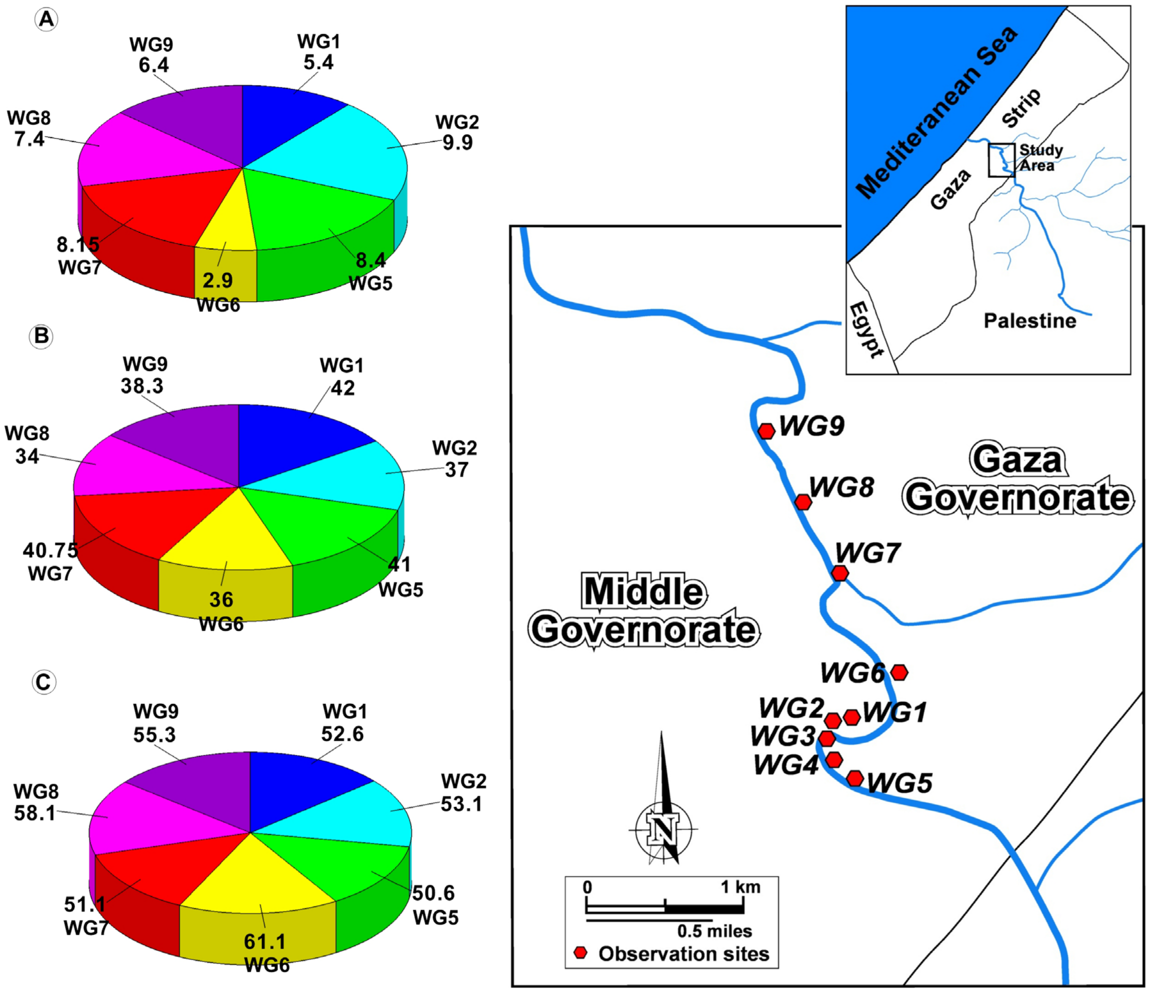

Figure 5. Shows the mean grain-size for samples in the studied sites. (A) Represents clay percentage, (B) Silt percentage, and (C) Sand percentage.

In the other side, there was no lateral variation in the fine-grained fraction due to relatively short investigated distance (Fig. 6). The shapes of particle are sub-angular to angular, which suggest proximal source of grains (Fig. 7). Mineralogically, it mainly composed of quartz and subordinates of feldspars (K-feldspars and plagioclase). The calcium carbonate contents range from 6 to 20% (Bk-horizons), with appearance differs from stains to nodules (Table 2 & Fig. 8A). The carbonate nodules are revealed to have form in situ (Wieder & Yaalon, 1982; Wieder et al., 2008). The organic matter contents in the loess range from 1 to 2% (Table 2 & Fig. 8B), and it contains plant remains.

Source of loess deposits

The dominant coarse silt and very fine-grained sands, in addition to quartz-rich composition in loess deposits in Wadi Gaza suggest that these grains are derived from proximal dust source located in the Sinai-Negev desert (Fig. 9). Additionally, the sub-angular to angular shape of the grains support this suggestion. The observations of coarse mode (silt- to very fine- to fine-grained sands) and mineral composition were used to identifying the source of loess Negev from adjacent source (Yaalon & Ganor, 1973; Pye & Tsoar, 1987; Tsoar & Pye, 1987). It is worthy to note that a distinction between coarse silt- to very fine- to fine-grained sands and mud (fine silt- to clay) is important because the coarse-grained fractions are transported short distances (<300 mk) through saltation and short-term suspension, whereas fine grains may be transported great distances (Yaalon & Ganor, 1973; Tsoar & Pye, 1987; Muhs *et al.*, 2007; Stuut *et al.*, 2009). The loess in the studied area have similar grain-size distribution and sedimentological features especially those in the

Netivot area (Netivot section) which located to east of the study area, at 11 km from Gaza border (Fig. 1) (Bruins & Yaalon, 1992; Wieder *et al*., 2008). Therefore, these features are considered to be derived from similar sources. The previous studies in loess of neighbor area (Netivot) (e.g., Bowman *et al*., 1986; Crouvi *et al*. 2008; 2009; 2010; Amit *et al*., 2011; Ben-Israel *et al*., 2015) observed that the evident directional decrease in the grain size in the loess led to the hypothesis that the source of the loess must be proximal and located in Sinai-Negev desert.

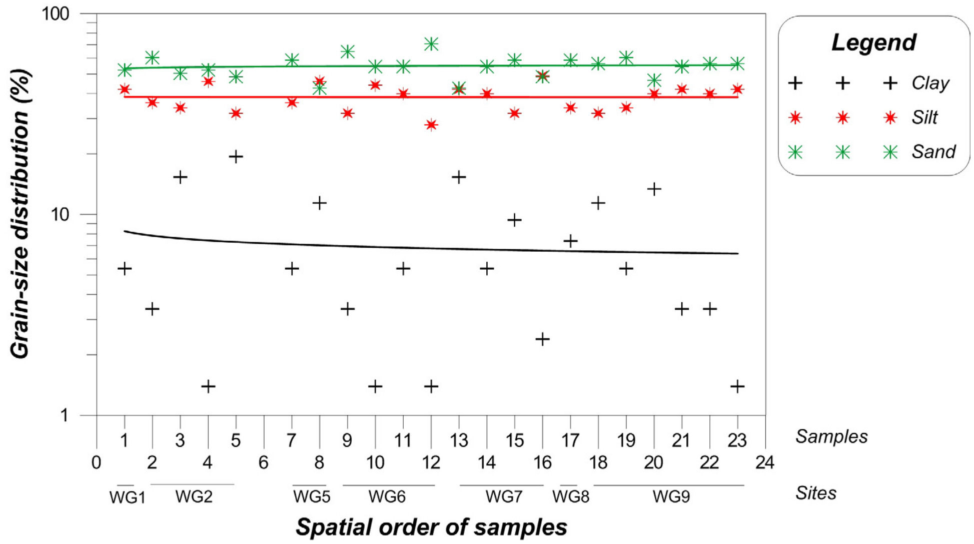

Figure 6. Correlation of grain-size distribution for samples in the study area.

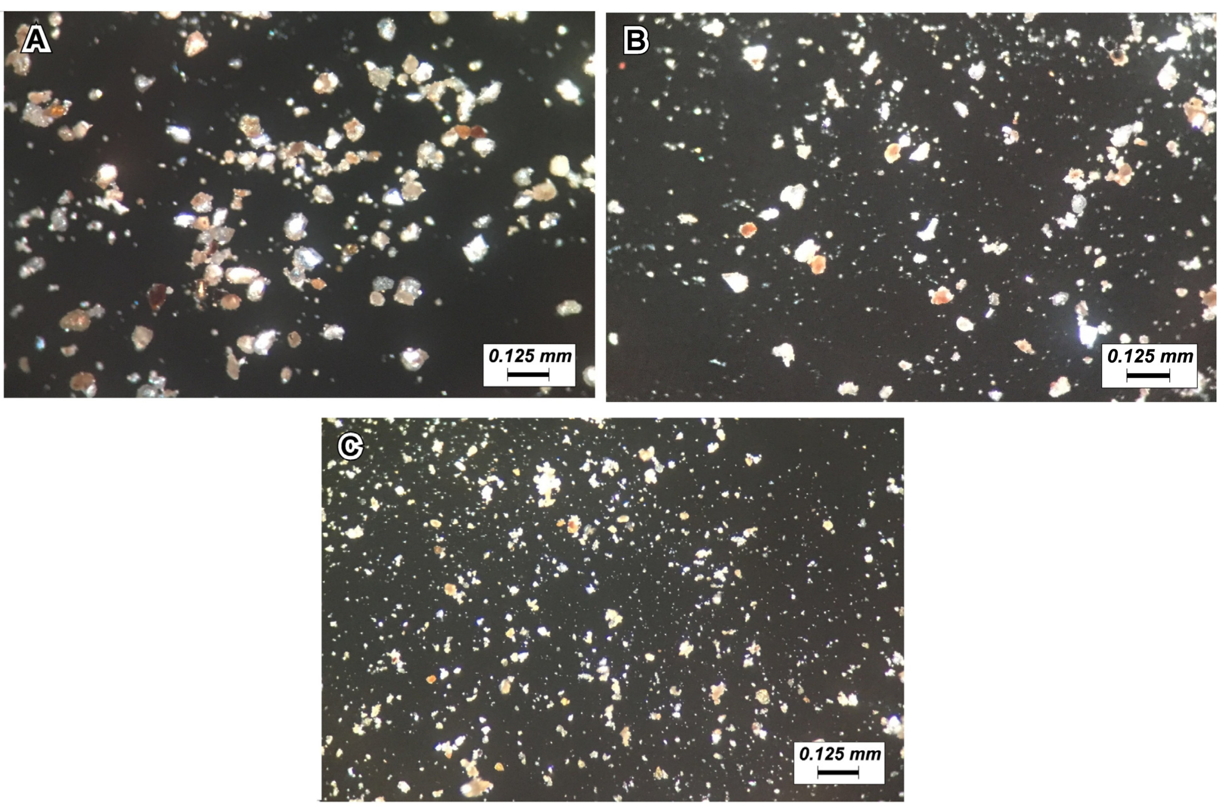

Figure 7. Shows the shape of fine grains in three sites of the study area ((A) Site WG6, (B) WG7, and (C) WG9).

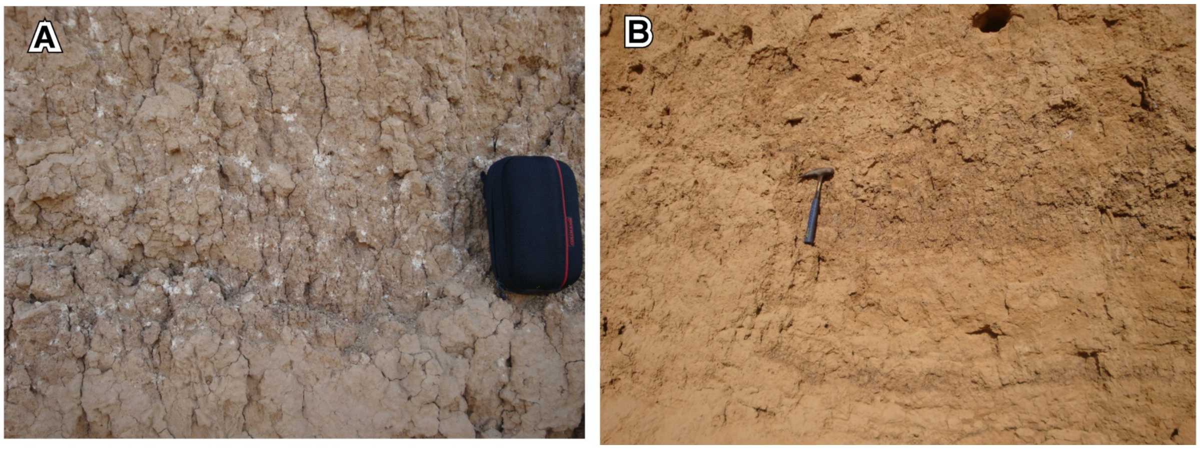

Figure 8. Fieldphotographs of the loess in the study area. (A) Shows the carbonates contents in the loess. (B) Shows organic contents in the loess (Dark color in the middle of the photo).

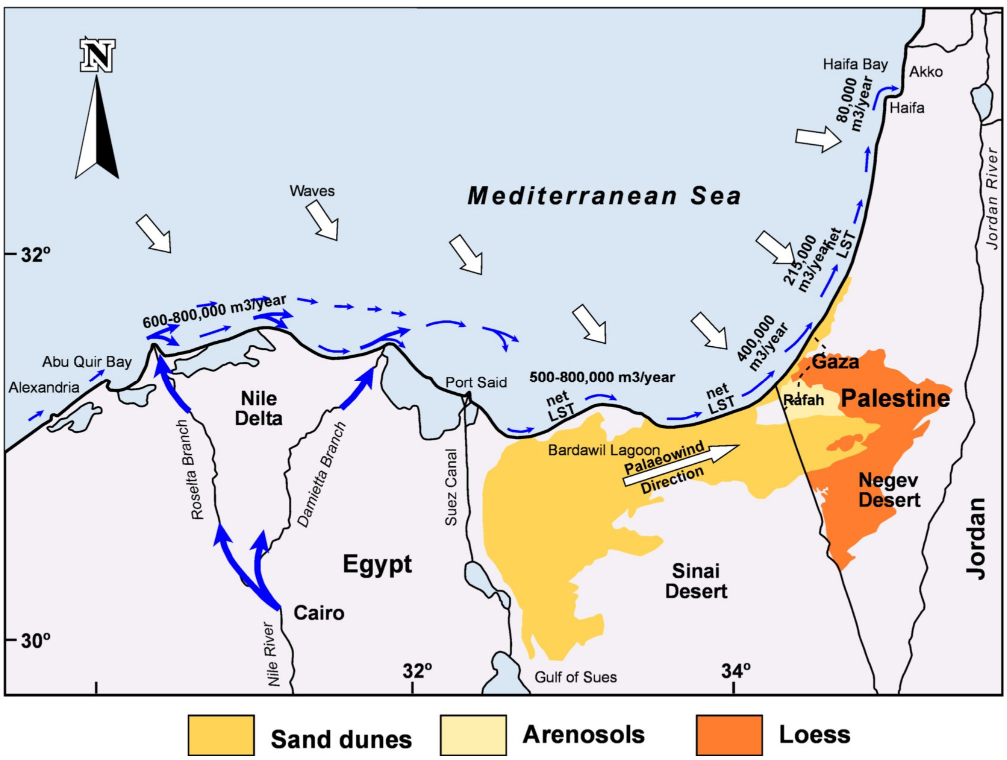

Figure 9. Shows the distribution of sand dunes, and loessial and sandy soils in the Gaza Strip and Negev desert (generalized after Dan & Raz, 1970; Bartov, 1990; Amit *et al*., 2006; Enzel *et al*., 2010; Ubeid&Albata, 2014).

This source supplies the silt- to very fine-grained sands, transported by short-term suspension and modified saltation, and accumulated by both dry and wet deposition. The proximal source of coarse silt and very fine-grained sands in the study area and in the neighbor area in the Negev have been attributed to sand-grain abrasion due to ballistic impacts within dunefields situated upwind of the loess (Crouvi *et al*., 2010).

Consequently, the sand dunes of the northern Sinai and the western Negev sands can be considered as reservoir of Aeolian sediments in the study area (Offer & Goossens, 2001; 2004; Tsoar *et al*., 2008; Crouvi *et al*., 2008; 2009; 2010). These sands cover an area about 1,500 km² and their eastern edge is near the Negev loess. Another suggested proximal source of loess that composed of coarse silt and very fine- to fine grained sands of quartz grains was thought to be in the Mediterranean shelf exposed during period of eustatically low sea levels in early MIS 4(73-60 ka) or even earlier. Where, the global sea level fell to 100 m or more below current sea level, exposing over approximate 50 km wide shallow shelf (about 20,000 km²) off the northern Sinai coast (Goring-Morris & Goldberg, 1990; Enzel *et al*., 2008; Crouvi et al., 2008).Another option is that the silt- to very fine-grained sands could be emplaced into the Sinai shores with the sand grains, sorted in the sand dunes and then sorted through transport and deposition (Coude-Gaussen & Rognon, 1988).

Moreover, sandy region Sahara is a source for the particles transported and deposited in the Sinai-Negev desert (Smalley & Vita-Finzi, 1968; Enzel et al., 2008).Where, through aeolian abrasion of sand particles that subsequently later form loess deposits. In the last 30 years several studies have demonstrated that aeolian abrasion is capable of reducing sand-sized quartz and feldspars to silt-size (Wright, 2001; Bullard *et al*., 2004; 2007). Field-based evidence for this process are scarce, but available for less-resistant minerals, e.g. carbonate that are resized through aeolian abrasion along transport of tens of kilometers (Arbogast & Muhs, 2000; Muhs *et al*., 2013). In the case of our study we suppose that the relation between the vast area of the Sinai-Negev sand sea and the Wadi Gaza area loess located downwind from it provides field-based observation in support of such process. The long enough distance between the source sand (Sinai-Negev desert) and depositional area in downwind (the study area) allow aeolian abrasion of quartz sands in large enough quantities to form the coarse fraction of the loess.

Palaeoclimatic implications

The Wadi Gaza as well as the whole Gaza Strip area and the NE Sinai- to NW Negev dunefield extends along a desert fringe between the climate zone of the Mediterranean Levant and the global desert belts (Fig.9). As a result the Wadi Gaza area has a characteristically semi-arid climate. The climate is characterized 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 per year. The daily relative humidity fluctuates between 65% in the daytime and 85% at night in the summer and between 60% and 80% in the winter. The wind direction is predominantly from the Northwest. There is a significant variation in the wind speed during the daytime, and the average maximum wind velocity is about 3.9 m/s. Moreover, storms have been observed in winter with a maximum wind speed of about 18 m/s (MedWetCoast, 2001; Ubeid, 2011).

Generally, the loess is widespread eaolian deposits dominated by coarse silt and very fine- to fine grained sands of quartz grains that serve as an important archive of information of Quaternary climate changes (Muhs, 2007). The sand dunes activity of the northern Sinai and the western Negev sands which considered as reservoir of aeolian sediments in the study area represent periods of increased aridity (Lancaster, 1981; Magaritz & Enzel, 1990; Schuster *et al*., 2006). Increased wind speed is itself sufficient to mobilize sand grains, create silt by spallation, and transport the silt downwind. There, coarse silt- to very fine-grained sandsare mostly dry-deposited, and the sedimentation rate is mostly controlled by wind energy rather than precipitation (Zhao *et al*., 2003; O'Hara *et al*., 2006). The calcium carbonate of loess deposits which mean values ranges from 10.7 to 14.9% in studied sites (Table 2) possibly referred to the leaching of precipitation through the loess deposits (Lewis & Fosberg, 1982). Where, the loess is commonly deposited during periods of increased precipitation (Coude-Gaussen & Rognon, 1988).

Overall, the palaeoclimate in the study area can be similar to that suggested from loess sequences (silt- to very fine-grained sand-rich) in the Netivot (11 km from Gaza border) in the northwestern Negev by Bruins &Yaalon (1979). They suggested that the palaeoclimate during the late Pleistocene was dry or moist semi-arid. The average rainfall based on the same sequence was 50-100% higher than today (Issar& Bruins, 1983).Early studies interpreted the time period of loess formation as characterized by wetter climate than today and dense vegetation which required to trapaeoliandust (Pye & Tsoar 1987; Tsoar & Pye 1987). According to this hypothesis, loess formation was limited to that last glacial interval and not observed during the Holocene owing to the wetter climate of the former. During glacial periods, the glaciations indirectly control intensified winds, dunes activity, and loess deposition (Sarnthein, 1978). However, the precipitation may enhance the loess formation not by wet deposition, but by preserving accumulations of dust sediments, and/or by increasing vegetation cover, thereby reducing wind speeds at the immediate desert surface below the threshold for reentraining silt and transporting it farther.

The intercalations of conglomerate with loess deposits suggest the intensive precipitation periods which able to carried coarse-grained quartzite and carbonates through the wadifrom El-Khalil mountains (part of the West Bank in the north-eastern part of the Gaza Strip), and northern Negev desert. The relatively strong rubification of dark brown loesses reflect warm conditions, whereas the somewhat colder climate resulted in the light brown loesses (Ubeid, 2011).

Conclusion

The study carried out in the Wadi Gaza, in the middle of Gaza Strip, Palestine. Where, the loess in the wadi well crops out. The Quaternary loess sequence in the study area overlies sand dunes, and intercalated by conglomerates in some locations. It consists of sandy loam to loam, with light brown to dark reddish brown color. The results analysis of twenty three sediment samples show that the loess composed of clay (1-20%), silt (28-49%), and very fine- to fine sand (43-71%). The carbonate contents range from 6 to 20%, and organic matter contents range from 1 to 2%. The dominant coarse silt and very fine-grained sands, and quartz-rich composition suggest that the sand dunes of the northern Sinai and western the Negev sands could be the most prominent reservoir of loess sediments in the study area. The palaeoclimate in the study area can be similar to that suggested from loess sequences in the Netivot (11 km from Gaza border), which its grain-size distribution and sedimentological features similar to those in the study area. Subsequently, the palaeoclimate in the study area during the late Pleistocene was dry or moist semi-arid. The average rainfall based on the same sequence was 50-100% higher than today. During the accumulation of the loess there were intensive periods of precipitation which indicated by the presence of conglomerates layers within the loess.

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