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QUATERNARY TERRESTRIAL STRATIGRAPHIC CORRELATIONS BETWEEN THE LEVANT AND THE CIRCUM-NORTH ATLANTIC REGION: CURRENT KNOWLEDGE AND CONSTRAINTS

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Abstract

Quaternary paleoclimatic signals from the Levant have been frequently correlated with the most widely used stratigraphic divisions of high latitudes. In this article, relevant data, underlying concepts and new information are critically reviewed to highlight sources of uncertainty. Comparison between four sites from the Bekaa Valley demonstrate the problem of correlations and paleoenvironmental diversity of the region.

Key words: Stratigraphic correlation, paleoclimates, environmental inhomogeneity, Bekaa Valley

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INTRODUCTION

The Levant region is an active tectonic area astride the Levant Fracture system. Most of the geological features in this region are linked to the history of earth movements along different segments of the Dead Sea transform fault system, a major element in the eastern Mediterranean tectonical framework, that marks the northwest boundary of the Arabian plate (Beydoun 1999). The geological development of the region has produced structural landforms; most of them run parallel or sub-parallel to the north-northeast-south-southwest trend of the Dead Sea fault system (Fig. 1). Thus major physiographical features of the region are composed of anticlinal highs (*e.g.* the Judean Mountains, Mount Lebanon, Anti Lebanon, Jebel el Nusseiriyeh and Jebel el Zawiyeh) and structural basins (*e.g.* the Dead Sea, the Bekaa Valley, and the Ghab basin). The uplifted mountain belts are composed dominantly of carbonate rocks with minor clastics and few interspersed volcanic horizons. However, in the southern part of the Dead Sea transform, Precambrian igneous and metamorphic rocks are exposed in the Aqaba-Sinai region. In the low-lying basins, thick Quaternary (lacustrine and alluvial) deposits prevail. The current climate of the region is Mediterranean with moist mild-cold winters, dominated by the westerly atmospheric cyclonic depressions, and rainless warm summers affected by the northern dry Etesian-trade winds and the southwestern continental warm and dusty winds (Al-Khamsin) of north African origin. The mean annual precipitation varies considerably from around 1560 mm (Mount Lebanon) to less than 100 mm (the Negev Desert). The physiography of the region, particularly the north-northeast-south-southwest trending mountain belts, plays a noticeable role in shaping and modifying the regional climate.

The Levant region was the migratory corridor for *Hominids* in their dispersal from Africa to other parts of the world (Out-of-Africa) in two phases in the Quaternary (Tchernov 1998 cited in Hewitt 2000, Hewitt 2000, Goren-Inbar *et al.* 2000, Gibbons 2001). In the Holocene, the region witnessed the major revolutions in the history of mankind: technological changes, sedentism, commencement of food production, and social complexity that led to the appearance of the first western civilizations. Since human migration and cultural changes are climatically influenced, Quaternary research in this part of the world is of particular importance.

CORRELATION TRENDS

Historically, local literature in the Levant region reveals two major correlation trends between the scanty local geomorphological/depositional features and high latitude stratigraphical subdivisions. One school of thought believed in the synglacial-wet concept and the second one favored the synglacial arid scenario.

Synglacial-wet concept

The classical work of Lartet (1865) was the pioneering step that introduced the synglacial-wet concept in the Levant and beyond. Lartet advanced the view that high Dead Sea levels during the Late Pleistocene were connected to Mount Lebanon glaciers. We know now that evidence on glaciation

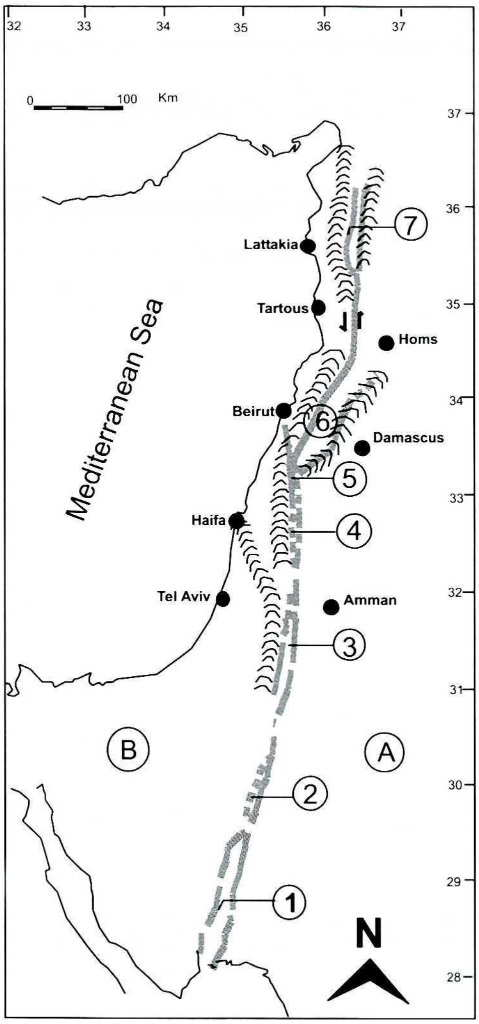

Fig. 1. Sketch map of the Levant region showing major structural lineaments (the Dead Sea fault system) and associated basins and mountain belts. 1 = Aqaba Gulf, 2 = Araba Valley, 3 = Dead Sea, 4 = Tiberia Lake, 5 = Hulla Valley, 6 = Bekaa Valley, and 7 = Ghab basin. A = Arabian plate, B = Sinai-Levant sub-plate.

of Mount Lebanon is still a controversial issue (see in historical sequence Diener 1886 cited by Butzer 1957, Klaer 1957, Messerli 1967, Kaiser 1963 and Suzuki, Fukuda 1971). Butzer's (1957) compilation of lacustrine, fluvial and geomorphological evidence available at the time, was based on the trend of correlating the Levant "pluvial" periods with Northern Hemisphere glaciations. In both cases the evidence was vague and highly descriptive.

Also Itzhaki (1961) based on a geological study on the coastal plain south of the Levant correlated the wet (pluvial) phases with Northern Hemisphere glacials. A somewhat similar conclusion was obtained from a study of the Dead Sea shoreline fluctuations during late Quaternary (Neev, Emery 1967). Vita-Finzi (1969) suggested that alluviation in the Mediterranean basin, including the Levant, had occurred at times of low sea levels (= glacials in northern latitudes) though he admitted the absence of an intimate link of what he called the "older fill" in Jordan and the post-Strombus regressive sea due to absence of unequivocal correlation between the Lisan Lake (the Pleistocene precursor of the Dead Sea, Begin *et al.* 1974) and the Mediterranean Sea. The incorporation of sedimentological evidence (gravelly fluvial/alluvial deposits) was used as a climatic proxy to indicate pluvial conditions beside the alternative view of relating these coarse clastics to the tectonic causative process of uplift and rejuvenation of erosion (see *e.g.* Lateef 1975, 1992). In a local, purely geomorphological study conducted in the Bekaa Valley (Lebanon), Besançon & Mahler (1966) correlated what they described as *surfaces d'aplanissement* (erosional surfaces) with major glacial phases in the Alpine scale. Ponikarov *et al.* (1967) in their comprehensive geological work in Syria distinguished four river terraces in both the Nahr el-Kebir Valley and the Al Furat (Euphrates) Valley. They correlated these alluvial terraces to four Mediterranean Sea beach terraces. Three of the four river terraces were assigned to pluvial phases and in turn correlated to the Mindel, Riss and Würm glacials. Later, Besançon (1981) correlated aggradational terraces in Lebanon and Syria with regressive sea phases, which imply correlations to northern hemisphere glacials, although he stated correctly, that it is unwise to use the Alpine and Northwest European time scales, and recommended the use of local time scales. In the last two studies, the chronology is based on archeological evidence, which is common practice in the Levant for the Late Pleistocene and Holocene. Reliance on archeological evidence to draw chronological basis for stratigraphical correlation is controversial and subject to potential error, as pointed out by Farrand (1994). In the south of the Levant Horowitz (1973a) used pollen spectra to support the synglacial-wet scenario when he correlated what he identified as pluvial inter-pluvial phases in the Hula basin with the glacial-interglacial phases of northern latitudes. Later, Horowitz (1989), based on palynological profiles derived from borehole samples, reconfirmed his earlier views. However, Farrand (1975, 1976, 1977) criticized Horowitz's interpretations and long-range correlations. On the correlation level which is relevant to our discussion, Farrand's criticism centered on the use of Alpine names for non-glacial deposits in areas far remote from the Alps, and the linkage of local sections to the Alpine framework. Issar (1979, 1980) also criticized Horowitz's approach on the grounds that sea-level fluctuations and hydrophilic flora, on which the correlations are based, could be interpreted in another way: the aquatic hydrophile species could be assigned to wet conditions not necessarily related to a pluvial phase (*e.g.* damming of river courses) and furthermore that sea level fluctuations in tectonically unstable coasts such as the eastern Mediterranean may not follow the eustatic theory. Further, Baruch & Bottema (1991) considered Horowitz's results to be of low stratigraphic resolution and doubtful chronology, and indicated that a revision of the original information led to quite different conclusions.

The reference pollen profiles in the Levant were all taken from lacustrine-marshy basins such as Lake Kinneret, Lake Hula and the Ghab depression. Because such subsiding basins are tectonically controlled their geological record does not necessarily reflect pluvial phases. For instance, the present Hor Al-Hammar basin in south Iraq, comprises an extensive marsh-lake environment formed by permanent flooding of both Euphrates and Tigris rivers. This vast lake, exceeding 15 m water depth in some areas, is attributed to tectonic subsidence (Lees, Falcon 1952). The deposits at the bottom of this lake-marsh comprise fine grained clastics rich in organic humus, irrespective of the current semi-arid climate in this part of Iraq and in juxtaposition to encroaching sand dune desert from both the north (Jezerat Sayed Ahmad el Refaee) and south (Tell el Lahm-Zubair). This modern example indicates that one should be cautious in interpreting ancient lacustrine-mire sediments in terms of paleoclimatic influences only.

Before considering the alternative scenario of synglacial aridity, two recent studies from the Dead Sea basin form suitable linkage. In his paleolimnological review, Stein (2001) concluded that while Lake Lisan (Late Pleistocene) shows correspondence between local high lake levels (wet periods) with Northern Hemisphere cold periods, the post-Lisan lake (the Dead Sea Lake) shows its lowest stand (dry period) during the Northern Hemisphere Younger Dryas. However, Bartov *et al.* (2002) suggest a more variable record of Lake Lisan levels in which numerous fluctuations of higher and lower stands have occurred during the period between ~55,000–15,000 BP with a dropping trend of the lake level after 23,000 BP with a maximum low stand of 300 m below msl at ~15,000 BP. Thus, during the LGM, Lisan Lake level decreased significantly and what was considered as contrasting features of the lacustrine record for the LGM and YD (Stein 2001) has been refuted.

Glacial-arid concept

Overviews of the Quaternary climate of the wider Mediterranean region and the Middle East were given by Hammen *et al.* (1965), Bonatti (1966), Wijmstra & Hammen (1974), Saranthein (1978), Yan & Petit-Maire (1994), Landman *et al.* (1996), and Lateef (1998). These authors suggest that the Pleniglacial was a period of general aridity. Further, the synthesis of many palynological results including those from archeological sites indicate, particularly for the last glacial maximum (the period between 24,000–14,000 BP), that most of the Near East region was dry (treeless) and cold (Watson 1991). High-resolution paleoclimatic records based on stable isotopes were reconstructed from a variety of sediments in the south of the Levant, particularly in the last decade (see review by Goodfriend 1999). Of particular importance are the long isotopic sequences gained from speleothems which enabled investigators to correlate the obtained paleoclimatic signals with isotope stratigraphies from deep-sea sediments and ice cores down to the scale of millennial instabilities. By virtue of their continuous deposition in warmer climatical settings, in variance with stalagmites from high latitudes which show long gaps during glacial phases, these stalagmites yielded relatively long climatic histories. In one such study a climatical record for a Pleistocene interval of 170,000 yrs was reported (Frumkin *et al.* 1999b). These stable isotope studies from speleothems (and to a lesser extent from travertines) indicated that phases of aridity are clustered particularly around the last glacial maximum and wetter periods are correlated to warmer (interstadial) phases of the last glacial period. This suggests temporal climatical variability (Magaritz 1986, Goodfriend, Magaritz 1988). Other paleoclimatic results from lake sediments and travertines from south of the Levant (Livnat, Kronfeld 1985) have shown cold phases in the northern latitudes to correspond to dry phases while warmer intervals are reflected by considerably wetter conditions. More recent evidence confirms that there are both dry and wet periods during the last glaciation, with dominant dry conditions culminating at 19, 25, 35 and 46 ka, whilst less pronounced pluvial conditions occurred around 36 and 54 ka. Thus dry conditions were dominant in the Levant during the last glacial period (Bar-Matthews *et al.* 1999, pers.comm.).

SOURCES OF UNCERTAINTY

There are numerous uncertainties in long-range stratigraphical correlations between the Levant and the circum-North Atlantic terrestrial stratigraphical schemes. Basically, these problems are related to the paucity of Quaternary geological information available in the Levant area in comparison to high latitudes. A major deficiency in the Quaternary geological information from the Levant region is also the lack of Quaternary geological maps for many parts of the area. Poverty in local and regional climatostratigraphic, lithostratigraphic, biostratigraphic and chronostratigraphic records from the Levant is another serious obstacle. The confusing state of the close association between chronostratigraphical and climate stratigraphical concepts in western data and also failure to recognize the local application of chronostratigraphical divisions in continental Quaternary sequences of high latitudes, has led in the Levant and the Near East to stratigraphical misconceptions among which is the use of high latitudes stage terminology for local phenomena.

INCONGRUENT PALEOCLIMATICAL RECORDS

Recent paleoclimatical results from speleothems, lacustrine and coastal sequences in local sites south of the Levant reflect the regional or eastern Mediterranean climate (*e.g.* Bar-Matthews *et al.* 1997, 1998, 1999, Gvirtzman, Wieder 2001, Stein 2001). However, the information available includes incongruent data sets.

For the wider area of the Middle East and North Africa, recent studies have indicated a mosaic-like climate pattern (*e.g.* Murzaeva *et al.* 1982), similar spatial incongruency is reported from the Near East and the Levant. For example the boundary that marks the first appearance of pistachio pollens in two lakes from Iran, Zeribar Lake (van Zeist, Bottema 1977) and Urmia Lake (Kelts, Shahrabi 1986) was found at two different time levels (10,900 BP in Zeribar and 9,000 BP in Urmia). Similar diachronism with Lake Van records was attributed to the diachronism of forest development in the region (Degens *et al.* 1984). In more recent regional palynological study for the Eastern Mediterranean-Near East (Bottema 1995), it was shown that pollen signals are non-uniform throughout the region and that climatic developments in Northern Turkey, Southern and Eastern Turkey, Northwestern Iran, Southern Levant and Northern Levant do not show a common trend for the late glacial and the first half of the Holocene.

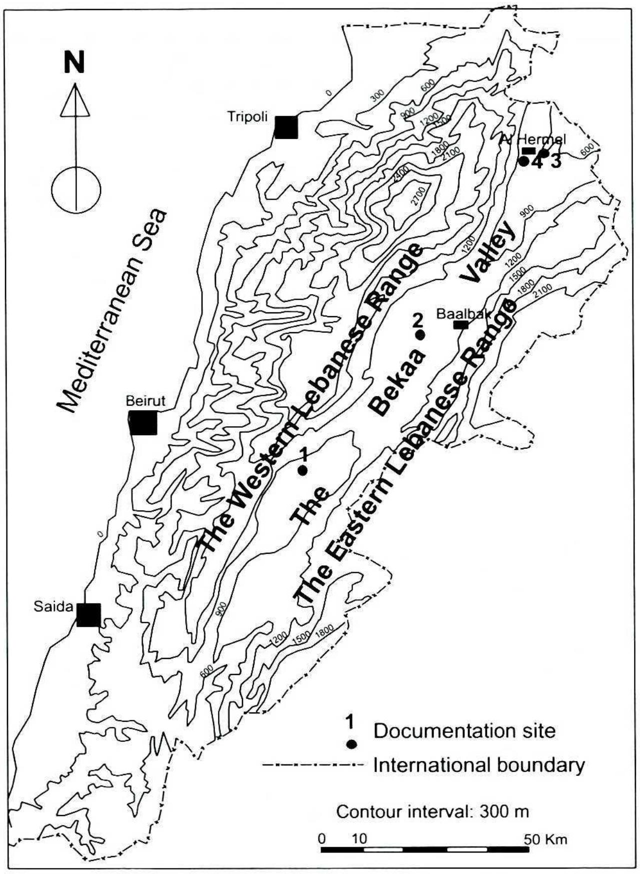

Fig. 2. The Bekaa Valley in the context of the topographical setting of Lebanon. The location of the four reported sections are: 1 = Bar Elias plain, 2 = Hosh Barada village, 3 = Jisr el Asi and 4 = Ras el Asi.

For instance, pollen evidence from two sites in the Levant, the Ghab depression in the north (Niklewski, van Zeist 1970, van Zeist, Woldring 1980) and the Hula basin in the south (Horowitz 1973a, 1989, Horowitz, Horowitz 1985, Baruch, Bottema 1991) with 300 km separation, revealed opposing climatic regimes during the Pleniglacial–Holocene times, with the Ghab region more humid during the Pleniglacial and extremely arid in the Late Glacial (Baruch, Bottema 1991). Bottema (1995) indicated also that while optimal conditions and deciduous oak forest developed in the south of Levant in the interval 14,000 to 11,500 BP, followed by much drier conditions, the Northern Levant, on the other hand, saw an increase in moisture at the beginning of the Holocene.

Such climatic variation is also evident in recent southwest-northeast and east-west transects through the Levant due to the local physiography (northeast trending mountains ranges). For instance, in north Lebanon three distinct climatic zones (coastal-subtropical, mountainous Alpine and inland semi-desert) are found in an east-west transect over a distance of 50 km. Facing the apparent lack of coherence in the climatic history in the Near East for the last glacial and the Holocene, Rossignol-Strick (1995) suspects that the discrepancies between the Zagros, Lake Van and the Levant records do not reflect diachronism but might result from imprecise ^{14}C data caused by contamination by older carbon. The last author also suggested that the conflicting interpretations should be made to fit the known marine-based oxygen isotope framework. Accordingly, Rossingol-Strick (1995) proposed that the major climatical changes in the region should be synchronous. The present author disagrees with this conclusion. It is suggested here that a better way to resolve the problem of incongruency between local climatic histories is to establish land-based independent chronologies.

APPARENT SPATIAL HETEROGENEITY: NEW INFORMATION FROM THE BEKAA VALLEY, LEBANON

A characteristic feature of the climate of the Bekaa Valley is the increasing aridity from the southwest to the northeast. This is reflected in the environmental conditions grading from marsh-wetlands in the southwest to semi-desert in the northeast. These environmental-climatic features are controlled to a large extent by the orographic effects of the western Lebanon range that increases in elevation and width from the southwest to the northeast. Locally, the hydrological aspect of the environment is amplified, by tectonical subsidence that created a flooded basin occupying the southwestern part of the Bekaa Valley.

The new geological information from the Bekaa Valley suggests that the present day climatic and environmental features have progressively developed in the basin through out the Quaternary Period and were closely associated with the progression of anticlinal upheavals and other structural phenomena resulted from the tectonic activity along the Dead Sea transform fault system (the Levant Fracture). These new geological data, which are briefly presented hereafter, are based on four sections-boreholes from the south Bekaa (Bar Elias plain) with ~ 650 mm rainfall, the middle Bekaa (Hosh Barada village) with ~400 mm rainfall and north Bekaa (Ras el Asi and Jisr el Asi sites) sites with 300–200 mm rainfall (Fig. 2).

Previous geological information from the south-middle Bekaa basin indicates lacustrine conditions for middle-upper Miocene represented by the Zahla Formation (Dubertret 1955, Malez, Forsten 1989, and Walley, unpublished). The new tentative data from the south Bekaa basin indicate definite watery conditions for the Holocene and late Pleistocene and possibly the older times. Samples from a borehole (65-m) in the Bar Elias-el Marj plain (site 1, Fig. 2) show an almost homogeneous sequence of organic-rich clay. Geophysical data from the same area (GEOFISICA 1966 cited in Besançon, Hours 1971) suggest 650 m of low resistivity (<40 ohm*meter) sediments with the upper 200 m of even lower resistivity (<20 ohm*meter). This suggests that the organic-rich clay profile may extend at least to a depth of 200 m. Although no absolute age is available from this sequence, considerations of the geological setting, thickness of the profile, type of sediment, and inferred sediment influx in this mire-lacustrine basin suggests that the 200 m profile covers at least the Holocene and upper Pleistocene.

The continuous presence of standing water bodies in the southern Bekaa Valley basin for this long time span has been strongly influenced by tectonics that converted this part of

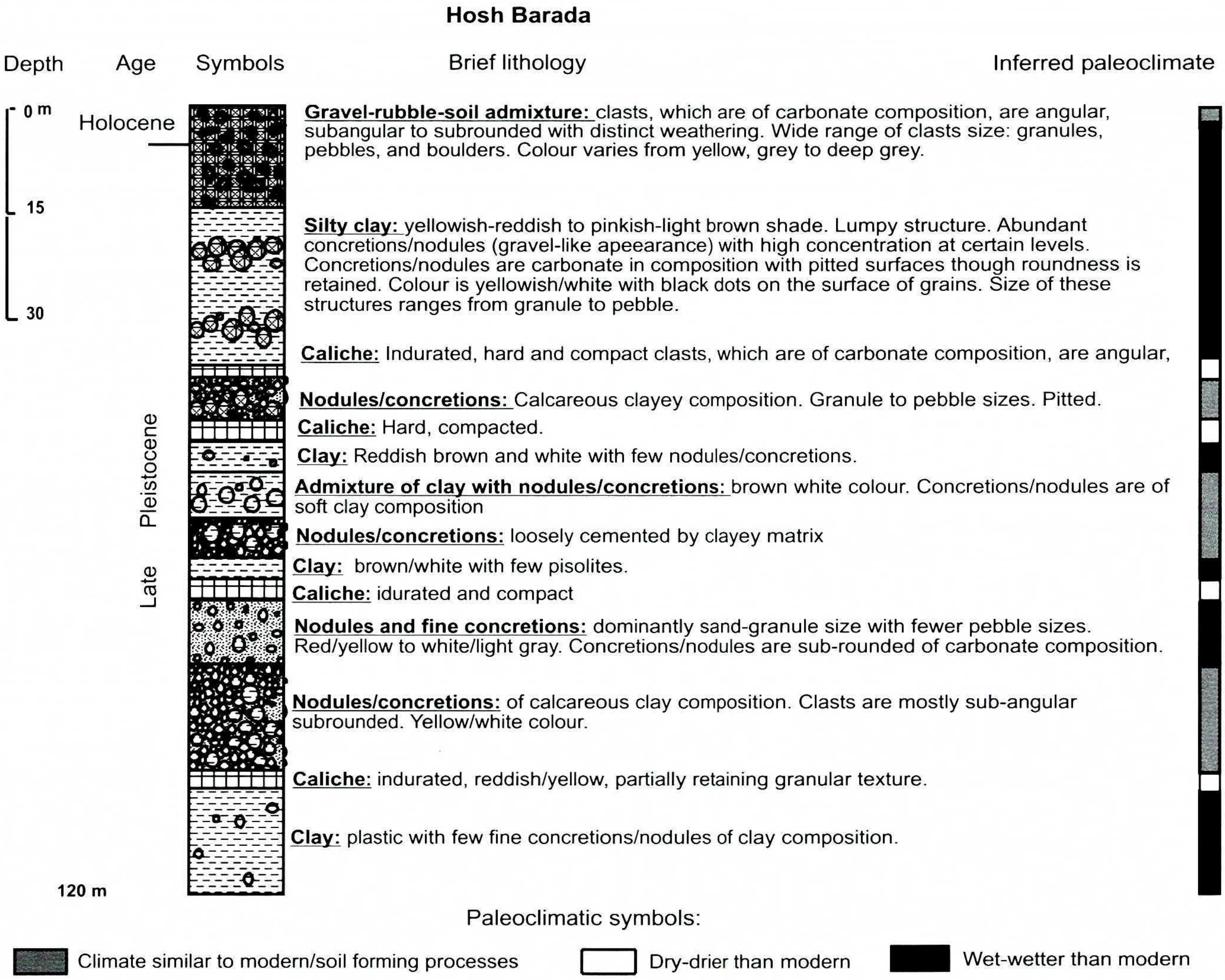

Fig. 3. Borehole log from Hosh Barada (site 2 of Fig. 2). The paleoclimatic interpretation is based on sediment types and inferred soil-forming processes. These reflect a succession of temporally variable phases of wetter than modern, similar to modern, and drier than modern paleoclimates for the Holocene and Late Pleistocene. The gravelly sequence of the topmost 15 m of the section was deposited in the Pleniglacial/Late Glacial and in the wet phase of the early Holocene. Pedogenic mature calcrete soil profile tops the section (not shown) and corresponds to modern drier conditions (relative to the spot of documentation) that characterises the second half of the Holocene. This topmost calcrete soil indicates also the cessation of clastic deposition in this part of the Bekaa Valley for the late Holocene. The indicated Holocene age for the uppermost part of the profile is based on archeological evidence (Besançon and Hours 1970-71, Besançon 1981) from a nearby pit in the Saaida Village that puts the Upper Paleolithic (and hence the terminal phase of the upper Pleistocene) at 3.0 m depth. Even by appreciating the low reliability of such an archeological age for fine-tuned stratigraphical purposes, the broad overall stratigraphical designation (on epoch level) of the section is correct. By considering the nature of sediments (fine clastics), inferred depositional environments, and the presence of numerous pedogenic horizons, the section may pass into the Middle Pleistocene in the lower part.

the Bekaa Valley, where the thickest Quaternary fill occurs, into a swampy area flooded by the Litani River system.

In the middle Bekaa (site 2, Fig. 2), a borehole of 120 m depth in the vicinity of Hosh Barada village reveals a succession of wet, dry and similar to modern climatical phases for the late Pleistocene–Holocene period. In the wet intervals (slightly wetter than modern climate in the same locality with average annual rainfall >450 mm) shallow lacustrine-pond environments and clay sedimentation occurred. In the dry (semi-arid) phases, caliche/duricrust developed (rainfall <400–500 mm). In conditions similar to today (annual rainfall 400–450 mm) pedogenesis and soil formation occurred. Thickness of the profile and composition of depositional-pedological horizons as well as extrapolation of provisional, rather precarious, archeological dates from a nearby pit of 10 m depth (Besançon, Hours 1970, Besançon 1981) permit to assign a Late Pleistocene–Holocene age to the Hosh Barada borehole sequence. These aspects and other details are shown in Fig. 3.

In the north Bekaa, geological evidence is gained from an exposed section next to the Al-Asi River Bridge (Jisr el Asi) some 15 km east-southeast of Al-Hermel town (site 3, Fig. 2). The section, which is part of a monocline flexure, shown by very hard compacted oncolite mudstone-grain-

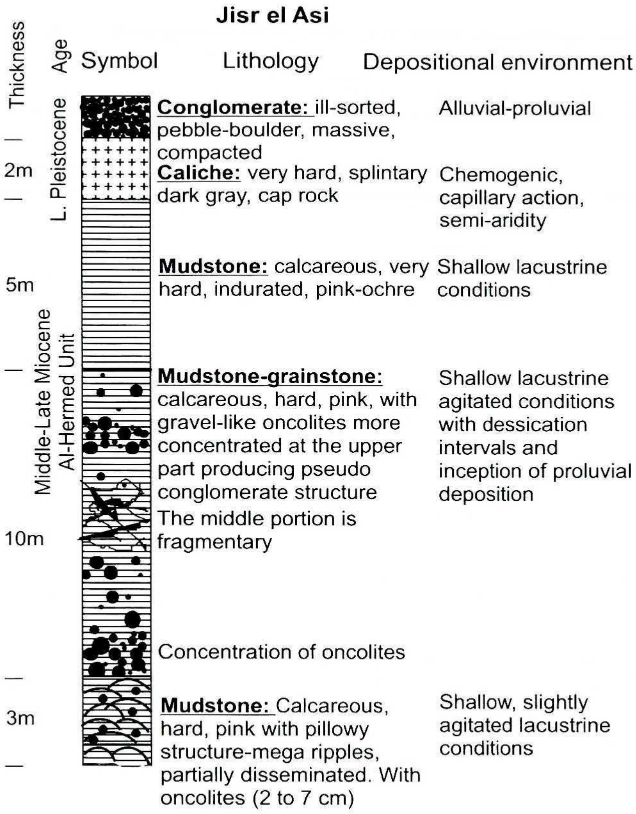

Fig. 4. Graphic representation of the Middle Miocene–Upper Miocene lacustrine sequence (Al-Hermel Unit) at Jisr el Asi, east of the Al Asi River course (*ca.* 2.8 km east southeast of Al-Hermel town, northeast Bekaa Valley, site 3 of Fig. 2). The interpreted depositional environments are shown and are based on sediment types and sedimentological features of the sequence. In this described part of the section, the basalt, that yielded the absolute age for the unit (see text), isn't encountered but it is exposed more to the south-west of the measured section. Stratigraphically, this part of the unit is above the basalt. $^{230}Th/^{234}U$ dating of the caliche cap gave an age of 239.0 ka (+56/–36). This puts the sampled chemogenic horizon into the upper third of Middle Pleistocene. Note the absence of the Al-Asi Unit, which widens the stratigraphical gap at the top of the lacustrine sequence.

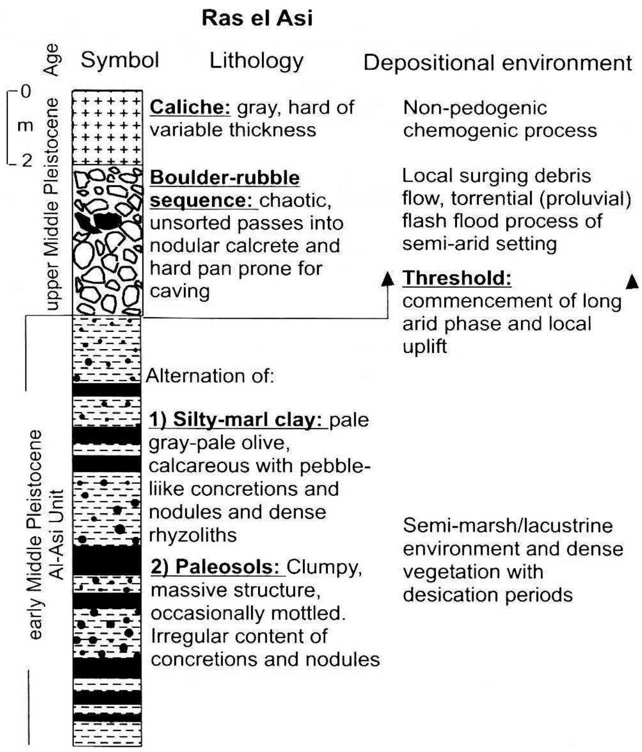

Fig. 5. The paludal sequence with interspersed paleosols at Ain al Zarqa locality (Ras el Asi section). The section is located 4.8 km south-southwest of Al-Hermel town, on the eastern bank of the Al-Asi River (the cliff above Ain Al-Zarqa spring, site 4, Fig. 2). The paleoenvironmental interpretation is based on sediment types, paleosols and fossil floral relics (rhizoliths and associated concretionary nodules). The paludal-paleosol section is topped by unsorted debris and thick caliche, both denoting semi-arid processes that continue to the present day. The age of the unit (early Middle Pleistocene) is inferred from the absolute age of the overlying caliche cap (see previous figure).

stone with intervening conglomerates and concordant emplaced basalt. Sedimentological evidence (oncolites) and the presence of vertical burrows (worm tubes-trace fossils) indicate shallow sub-aqueous palaeolacustrine conditions interrupted by sub-aerial conditions. $^{40}Ar/^{39}Ar$ dating of the enclosed basalt (10.77±0.24 Ma and 10.87±0.31 Ma) and paleomagnetic evidence (transition between 5n and 5r chrons on the expanded MPTS of Cande, Kent 1992) put the basalt at the base of the Upper Miocene. However, because the lacustrine sequence of Al-Hermel Unit extends below the dated basalt, we suggest a middle Miocene–late Miocene age for this paleolake that we call, here, Al-Hermel Lake-1. The determined age makes these newly identified lacustrine deposits from northeast Bekaa time-equivalent to the lacustrine Zahla Formation conditions of south-middle Bekaa. The Al-Hermel Unit section is shown in Fig. 4.

In another section from northeast Bekaa, at Ras el Asi (Ain el Zarqa), some 5 km south of Al-Hermel town (site 4, Fig. 2), a sequence of paludal silty clays and interspersed paleosols have been documented (Fig. 5). The thick silty clay sequence bears evidence (dense petrified stems or rhizoliths, Fig. 6) of deposition in a fertile freshwater lake in an area that is now a semi-desert. The whole sequence is termed the Al-Asi Unit. This unit overlies the Al-Hermel Unit with structural and stratigraphical unconformity. It is envisioned here that the Plio-Pleistocene tectonic phase of transgressive regime in Lebanon has caused folding, flexuring and faulting in north Bekaa that led to the creation of a daughter sub-basin. In this sub-basin, a semi-stagnant water body developed, called here Al Hermel Lake-2, interrupted by short periods of desiccation (drying-up). These semi-marshy conditions represent the last standing water body in north Bekaa. A caliche crust of variable thickness caps this sequence of Al Asi Unit. A $^{230}Th/^{234}U$ date obtained from this calcrete unit of 239.0 (+56/–36) ka puts the caliche formation in the late Middle Pleistocene. This date and the structural disposition (gentle tilt) of the sequence, permit us to estimate the age of the Al-Asi Unit as early Middle Pleistocene. The caliche cap is taken to indicate the establishment of complete semi-arid conditions in the north Bekaa Valley during the upper Middle Pleistocene and early Upper Pleistocene that continue to the

Fig. 6. Close-up view of the dense petrified "stems" or rhizoliths of inferred fresh-water reed vegetation. Note particularly the associated concretionary "nodules" which are interpreted as being formed around vegetation roots. The high density of rhizoliths suggests dense vegetation in what is now a semi-desert, providing evidence for the last standing water body in the north-east Bekaa Valley. Pencil for scale. The site is located at the road from Mar Maroun caves towards Ras el Asi village, some 400 m from the caves.

present day. No significant fluvial deposition took place since that threshold, and depositional processes were restricted to alluvial fan and debris flow deposition in proximity of the feet of the anticline flanks. This scenario emphasises the role of events/flash floods in the deposition of the gravelly sediments of the Bekaa Valley rather than the traditional view that considers massive gravelly sequences as indicators for wet (pluvial) periods. If the dating is correct, local uplift in the Ras el Asi area took place almost concurrently with the inception of the semi-arid conditions that converted the Al-Asi River into a landscape of denudation and caused the entrenching of both the Al Asi and the Al Hermel units.

From these four records from the south, middle and north Bekaa Valley, Lebanon, it can be concluded that paleoenvironmental-paleohydrological conditions in the middle-late Miocene times were almost homogeneous throughout the Bekaa Valley. Taking into consideration that this time interval represents the commencement of tectonic processes and orogenic movements along the Levant Fracture (although relief inversion has started earlier in the late Middle Eocene) it becomes apparent that the western Lebanon Range was in its infant stage then, with low scale relief. Paleoclimatically, this means that the western range exerted no noticeable orographical effects on the Bekaa Valley. Consequently, lacustrine conditions co-existed in different parts of the basin. This general paleoenvironmental-paleohydrological homogeneity in the Bekaa basin got increasingly heterogenous throughout the Pliocene, Early Pleistocene and early Middle Pleistocene. During this time interval, progressive formation of the orographical features of the western Lebanon range took place as a result of anticlinal upheavals during both the Late Miocene and the Plio-Pleistocene tectonic phases. The sequence of paleoclimatic/paleoenvironmental conditions in the Bekaa Valley is shown in Fig. 7.

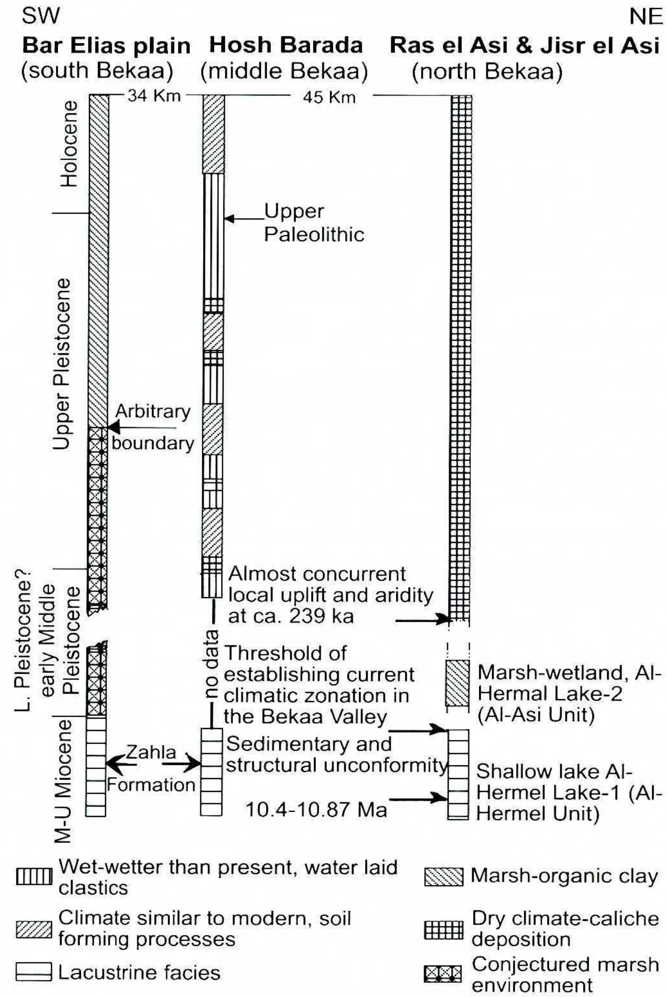

Fig. 7. Geological record of environmental and climatic variability in the Bekaa Valley. Changes of sediment type from boreholes (south and middle Bekaa) and surface sections (north Bekaa) illustrate the paleoenvironmental variability even for closely-spaced sites within one region. Paleosols, lithological, sedimentological and paleobotanical relics from lacustrine, mire (bogs) and fluvial/alluvial sediments are utilized to interpret the indicated paleoenvironments. The section from the southern basin is known in least detail and future subsurface logging is highly recommended for this part of the Bekaa depression. Note how spatial inhomogeneity (environmental variability) becomes pronounced in the Upper Pleistocene and Holocene. The observed variability is related to both local climate and non-climatic geological effects. Non-climatic effects (tectonic subsidence in the case of the southern basin) amplify even a weak climatic signal and have enhanced the continuation of a standing water body in the south basin to the present time. The absence of an independent chronology for the southern basin does not invalidate the indicated broad age designation (Holocene and Upper Pleistocene) of the section from the Bar Elias plain. Such a stratigraphical connotation is an approximation warranted by the general geological setting, scale and nature of the deposits. However, the indicated boundary between the Holocene and Pleistocene remains conjectural. The vertical scale of the sections reflects time spans and has no bearing on the true thickness of the deposits.

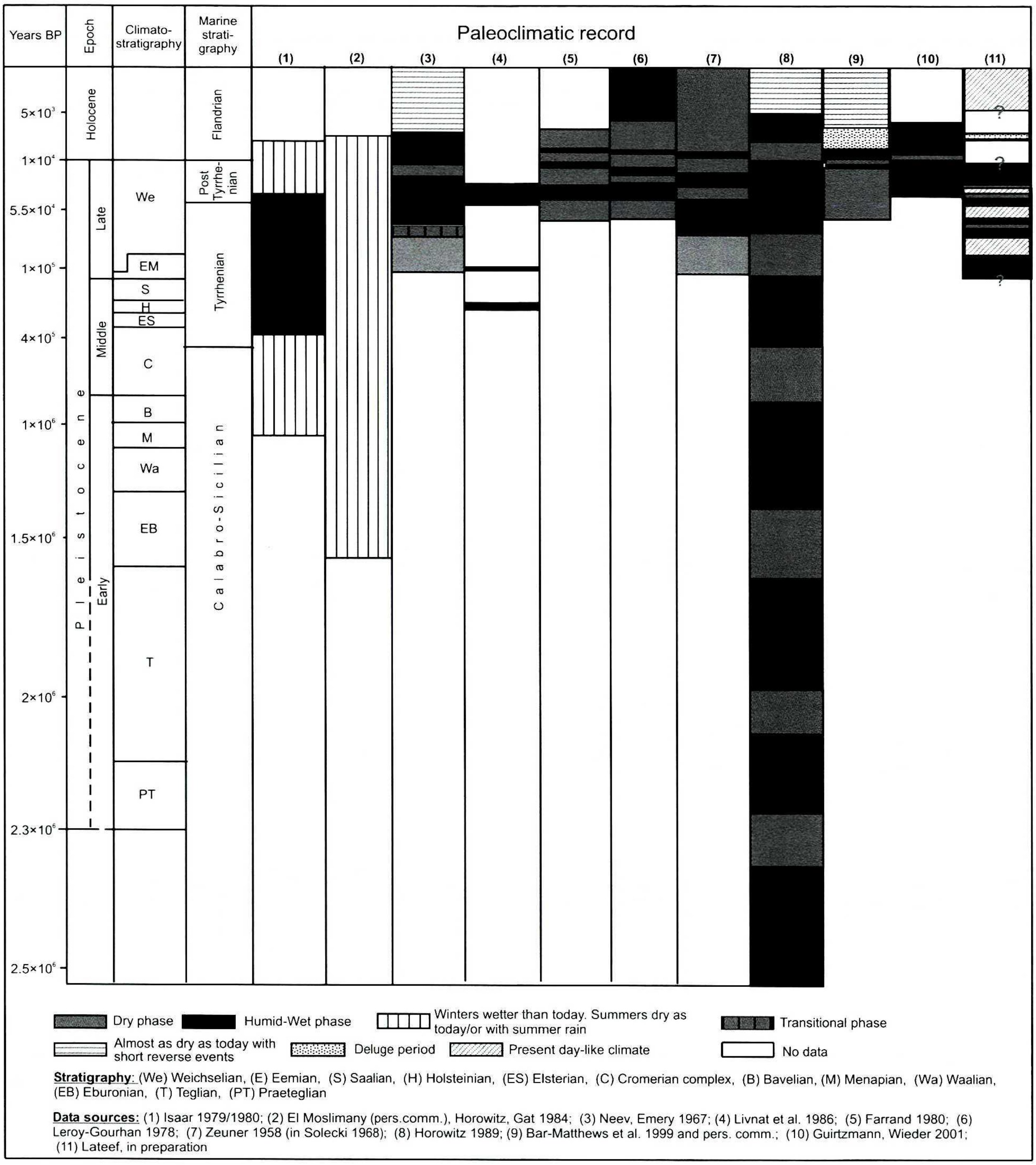

Fig. 8. Compilation of some available paleoclimatic data for the whole Quaternary Period in the Levant. Note the contrasting interpretations. The Northwest European scale was added to emphasise the problem of overregional correlation.

Spatial variability in continental climate record has been suggested for other non-glaciated regions in low and middle latitudes (Dawson 1994). To illustrate the incongruence of available data in the Levant region for both the Quaternary Period as a whole and for the Holocene we incorporate available data from various sources to produce two reconstructions, Fig. 8 and Fig. 9.

Incompatibility of the data from different sites in the Levant region can not only be attributed to incoherent regional climate histories. Other causes involved are insufficient chronologies, low resolution, variable sensitivity of the climate proxy used, and the fragmentary nature of the sedimentary record. Non-climatic factors can create or eliminate specific paleohydrological conditions and hence cause incongruence of paleoenvironmental conditions between closely spaced sites. We have already mentioned two such effects (tectonical subsidence creating wetlands in south Bekaa and local uplift causing shift of Al-Asi river regime from in-

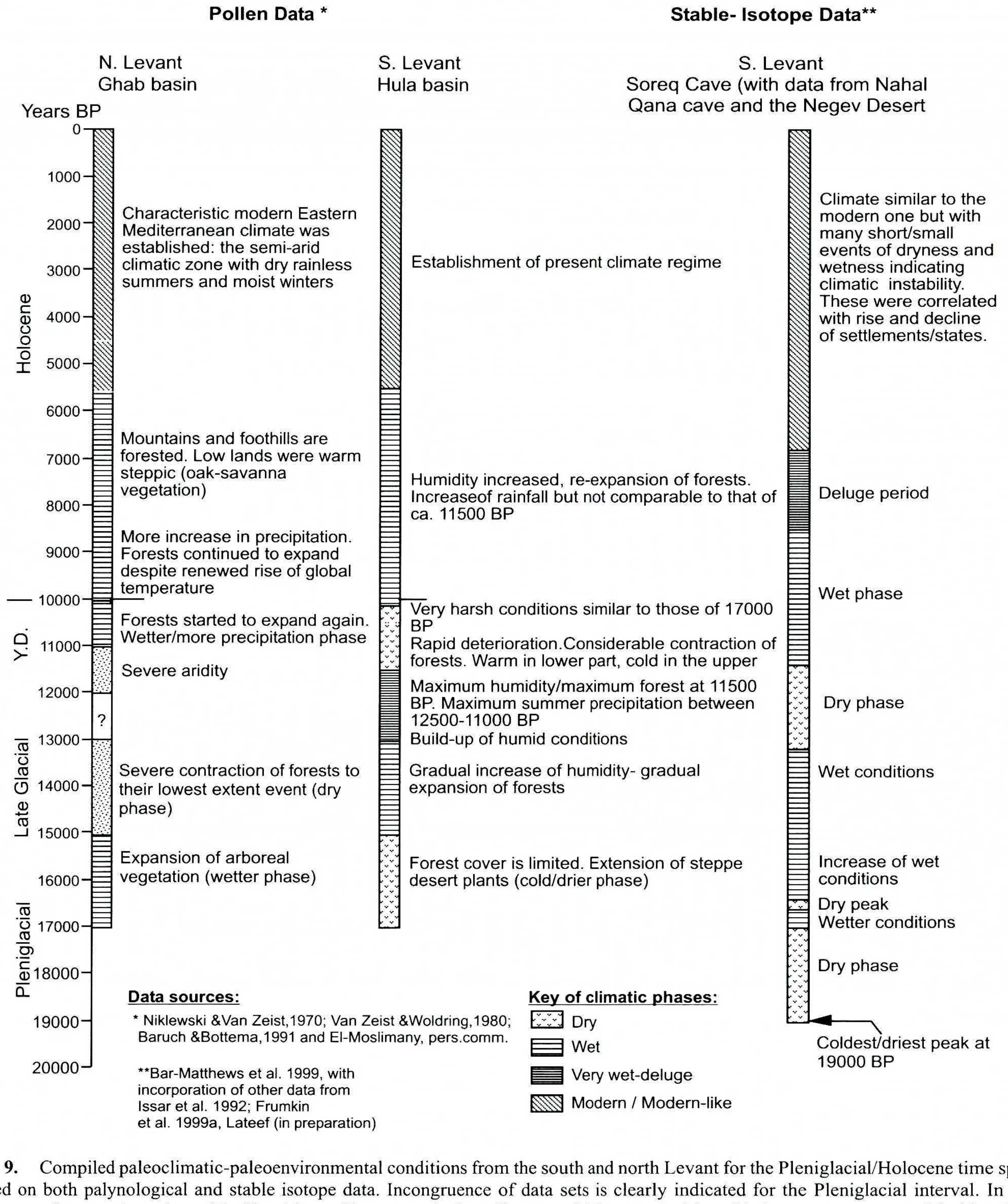

Fig. 9. Compiled paleoclimatic-paleoenvironmental conditions from the south and north Levant for the Pleniglacial/Holocene time span based on both palynological and stable isotope data. Incongruence of data sets is clearly indicated for the Pleniglacial interval. In the Holocene, the upper boundary of the Hypsithermal is younger in the pollen record (almost coincides with the commencement of the historical period) than suggested by the stable isotope data. The present author (Lateef, in preparation) identified a highly wet phase (stable isotope evidence) in the interval 7100–6690 BP ($\delta^{18}O$ values between –7.45 ‰ and –9.29 ‰) in a short lacustrine core from Al-Yemmona Lake, Lebanon. "Y.D." in the figure stands for Younger Dryas.

undating to denuding phase in north Bekaa). Other non-climatic factors leading to environmental changes include: 1) tectonic activity that tends to increase secondary porosity of rock bodies which lead in turn to enhancement of groundwater discharge 2) plugging of subterranean (karstic) ground water conduits as result of seismic activity or lava flows 3) plugging of groundwater outlets by mass wasting 4) damming of rivers by lava flows or the formation of local anticlines which is not unusual in active seismic regions such as the Levant. A typical example is Al-Yemmouna Lake, an inter-montane ephemeral lake on the eastern flank of Mount Lebanon. A detailed study of a short core taken from the lake bottom revealed two contrasting results: the lithological composition suggests low lake level in the time interval 6680–7090 BP while the stable isotope evidence indicates a very wet period (Lateef, in preparation). The discrepancy is caused by the paleohydrological effect of sinkholes at the lake bottom through which groundwater recharge occurred, lowering the lake level or even transforming the standing water body into an ephemeral lake in spite of the very wet conditions prevailing at the time.

Thus, various factors, climatical and non-climatical, may produce incongruent paleoenvironmental records at different sites in the region. Therefore a careful analysis of the local geological conditions is necessary before making regional climatic generalisations.

CONCLUSIONS AND PROSPECTS

Many problems have hampered our understanding of the Quaternary record of the Levant, and have produced, at times, incompatible interpretations and conflicting regional and extra-regional correlations. This review and the incorporated new data indicate that the status of current geological information does not provide a sufficient background to conduct reliable over-regional stratigraphical correlations between the Levant and the terrestrial stratigraphical schemes of higher latitudes. In this context we are able to state:

1. Quaternary deposits in many parts of the Levant region lack stratigraphical nomenclature and classification. Therefore, there is a need to establish local litho-, bio-, chrono- and climatostratigraphical frameworks. Provision of these local Quaternary stratigraphical sequences would provide the reliable basis to conduct stratigraphical correlations on any scale. We adhere at this stage to lithostratigraphical principles and land stratigraphical subdivisions and stages as the basis for correlation. The poor status of Quaternary stratigraphical information in most parts of the Levant makes it premature to adopt oxygen isotope stages as a universal correlation reference framework.

2. Non-global spread of some circum-North Atlantic triggering climate events, weak triggering climatic signals, presence of local/regional interactions of both climatic and non-climatic connections, low resolution, variable sensitivity of the climate proxies used and the incomplete nature of the sedimentary record, mean that not all sedimentary records based on northern latitude stratigraphical standards are necessarily reflected in the local sections of the Levant. Furthermore, Quaternary terrestrial chronostratigraphical units have local application. This strongly advocates against long-range correlations.

3. The incongruent available paleoclimate data sets in the Levant region do not provide a coherent regional record. To solve the problem of whether current discrepancies reflect real intra-regional spatial climate inhomogeneity or not, there is a need for:

a) establishment of multiple, well-dated climate stratigraphical sequences based on local lithostratigraphical, biostratigraphical and chronostratigraphical frameworks for a better evaluation of climate records and to establish proper temporal relations among various records, and

b) incorporation of analysis of local geological conditions of the various studied basins before attempting regional climatical generalisations or interpreting regional climatic trends.

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