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Tufa deposits in Bet She'an Valley - Stratigraphic analysis of the tufa plateau

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Abstract

An extensive thick sequence of tufa builds a sedimentary plateau, which extends in the Bet She'an Valley (BSV) between Nahal Harod in the north and the Sedé Trumot settlement in the south. 40 m of the sequence are exposed along the escarpment of the western marginal fault of the DSR, and additional 30 m where penetrated by drillholes.

Three stages of tufa deposition were identified: The first dominated by perched springline environments distinguished by thick autochthonous facies in the proximal zone, whit microdetrital tufa in the distal zone. The second stage presents a mixture of perched springline and braided fluviatile environments characterized by allochthonous facies. Chalk and marl containing abundant allochems were deposited during the third stage in a mixture of paludal and braided fluviatile environments.

The tufa sequence in the BSV was deposited in an amalgamated system of floodplains of east-flowing shallow waters springs, which drained to a lake situated in the Jordan Valley. This fluvial system was dominated by low energy environments that were interrupted by periods with more energetic floods. The accumulation of thick subhorizontal sequence can be attributed to a slow subsidence of the Valley or a gradual rise of the lake level.

1. Introduction

The Bet She'an Valley (BSV) is a triangular depression (Belitzky, 1996) located west of the Jordan Valley section of the Dead Sea Rift (DSR) (Garfunkel, 1981). The BSV is bounded in the west by the Mount Gilboa' block and in the east by escarpment of the western marginal fault of the DSR (Belitzky, 1996; Gardosh and Bruner, 1998; Zilberman et al., 2002, 2004). The marginal fault is expressed as a morphological step that separates the uplifted block of the BSV in the west from the down-faulted Jordan Valley (Zilberman et al., 2004).

The thick tufa sequence of the Bet She'an Unit (Rosenthal, 1980) cover an extensive area in the BSV and is mainly exposed along the escarpments of the western marginal fault of the DSR. U-Th ages suggest that most of the tufa sequence was deposited during the last glacial period (Zilberman, et al., 2003). Tufa is a cool water deposit of highly porous, spongy freshwater carbonate rich in microphytic and macrophytic growths, leaves and woody tissue (Pedley, 1990).

This study is part of a project, which aim is to examine the relationship between tufa deposits and tectonic activity in the Bet She'an Valley (BSV) during the Late Pleistocene. The present report presents a detailed description of two type sections of the tufa measured along the escarpment that forms the morphological boundary between the Bet She'an and the Jordan Valleys.. Based on this data the deposition environments of the tufa and the paleogeography Late Pleistocene fluvial system are reconstructed.

2. Geological Background

2.1 Geology of the Bet She'an Valley

The BSV is underlain by a Neogene-Quaternary continental sequence 500 to 900 m thick (Gardosh and Bruner, 1998). In this sequence Picard (1965) identified three major cycles of volcanic activity separated by alluvial sediments, which coincide with the sequences studied by Schulman (1962) and Shaliv et al. (1991). However, most of the Neogene sequence of the Tiberias Group (Picard, 1943) is not exposed in the study area (Hazor, 1991).

The Quaternary Dead Sea Group (Zak, 1967) in the BSV comprises the *Wadi Malih Conglomerate*, the *Lisan Formation* and younger sediments.
The early Pleistocene *Wadi Malih Conglomerate* (Schulman and Rosenthal, 1968), is a thick, coarse gravel fanglomerate, cemented by carbonate.
The late Pleistocene *Lisan Formation* (Lartet, 1869) is exposed in the Jordan Valley east of the BSV, where it unconformably overlies the Wadi Malih Conglomerate (Rosenthal, 1965). The bedded lacustrine Lisan sequence forms a flat, wide surface at an altitude of -240 m (Zilberman et al., 2004). The Lisan formation is overlain by fluvio-lacustine sediments of the "unnamed clastic unit" (Begin et al., 1974), termed by Horowitz (1979) as Faza'el Member of the Lisan Formation, and interpreted by Kronfeld et al. (1988) as a period of lake retreat.
Neev (1967) described a lacustrine sequence of silts and clays with melanopsis (freshwater gastropods), which overlies the Lisan Formation in the Jordan Valley. Horowitz (1979) estimated an age of 5 Kyr. for this unit, based on archaeological evidence and ^{14}C age of a melanopsis. Zilberman et al. (2004) observed in a trench near Tel Rehov that the Bet She'an Unit is overlain by colluvial sediments, which contain tufa litoclast.
The soil dominated the terrain of Mount Gilboa' is Terra Rosa, also are observed brown and pale Rendzina, (Dan and Koyumdjisky, 1963; Dan, 1988). Calcareous brown and calcareous serozems (that could be highly saline and gypsiferous in deep) and hydromorphic grey calcareous soils are widespread in the lower and central Jordan Valley while alluvial soils and solonchaks are found along the Jordan floodplain (Dan, 1988). The parental materials of these soils are chalk, marl lake sediments and travertine (Dan, 1988).

Schulman (1962) and Shaliv (1991) described three normal fault systems in the area: A NW and a secondary ENE oriented fault systems developed during the middle Miocene. A NNW to N-S fault system probably formed in the late Miocene in relation to a rapid subsidence along the DSR, and an N-S fault system that post-dated the eruption of the Cover Basalt.

Baer and Mimran (1993) suggested that post-Miocene block rotation could have been involved in the creation of the BSV. Belitzky (1996) proposed that the eastern side of the BSV was formed by N-S faults of the DSR. These faults were detected in seismic surveys by Gardosh and Bruner (1998) and Bruner et al. (2002), who found that the morphostructural step 20-40 m high, which separates Bet She'an from the Jordan Valley, marks the trace of the western marginal fault of the DSR. Paleoseismic analysis carried out by Zilberman et al. (2004) in a trench near Tel Rehov, found evidence for a long period of tectonic activity that postdated the tufa unit, and proposed that the fault escarpment was formed after the deposition of the tufa sequence.

2.2 Previous studies of the Bet She'an Tufa

The tufa sequence of Bet She'an Valley (BSV) was first described by Anderson (in Lynch, 1852), Blanckehorn (1907) and Blake (1936). Picard (1929) named the tufa "Kalksinter von Beisan" of Late Pleistocene-Holocene age. He divided it into two units: *Rabu*: a hard, coarse grained sinter limestone, rich in plants, and *Trab*: a "dusty" carbonate rock, and observed that the tufa is still precipitated today. He described the unit as a broad terrace that is located at -110 to -100 m.s.n.m.

Schulman (1962) described an erosive discontinuity between the tufa and the underlying Cover Basalt. Rosenthal (1980) named the tufa "Bet She'an unit", and estimated its thickness at a minimum of 80 m. Zilberman et al. (2004) described the tufa as an extensive sub-horizontal, thick, bedded sequence, which characterizes low energy braided fluviatile environments.

Kronfeld et al. (1988) obtained ages of 41 to 22 Kyr. for the upper part of the tufa deposits using ^{14}C and U-Th α spectrometry methods. They correlated the tufa with the Ami'az Member of the Lisan Formation, which represents high lake levels. They also studied the $\delta^{18}O$ and $\delta^{13}C$ of the tufa and suggested that it was precipitated from fresh groundwater without any significant evaporation. Horowitz (1979) allocated a Late Pleistocene age (18 to 11 Kyr.) to the tufa and correlated it with the Fatza'el Member. He suggested that the tufa deposition reflects significant spring activity due to a pluvial climate.

Zilberman et al. (2004) reported α spectroscopy U-Th tufa ages from both sides of the marginal fault of the DSR exposed in a trench near Tel Rehov; an age of 64 Kyr. for the upper block, and an age of 32 Kyr. for the lower block. They suggested that the tufa was deposited in equilibrium with a stable base level, probably a lake that coexisted with Lake Lisan and the source of water was a spring belt, which existed along the Gilboa' fault zone.

3. Materials and Methods

Mapping, field study and sampling of the tufa rocks from selected outcrops in the Bet She'an Valley. Geological mapping of the tufa units was performed using air photos of the British Authorities period (1945) and air photos taken in 1970, combined with field work. Two type sections (Fig. 4, 5, 6) were measured, described and sampled for dating and geochemical analysis.

The lithology of the tufa sequence in outcrops and drill-holes was studied using the classifications of Pedley (1990) and Ford and Pedley (1996).

4. Tufas Basics Concepts

Tufa is the product of calcium carbonate precipitation under cool water (near ambient temperature) regime and typically contains the remains of microphytes, macrophytes, invertebrates and bacteria (Ford and Pedley, 1996).

The present chapter follows mostly the concepts of Pedley (1990) and Ford and Pedley (1996). Table 1 summarizes the classification used in the area for tufa deposits.

4.1 Phytoherm tufa (Ford and Pedley, 1996): These are the autochthonous tufa.

4.1.1 ***Phytoherm boundstone*** (Pedley, 1990, after Buccino, et al., 1978). This facies of tufas is distinguished by its thick laminated crust formed by calcified cyanobacteria, they are manifested mostly as heads of stromatolites (Pedley, 1990; Riding, 2002). The phytoherm boundstones occur in shallow braided rivers, in the margins or in the substrates of channels carrying little bedload, in lake margins, and sometimes in gullies in a perched springline (Pedley, 1990; Ford and Pedley, 1996).

<table>
<tr><th colspan="2">ALLOCHTHONOUS</th><th>AUTOCHTONOUS</th></tr>
<tr><th colspan="2">CLASTIC TUFA DEPOSITS</th><th rowspan="2">PHYTOHERM TUFA</th></tr>
<tr><th>Micro detrital tufa</th><th>Macro detrital tufa</th></tr>
<tr><th>Matrix supported</th><th>Grain supported</th><td rowspan="5">a- Boundstone sheets of micrite and peloids (stromatolite).

b- Microherm shrubby framework of bacterial colonies.

c- Framestone true ‘reef’ framework of macrophytes coated with mixed micritic and sparry fringe cements.</td></tr>
<tr><td>Micrite tufa</td><td rowspan="2">Oncoidal and cyanolith tufa
Intraclast tufa</td></tr>
<tr><td>Peloidal tufa</td></tr>
<tr><td>Sapropelitic tufa
(organic rich)</td><td>Phytoclast tufa</td></tr>
<tr><td>Lithoclast tufa
(inorganic rich)</td><td>Lithoclast tufa</td></tr>
<tr><td>Lime Mudstone</td><td>Wackestone / Packstone Grainstone</td><td>Boundstone</td></tr>
</table>

Table1. Classification of tufa deposits(from Pedley(1990), and Ford and Pedley (1996))

4.1.2 ***Phytoherm framestone*** (Pedley, 1990, after Buccino, et al., 1978). This facies consists of encrusted macrophytes that produce $CaCO_3$ external crust by themselves and or with microphytes (Schneider et al., 1983). Phytoherm framestones are exposed as sets of vertical or recumbent cylinders of carbonate. This facies occurs in waterfalls as the dominant facies, in fluvial braided environment in the margins of the streams, and in a perched springline environment (slope system) precipitate closer to the springs, but frequently it develops downslope.

4.2 Clastic tufa deposits (Pedley, 1990). These are the allochthonous tufa deposits, divided by grain size to macrodetrital and microdetrital tufa (Ford and Pedley, 1996).

Macrodetrital tufa (Ford and Pedley, 1996).

4.2.1 ***Phytoclast tufa*** (Pedley, 1990 after Buccino et al., 1978). This tufa is composed of cylindrical clasts, consisting of phytoherms. They form a grain supported fabric with leaves and branch fragments, which were cemented during and or after transport (Pedley, 1990, Glover and Robertson, 2003). The phytoclast tufa is found in shallow braided rivers, where distributaries channels diverge, in a barrage system that is produced by destruction of the phytoherm framestones, in perched spring line environments they occur in distal deposits, also this facies is presented in waterfalls and in restricted paludal environments.

4.2.2 ***Cyanolith "oncoidal" tufa*** (Pedley, 1990). This facies is characterized by a grain supported fabric with a variable quantity of matrix, which formed by transport of phytoherm boundstones (Riding, 1983). Oncoid is the main allochem of this facies. An oncoid is a coated grain with a calcareous cortex of irregular partially overlapping laminae (Tucker, and Wright, 1990), comprising a granule to pebble clast with rounded to oval shape (Nickel, 1983). The shape of the oncoids is influenced by the morphology of the detrital nucleus and the energy of the environment (Nickel 1983; Riding 1983). Highly spheroidal forms dominate rivers whereas strongly oblate forms are typical of sluggish flow regimens, and free forms indicate static conditions (Pedley, 1990).

4.2.3 ***Intraclast tufa*** (Pedley, 1990). These are commonly reworked silt and sand size detrital tufa (Glover and Robertson ,2003) that resulted from the transport of tufa grain-supported fabrics in fluvial channels. They also are found accumulated around phytoherm framestones facies in static water bodies (Pedley, 1990).

Microdetrital tufa (Pedley, 1990; Ford and Pedley, 1996).
4.2.4 ***Micritic tufa*** (Pedley, 1990) is mostly composed of structureless micrite. In thin section it is possible to identify clotted texture (Pedley, 1990). This facies is present in lakes, ponds and marsh deposits (Pedley, 1990).

4.2.5 ***Peloidal tufa*** (Pedley, 1990). Only are detectable petrologically. Peloids often are grouped into polynucleated masses 10-70 µm in diameter (Pedley, 1990). Riding (2000) proposed that the peloids can originated by calcified bacterial aggregates.

5. Results

5.1 Stratigraphy of the Bet She'an valley tufas

5.1.1 ***Outcrops of tufas***: The tufa outcrops extend between the foothills of Mount Gilboa' and the Jordan Valley. The sequence of tufa is exposed along the 30-50 m high escarpment of the western marginal fault of the DSR, which separates between the Jordan and the BSV (Fig. 1).

The southern outcrop extends from Sedé Trumot to Tel Rehov and the northern outcrop spreads from the northern side of Kibbutz En' HaNaziv to the northern part of Bet She'an City. Both, the southern and the northern outcrops form a tufa plateau, which extends westward from the DSR western escarpment, where it is covered by alluvial soil. A 30 m thick, horizontally bedded sequence of the tufa is exposed in a quarry south of Tel Rehov settlement, and another 40-50 m thick sequence is exposed in a trench and a dry water reservoir, north of Kibbutz En' HaNaziv.

The tufa is also well exposed in the stream valley of Nahal Harod, where it can be traced eastward and westward from Bet She'an. Near Bet She'an City, the exposed tufa sequence is at least 40 m thick (its base is not exposed) but further to the east in Nahal Harod "Basalt Creek", a few meters thick tufa overlies directly a basalt unit, probably part of the Pliocene cover basalt, which is exposed further to the northwest in the Harod Valley.

There are two small outcrops of tufas along the creeks of En' Tzemed and En' Etan springs. Near others springs only alluvial chalk is observed. In some drill-holes closer to the springs, fragments of tufa can be found up to a depth of 80 m.

5.1.2 The tufa facies in the outcrops

5.1.2.1 Tufa facies in the southern outcrop

5.1.2.1.1 Tufa facies in the Quarry south of Tel Rehov (southern outcrop)

South of Tel Rehov the tufa plateau is bounded in the east by an escarpment 20-30 m high. A bedded tufa sequence 30 m thick, which is exposed in a quarry excavated in the escarpment east of Rehov settlement (coordinates 19750/ 20580), was studied (Fig.2). Five different tufa facies were identified in this outcrop: phytoherm framestone, phytoherm boundstone, phytoclast tufa, intraclast tufa and microdetrital tufa. The upper part of the sequence consists of chalk and marl facies covered by soil.

Three different vertical facies associations can be identified in the quarry.

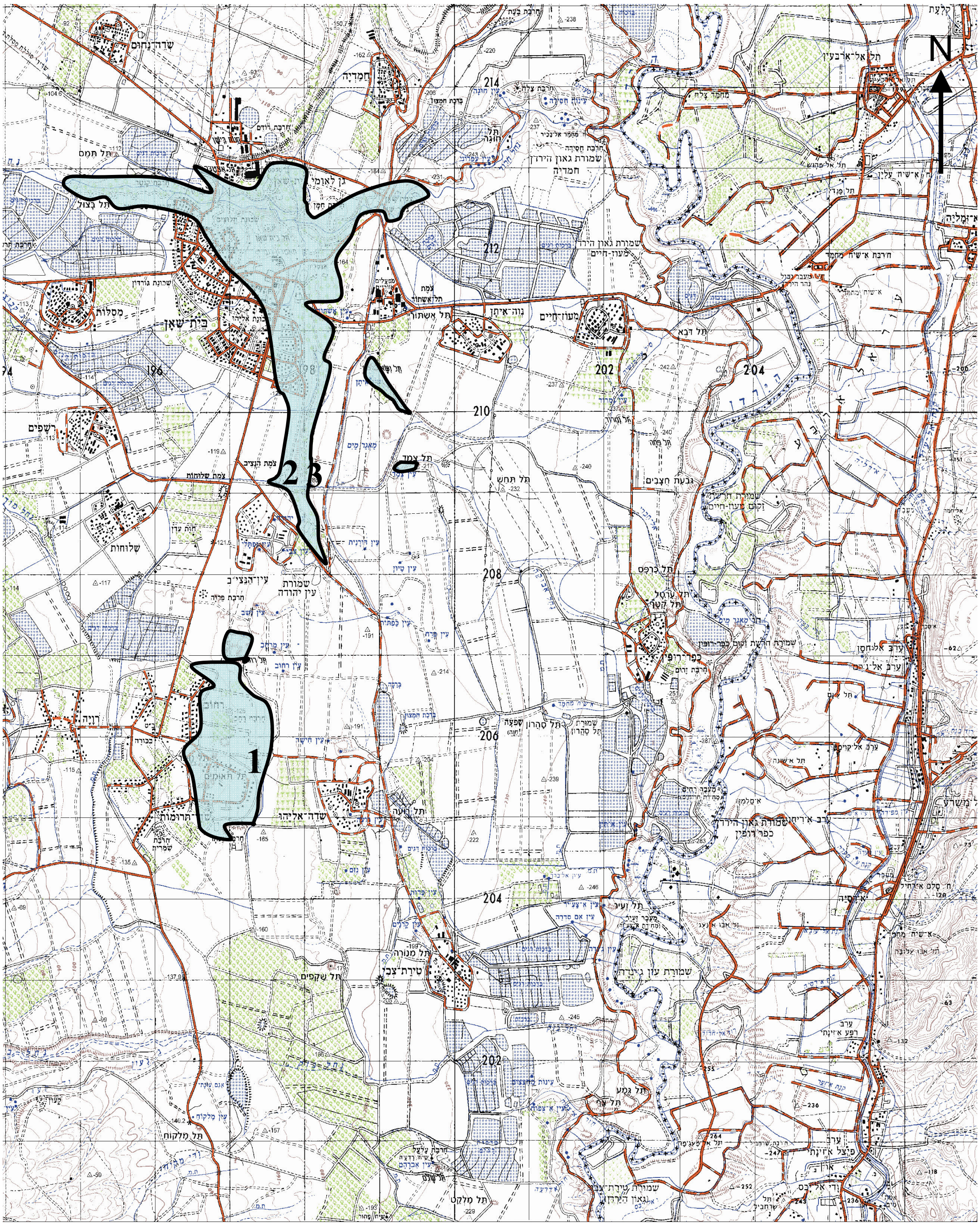


Fig.1. Preliminary map of tufa outcrops in the area of Bet She'an Valley (Based on the topographic map of Bet She'an 1:50,000, 1999).

Legend	Location of the profiles (columnar sections)
Tufa	1- Columnar Section N°1. 2- Columnar Section N°2. 3- Columnar Section N°3.

a) The lower 16 m of the section (Fig.2) consist mainly of subhorizonal intercalations of autochthonous facies of phytoherm framestones and boundstones. The sequence also contains phytoclast, intraclast and microdetrital tufa facies. All the layers can be traced along the entire exposure where they form tabular subhorizontal architectures.

The phytoherm boundstone (freshwater stromatolite) comprise layers of 0.50 to 2.00 m thick beds that show wavy and laminar structures.

The phytoherm framestone forms layers from 0.50 to 1.30 m thick consisting of encrusting phytoclast elements in a vertical or diagonal west-east oriented position; microfacies of phytoherm boundstone are intercalated with this facies (Fig. 7).

The phytoclast tufa facies is built of layers 0.30 to 1.00 m thick composed of encrusted phytoclast elements and others allochems.

The intraclast tufa facies forms layers 0.30 to 1.00 m thick, which present intraclast and oncoids encrusted tufa elements.

The microdetrital tufa was identified only in a 0.30 m thick subhorizontal layer.

b) The upper 14 m of the section consist of allochthonous phytoclast tufa facies that laterally and vertically passes to intraclast (Fig. 8) and microdetrital tufa facies.

The phytoclast tufa is the main facies in the upper part of the sequence, and it is composed of layers 0.30 to 3.00 m thick.

At the middle part of the section (between 14 and 21 m), the phytoclasts show west-east imbrication (Fig. 8) while the upper part (between 23-30 m) contains a continuous grain masses with broken phytoclast with no preferred orientation.

Most of the tufa consists of grain texture mass of preserved and broken phytoclasts ranging in size from fine sand to small pebbles, encrusted with fragments of stromatolites, intraclasts, and leaves (Fig. 9).

The intraclast tufa is built of layers 0.30 to 0.60 m thick. In the middle part of the section (between 14-21 m) it occasionally shows west-east imbricated (Fig.8) intraclasts, while in its upper part (between 23-30 m) it contains lenses of allochems with no preferred orientation. The facies contains intraclast of sand size, encrusted with others allochems.

The microdetrital tufa facies was identified in a 0.46 m thick layer; which forms lense-shaped bodies.

c) The top 3 m of the section (from 31 to 34 m) is integrated by chalk that passes laterally and vertically to marl. The chalk is 1.87 m thick and contains many phytoclasts from pebble to fine sand size, scattered randomally in the chalky matrix. The amount of phytoclasts decreases upward.
Shells of Melanopsis buccinoidea (Oliver) species are embedded in the chalk. The chalk facies has a gradual contact with the lower phytoclast tufa facies and it is covered by brown soil with columnar structure, which also contains melanopsis shells.

5.1.2.1.2 Interpretation of the profile of the Quarry south of Tel Rehov (southern outcrop)

The lower part of the sequence manifests subhorizonal architecture of mainly thick autochthonous facies (Fig.2). This kind of association is more accentuated in floodplains than in channels (Nickel, 1985). Phytoherm boundstones and framestone facies are deposited at relative low energy and could indicate groundwater seepages (Nickel, 1985).

The upper part of the southern tufa plateau is composed only of allochthonous facies which is characterized by imbricated allochems and grain masses of well preserved and broken allochems. The irregular limit between the facies suggests cut and fill structure of fluvial channels, indicating an increase in the fluvial energy in relations to the lower part. The imbricated allochems (Fig. 8) represent stream channels while the grain masses are reworked allochems transported and deposited by floods. The presence of microdetrital tufa could indicate low water table product of drier periods (Pedley, 1990).
The randomly oriented allochems and the shape of the layers indicate an increase in the hydrodynamic conditions form the base to the top of the upper part of the profile.

The top of the section shows a gradual change from phytoclast tufa facies to chalk and marl. The abundant quantity of marl and chalk is indicator of long periods of slow water flow. However, the abundant phytoclasts elements embedded within this unit reflect episodic floods which disturbed the channel network on the floodplain.

The melanopsis buccinoidea, which appears in the chalk and the marl live today in dwells of springs and streams in the Jordan Valley (e.g. Grossowicz et al., 2003; Bandel, 2000; Heller et al., 1999) and they might be introduced to the low-energy chalky sequence by the seasonal floods.

Apparently the source for the water that deposited the tufa in this area could be situated 2 km to the west where the Rehavia spring is located today.

5.1.2.2 Tufa facies in the northern outcrop.

The northern scarp is a high tufa plateau characterized by horizontal bedded surface. This section was studied in two outcrops: the lower part in a trench excavated in the base of the escarpment (cords. 19770/20920) and the upper part in the dry water reservoir (cords. 19780/ 20920). The middle part of the sequence is not exposed.

5.1.2.2.1 Tufa facies in the trench

The trench is (Figs. 4 and 5) excavated in the foot of the escarpment, east of the dry water reservoir, and exposes a 5.80 m thick tufa sequence. Three tufa facies, which are arranged in three vertical associations, were recognized in this exposure: microdetrital tufa, intraclast tufa and phytoclast tufa facies.

a) The lower 1.50 m is a tabular body of microdetrital tufa facies, which consists of a massive micrite that includes small patches (0.10 m thick) of phytoclast and intraclast tufa facies. The amount and size of the patches increase from the lower to the upper part of this section (Figs. 5 and 11). This unit is truncated and a flat erosion contact marks its top.

b) The middle part (2.00 m thick) is a tabular body of allochthonous facies compose of intraclast tufa facies intercalated with microdetrital and phytoclast tufa facies (Fig. 5).

The thickness of intraclast tufa facies ranges between 0.15 to 2 m (Figs. 4 and 5). The intraclast contains fragments of stromatolites from pebbles to cobble size (Fig. 11) and phytoclasts of sand to pebble size. Many intraclasts are coated by patina of black manganese and red iron oxides, which form subhorizontal staining.

The phytoclast tufa facies builds a layer and patches 0.30 to 0.70 m thick (Figs. 4 and 5).

The size of the phytoclasts range between fine sand and pebble, and they are encrusted with others allochems. The fragments of some units are coated by black manganese and red iron oxides, which show subhorizontal distribution.

The microdetrital tufa facies is a massive micrite, which builds a layer 0.50 to 0.07 m thick.

c) The upper part (1.80 m thick) consists of a sequence of curved layers, which show vertical intercalations of intraclast and microdetrital tufa facies and contains ellipsoidal lenses of phytoclast tufa facies (Figs. 5 and 10).

The intraclast tufa facies consists of 0.15 to 0.57 m thick layers and it thickness increases eastward. The intraclasts are generally from sand to pebble size but some stromatolite fragments from sand to cobble size, are also exist.

The microdetrital tufa facies consists of layers 0.15 to 0.35 m thick. Their thickness increases eastward (Fig. 5).

The phytoclast tufa facies form 0.30 m thick hard lenses, which are composed of grain mass of broken allochems of phytoclast of sand size (Fig. 10).

5.1.2.2.2 Interpretation of the profile of the trench

The facies and the architecture of the lower part of the trench indicate deposition in lacustrine and palustrine (Arenas et al., 2000) environments (Pedley, 1990). Paludal facies are laterally more extensive (particularly flood plain deposits) (Pedley, 1990; Buccino et al., 1978; Heimann and Sass, 1989).

The grain supported allochthonous facies (intraclast and phytoclast tufa) in the middle part reflects an increase in the fluvial energy of the tufa deposition in respect to the lower part of the profile (Figs. 4 and 5).

The upper part of the section was dominated by palustrine deposits of microdetrital tufas, although, the occurrence of lense- shaped bodies (of grainstone masses of phytoclast tufa facies) (Figs.5 and 10) probably indicates local energetic fluvial environments.

5.1.2.2.3 Tufa facies in the dry water reservoir

The dry water reservoir, north of En HaNaziv exposes 14 m of tufa sequence (Fig.3), which builds the upper part of the tufa plateau.

Five different tufa facies were identified in this outcrop: phytoherm framestone, phytoherm boundstone, phytoclast tufa, oncoidal cyanolith tufa and microdetrital tufa.

The section gradually changes from a vertical intercalation of autochthonous and allochthonous facies (0 to 5.50 m) to solely allochthonous facies (5.50 to 11.50 m). The upper part of the sequence consists of marl sediments covered by soil (11.50 to 13.30).

The phytoherm boundstone appears in a 2 m thick bed, which has encrusted phytoclast, oncoids and intraclast elements and laterally changes to phytoherm framestone facies (Fig. 6) (the lower phytoherm framestone layer of the profile of figure 3).

This facies is composed of wavy laminas of stromatolites arranged in subhorizontal bedding with irregular architectures of cut and fill structure.

The phytoherm framestone (Fig.3) is built of layers 0.30 to 1.70 m thick, which are located in the lower part of the section (0 to 5.50 m). The phytoherm framestone presents subhorizontal and irregular architectures probably resulted from cut and fill processes.

The phytoclast tufa facies is observed in all the exposure. It consists of 0.20 to 1.30 m thick layers, which contain mostly preserved and broken phytoclasts from fine to coarse sand size. This facies show subhorizonal grain masses, which can be traced laterally.

The cyanolith oncoidal tufa facies builds 0.20 to 0.40 m thick layers. The oncoids range in size from sand to pebble and exhibit ellipsoidal, and subrounded shapes. These facies exhibit sub-horizontal and irregular architectures.

The microdetrital tufa facies form 0.30 to 1.00 m thick subhorizontal layers.

The marl unit in the upper part of the sequence contains a lot of subrounded and ellipsoidal oncoids (up to 2 cm), pebble to sand size phytoclasts and fragments of stromatolite and melanopsis. This sequence has a lower gradual contact with the underlying phytoclast tufa facies and with the 0.30 m thick upper brown soil.

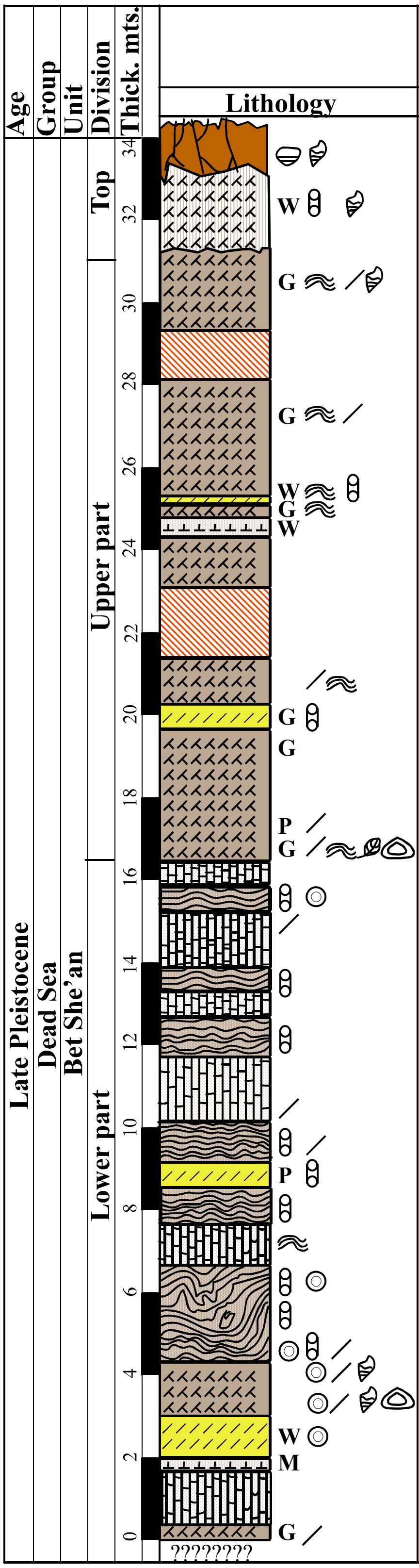
5.1.2.2.4 Interpretation of the profile of the dry water reservoir (upper part of the northern outcrop)

The architecture of the facies and the gradually upward transition from intercalation of autochthonous and allochthonous facies to dominantly allochthonous facies reflects hydrodynamic changes. For the lower part that correspond to interchannels (autochthonous facies) to channels (allochthonous facies) environments, to the upper part that characterized deposited produced by turbulent ephemeral streams that build floodplains composed of allochems. The tufa unit (Fig. 3) is distinguished by the presence of rounded to ellipsoidal cyanolith and broken phytoclasts encrusted with preserved phytoclasts, which were deposited in high hydrodynamic conditions (Pedley, 1990) and turbulent energy of deposition (Nickel, 1985).

The marl unit in the top of the sequence was deposited in a low-energy fluvial system, probably ponds. The high amounts of allochems, specially sub-rounded oncoids were transported to this area by floods, which interrupted the low-energy environments.

The source of the water was probably a series of springs located along the fault belt running along the foot of the Gilboa' (En Soqeq, En Hamal, En Muda) at 4 to 6 km west of the studied outcrop.

Location: South of Tel Rehov
Coords.: 19750/20580
Columnar Section N: 1 **Scale: 1:150**



Lithologic description

-Brown soil (1,50 m) . The soil has columnar structure in a vertiucal way and columnar in azarous way product of recycling of soil by agriculture activity in the lower 0.70 m.
-Chalk with tufa fragments. Wackstone, beige, soft, (1,87 m). Fossils of melanopsis.

-Phytoclast tufa. Grainstone, beige, medium, (1,90 m). Fossils of melanopsis.

-Talus. Compose of a beige, soft mass of tufa, (1,20 m).

-Phytoclat tufa. Grainstone, beige, hard, (2,85 m).

-Intraclast tufa. Wackstone, beige, hard, (0,15 m).
-Phytoclast tufa. Grainstone, beige, hard, (0,30 m).
-Microdetrital tufa. Wackstone, beige, massive, (0.46 m).

- Phytoclast tufa. Grainstone, beige, hard, (1,20 m).

-Talus. Compose of a beige, soft mass of tufa, (1.70 m).

- Phytoclast tufa. Grainstone, beige, hard, (0,60 m).

-Intraclast tufa. Grainstone, beige, soft, (0,60 m).
- Phytoclast tufa. Grainstone, beige, medium, (0,97 m).
-Phytoclast tufa. Packstone, beige, soft, (0,92 m).

-Phytoclast tufa. Packstone, beige, soft, (1,00 m).
-Phytoclast tufa. Grainstone, beige, soft, (0,30 m).
-Phytoherm framestone. Framestone, beige, soft, (0.56 m).
-Phytoherm boundstone. Bindstone, beige, very hard, (0,60 m).

-Phytoherm framestone. Framestone, beige, hard, (1,37 m).
-Phytoherm boundstone. Bindstone, beige, soft, ondulated, (0,57 m).
-Phytoherm framestone. Framestone, beige, hard, (0,62 m).
-Phytoherm boundstone. Bindstone, beige, soft, (0,96 m).

-Phytoherm framestone. Framestone, beige, hard, (0,57 m).
-Phytoherm framestone. Framestone, beige, soft, (1,00 m).

-Phytoherm boundstone. Bindstone, beige, soft, (0,97 m).
-Intraclast tufa. Packstone, beige, soft, granular, (0,65 m).
-Phytoherm boundstone. Bindstone, beige, soft, (0,90 m).
-Phytoherm framestone. Framestone, beige, soft, (1,00 m).
-Phytoherm boundstone. Bindstone, beige, hard, (0,70 m).
-Phytoherm boundstone. Bindstone, beige, soft, ondulated, (0,30 m).
-Phytoherm boundstone. Bindstone, beige, hard, (0,40 m
-Phytoherm boundstone. Bindstone, beige, hard, (0,30 m).
-Phytoherm boundstone. Bindstone, beige, soft, (0,65 m).
-Phytoclast tufa. Grainstone, beige, soft, granular, (0,30 m).
-Phytoclast tufa. Wackstone, beige, soft, granular, (1,00 m).
Fossils of gastropods.
-Intraclast tufa. Wackestone, beige, soft, granular, (1,00 m).
-Microdetrital tufa. Mudstone, beige, compacted, granular, (0,30 m).
-Phytoherm Framestone. Framestone, beige, hard, (1.30 m).
-Phytoclast tufa. Grainstone, beige, soft, granular, (0.30 m).

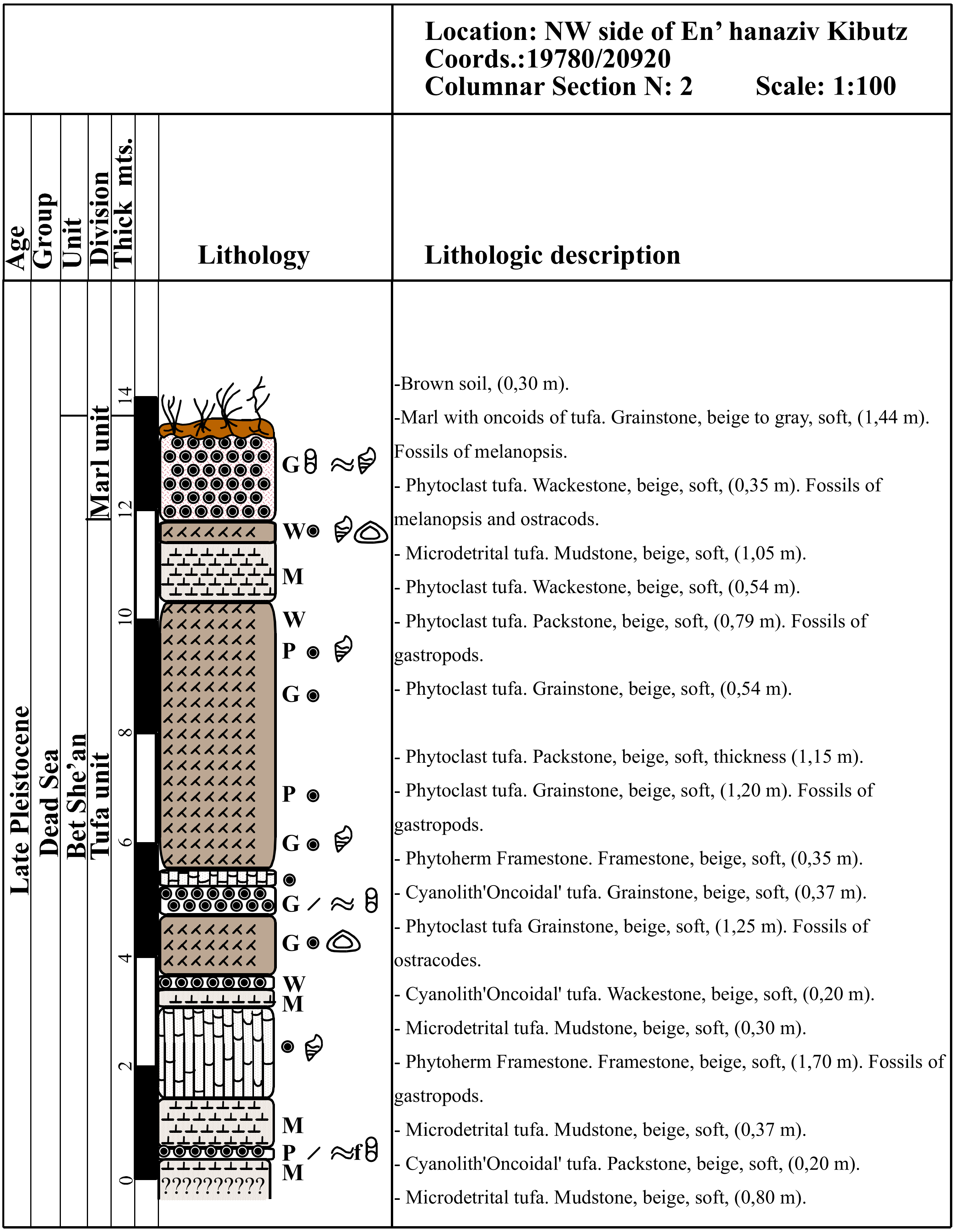


Fig.3. Columnar section of the upper part of the northern outcrop of the escarpment.

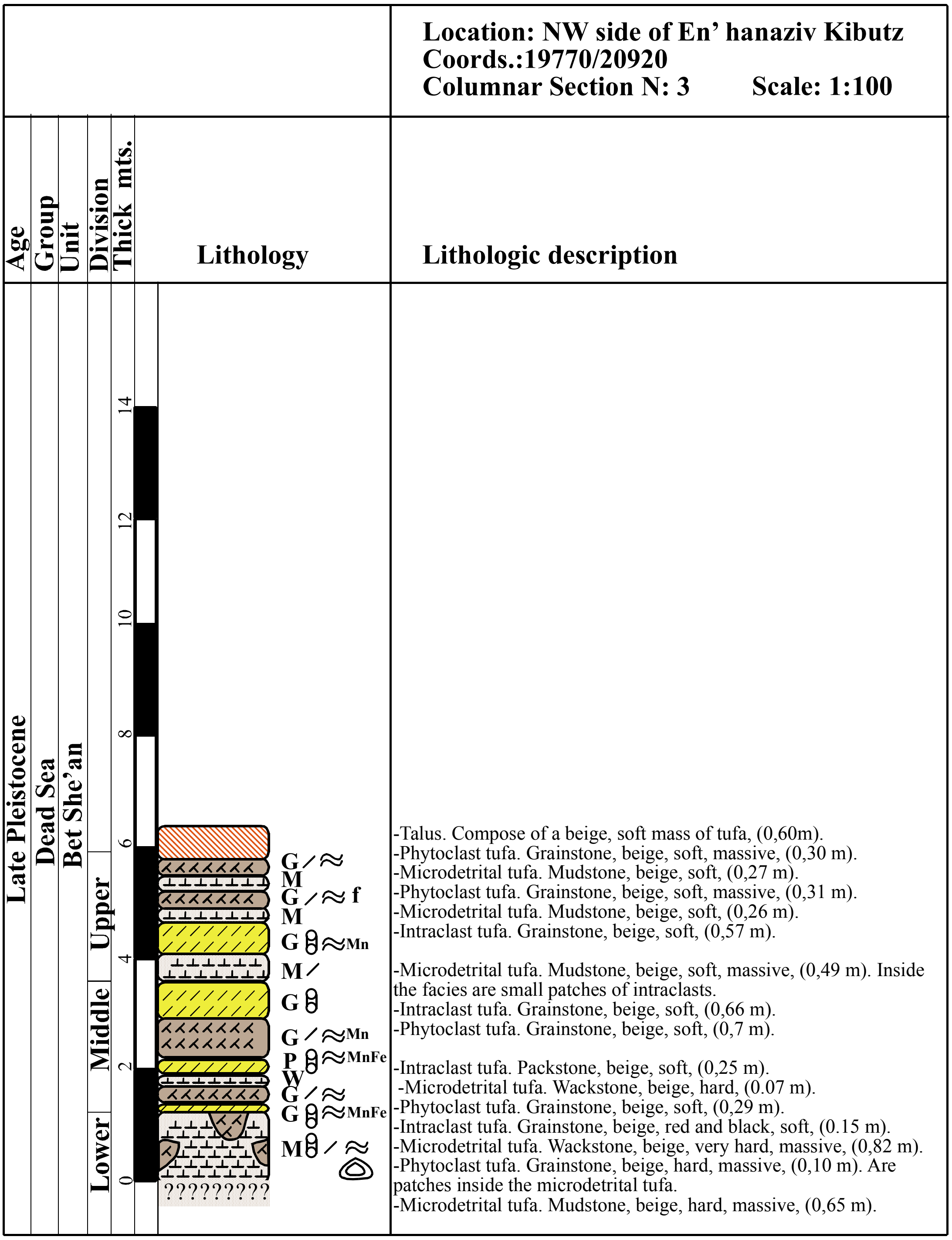


Fig. 4. Columnar section of the trench in the lower part of the northern outcrop of the escarpments

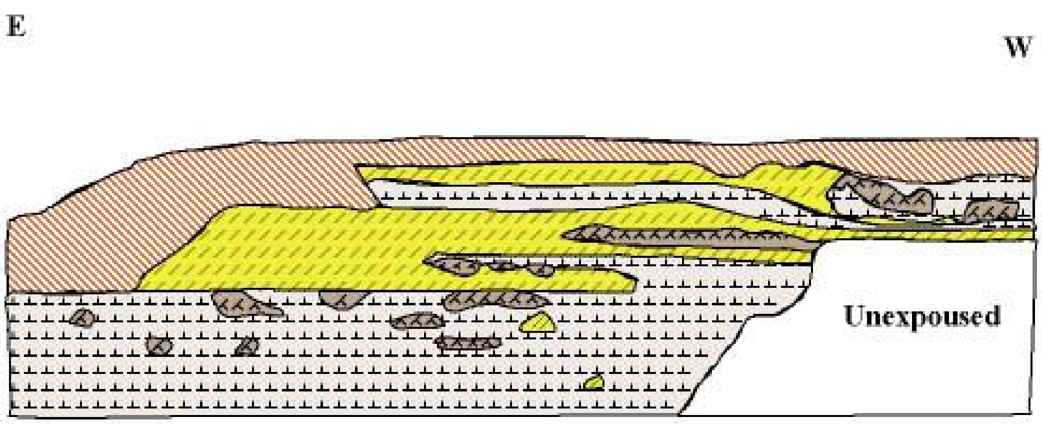


Fig. 5 Schematic profile of the lower part of the trench, northern outcrop.

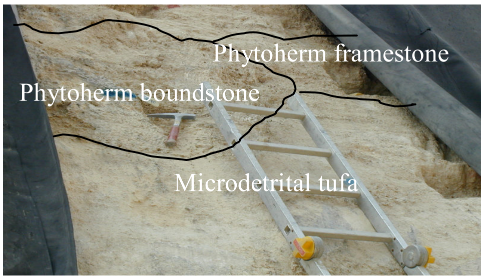


Fig. 6. Exposure of the facies in the lower part of the dry water reservoir, northern outcrop.

Fig. 7. Phytoherm framestone facies that show phytoherm boundstone microfacies, in the southern outcrop.

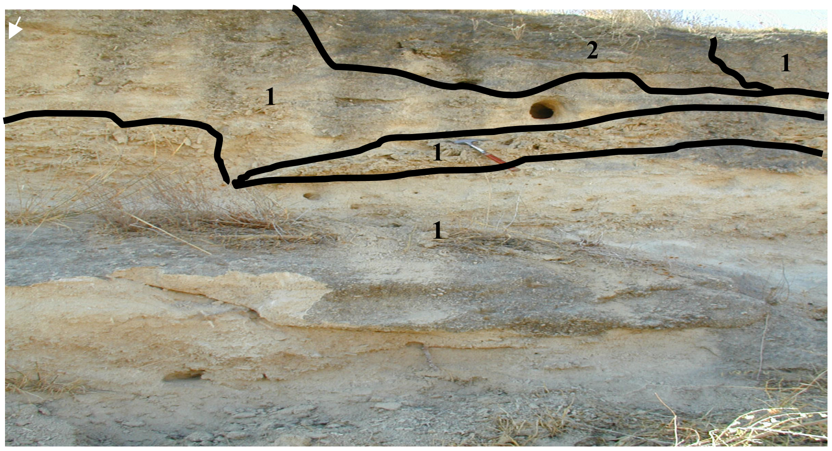


Fig. 8. Middle part of the southern outcrop Phytoclast tufa (1, showing west-east imbrications (manifested by the Hammer).. Laterally the phytoclast tufa (1) can pass to intraclast tufa (2).

Fig. 9. The southern outcrop. Phytoclast tufa facies, which presents randomly oriented phytoclasts with fragments of stromatolite intraclasts and leaves.

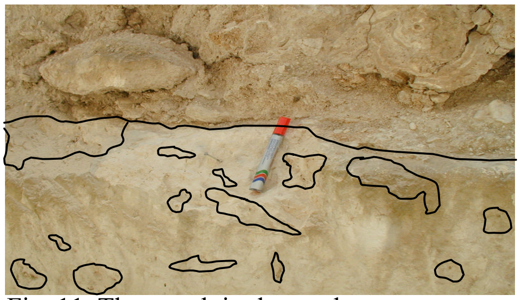


Fig. 11. The trench in the northern outcrop. Sharp contact between the lower microdetrital tufa and the intraclast tufa facies. Patches of phytoclast and intraclast tufa facies are embedded in the microdetrital facies. The intraclast tufa facies contains some fragments of stromatolite of gravel to cobble size.

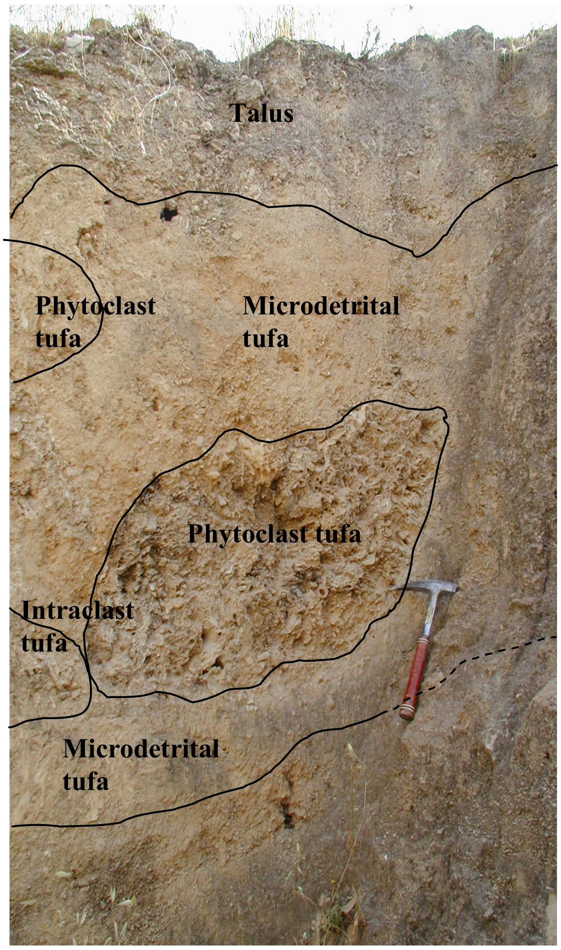


Fig. 10. The facies of the tufas exposed in the western part of the trench in the northern outcrop.

5.2 Discussion

5.2.1 Tufa depositional models

Infrequently tufa deposits can be fit into a single model. The basic perched springline, lacustrine, paludal, and fluvial tufa environments represent end members of a spectrum of interrelated systems (Ford and Pedley, 1996; Carthew et al., 2003). These models are described in detail by Pedley (1990).

5.2.1.1 Perched springline model (Fig. 12B)

The model developed in hilly areas where carbonate-rich springs emerged from the valley sides. The configuration of the deposits is fan-shape in plan view and wedge-like in cross section (Chalfetz and Folk, 1984), with the thickest sequence near the springs (Pedley, 1990). This environment could be divided into proximal and distal (Pedley, 1990).

(a) Proximal deposits: Lobate or multilobate, convex to flat surface deposits, thickening away from the source and developed from springs or stream system resurgence (Ford and Pedley, 1996). Rapid progradation of the deposits often causes a combination of vertical and lateral bedform migration (Pedley, 1990). Areas near the sources in well developed sites may become subhorizonal and partly ponded with very slow aggradations associated with paludal conditions (Ford and Pedley, 1996). Moreover, downslope in the slope face small terraces and waterfalls are present (Pedley, 1990).

(b) Distal deposits: These are low-angle sheet-like deposits mainly of microdetrital tufa with fine intraclast tufa derived from the proximal region and seldom with phytoclast tufa sheets related to local channels. The deposits could be cut in places by incised channels filled by tufa. Paleosols can be found between the tufa sheets (Pedley, 1990).

5.2.1.3 Paludal model (Fig. 12C)

Low relief sheets of tufa are deposited in shallow, low energy palustrine or swamps environments (Arenas et al., 2000). Sheets of chalk can be laterally extensive (floodplain associated deposited) and they contain small or continuous bodies of vertical phytoherm facies (Pedley, 1990). Small ephemeral ponds where microdetrital tufa is deposited are also included in paludal models (Ford and Pedley, 1996).

5.2.1.2 Lacustrine model (Fig. 12D)

Large static water bodies are characterized by laminar phytoherm boundstone developed laterally and upwards from the margin of the lake (Ford and Pedley, 1996). Oncoids are also common in this facies. The deep water zone is typified by microdetrital tufa (Carthew et al., 2003).

5.2.1.4 Fluvial tufa models

5.2.1.4.1 Braided fluviatile model (Fig. 12E)

Frequently this model is characterized by thick deposits of oncoids. Local phytoclast lenses are common and distributary channels may diverge around them and around phytoherm framestone facies. Phytoherm boundstones can be formed on stabilized substrates in channels that carry little bedload or on channel margins. Alignment of associated oncoids and phytoclasts take place in this environment. Water velocities are more constant in braided tufas streams and usually water depth is a few centimeters (Pedley, 1990).

5.2.1.4.2 Barrage model (Fig. 12F)

Usually grow in gorge sites from the damming of flowing water by arcuate downstream narrow phytoherm barrages or dams (Ford and Pedley, 1996). Massive microdetrital tufa and sapropels (Andrews et al., 1996; Pedley et al., 1996) are deposited in ponded upstream areas and may be related with phytoherm patches (Ford and Pedley, 1996).

5.2.1.4.5 Cascade model (Fig. 12G)

Cascades are like tufa barrage in their water morphology but they are characterized by the absence of upstream lake deposits (Pedley, 1990). Moss curtains are common on the downstream side, resulting in the formation of tufa caves (Ford and Pedley, 1996).

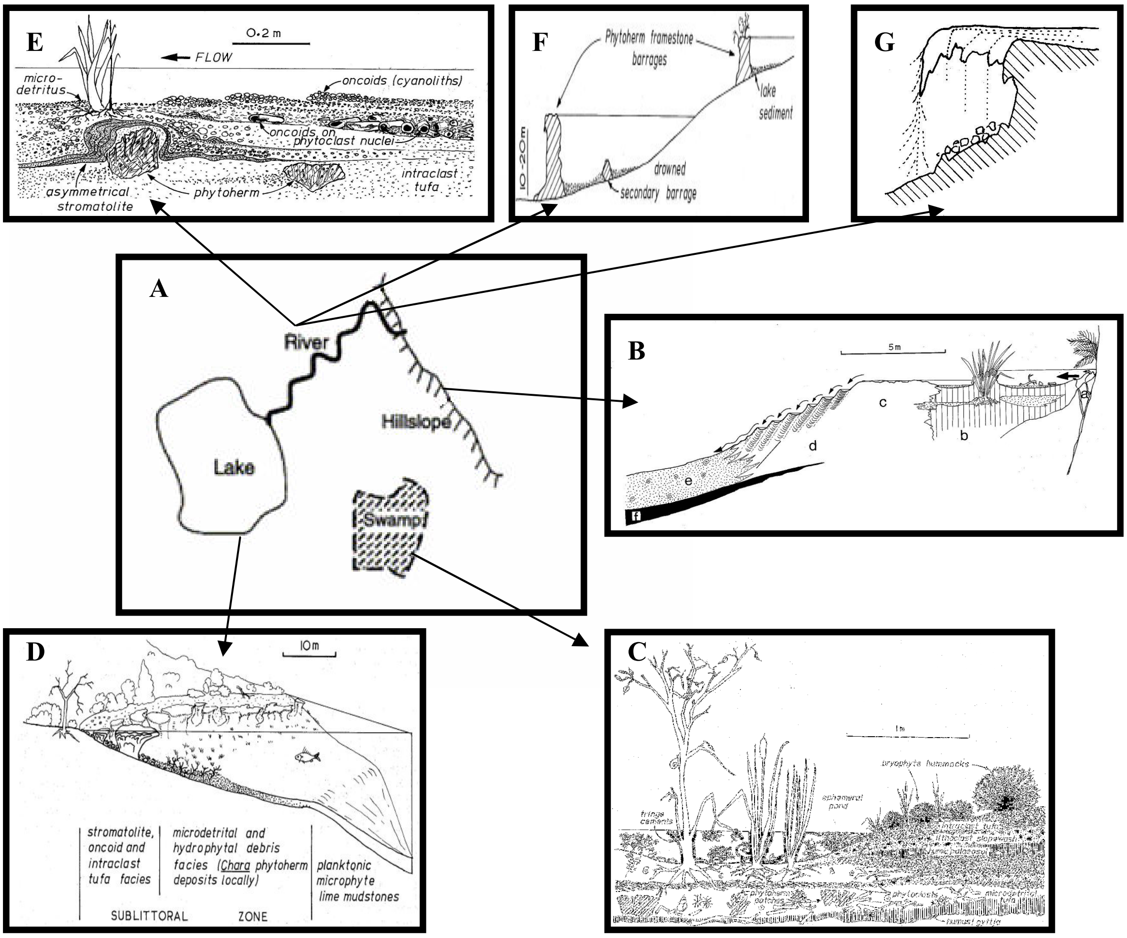


Fig.12. A- Tufa sedimentary models (adapted from Pedley (1990) and Carthew et al. (2003)) can be formed in hillslope, paludal, lacustrine and fluvial environments. (B) Perched springline or slope tufa systems are fed by groundwater emerging part way up a hillslope: (a) Resurgence point, (b) local paludal deposits near the spring, (c) massive bedded proximal terrace, (d) waterfalls and channels, (e) massive microdetrital tufa containing gastropod fossils covers the lower slopes in the distal zone, (f) palaeosols could be intercalated with e. (C) Paludal tufa model distinguish poorly drained, humid areas. Broad flat areas of poorly drained ground promote the development of ephemeral ponds. (D) Lacustrine tufa model. Vertical development of tufas occurs in the sublitoral zone. The shallow area presents phytoherm boundstones associated with oblate oncoids and phytoclastic sediments. Lime mudstone deposited in the deeper part of the lake.
(E) Braided tufa systems may form asymmetrical stromatolites, phytoherm framestones patches and phytoclast layers. Layers with allochems of phytoclasts, intraclasts and oncoids typify the braided environments. Erosion surface, grading and local climbing ripple bedforms are common. (F) Barrage tufa systems consist of a series of tufa dams. Rapid vertical barrages growth tends to drown upstream secondary small phytoherm barriers and the lakes produced between the barrages accumulate sediments slowly except in marginal areas. (G) Cascade tufa commonly includes tufa stalactites created behind an overhanging moss curtain.

5.3 The building and development of the tufa plateau

The tufa sequence exposed along the southern and the northern parts of the escarpment manifests deposition in three successive, vertically arranged environments, which prevailed throughout the Bet She'an Valley.

The first deposition stage occurs in a perched springline environment, characterized by tufa sediments precipitated at relative low energy in both the proximal and the distal areas. The proximal area presents subhorizonal floodplains deposits composed mainly of autochthonous facies. The distal area show palustrine deposits of low-angle massive microdetrital tufa with patches of macrodetrital tufa derived from the proximal region. The regional flow direction was eastward.

The second deposition stage is characterized by a mixture of a perched springline and braided fluviatile environments, distinguished by tufa accumulations in relatively high energetic fluvial conditions. In the early part of this stage the tufa consists of channels and interchannels deposits, changing to floodplains products of ephemeral streams in the upper part of the sequence.

It seems that the fluvial energy gradually increases toward the upper part of the second stage. This is more evident in the base of the tufa plateau where subhorizonal shallow channels vertically pass to deeper channels incised into the floodplain.

The sequence deposited during the third stage represents a mixture of paludal and braided fluviatile environments. The thickness and distribution of the chalk and marl sediments suggest that they were accumulated in shallow water bodies.

The presence of Melanopsis buccinoidea (Oliver) in the marl and chalk sediments indicates that stream channel network crossed the tufa plateau between the ponds.

Therefore, it appears that wide, shallow floodplains occupied the flat top of the tufa plateau. Sporadic events of high energy flows flooded the area and transported and deposited allochems and melanopsis shells throughout the entire plateau.

The brown soil developed above the tufa plateau after it was abandoned and it is rich in weathered tufa fragments. Dan (1988) suggests that tufa (travertine), chalk and marl are the parent materials of the calcareous brown soils in the central and lower Jordan Valley.

5.4 Summary of the development of the tufa plateau

The sedimentary evolution of the tufa plateau in the Bet She'an valley can be subdivided three stages, each represent a certain association of depositional environments:
The first stage is characterized by a perched springline environment where a thick autochthonous facies was deposited in the proximal zone and a thick massive microdetrital tufa in the distal zone.

During the second stage a combination of perched springline and a braided fluviatile environment dominated the area. The tufa deposited in these environments presents imbrication of allochems, and grain supported allochthonous facies with sporadic layers of microdetrital tufa facies. These facies reflects long periods of high hydrodynamics conditions interrupted by periods of low water table, reflecting dry climatic episodes.

The environments prevailed during the third stage were a mixture of low energy paludal and high energy braided streams. Thick marl and chalk sediments with a lot of allochems were accumulated on a flat relief.

Finally, the northern and the southern section present currently a similar altitude (-140 m.s.n.m.), which suggest a similar rate of tufa deposition in both sections during the three stages of development of the tufa plateau. Such simultaneous deposition along a floodplain almost 10 km wide, suggests a base level control on the accumulation rate and the flat morphology of tufa plateau.

6. Future work

The BSV experienced tectonic activity during the Quaternary as is evident by archeological (Ben-Menahem, 1991), seismic (Gardosh and Bruner, 1998; Bruner et al., 2002; Zilberman et al., 2002, 2004), morphological (Belitzky, 1996 and Zilberman et al., 2004), and field data (Zilberman et al., 2004). The tufa unit is the only stratigraphic marker that can provide identification of the time and amount of young tectonic displacement in the Bet She'an area. Hence, the study of the tufas can contribute substantially to understand the tectonic conditions in the BSV during the Quaternary.

To accomplish the purpose of our research it is a requisite to integrate the ages from the tufa outcrops with the field data. In order to achieve this goal it is required to complete the field work principally across the Harod River, and the springs east of the marginal fault, where the tectonic activity is more clearly expressed. We will date by U/Th method sections of the profiles of tufa described in this study, some faulted tufa units in the Harod River, exposed in the lower part of the marginal fault escarpment, and some tufa units penetrates by drill holes.

The mineralogy and petrography of the tufa samples will be studied using petrographic microscope, SEM (EDS and BSE), and XRD. Geochemical analysis of Ca, Mg, Sr, Ba, U, Al, Fe, Ti, Th, Si will be performed using ICP-AES and ICP-MS.

LEGEND

	Phytoherm boundstone		Soil
	Phytoherm framestones		Talus
	Phytoclast tufa		Marl
	Cyanolith 'Oncoidal' tufa		Chalk
	Intraclast tufa		Fragments of phytoherm boundstone (Stromatolite)
	Microdetrital tufa		Phytoherm
	Colluvial deposits		Fragments of leaves and plants
	Indistinguishable unit	◎	
	Unconformity		Intraclast
	Bivalve	⊥	
	Ostracoda	f	Fossil
	Gastropoda	G	Grainstone
	Ceramic fragments	P	Packstone
			Wackestone
			Mudstone

7. Schedule of the research work

N°	Stage	Nov 2004	July 2005	Dec 2005	Apr 2006	Dec 2006
First report	1					
Second stage	2					
Third stage	3					
Forth stage	4					
Final report	5					

Third Stage: at December, 2005.

1. Dating two sections (south and north of Tel Rehov) of tufas by the U-Th method.
2. Description of the paleogeographical conditions that promote the precipitation of tufas during the Pleistocene across the high morphological step in the Bet She'an Valley.
3. *Report to the Geological Survey will be submitted at December 2005*.

Fourth stage: at April, 2006

1. Study and sampling of additional stratigraphic profiles relevant for a better understanding of the environmental and tectonic conditions during the tufa deposition.
2. Dating the points of control of these sections of tufa by U-Th method.
3. Study of the tectonic relationships between structural elements and the tufa deposits.

Fifth stage: at December, 2006.

1. Petrographic and mineralogical study of the tufa rock by XRD and SEM.
2. Combination of field mapping and drill-hole study, to evaluate the distribution of the tufa sequence in surface and subsurface on both sides of the marginal fault of the DSR.
3. Apply the dates obtained by the U/Th method for determining the period of tufa deposition.
4. Examination of the relations between the tectonic elements and the tufa sequence in the Bet She'an area, in order to introduce time constrain to young tectonic activity.
5. *Final report will be submitted to the Geological Survey at December 2006.*

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16. Abstract (Limit 200 words): An extensive thick sequence of tufa builds a sedimentary plateau, which extends in the Bet She'an Valley (BSV) between Nahal Harod in the north and the Sedé Trumot settlement in the south. 40 m of the sequence are exposed along the escarpment of the western marginal fault of the DSR, and additional 30 m where penetrated by drillholes.

Three stages of tufa deposition were identified: The first dominated by perched springline environments distinguished by thick autochthonous facies in the proximal zone, whit microdetrital tufa in the distal zone. The second stage presents a mixture of perched springline and braided fluviatile environments characterized by allochthonous facies. Chalk and marl containing abundant allochems were deposited during the third stage in a mixture of paludal and braided fluviatile environments.

The tufa sequence in the BSV was deposited in an amalgamated system of floodplains of east-flowing shallow waters springs, which drained to a lake situated in the Jordan Valley. This fluvial system was dominated by low energy environments that were interrupted by periods with more energetic floods. The accumulation of thick subhorizontal sequence can be attributed to a slow subsidence of the Valley or a gradual rise of the lake level.

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