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Floodplain degradation and settlement history in Wadi al-Wala and Wadi ash-Shallalah, Jordan

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ABSTRACT

This study investigates a Mid-Holocene cycle of stream aggradation and incision in Wadi al-Wala and Wadi ash-Shallalah, western Jordan. Aggradation took place sometime between 7 ka and 6 ka, followed by stability as evidenced by a floodplain soil that was mantled by colluvial deposits between 4.6 and 4 ka. Stream incision around or after 4 ka eroded the floodplains. A second cycle of aggradation and incision occurred in the late Holocene, but this cycle is not synchronous between the two streams. Causes of the stream incision around 4 ka are hypothesized in the context of local geomorphological and hydrological characteristics, regional climatic change, Dead Sea level changes, and cultural landscape changes interpreted from archaeological and pollen records. In the context of available local and regional evidence, this study discusses the relation between Early Bronze Age settlement and stream degradation.

1. Introduction

Late Quaternary cycles of stream aggradation and incision have been reported in several valleys of the Levant. Unfortunately, a region-wide chronology of fluvial events cannot be established yet because of the small number of streams studied and to scarcity of data, particularly numerical ages. Nonetheless, observations on stratigraphic sequences already pointed to fluvial event synchronicity in some streams of southern Israel, the Negev, and the northern Sinai (Goldberg, 1994) and along streams draining the eastern side of the Jordan Valley (Mabry, 1992). The paucity of radiocarbon dating, due in part to the scarcity of organics, and the use of other dating methods in the region, have retarded a comprehensive chronology.

Interest in establishing a regional chronology of fluvial aggradation–incision cycles in Jordan began with the work of Claudio Vita-Finzi (1964, 1966), who identified two alluvial fills he correlated with the “Older” and “Younger” fills that he had previously identified elsewhere in the Mediterranean region. Based on associated archaeology the Older Fill occurred sometime in the Late Pleistocene, while the Younger Fill occurred in the Late Holocene, probably during Roman–Byzantine times. In the ensuing decades, extensive research in many localities around the Mediterranean Basin proved that the chronology of alluvial fills was more complex than Vita-Finzi's two-fill model (Grove, 1997; Beach and Luzzadder-Beech; Casana, this volume).

In Jordan, Vita-Finzi's model eventually evolved into a four-fill system, which as the original two-fill system (Copeland and Vita-Finzi, 1978), lacked the support of numerical dating. The alluvial localities studied by Vita-Finzi in Jordan were studied in more detail by Schuldenrein and Clark (1994, 2001) in the Wadi al-Hasa and by Mabry, (1992) in the Jordan Valley.

Schuldenrein and Clark (1992, 2001) identified more than two fills, pointing to the drying of Pleistocene Lake Hasa and tectonic dislocations as events that complicated the development of cut-fill cycles along the Wadi al-Hasa.

In the wadis draining the east side of the Jordan Valley, Mabry, (1992) identified fifteen Late Quaternary alluvial fills, eight of which are Holocene. He attempted a correlation of these fills with alluvial deposits reported elsewhere in the Levant. Despite the scarcity of numerical dates, Mabry, (1992) correlated the Holocene cut-fill cycles with regional cultural developments. One of the main aspects of this correlation focuses on the Middle Holocene, a period encompassing the Chalcolithic and Early Bronze periods, which is also the subject of other studies in southern Israel (Rosen, 1986, 1995, 1997a) and the Dead Sea area of Jordan (Donahue 1981, 1984, 1985; Donahue et al. 1997). In addition to other alluvial chronology studies, these studies pointed to a dramatic change in fluvial geomorphology of wadis in the Levant during the Chalcolithic and Early Bronze Age (Fig. 1; Table 1).

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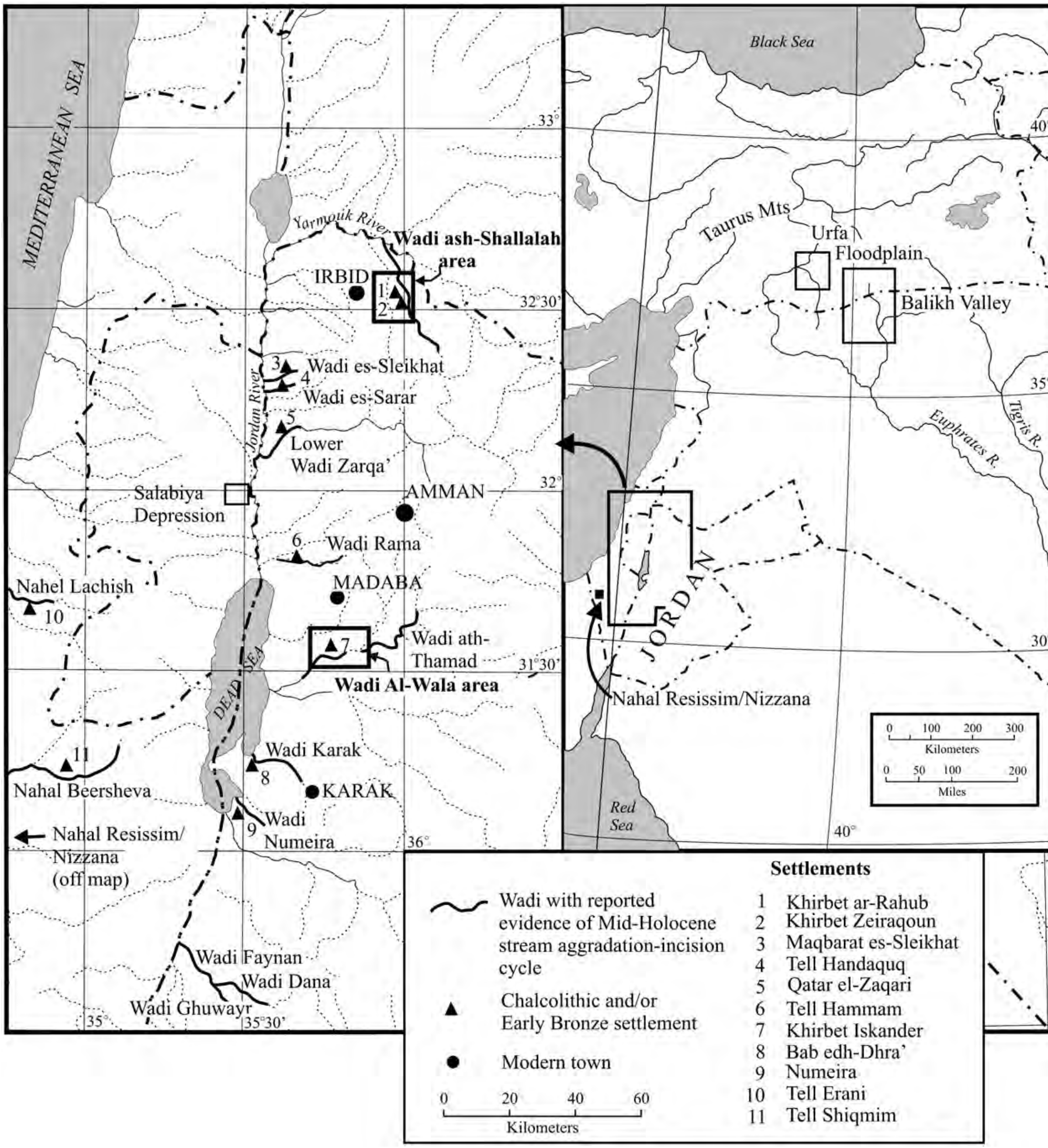

Fig. 1. Study areas and reported Mid-Holocene stream incision in the Levant and other localities mentioned in the text. Circles indicate locations of paleoenvironmental data mentioned in the text. See Table 1 for sources of alluvial records.

In Wadi Beersheva and Wadi Lachish (Israel), Rosen (1995, 1997a) observed that alluvial fills containing Chalcolithic and Early Bronze Age material were incised sometime at the end of the Early Bronze. The main causes of stream incision hypothesized by Rosen suggest that water table drop in the floodplain is associated with a series of environmental changes involving extreme climatic cycles. Similar events elsewhere, however, have not always been associated with climate or other environmental changes. In the wadis near the sites of Baba dh-Dhra' and Numeira, Donahue (1981, 1984, 1985) attributed stream incision in the Middle Holocene to tectonic changes prompted by earthquakes at the end of the Early Bronze age. Years later, Donahue et al. (1997), however, associated incision with lowering of base level prompted by the decline in Dead Sea levels, previously reported by Frumkin et al. (1994).

Without denying the effects of climate change, Mabry, (1992) reaches the conclusion that the rapid sprawl of settlements and agricultural intensification during the Early Bronze Age prompted incision that eventually eroded floodplains of the valleys along the streams draining the east side of the Jordan Valley. Furthermore, Mabry, (1992) implies that most of the declined settlements were associated with the floodplains degraded by this event. Such a hypothesis builds upon an observation made by Albright (1925) regarding the geographical proximity between Chalcolithic–Early Bronze settlements and stream valleys, which was interpreted as high dependence on floodplain irrigation. The rationale of Mabry's study implies that stream incision degraded the floodplains that provided these towns with fertile soils and flood irrigation.

Although these studies lack numeric dates, the sediments of the degraded floodplains contain Chalcolithic and Early Bronze Age archaeological remains, which suggests that the floodplain degradation occurred sometime around 4 ka (Table 1).

The study presented here examines the Holocene geomorphological history of Wadi al-Wala and Wadi ash-Shallalah, both of which

Table 1
Mid-Holocene alluvial units and reported incision around 4 ka (see Fig. 1 for locations)

Stream	Nearby Chalco-EB sites	Alluvial aggradation 7–5 ka	Stream incision ca. 4 ka	References
Wadi ash-Shallalah	Kh. Zeiraqoun, Kh. ar-Rahub	Unit I (W)	I	This study
Wadi es-Sleikhat	Maqbarat es-Sleikhat	H6 Unit (W)	X	Mabry (1992)
W. es-Sarar	Tell Handaquq	H6 Unit (W)	X	Mabry (1992)
Lower W. Zarqa'	Qatar el-Zaqari	H6 Unit (W)	I	Mabry (1992)
Wadi Rama	Tell Hammam	H6 Unit	I	Mabry (1992)
W. al-Wala	Khirbet Iskander	Iskanderite alluvial inset (W)	I	This study
W. Karak	Bab edh-Dhra'	Unnamed alluvium	X	Donahue (1981, 1985), Donahue et al. (1997)
W. Numeira	Numeira	Unnamed alluvium	X	Donahue (1981, 1984)
Wadis Faynan/Dana/Ghuwayr	Various Chalco-EB settlements	Faynan Unit	I	Barker et al. (1997,1998), Hunt et al. (2004)
Salibiya Depression		Fz III	I	Schuldenrein and Goldberg (1981).
Nahal Lachish	Tell Erani	Unnamed alluvium (W)	X	Rosen (1986, 1995, 1997a)
Nahal Beersheva	Shiqmim	Chalcolithic Fill (W)	X	Goldberg (1986)
Nahal Resissim/Nizzana	Be'er Resissim	Unnamed alluvium	X	Cohen and Dever (1981), Goldberg and Bar-Yosef (1990)

(W) Evidence of high water table.
Incision: I Inferred event; X Reported event.

present remains of Chalcolithic and Early Bronze Age occupations along their margins. Although the sequences are limited in the number of numerical dates, a geomorphological, pedological, and palynological analysis aids the reconstruction of landscape changes associated with Middle Holocene events of stream aggradation and incision.

2. Methods

2.1. Geoarchaeological research strategy

The survey and description of alluvial sequences in Wadi al-Wala were carried out in conjunction with archaeological surveys along Wadi al-Wala itself and its upper tributaries (Wadi ath-Thamad, Wadi ar-Rumeil, and Wadi al-Koum) (Fig. 2-A). Interpretation of cultural events in the area draws on archaeological data obtained at Khirbet Iskander by Richard (1980, 2000) and Richard et al. (2001). The main alluvial units and paleosols in the sequences of these wadis were previously described, dated, and named by Cordova (1999a, 1999b, 2000) and Cordova et al. (2005). The 1:50,000 geological map (Madaba Sheet 3153-II) by Al-Hunjul (1995) provided the basic lithological and tectonic-structural information.

The study of Wadi ash-Shallalah was carried out through an independent research focused on ancient soil erosion on the Irbid Plateau (Fig. 2-B). Although this project was not directly associated with archaeological surveys, it was located in close proximity to several Early Bronze Age sites surveyed by Mittmann (1970), and later studied by Ottosson (1991), Kamlah (2000), and Genz (2002).

2.2. Geomorphology and soil research

Sediment and paleosol stratigraphy in Wadi al-Wala and Wadi ash-Shallalah were described on cut-bank exposures. Dating was obtained from AMS assays of charcoal and humic sediments (Table 2), supplemented by relative dating based on diagnostic lithics and ceramics embedded in alluvial deposits and paleosols.

Descriptions of soil profiles were completed at various sections in the two wadis, but only the most representative have been included in this paper. Descriptions of soil horizons of these sections are summarized in Tables 3 and 4. Broader descriptions of some sections in Wadi al-Wala and upstream tributaries have been previously published in Cordova (2000) and Cordova et al. (2005).

2.3. Palynological research

Pollen assemblages were obtained from Middle Holocene alluvial deposits with acceptable concentration and preservation of pollen grains. The best preserved pollen assemblages corresponded with low-energy flood facies and paleosols in sections GWW-1 and GWW-2 in Wadi al-Wala, and section WHS-1 in Wadi ash-Shallalah. Samples with poor preservation and amounts lower than 100 grains were not used. Taxa identified in the samples range from twenty to forty five, which if presented here would make the diagram difficult to read. Therefore, the pollen diagrams presented here contain only selected taxa relevant to the discussion of the paper.

Regional paleoenvironmental proxy data, discussed in this study, include fluctuations of the Dead Sea level recorded in salt caves (Frumkin et al., 1994; Frumkin and Elitzur, 2002), rainfall reconstruction based on $\delta^{18}O$ values from cave speleothems (Bar-Matthews et al. 1998), and frequencies of olive pollen from three lakes: Lake Kinneret (Baruch, 1990), Hula Lake (Baruch and Bottema, 1999; Meadows, 2005), and Birkat Ram (Schwab et al. 2004). Olive (*Olea europaea*) was the only pollen taxa used here because its high frequencies are often correlated with some phases of settlement expansion in the Levant (Baruch, 1990). *Olea* pollen frequencies from the deposits of Wadi al-Wala and Wadi ash-Shallalah showed strong correlation with the regional pollen sequences mentioned above.

3. Study areas

3.1. Wadi al-Wala

Wadi al-Wala and its upper tributaries dissect the Madaba and Dhiban Plateaus (Fig. 2-A). The upper stretch of the main stream is Wadi ath-Thamad, located at elevations between 700 and 750 m. Wadi al-Wala proper descends from about 700 m to its confluence with Wadi al-Mujib at elevation −100 m before reaching its base level at the Dead Sea. The area of this study comprises the 2.8-kilometer reach of Wadi al-Wala between 450 and 500 m of elevation. This reach of the stream runs by the site of Khirbet Iskander, located at N 31° 33′ 58″ and E 35° 44′ 37″. Annual precipitation varies along the wadi system varies from 100–150 mm in the Wadi ath-Thamad to 200–250 mm in Wadi al-Wala next to Khirbet Iskander, to less than 100 mm at its confluence with Wadi al-Mujib near the Dead Sea shore. The rainy season occurs between November and April, with maximum precipitation in the months of December and January.

The rocks forming the plateau, dissected by Wadi al-Wala, consist of horizontal and subhorizontal strata of Cretaceous limestone, marls, and phosphorites. The Wadi ath-Thamad-Wadi al-Wala system is controlled by strike–slip and normal faults associated with the formation of the Jordan Rift in the Tertiary and Quaternary (Al-Hunjul, 1995). In the particular location of Wadi al-Wala, bedding and dipping of the Cretaceous sedimentary strata control sedimentation. In particular, the relatively hard beds of the Wadi as-Sir Limestone (WSL) mark the lowest level of incision of most streams (Fig. 3-A). Consequently, the east-dipping beds of the WSL control the gradient

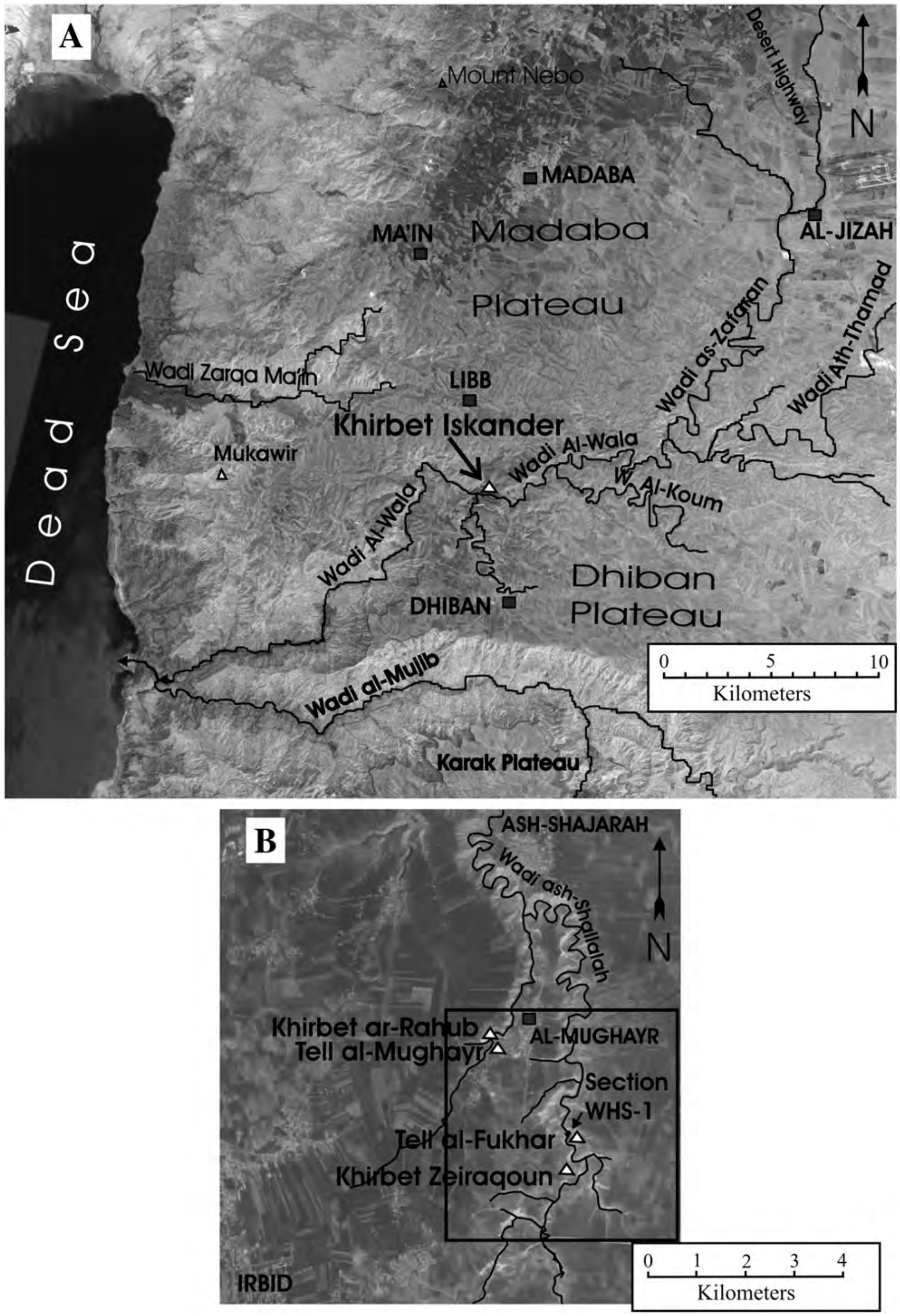

Fig. 2. (A) Regions surrounding Wadi al-Wala and (B) Wadi ash-Shallalah. Courtesy of National Imagery Agency (NIMA) CNES/SPOT Image 1992–1994.

of the west-flowing stream of Wadi al-Wala (Cordova, 2000; Cordova et al., 2005). Faulting of the WSL beds about 800 m downstream from Khirbet Iskander created a knickpoint that forms a water drop used by Ottoman grist mills. Downstream from this point the stream gradient increases and allows little deposition, but upstream from here deposition created several alluvial units during the Late Quaternary.

Before intense water pumping began in the late 20th century, Wadi al-Wala carried a permanent flow of water. Its bed, dry now for most of the year, carries water only after storms. The landscape around Wadi al-Wala is generally barren, except for olive groves and vegetable orchards irrigated with pump water.

3.2. Wadi ash-Shallalah

The studied area in Wadi ash-Shallalah (WHS-1) is located at N 32° 35′ 34″ and E 35° 56′ 57″ at an elevation of 380–390 m at the bottom of the Wadi ash-Shallalah canyon and 430–500 m on the tops of the adjoining plateaus (Fig. 2-B). Wadi ash-Shallalah, a tributary of the Yarmouk River, dissects the Irbid Plateau, which is formed by the Late Cretaceous Muwaqqar Chalk Marl and Paleocene Umm Rijam Chert Limestone. Its permanent water flow is fed by springs, some of which have been tapped for canals since the Roman and Byzantine periods.

Table 2
AMS radiocarbon dates from the sediments in Wadi al-Wala and Wadi ash-Shallalah

Section and depth	Terrace and unit	Lab number	Conventional ^{14}C age (yr BP)	2-sigma calibrated dates[a]	Material dated
GWW-3-5 86 cm	Mazra'a	Beta-121656	1190+/−50	1245–970 BP (AD 705–980)	Charred material
GWW-1-7 97 cm	Iskanderite alluvial inset	Beta-133945	4350+/−60	5055–4830 BP (BC 3105–2880)	Charred material
GWW-1-I-5 260–275 cm	Iskander alluvium	Beta-142336	12,990+/−90	16,070–14,015 BP (BC 14,120–12,765)	Bulk sediment
GWW-3-1-3 505–515 cm	Iskander alluvium	Beta-134556	14,520+/−50	17,750–17,035 BP (BC 15,800–15,085)	Bulk sediment
WHS-1-1 320 cm	Units V–VI transition	Beta-147237	2670+/−40	2795–2740 BP (BC 845–790)	Charred material
WHS-1-9 675 cm	Unit I	Beta-147282	5740+/−50	6660–6410 BP (BC 4710–4460)	Charred material

[a] Calibration database used, INTCAL1998 Stuiver, M. et al. 1998. Radiocarbon 40 (3), 1041–1083.

Agriculture on the surrounding plateaus is mainly focused on wheat and barley. Pleistocene alluvial terraces in the canyon sustain orchards and olive groves. The area receives between 300 and 400 mm of annual precipitation. Overall, the landscape of the Irbid Plateau is similar to the area north of Wadi al-Wala. The area has long sustained sedentary populations as evidenced by numerous sites dating from the Neolithic to the present.

3.3. Environmental context of the two studied areas

Biogeographically, the two regions are located on the transition zone between the Non-Forest Mediterranean and Irano-Turanian vegetation zones (Al-Eisawi, 1996). Because of the relatively low annual precipitation and long history of farming and grazing, most of the area is treeless, except in areas where pistachio (*Pistacia atlantica*) stands have survived. Because of intense grazing by goats and sheep, most of the area is dominated by scrub vegetation such as *Peganum harmala*, *Salvia dominica*, *Ballota undulata*, *Alhagi marorum*, and *Urginea maritima*.

Precipitation diminishes eastward as moist air masses from the Mediterranean dissipate, resulting in steppe communities of *Anabasis syriaca* and *Artemisia herba-alba* on uplands, and *Raetama raetam* and *Nerium oleander* in the wadis. Precipitation also diminishes locally with elevation. Thus, slopes and deep valleys near the Dead Sea present tropical xerophytic vegetation typical of the Sudanian vegetation province (Al-Eisawi, 1996). Most of the areas on the plateau, although classified as Mediterranean vegetation, are all under cultivation of wheat and barley, and olive trees.

Soils on the plateaus above the two wadis are classified as Red Mediterranean Soils (Moorman, 1959). They are the equivalent of xerochrepts, xerorthents, and chromoxererts in the USDA classification (Soil Survey and Land Research Centre, 1993; Khresat, 2001). To the east soils are thin and stony. In some areas, accumulations of eolian silt have produced Yellow Soils (Moorman, 1959), which are the calcixerollic xerochrepts of the USDA classification.

3.4. Middle Holocene settlement history along the two studied streams

Chalcolithic and Early Bronze Age settlements in the Wadi al-Wala area were originally reported by Glueck (1939). The most extensively studied and excavated site is Khirbet Iskander, which followed a typical regional trajectory of a site of its time, from a small Chalcolithic settlement to Early Bronze Age town (Harrison, 1997; Richard, 2000). It is generally implied that the transition from Chalcolithic village to an Early Bronze town involved agricultural intensification and strengthening in foreign trade (Richard, 1980, 2000; Philip, 2001).

Archaeologists have divided the Levantine Early Bronze Age into four phases (Table 5) based primarily on pottery styles tied to radiocarbon dates, as well as changes in architectural and settlement patterns (Philip, 2001). The sequence of settlement change in the Levantine Early Bronze Age begins with rapid increase of settlements during the EBI and EBII (Rosen, 1995; Philip, 2001). Slow decline took place during the EBIII, followed by a considerable settlement decrease in size and abandonment during the EBIV and early Middle Bronze (Rosen, 1995; Palumbo, 2001). Although originally the EBIV was seen as a period of depopulation, recent research from all areas of the

Table 3
Summarized descriptions of soil horizons in sections of Wadi al-Wala (Fig. 3)

Section	Horizon	Depth	Texture	Structure	Color	Mottles
GWW-3	Ap	0–21	S-L	ms	2.5YR 6/6	
	AC	21–29	S-L	1f sbk	10YR 6/3	
	2Ab	29–56	L	2f sbk	10YR 6/3	
	2Bk[a]	56–74	L	1f sbk	10YR 6/3	
	2C	74–260	SiL, S-L	ms	10YR 6/3–6/4–7/3	1[b]
	Gravel	260–280	Gr	ms	10YR7/3–6/3	
	3ACb	280–310	S-L	1f sbk-ms		1[a]
GWW-1	Ap	0–30	S-L, G	ms	10YR6/6	
	AC	30–85	S-L, G	ms	10YR6/6	
	2Ab	85–120	St-L	ms-1f sbk	10YR6/3	1[c]
	2Bw	120–152	St-L	2f sbk	10YR6/4	1[c]
	2C	152–205	St-L	ms-1f sbk	10YR6/6	3[c]
	3ABwb	205–255	L, G	2 m sbk	10YR6/6	3[c]
	4AC	255–325	L, G	ms	10YR6/4	3[c]
	5ABwb	325–355	L, G	ms- 1 m sbk	10YR6/4	3[c]
	5Bw	355–389	L, G	1 m sbk	10YR6/4	3[c]
	6Avb	389–428	L	2 m sbk	10YR6/4	3[c]
	6Bw	428–520	C-L	2 m abk-cpr	10YR5/6	2[c]
	6C	520–581	C-L	2 m sbk-ms	10YR6/4	2[c]

Texture: L = loam; St-L = silty loam; S-L = sandy loam; C-L = clay loam; G = gravel.
Structure: 1 = weak; 2 moderate; 3 strong; f = fine; m = medium; c = coarse; ms = massive; sbk = subangular blocky; abk angular blocky; cpr = columnar/prismatic.
Mottles: 1 = few; c = common; 3 = abundant.
[a] Carbonate filaments (stage I).
[b] Mottle color: 7.5YR 6/6–7.5 Y 6/6.
[c] Mottle color 7.5YR 6/6.

Table 4
Summarized descriptions of soil horizons in section WHS-1of Wadi ash-Shallalah (Fig. 7)

Section	Horizon	Depth	Texture	Structure	Color	Mottles
WHS-1	Avb	0–40	St-L, G	1 m sbk	10YR6/3	
	C	40–110	St-L, G	ms-1c sbk	10YR6/3	1[a]
	2ACb	110–146	St-L	1 m sbk	10YR6/3	1[a]
	3ABwb	146–170	St-L	1 m sbk	7.5YR5/4	
	C (silt beds)	170–306	St-L	Ms	7.5YR5/4–5/3	
	4ACb	306–326	St-L	ms-1 m sbk	10YR4/3	
	4C (silt and sand beds)	326–455	St-L	ms	10YR5/4–7.5YR6/4–5/4	
	Sand and gravel fill	455–660	S, G	ms		
	5ACb	545–602	St-L, G	ms-1 m sbk	10YR6/3	1[b]
	6ACb	538–630	St-L, G	ms-1 m sbk	10YR6/3	2[b]
	7Ab1	630–690	L	1 m sbk	10YR6/4	
	7Ab2	690–740	L	1 m sbk	10YR5/3	

Texture: L = loam; St-L = silty loam; Gr = gravel.
Structure: 1 = weak; 2 moderate; 3 strong; f = fine; m = medium; c = coarse; ms = massive; sbk = subangular blocky.
Mottles: 1 = few; 2 = common.
[a] Mottle color: 5YR5/4.
[b] Mottle color: 7.5YR5/3.

Levant has shown that this period involves a transition from urbanization to a ruralization process involving increase in pastoralism (Palumbo, 2001; Dever, 2003). Although some sites were resettled during the Middle and Late Bronze, a large number of settlements were never reoccupied in post-EBIV period, which is the case of Khirbet Iskander on the banks of Wadi al-Wala and Khirbet Zeiraqoun on the plateau next to Wadi ash-Shallalah (Fig. 2).

4. Results

4.1. Stratigraphic units and geomorphic event reconstruction

The Pleistocene alluvial units identified by Cordova et al. (2005) in Wadi al-Wala are the Al-Wala Gravels, Al-Wala Silts, Al-Wala Colluvium, which form the terrace where the site of Khirbet Iskander was built (Figs. 3 and 4). Major erosion occurred at an unknown time, leaving a scoured surface that was filled in by the Iskander Alluvium during the Terminal Pleistocene (Figs. 3 and 4). Sometime during the Early Holocene, the Iskander Alluvium was eroded, an event that was followed by the accumulation of the Iskanderite Alluvium (Fig. 5). At section GWW-1 the Iskanderite Alluvium forms an alluvial inset resting on erosional unconformities on the Iskander Alluvium and the Al-Wala Silts (Fig. 4).

The accumulation of Iskanderite Alluvium occurred sometime between 7 and 5 ka. The minimum age is evidenced by Chalcolithic pottery fragments and a calibrated AMS date of 5055–4830 BP (Table 2). The soil developed on the Iskanderite Alluvium is named here the Iskanderite Soil, which is a silt–loam, relatively dark floodplain soil

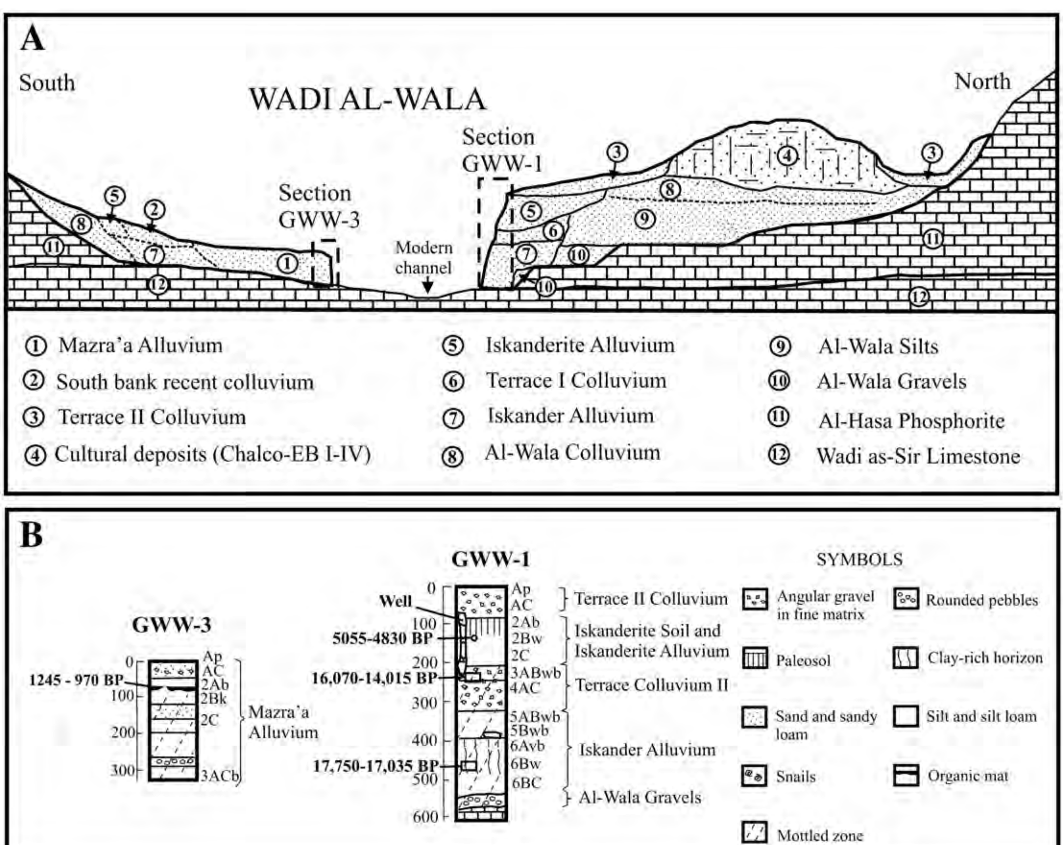

Fig. 3. (A) Section across Wadi al-Wala at Khirbet Iskander and (B) detailed stratigraphy of sections GWW-1 and GWW-3.

Table 5
Early Bronze Age subdivisions and socioeconomic characteristics

Periods and phases	Time ranges in years BC	Time duration ranges in years BP
Chalcolithic	5750–3600	7700–5550
EB I	3600–3100/3000	5550–5000
EB II	3100/3000–2850/2750	5000–4750
EB III	2850/2750–2400/2300	4750–4300
EB IV	2400/2300–2000	4300–3950

Chalcolithic period duration is based on radiocarbon date bank compiled by Bourke (2001) and time ranges for EB I–EB III are based on Philip (2001) and for EB IV on Palumbo (2001).

with poorly developed blocky subangular structure (horizons 2Ab/2Bw/2C; Table 3). The soil is very conspicuous at section GWW-1 (Fig. 4), although it appears in other sections along a 3 km stretch of Wadi al-Wala (dots in Fig. 5-A). By connecting the locations of remnants of the Iskanderite Alluvium and Iskanderite Soil it is possible to reconstruct an approximate surface occupied by the Iskanderite floodplain (Fig. 6). The area estimated for its surface is 5.9 ha, which presumably was the surface of the fertile floodplain that existed at the time of the Chalcolithic and Early Bronze Age occupation of Khirbet Iskander.

The silty, organically rich sediments of the Iskanderite alluvial fill and soil suggest that the annual flow of water in the floodplain was relatively stable, experiencing mainly mild floods that could have been steered to irrigating fields in the floodplain. Roughly, this stability period coincides with the late Chalcolithic and EBI-EB-III occupations at Khirbet Iskander. The stability of the floodplain was at times interrupted by accumulation of the Terrace II colluvium, suggesting destabilization of slopes.

Stream incision and erosion of the Iskanderite alluvial fill took place sometime around 4 ka BP (Fig. 5). This event eroded away most of the Iskanderite Alluvium and older sediments, bringing the streambed to the bedrock. Three millennia after the Iskanderite floodplain was eroded by stream incision, an event of sediment build-up formed a new floodplain, whose deposits form the Mazra'a Alluvium (Fig. 5). This alluvial fill consists of laminated silts and gravel lenses capped by a sequence of A horizons on colluvium and an underlying Bk horizon (Table 3). AMS dates from organic mats developed in the upper part of the silt deposits in section GWW-3 provide dates that put the accumulation of this event in the 10th–11th century AD, namely during the Early Islamic period (Table 1). The Mazra'a floodplain was subsequently destroyed by stream incision. Ottoman gristmills were built on the remains of Mazra'a Alluvium, suggesting that the incision took place sometime during the first half of the 2nd millennium AD. Since then, no accumulation event is recorded in Wadi al-Wala. Headward erosion originated in the knickpoint formed by dipping strata, however, created a v-shaped channel that eventually eroded down to the Wadi as-Sir Limestone forming the present valley (Fig. 6).

In Wadi ash-Shallalah, the stratigraphic section studied is on the right bank of the stream (Fig. 7-A). The lowest exposed deposit is Unit I, a wetland deposit, which, based on an AMS of cal. 6660–6410 BP, formed during the Chalcolithic period. Accumulation continued with Unit II, a colluvial deposit with two phases of accumulation and the formation of two AC horizons (Fig. 7-B; Table 4). Mottling on these soils suggests that during or after colluvial accumulation, the water table was still high.

Gully erosion cut through the existing floodplain wetland deposit (Unit I) and colluvial soils (Unit II). The gullies formed during this event were subsequently filled in with rounded and sub-rounded gravel (Unit III) and coarse sand (Unit IV). Sedimentation continued in the form of low-energy flood deposits, characterized by bands of red and grey silt (Unit V). The presence of red bands of silt and silt–loam deposits is interpreted as pulses of soil erosion in the uplands.

A short period stability is evidenced by an A/C horizon at 300–330 cm. Charcoal from a hearth lying on this horizon yielded an age of cal 2795–2740 BP. After this short stable period, sedimentation continued again with bands of grey and red silt and occasional sand and gravel lenses (Unit VI). Another A/C soil horizon developed on top of unit IV, marking the end of this cycle of alluvial deposition (Table 4). On top of this soil, a gray colluvial deposit accumulated (Unit VII). No material datable by radiocarbon was found in this colluvium, but pieces of Hellenistic, Roman, and Byzantine pottery are scattered in it. Incision followed the deposition of the Unit VII colluvium, consequently forming the present wadi course, which is slowly filling up with coarse sediments deposited by the modern channel.

The reconstructed sequence of fluvial events in Wadi ash-Shallalah shows one cycle of accumulation (Units I and II) followed by gullying (filled Units III–IV) in the Middle Holocene, and followed by the accumulation Units V–VII in the Late Holocene (Fig. 8). The presence of the wetland deposit, contemporary with the Iskanderite Soil in Wadi al-Wala, correlates with the Chalcolithic and Early Bronze occupations of the surrounding sites.

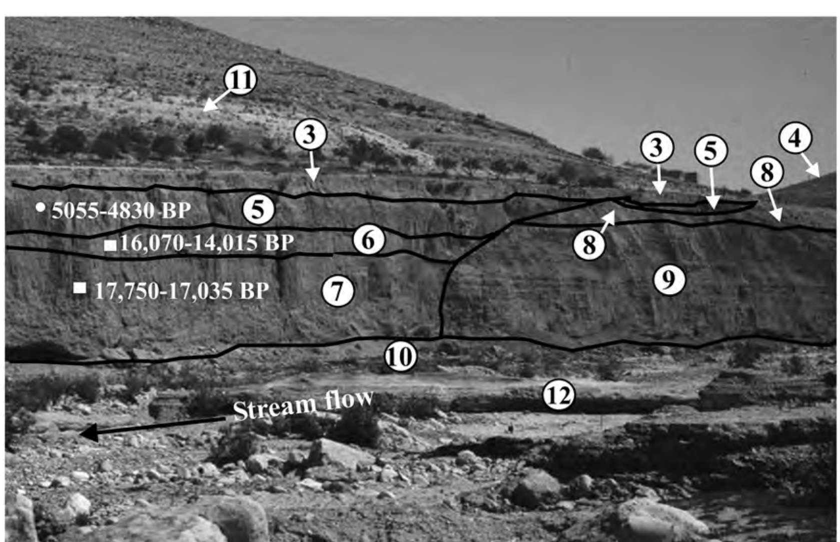

Fig. 4. View of cut-bank section (GWW-1) in Wadi al-Wala. For stratigraphic unit numbers refer to legend on Fig. 3-A.

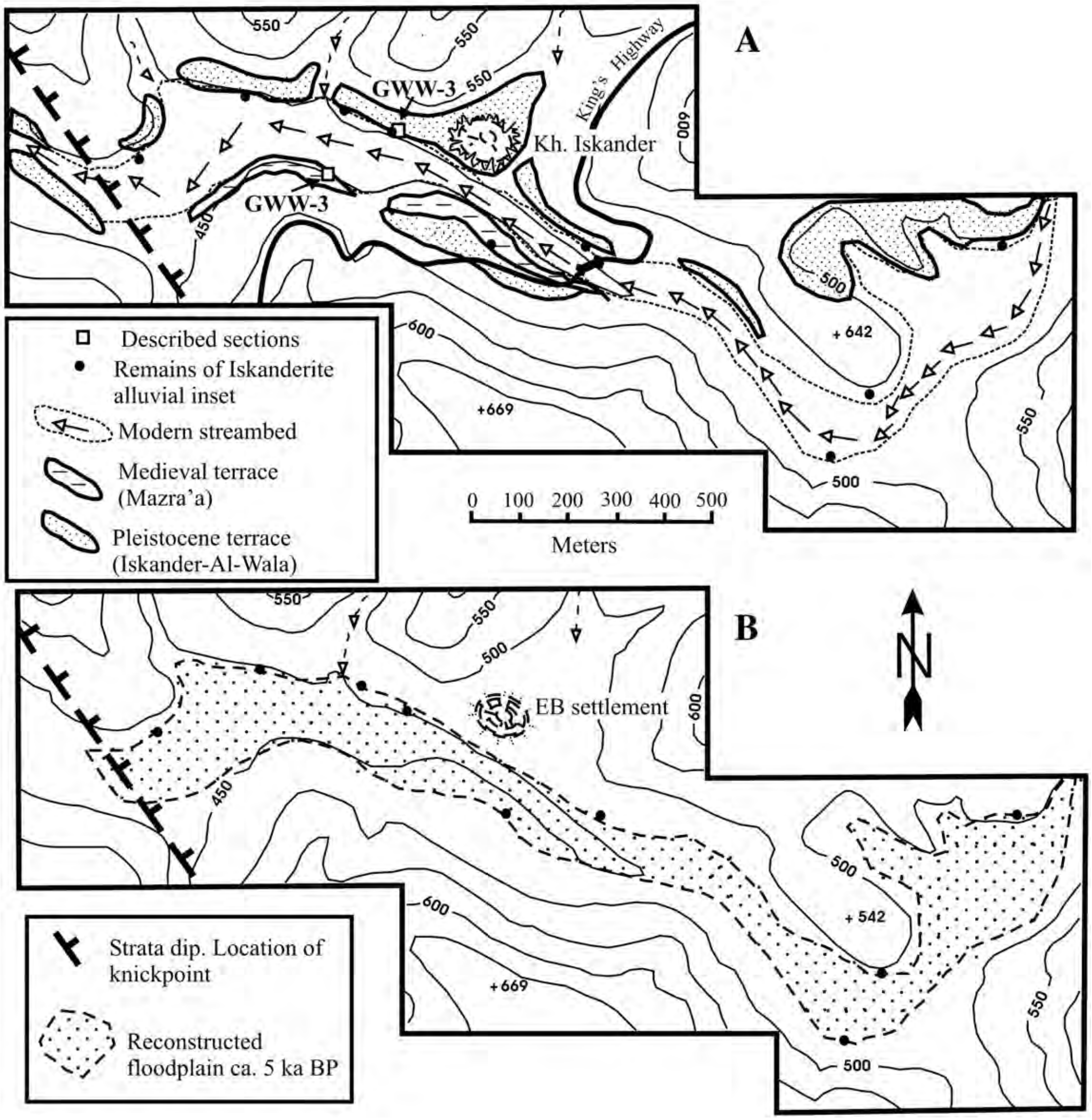

Fig. 5. Reconstruction of Holocene cut-fill events in Wadi al-Wala.

4.2. Vegetation reconstruction in relation to settlement history and geomorphic events

The pollen assemblages obtained from silt–loam deposits of the Iskanderite Alluvium at GWW-1 yielded pollen assemblages that depict a humanized landscape of cultivated plants, weeds, and scrub (Fig. 9). *Pistacia* (pistachio) and *Quercus* (oak) pollen frequencies are considerably low, indicating that these trees were very scarce around the site, but higher than the modern frequencies (see modern samples on top of diagram in Fig. 9).

High frequencies of weed pollen (mainly Asteraceae, *Noaea*, and *Mentha* types) and cultivated plants (Cerealia and *Olea*) indicate intensive agriculture in the area. In particular, the percentage of *Olea* (olive) pollen in the Iskanderite alluvium and soil (8–13%) is relatively high compared to modern pollen surface frequencies (6–11%). Today, olive cultivation is widespread in this region. Prevalent olive cultivation is evident in most of the regional pollen diagrams in Lake Hula, the Sea of Galilee, and the Dead Sea for the Early Bronze Age (Baruch, 1990; Baruch and Bottema, 1999). Additionally, the relatively high frequencies of cereal (Cerealia-type) pollen suggest intense cultivation on the floodplain soils during the Chalcolithic and EB. The strong presence of aquatics, such as *Typha* (cattail) and *Lemna* (duckweed), suggests that the floodplain may have been either subjected to impoundment or irrigated with impounded water.

Frequencies of pollen from the Terrace Colluvium II deposit show a decline in *Olea*. The relatively high amounts of Cyperaceae (sedges) and *Typha* pollen suggest that this colluvium accumulated on a still wet floodplain. In the geomorphic and cultural context of this deposit, this pollen assemblage suggests that the accumulation of the Terrace Colluvium II could have occurred during a phase of abandonment previous to the incision of the Iskanderite floodplain. This could have happened during the phase of settlement decline in the EBIII or during the final settlement decline in the EBIV. Unfortunately, the Terrace II Colluvium could not be placed chronologically in detail because of the lack of datable material and diagnostic pottery.

Typha and Cyperaceae pollen are abundant in the samples from the Mazra'a Alluvium, which suggest that these deposits correspond to a wet floodplain environment. *Olea* pollen appears in low amounts, and Cerealia-type pollen is absent. This picture contrasts with the intense agriculture practiced in the area during the EB. Based on two AMS dates (Table 2), the Mazra'a Alluvium accumulated during the Early Islamic period, when according to LaBianca (1990), olive cultivation was not important in this region of Jordan.

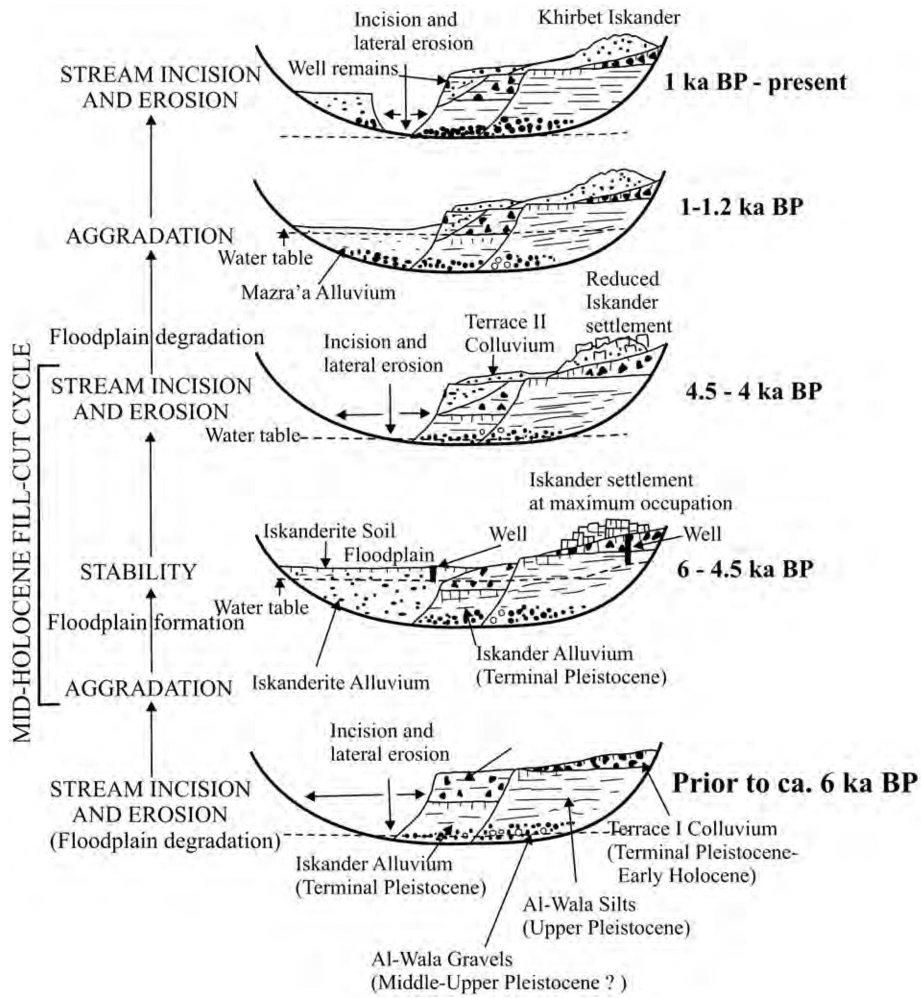

Fig. 6. Present alluvial geomorphology of Wadi al-Wala and reconstructed geomorphic features extant at the time of EBI-III occupation of Khirbet Iskander. Iskanderite floodplain was constructed by linking localities where Iskanderite alluvium and/or Iskanderite soil are exposed (circles).

Pollen assemblages in the modern samples show abundance of *Noaea*-type pollen, which corresponds to *Noaea mucronata* and *Anabasis* spp., both of which form scrub plants that abound on the overgrazed environment on the denuded slopes around the valley. *Olea* pollen is abundant, which reflects the widespread distribution of olive orchards in the region.

The pollen sequence obtained from sediments in the WHS-1 begins around 6 ka BP, showing first assemblages indicative of wet floodplain vegetation (Fig. 10). *Typha* and Cyperaceae dominate the assemblages of Units I and II. The frequencies of the two types of *Quercus* pollen (evergreen and deciduous oak) are relatively high compared to later periods. *Olea* pollen shows high frequencies (up to 34%) in Unit I and suggests extensive olive cultivation on the slopes around the wetland. This is consistent with peaks of *Olea* pollen recorded in pollen sequences from lacustrine cores in Lake Kinneret (Baruch, 1990), Hula Lake (Baruch and Bottema, 1999), and Birkat Ram (Schwab et al., 2004) for the Middle Holocene.

Unit II contains lower frequencies of aquatic plant pollen, which reflects the drying of the floodplain, perhaps as a result of deterioration caused by rapid silt accumulation. *Olea* pollen remains high and suggests that the accumulation of this colluvial unit may have occurred at the peak of olive cultivation, probably during the EB I–EBII period. Units III and IV were not tested for pollen because it is composed mainly of gravel and coarse sand.

The pollen assemblage below the hearth dated to cal 2795–2740 BP shows the return of Cyperaceae, which correlates with the formation of soil (i.e. geomorphic stability) between Units V and VI. The slopes may have been stable, since *Pistacia* and the two species of *Quercus* appear in fair percentages. *Olea* pollen suggests olive cultivation, but not to the degree of Units I and II.

The frequencies of *Quercus* from the Unit VII colluvium show that oak woodlands slightly recovered, although an increase in *Olea* pollen suggests that olive cultivation began to increase again, which correlates with deposits of the same age in GWW-3 and those recorded in pollen cores in the region for the Early Bronze Age and the Roman–Byzantine periods. One of the samples, however, has very few *Olea* pollen grains. Rather, it contains abundant *Vitis* (grapevine) pollen, which is another crop that is prominent in the Western Highlands during the Byzantine period (LaBianca, 1990).

The pollen assemblage from the modern alluvium contains taxa mainly of shrubs, scrub (mainly *Noaea*-type), and various Asteraceae that account for most of the weeds in the area today. Abundant *Olea* pollen frequencies in modern assemblages reflect the present olive cultivation in the area. Neither here nor in Wadi al-Wala are the levels of olive pollen as high as they were during the Early Bronze Age and the Roman–Byzantine period.

5. Discussion

5.1. Chronological sequences of fluvial geomorphic events at regional scale

The Middle Holocene alluvial records from Wadi al-Wala and Wadi ash-present parallel sequences of Middle Holocene fluvial events

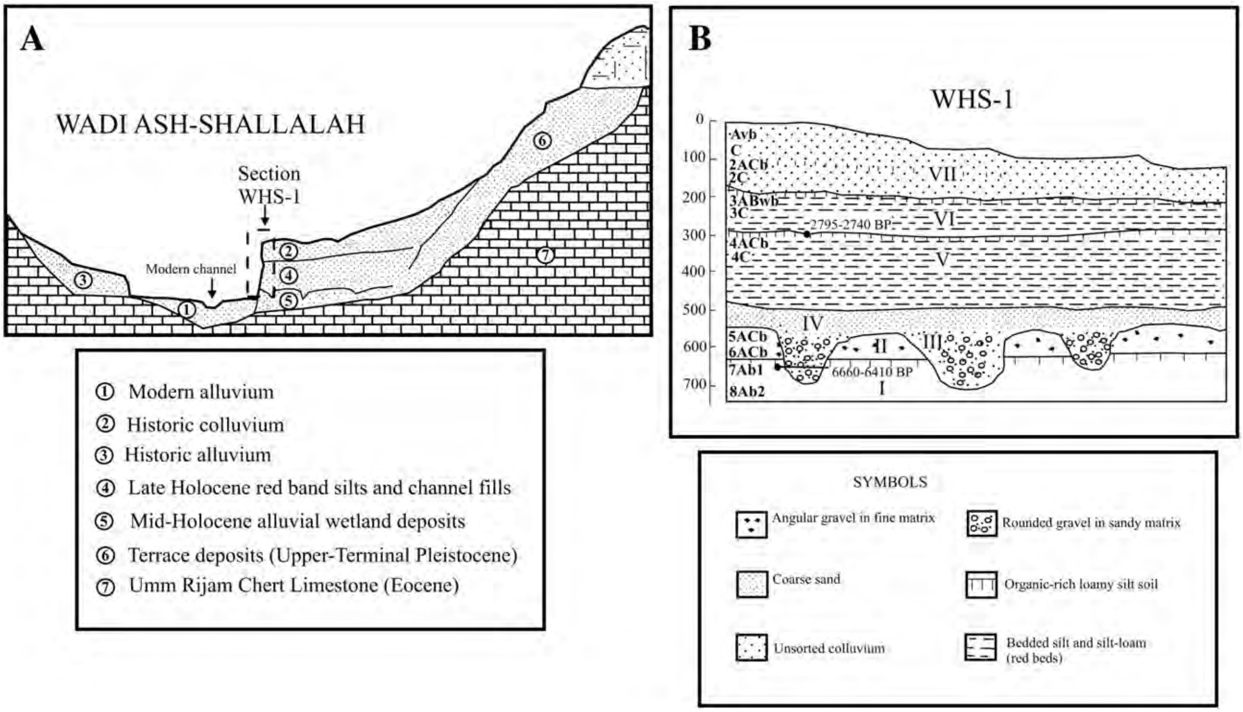

Fig. 7. (A) Section across Wadi ash-Shallalah and (B) stratigraphy of section WHS-1.

beginning with aggradation, followed by stability and high water table, followed by colluvial accumulation, and ending with stream incision. The aggradation phase of this sequence correlates with records of other wadis in the region. Mabry (1992) reports middle Holocene aggradation (units H5 and H6) in Wadi es-Sarar, Lower Wadi Zarqa, Wadi Shleikhat, and Wadi Rama, all of which are located in the Jordan Valley (Fig. 1; Table 3). These aggradation units are associated with Chalcolithic and Early Bronze Age ceramics (Mabry, 1992). Correlative events are also reported in Nahal Lachish (Rosen, 1986, 1995, 1997a), Nahal Beersheva (Goldberg, 1986), and Wadi Resissim (Goldberg and Bar-Yosef, 1990). The localities described in these streams are in close proximity to Chalcolithic–Early Bronze sites.

Middle Holocene alluvial units have also been identified in the Wadi Faynan and its tributaries, Wadi Ghweir and Wadi Dana (Barker et al., 1997, 1998; Hunt et al., 2004). The main unit related to the mid-Holocene aggradation phase is represented by the Wadi Faynan alluvium (Hunt et al., 2004). It is implied that it was incised sometime in the middle-to-late Holocene. In Upper Mesopotamia, middle Holocene aggradation and incision events are also reported in the Urfa Floodplain (Rosen, 1997b) and in the Balikh Valley (Wilkinson, 1997, 1998, 1999) (Fig. 1). In particular the latter contains abundant Early Bronze settlements, which also decline about the same time as in the Levant.

The relative geomorphic stability evidenced by the formation of the Iskanderite Soil in Wadi al-Wala and the wetland soil of Unit II in Wadi ash-Shallalah suggests a relatively humid environment. High water tables are evident by the formation of mottling in the lower units of section GWW-3 and the wetland conditions of Unit I of section WHS. Reports of a high water table exist also from Wadi es-Sarar and Wadi Rama (Mabry, 1992).

Evidence of high water tables is also reported from several of the wadis in the Jordan Valley, Nahal Lachish, and Nahal Beersheva (Table 1). The accumulation of the Terrace II colluvium and the Unit II colluvium in Wadi ash-Shallalah and Wadi al-Wala correlates with the H7 alluvial unit recognized by Mabry (1992) in Wadi Rama and other wadis of the Jordan Valley.

The stream incision of the Iskanderite Alluvium in Wadi al-Wala and the gullying of Units I and II in Wadi ash-Shallalah correlates with erosional events reported in other Levantine wadis (Table 1). Because settlement decline was a widespread phenomenon in the Levant at the end of the 3rd millennium BC, the regional event of stream incision needs to be analyzed in the context of climate change and cultural development.

5.2. Climatic context of stream incision

Bar-Matthews et al. (1998) reconstructed a paleorainfall curve for the period 7–0 ka BP using $\delta^{18}O$ values obtained from speleothems in Soreq cave and modern rainfall analogs (Fig. 11). They divided the curve into four stages. Stage 1 marks the gradual decline in precipitation that marked the last part of the wet period that characterized the early Holocene. Stage 1 encompasses the Chalcolithic period.

Stage 2 coincides with the Early, Middle, and Late Bronze ages, during which precipitation alternated between exceptionally wet and dry phases. This period includes two noticeable dry phases centered on 5.3 and 4.2 ka BP, both of which are referred to by Weiss (2000) and Issar (2003) as having consequences on settlement throughout the Near East. Stages 3 and 4 correspond to the dry and more stable climate that characterizes the late Holocene.

The events involving the cycle of aggradation, stability, colluviation, and incision in the streams studied here occur during stages 1 and 2 (Fig. 11). The aggradation phase occurs at the end of stage 1 and beginning of stage 2. Floodplain stability may have occurred after levels of moisture reached a maximum around 5.5 ka BP and lasted relatively high for about one millennium. The high moisture levels may have contributed to raise water tables and create wetlands along the floodplains; hence, creating fertile soils and available moisture. The middle and late part of stage 1 is characterized by high precipitation with low variability (Fig. 11). This may have implied a more uniform flood regime, as opposed to the flashy floods typical of dry climates that resulted from high precipitation variability during the middle of stage 2.

Precipitation amounts fluctuated dramatically after 4.5 ka and becoming lower towards the end of stage 2. Alternating dry and wet periods, which lasted for periods of two to three centuries, may have had effects on destabilizing slopes, consequently favoring colluviation.

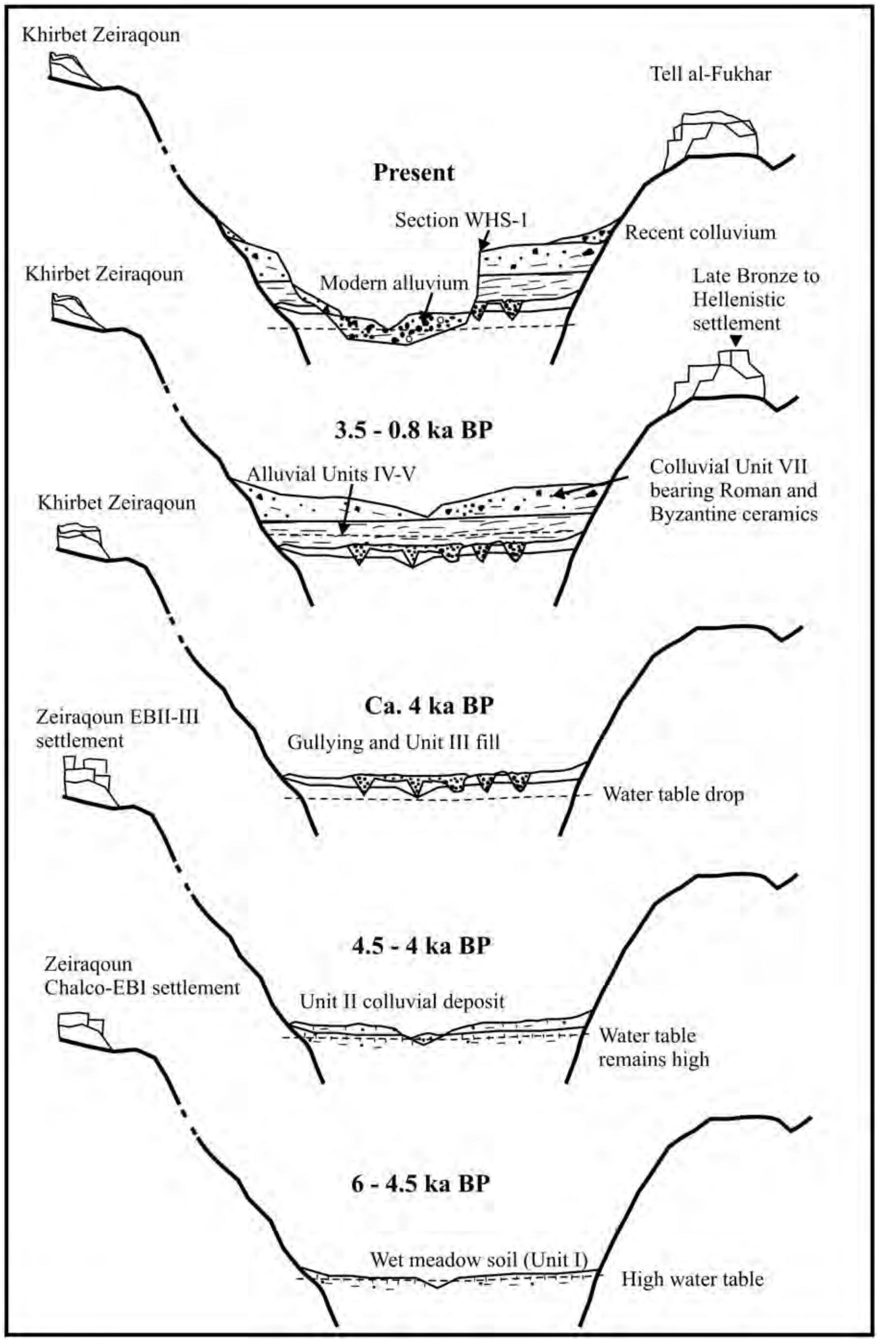

Fig. 8. Reconstruction of Holocene cut-fill events in Wadi ash-Shallalah.

The incision phase of the cycle occurred as precipitation becomes more variable and decrease in average. The effects of such a combination of wet and dry phases led to channel and floodplain destabilization. If a drying trend occurred, then reduced effective moisture and increased rain variability could have caused the water table to drop and more sparse flash floods. Modern analogs observed in dry areas of Jordan suggest that a dry climate is characterized by very low water table and flash-flood regime. A similar scenario can be seen in the more recent analog of arroyo cutting in the American Southwest, where between wet–dry cycles linked to El Niño and non-El Niño conditions have been identified as one of the main climatic factors that impacted stream regime and biotic conditions leading to stream incision (Waters and Haynes, 2001). In the case of the Levant, wet and dry cycles are controlled by fluctuations in cyclone development patterns over the Mediterranean Sea (Bar-Matthews et al., 1998), which in turn are controlled by changes in sea surface temperatures in the North Atlantic, fluctuation in intensity and paths of the Westerlies, and by latitudinal movements of the ITCZ and the Indian Monsoon (Wigley and Farmer, 1982; Roberts and Wright, 1993).

Fluctuations of the level of the Dead Sea have also been associated with climatic change. One of the most comprehensive records of lake level change was obtained by Frumkin et al. (1994) from lake level marks in salt caves in the Mount Sedom area on the southwestern shore of the Dead Sea (Fig. 11). The curve of lake level change shows a rapid descent of the lake between 4.5 and 4 ka BP. This correlates with the overall decrease in precipitation during this time. In view of these changes, Donahue et al. (1997) associated incision in the wadis of the southwestern Dead Sea plain with this drop in base level. The streams studied by Donahue et al. (1997), however, were directly emptying water into the Dead Sea. Wadi al-Wala is a tributary of a major stream

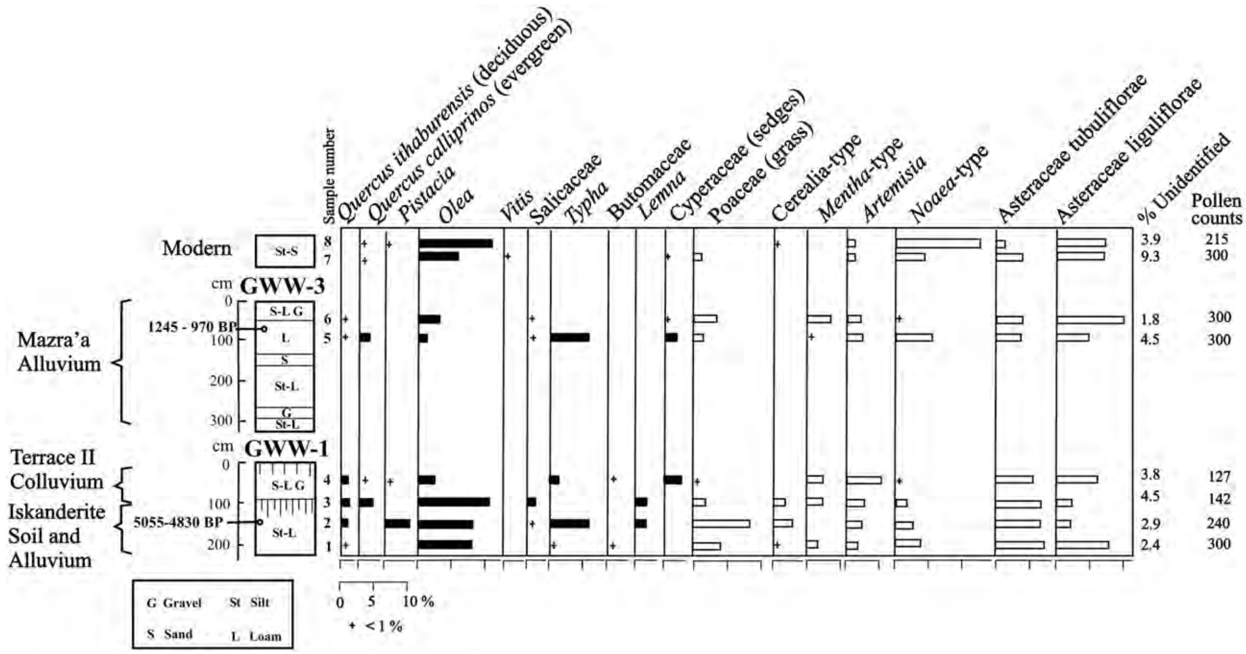

Fig. 9. Pollen assemblages obtained from deposits and soils in sections GWW-1 and GWW-3 (Wadi al-Wala).

(Wadi al-Mujib) that empties in the Dead Sea. Wadi al-Wala is so far upstream from the Dead Sea, however, that a headward migration of a knickpoint caused by base level change would have not easily reached the section studied here, particularly because several knickpoints on bedrock that already exist. Therefore, the lake level drop in the Dead Sea can only be used as a proxy for regional drying conditions.

5.3. Cultural implications

The increasing agricultural intensification experienced by the Levant at the end of the Chalcolithic period and through EBI-III phases is apparent in the local and regional pollen diagrams, particularly by the reduction of native tree cover (e.g. oak and pistachio), and the increase of pollen of some cultivated plants and associated ruderals. A conspicuous peak in *Olea* pollen appears in the records of Birkat Ram, Lake Kinneret, and Hula Lake for the Chalcolithic and Early Bronze (Fig. 11). Macrobotanical remains from various sites in the region testify to large harvests of olive, cereals, grapes and other agricultural products during this period, most of which were for export (Fall et al., 1998; Philip, 2001).

Part of the clue to land use changes before incision comes from the colluvial deposits laid before incision. The colluvial accumulation in Wadi al-Wala, i.e., Terrace II colluvium, may have been the result of either intensification of rain-fed farming and grazing on high slopes, or the destruction of abandoned terraces on slopes. Remains of terraces are found on the slopes surrounding Khirbet Iskander. Although very few diagnostic Chalcolithic and EB materials are found in them, it is possible that if not the original ones, these terraces were in more recent periods rebuilt on the basis of Early Bronze ones.

Mabry, (1992) attributes some of the alluvial changes to land use and settlement changes, considering that climatic factors played also

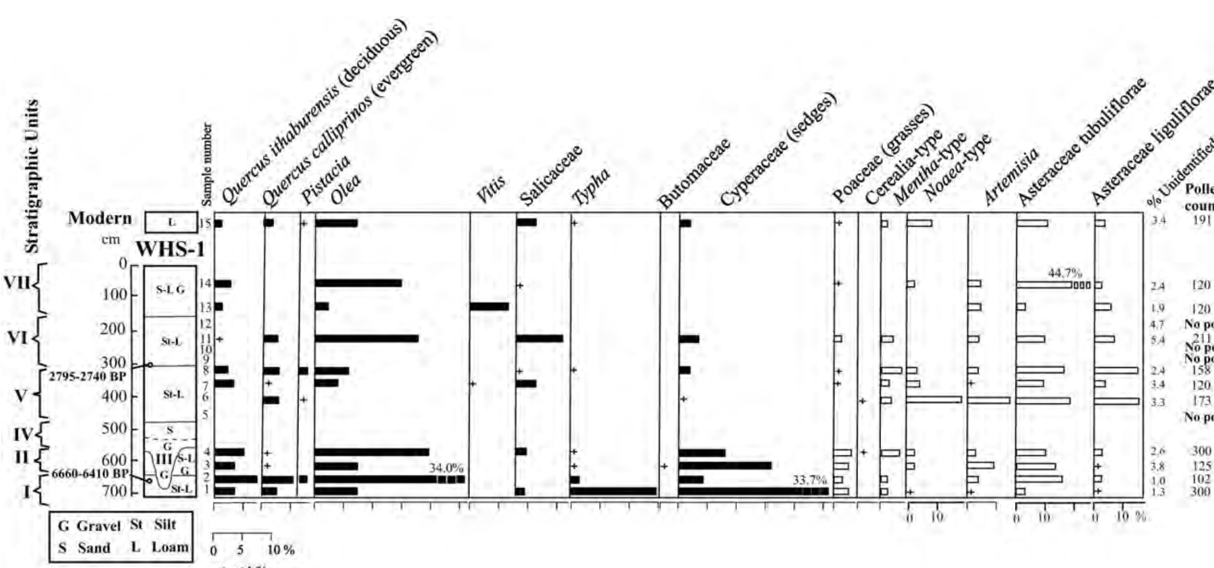

Fig. 10. Pollen assemblages obtained from deposits and soils in section WHS-1 in Wadi ash-Shallalah.

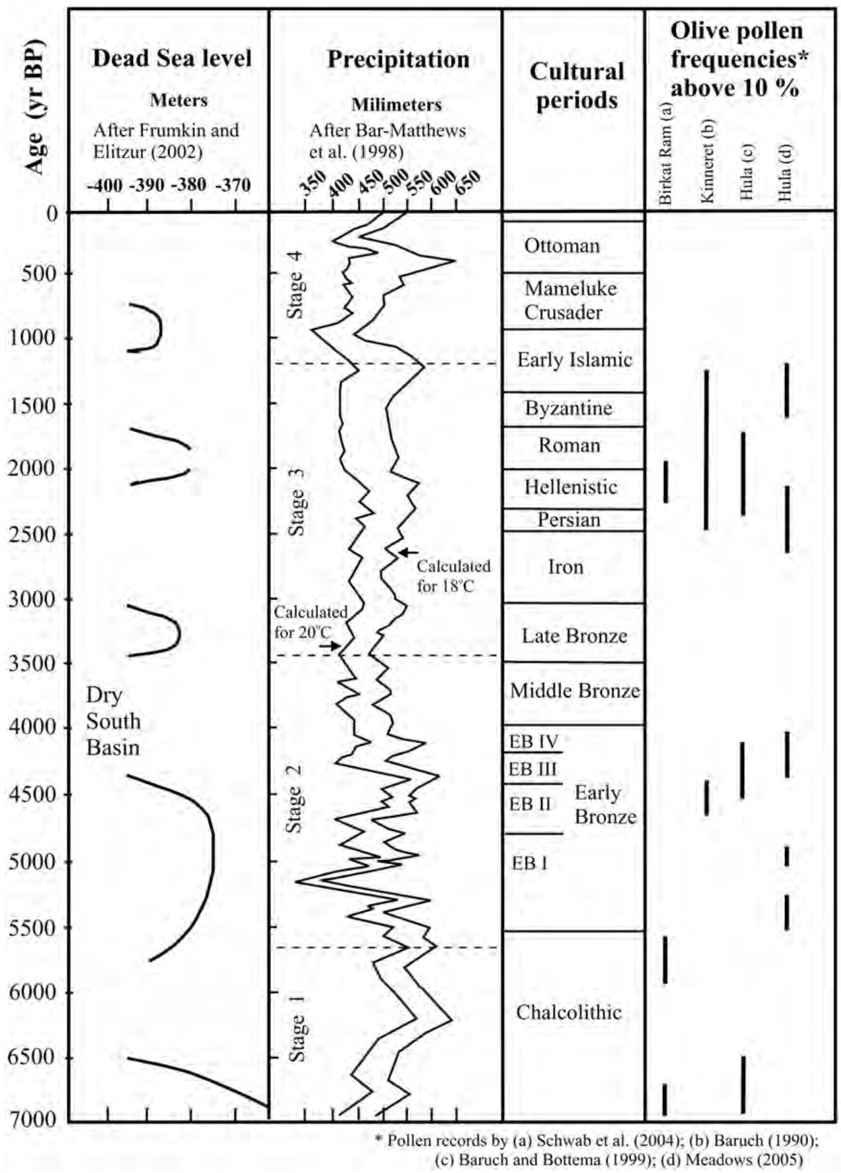

Fig. 11. Middle-to-Late Holocene Dead Sea levels, paleorainfall, and peaks of olive pollen in regional palynological records.

an important role in such changes. Wilkinson (1997, 1998, 1999) interprets settlement decline, climate deterioration, and stream degradation as related events. Perhaps these two regional examples suggest that the degradation of the floodplains in Wadi al-Wala and Wadi ash-Shallalah is related to land use changes and climate deterioration.

5.4. Geomorphic reasons for aggradation and stream incision

The Middle Holocene fluvial aggradation and incision events reported for wadis throughout the Levant seem to correspond to shifts in precipitation (Fig. 10). Nonetheless, increasing grazing and farming prompted by population growth, a characteristic of the Chalcolithic and EBI, may have also eroded upland soils, which contributed to the stream deposition implied by Mabry, (1992) in wadis of the Jordan Valley.

The causes of Middle Holocene stream incision in the Levant are also difficult to pinpoint because of the combination of climatic, tectonic, and human factors recorded by different geoarchaeological research. Although a decline in moisture is evident in the isotopic data of Soreq Cave and the lowering of Dead Sea levels around 4 ka (Fig. 10), other causes have to be taken into account. In particular the land use changes created by rapid growth and sudden decline could have caused changes on the catchments, which may have contributed to slope instability, as proposed by Wilkinson (1997).

A drop in the water table in the floodplains could have been caused by catchment management changes and water extraction. Therefore, although climatic change seems to have led to the incision event, land use changes may have exacerbated the processes of floodplain destruction by erosion, a statement that needs more investigation and more detailed dating in wadis across the region.

The long-studied case of arroyo entrenchment in the American Southwest during the 19th century shows that widespread incision of floodplains is derived from a number of combined causes, including changes in climate, vegetation and groundwater conditions, and in more recent centuries, human-induced changes (Waters and Haynes, 2001). Vegetation and groundwater changes, however, could also be the direct effect of human agency, as the case of entrenchment in the American Southwest Arroyos, particularly through the intensification of cattle grazing (Cooke and Reeves, 1976). Although the case of the Levantine Early Bronze Age lacks the amount of historical and meteorological data that the 19th–20th century Arroyo studies had in the American Southwest, it is presumed that grazing and intensification of farming played an important role in reducing the levels of the water table. Indirect data from archaeological contexts suggest an intensification of food production (Fall et al., 1998) and population growth (Philip, 2001) must have translated into more pressure on the land and water resources, which in turn had an impact on floodplain hydrology.

6. Conclusions

Wadi al-Wala and Wadi ash-Shallalah completed a cycle of stream aggradation, stability, and incision between 7 and 4 ka BP. The phase of stream aggradation occurred during a period of relatively high precipitation events concomitant with rapid growth of agriculture and settlement that culminated in the rise of urbanization. Aggradation formed floodplains that became wet and stable, an event that coincides with the height of economic prosperity of the Levantine Early Bronze Age. Pollen data from the floodplain soils of both Wadi Al-Wala and Wadi ash-Shallalah show high amounts of *Olea* pollen, indicative of intensive olive cultivation on surrounding slopes. Cereal cultivation in the floodplain, probably through irrigation, appears only in the pollen assemblages of the Wadi al-Wala floodplain. Subsequent colluvial accumulations on the floodplain soils suggest that slopes became unstable most likely because of precipitation variability and mismanagement.

Stream incision occurred sometime between around 4 ka BP or shortly afterwards, coinciding with the decline of urban settlement that marked the end of the Early Bronze Age. The degradation of floodplains after the stream incision event eliminated the possibility of flood irrigation in Wadi al-Wala and Wadi Shallalah. This may explain why a large number of EB settlements near the degraded floodplains were never reoccupied in subsequent periods, a phenomenon reported by numerous archaeologists for decades.

Climatic causes for stream incision in the wadis studied seem to be related to rainfall variability involving alternating dry and wet phases that ended in dry conditions between 4.3 and 4 ka BP. Dryness caused a drop in the water table and a flashy flood regime that led to erosion of floodplain sediments. The drop of Dead Sea levels, which contributed to incision in stream valleys in its close catchment area, could not have had impact on the incision in the streams of the plateau. The impact of human influences is not clear, but this research suggests that the rapid increase in agricultural development may have altered slope stability and resulted in an increase of colluvial materials on the floodplain.

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