THE MINISTRY OF NATIONAL
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A. Matmon, E. Zilberman, and Y. Enzel



Report GSI / 25 / 2000
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A. Matmon[1], E. Zilberman[1], and Y. Enzel[2]

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Abstract

A morphometric study of the Bet-Ha'Emeq drainage system, Upper Galilee, combined with available geologic and structural data, enable the detection of tectonic stages that took place in the region and a better understanding of the influence of tectonic activity on surficial processes. The preservation of Senonian and sometimes Eocene rock units in the down faulted blocks of the Bet Ha'Emeq Valley implies that normal faulting at rates compatible to denudation initiated during the Miocene and lasted ~10 million years. During that time ongoing truncation continued on the uplifted block eliminating completely the Senonian units. The relation between the Bet-Ha'Emeq drainage system and adjacent structures implies that the relief of the Bet-Ha'Emeq Valley and the development of the drainage system in it preceded the development of the secondary uplifted blocks within the Bet-Ha'Emeq low structure, the neighboring Zurim Escarpment and the formation of the regional tilt of the Upper Galilee. The present relation between the Zurim Escarpment and the Bet-Ha'Emeq drainage system suggests no observable retreat of the escarpment since its formation more than 4 Ma. Morphologic considerations and the existence of quartz geodes derived from the Cenomanian Deir-Hanna Formation on abandoned saddles along the present water divide of Nahal Bet-Ha'Emeq suggest that the headwaters of the Bet-Ha'Emeq drainage system used to be in the Bet-Jann tectonic block. This block is currently disconnected from the Bet-Ha'Emeq drainage system due to normal displacement along the Sumi and Peqi'in faults. The present morphology of the Bet Ha'Emeq Valley developed since the Pliocene. A fresh fault scarp in dolomite and knick points in Pleistocene travertine units in the western part of the Bet-Ha'Emeq Valley indicate late Pleistocene activity on the Bet-Ha'Emeq fault system. Incision of the Bet-Ha'Emeq drainage system as well as adjacent streams into alluvial terraces signals the response of the drainage system to the regional-scale uplift and is not associated with normal faulting of the Bet-Ha'Emeq system. The regional uplift is also expressed in the steep gradient of the Upper Galilee streams.

The data collected in the Bet-Ha'Emeq and neighboring valleys indicate that faulting was active since the Miocene and until the Late Pleistocene and that the development of the landscape is mainly controlled by rates of faulting and regional uplift and less by surficial processes.

Introduction

Active tectonics influence fluvial systems by either subsidence or uplift and by direct faulting on all temporal scales (e.g. Wallace, 1967; Stevens, 1974; Schumm, 1977, 1986). The change in slope cause changes in stream pattern and aggradation and/or incision of the stream. When stream incision occurs more slowly then uplift a disruption of the drainage pattern will follow (Sparling, 1967; Twidale. 1971; Ollier, 1981; Harvey and Wells, 1987; Gupta, 1997; Burbank et al., 1996). The effect of direct displacement by faulting can be very dramatic (e.g. Keller, 1986; Rockwell et al., 1988; Spitz and Schumm, 1997). Slower deformation is more difficult to detect. However, long-term activity will result in the accumulation of both recognizable tectonic structures and deformation of the fluvial system (e.g. Ouchi, 1985; Gerson et al., 1984; Markewich, 1984; Chorowicz and Fabre, 1997; Merritts and Vincent, 1989; Spitz and Schumm, 1997).

In Israel fluvial systems have been largely modified by recent tectonics (e.g. Bentor and Vroman, 1951; Garfunkel and Horovitz, 1966; Freund et al., 1968; Kafri and Heimann, 1994; Ginat et al., 1997; Kafri, 1997) and the drainage pattern has adjusted to the development of different morphotectonic features.

In this study we reconstruct the development of a main drainage system in the Upper Galilee, northern Israel, and explain this development in relation to tectonic activity that took place in the region since the Miocene. The area is located at the margins of the Dead Sea Transform valley (DSTV), so drainage development was affected both by the large-scale tectonics and by local inner Galilee faulting. Based on this reconstruction we will evaluate the influence of the tectonic activity on the drainage system.

Study area

The Upper Galilee is located in northern Israel between the Mediterranean in the west and the DSTV in the east and between the Bet-Kerem Valley in the south and southern Lebanon in the north (Fig. 1a). The surface of the Upper Galilee is a mountainous area that rises moderately from the coastal plain to an altitude of approximately 1000 meters and is part of a regional erosional surface that

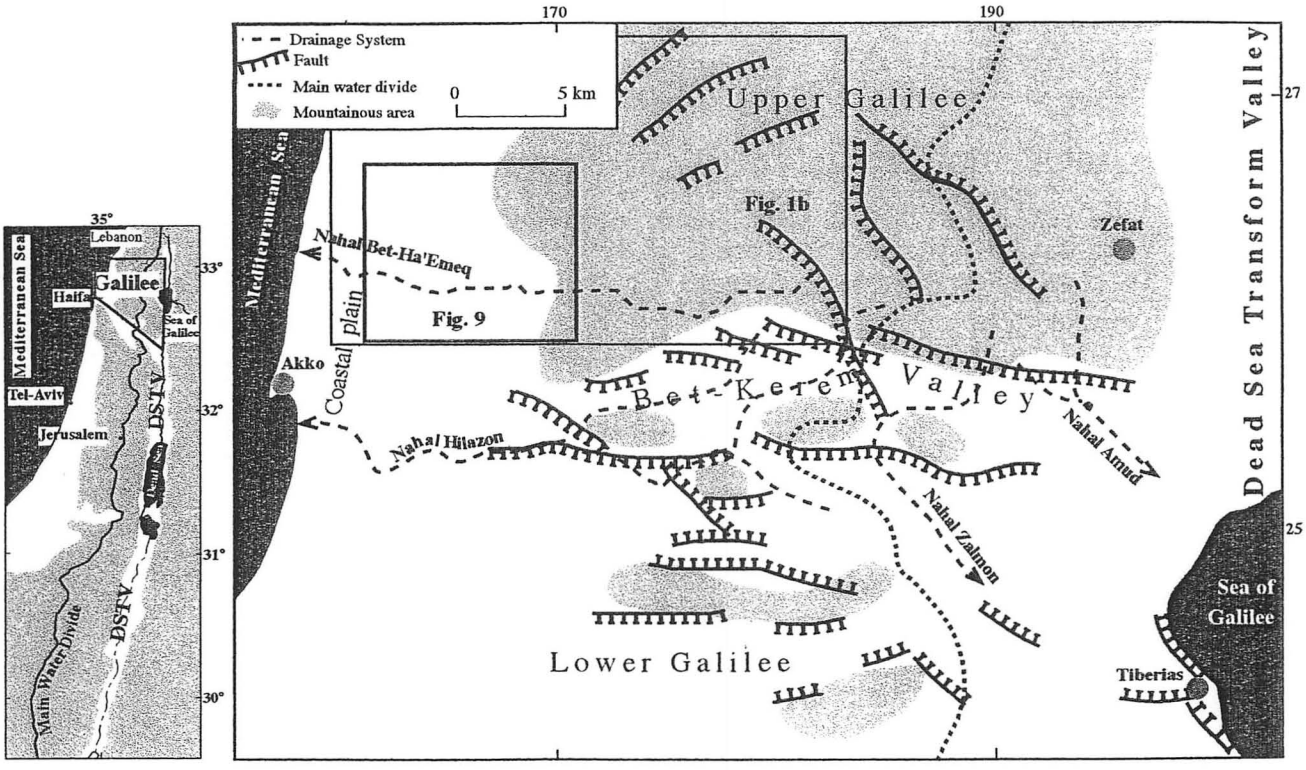


Fig. 1a – Generalized location map. DSTV – Dead Sea Transform (Geology after Picard and Golani, 1965).

developed during the Oligocene to Miocene (Garfunkel, 1988). The N-S oriented main water divide is subparallel to the DSTV and the distance between them increases from 2 km in the northern Galilee where the divide is located at the top of the rift`s western rim, to 30 km in the southern part of the Galilee.

The Upper Galilee is crossed by two systems of faults trending north-west and north-east, which have sinistral and dextral displacements respectively accommodating N-S extension (Ron et al., 1984; Fig. 1a). Some of these faults curve to become east-west normal faults (Ron et al., 1984). Most of the folds that developed during the late Mesozoic as part of the Syrian Arch (Flexer et al., 1970) have no morphologic expression.

The tectonic development and erosional pattern that persisted in the Galilee since the Miocene did not leave a sedimentary record that can testify for stages of landscape formation. The absence of topographic expression on most of the Upper Galilee normal faults implies that they have not been active since the end of the Miocene when an extensive erosional surface was formed in this area (Garfunkel,

1988; Picard, 1943; Yair, 1962). Alternatively, it may imply that the rates of tectonic activity since the end of the Miocene did not exceed the regional denudation rates.

The stratigraphic sequence exposed in the Upper Galilee includes: (a) Lower Cretaceous sandstone and marls of the Kurnub Group (Eliezri, 1965), which are exposed only at the base of the Zurim and Ramim escarpments. (b) Upper Cretaceous limestone and dolomite of the Judea Group (Baida, 1963; Kafri, 1972), which cover most of the central hilly part of the Galilee. This sequence includes the quartz geodes in the Cenomanian Dier-Hanna Formation, which is widely exposed in the Bet-Jann area (Fig. 1b). (c) Senonian to Paleocene chert, chalk and marl of the Mt. Scopus Group (Flexer et al., 1970; Kafri, 1972). (d) Eocene limestones and chalks of the Avedat Group (Baida, 1963; Kafri, 1972) which are exposed at the eastern and western margins of the Galilee or in down-faulted blocks and small synclines in the center of the Galilee. In the eastern part of the Upper Galilee there are late Pliocene to early Pleistocene volcanic fields. The Valley floors in the Galilee are generally covered with Pleistocene to Holocene alluvial sediments with local silty clay deposits and soils. The climate of the area is semi-humid Mediterranean (annual mean precipitation is 700-900 mm/year). Karst is the main erosion process in this carbonatic terrain resulting in low amount of coarse material delivery to the stream channels. The thin colluvial mantle on the slopes consists generally of silty soil with carbonate rock fragments, generally not larger than 10 cm. Alluvial fans are not common and mass wasting processes are rare.

The Bet-Ha'Emeq Valley

The faults that bound the Bet-Ha'Emeq Valley (located in the western Upper Galilee; Fig. 1b) are unique in their prominent topographic expression (Fig. 2). The eastern part of the valley is a graben bounded in the north by the Bet-Ha'Emeq – Yanuh (BHYF) normal fault and in the south by the Yirka normal fault (YF; Fig. 1b). The western part is a tilted block bounded in the north by the Bet-Ha'Emeq - Yanuh normal fault (Fig. 1b; Freund, 1959, 1970; Baida, 1963; Kafri, 1972). The vertical displacement along these faults ranges between 100 and 400 meters (Freund, 1970; Kafri, 1972). In the up lifted blocks limestone and dolomite of the Cenomanian to Turonian Judea Group are exposed, whereas the base of down-faulted block is composed of chalk of the Mt. Scopus Group. The outstanding morphostructural expression of the Bet-Ha'Emeq normal faults indicates tectonic

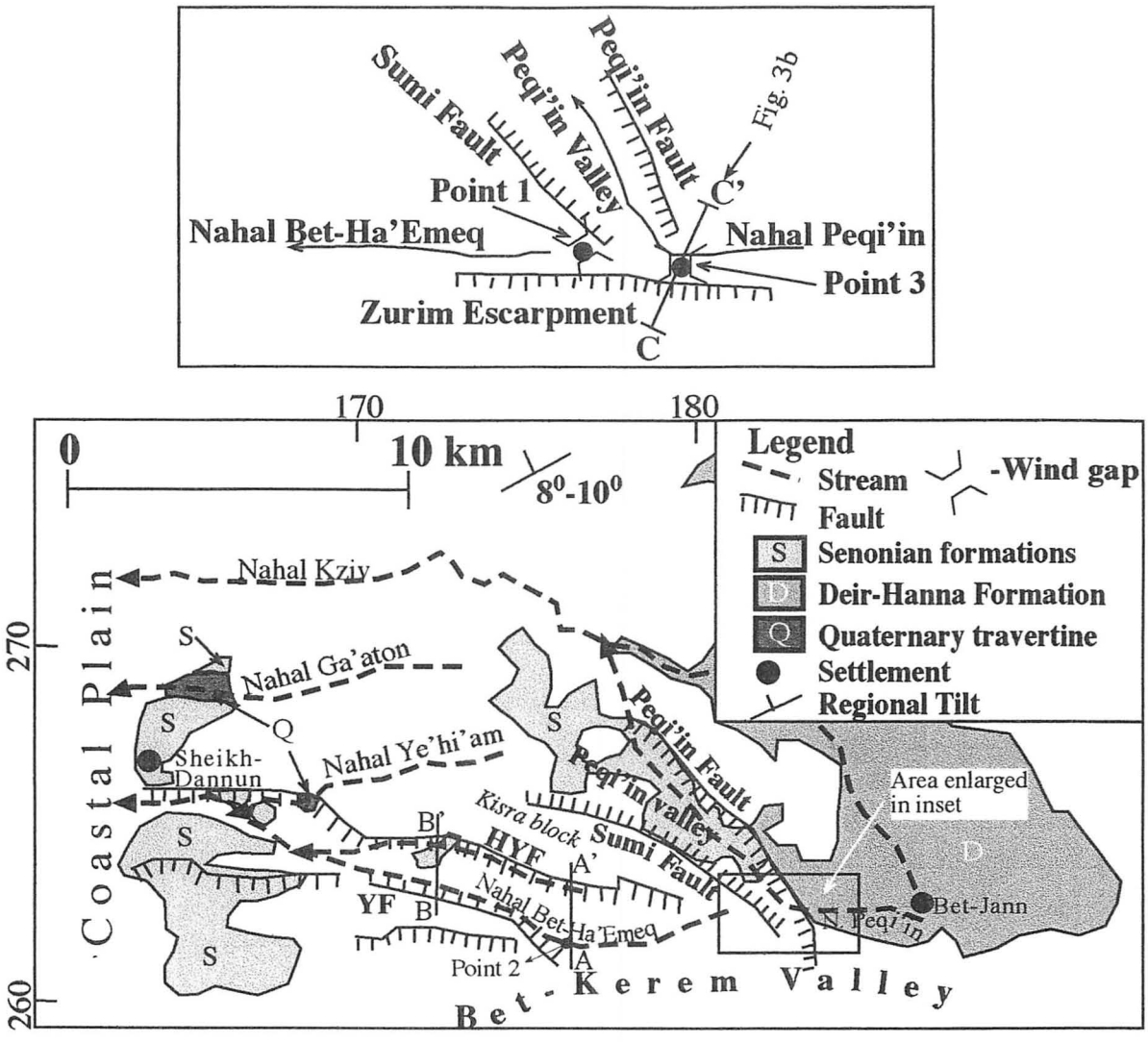


Fig. 1b - Detailed map of the Bet-Ha'Emeq area. The area of capture of the former head-waters of Nahal Bet-Ha'Emeq is schematically enlarged at the top of the figure. Only faults that are mentioned in the text appear in the figure. BHYF – Bet-Ha'Emek - Yanuh Fault. YF – Yirka Fault. B-B' – Cross-section in Fig. 6. A-A' – Cross-section in fig. 3a. C-C' – Cross-section in Fig. 3b. ⊢ – Regional dip direction. Geology: after Eliezri, 1965; Kafri, 1972.

activity that exceeded denudation rates and enabled the formation of substantial topography. Therefore, the Bet-Ha'Emeq low structure serves as a sedimentary trap for Miocene to Quaternary sediments that accumulated on top of the Senonian units, whereas most of the Galilee has been under erosional conditions during that period.

Several geological studies were carried out in the area. Baida (1963) and Kafri (1972) mapped the western part of the Galilee. Freund (1959) described the Cretaceous sequence and tectonics of the area and later calculated the extension of the

normal fault system in the Galilee during the Neogene including the Bet-Ha'Emeq system (Freund, 1970). Kafri (1997) proposed that the western part of the Bet-Ha'Emeq graben was part of an extensive Neogene drainage system that flowed from the eastern Galilee to the Mediterranean.

Methods

A morphometric analysis of Bet-Ha'Emeq stream (Nahal Bet-Ha'Emeq), which is the stream that drains the Bet-Ha'Emeq Valley (Fig. 1b) and its surroundings was conducted. The analysis includes the construction of topographic cross sections perpendicular to Nahal Bet-Ha'Emeq at several points, longitudinal profiles of Nahal Bet-Ha'Emeq and other streams and the calculation of the Vf parameter, which is indicative of the

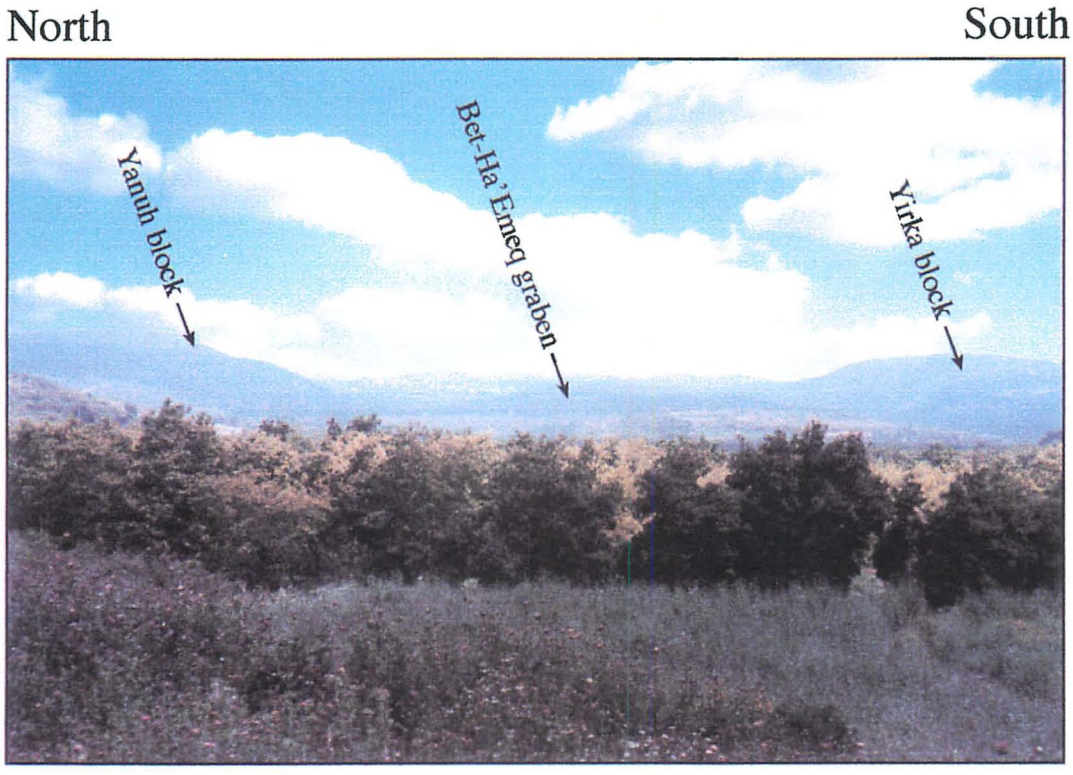


Fig. 2 –Bet-Ha'Emeq structure. View to the east. The uplifted block on the left (north) is the Sheikh-Dannun Yanuh block. The uplifted block on the right (south) is the Yirka block. Both blocks are bounded by normal faults. The surface of the down faulted block is incised in the north and south by the Yanuh and Bet-Ha'Emeq streams, respectively.

degree of incision. Vf values express the ration between the width of the stream bed and the average depth of the stream bed below its interfluves on both sides. Vf values were calculated at 32 points, evenly spaced, along Nahal Bet-Ha'Emeq following the method described by Keller (1986). All topographic cross sections and profiles were constructed using GIS procedures and Digital Terrain Model (DTM; Hall, 1993) database.

Mapping of alluvial terraces at the western part of the Bet-Ha'Emeq Valley and adjacent drainage systems and analysis of thin sections of calcrete horizons that formed on the alluvial material help to determine the minimum age of the terraces using calcrete stage index (Birkeland, 1984; Machette, 1985; Birkeland et al., 1991). Topographical maps were analyzed to detect remnants of the ancient coarse of Nahal Bet-Ha'Emeq drainage system. Topographical features such as wide saddles were marked for later field work which, was based on the analyses of the maps. The sites which, appear to be remnants of ancient streams were surveyed for direct evidence of fluvial deposits. At sites where these deposits were identified, we concentrated our efforts on exotic gravel that has no source in the present-day drainage basin. Possible sources for exotic gravel such as quartz geodes were marked. This enabled us to trace the gravel to their source, reconstruct the ancient drainage basin of Nahal Bet-Ha'Emeq and evaluate the tectonic activity that took place in the area.

Combining available geologic and structural data with the topographic and morphometric analysis enabled us to locate segments of the drainage system that were influenced by tectonic stages that took place between the early Miocene and the Pleistocene. Comparing longitudinal profiles of main stream channels in the Upper and Lower Galilee (including Nahal Bet-Ha'Emeq and its tributaries) and correlating alluvial terraces in the western Upper Galilee streams helped to distinguish between deformation that was related to normal faulting of the Bet-Ha'Emeq Valley faults and regional uplift that was followed by a change in base level and regional incision of streams.

Field Observations

The pattern of Nahal Bet-Ha'Emeq

The general flow direction of Nahal Bet-Ha'Emeq is westward from its eastern divide to the Mediterranean. At the eastern and central reaches of the drainage system

the divide between the Bet-Kerem Valley and the Bet-Ha'Emeq Valley lies right above the northern escarpment of the Bet-Kerem Valley. Nahal Bet-Ha'Emeq meanders very close to the water divide between the two basins (point 2, Fig. 1b and Fig. 3a). Even though the deep Valley of Bet-Kerem is much closer to the upper reach of Nahal Bet-Ha'Emeq than the Mediterranean, Nahal Bet-Ha'Emeq flows to the further base level, the Mediterranean, along a gentler gradient. In addition, the course of Nahal Bet-Ha'Emeq does not follow the direction of the NW regional tilt of the Upper Galilee. Similar relations are observed in point 3 (Fig. 1b) near the village of Bet-Jann. There, the divide between the Bet-Kerem Valley and the former headwaters of Nahal Bet-Ha'Emeq rises only 1-2 m above the channel bed (Fig. 3b).

Nahal Bet-Ha'Emeq crosses several uplifted structures (Fig. 4). The Nahal Bet-Ha'Emeq stream bed alternates from a wide and a gentle gradient stream to a narrow and steep gradient stream as it crosses between uplifted to down faulted blocks (Fig. 4). The correlation between Vf values and structure is good. Lithology does not seem to influence Vf values (Fig. 4). At the western reach of the Nahal Bet-Ha'Emeq, Vf values increase as the stream enters the coastal plain and the local structure of uplifted blocks does not cause incision.

Marine and Alluvial sediments dating from the Late Eocene to Pliocene, exposed at the western end of the Bet-Ha'Emeq Valley, indicate that the area subsided and trapped sediments since at least the Early Oligocene (Matmon et al., in preparation). This is in contrary to the rest of the region that has been uplifted and under erosion since the Middle Eocene.

These observations regarding Nahal Bet-Ha'Emeq imply that:

1) The stream valley of Nahal Bet-Ha'Emeq developed prior to both the development of the Zurim Escarpment and the tilting of the Upper Galilee to the north-west, but later or contemporaneous with the formation of the Bet-Ha'Emeq graben.
2) The Zurim Escarpment did not retreat substantially since its formation and there is no process of river capturing.
3) The drainage system of Nahal Bet-Ha'Emeq is incised through the structures it crosses and is not blocked or diverted by uplifted blocks. This implies that the drainage system developed before or at the same time the blocks were uplifted and that the rate of uplift did not exceed the rate of incision.

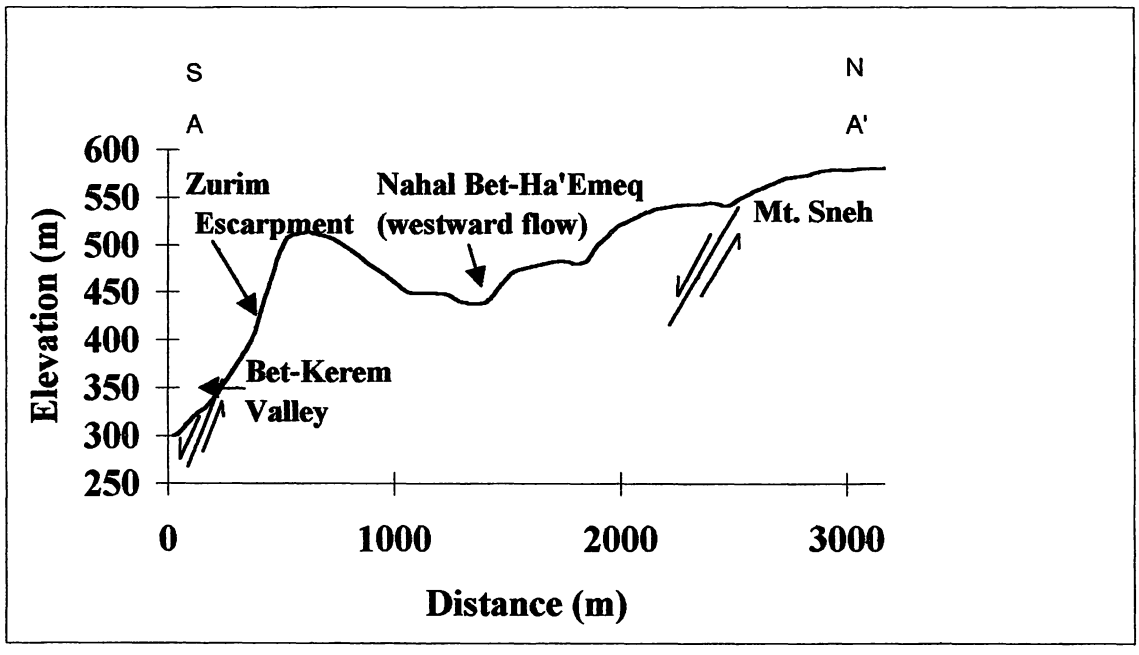


Fig. 3a – Topographic cross-section of the area where Nahal Bet-Ha'Emeq reaches the closest to the Zurim Escarpment. For location of cross section see Fig. 1b.

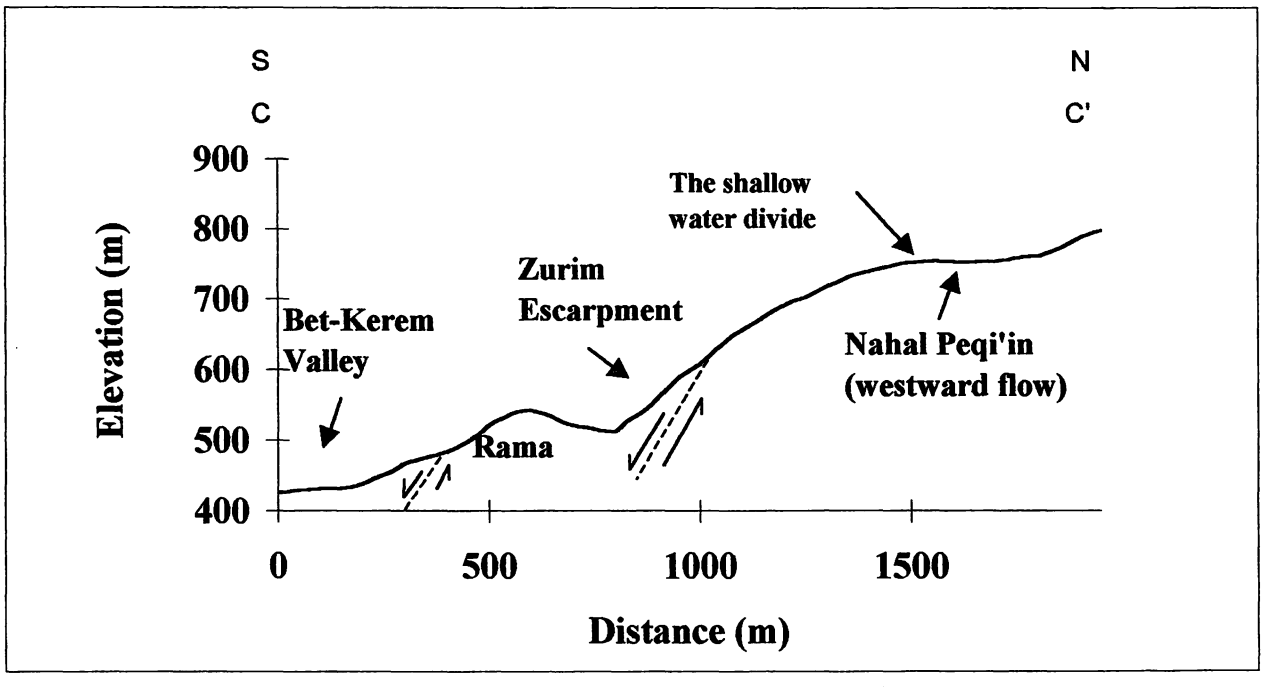


Fig. 3b – Topographic cross section of the area where Nahal Peqi'in reaches the closest to the Zurim Escarpment. For location of cross section see Fig. 1b in enlarged area at top of figure.

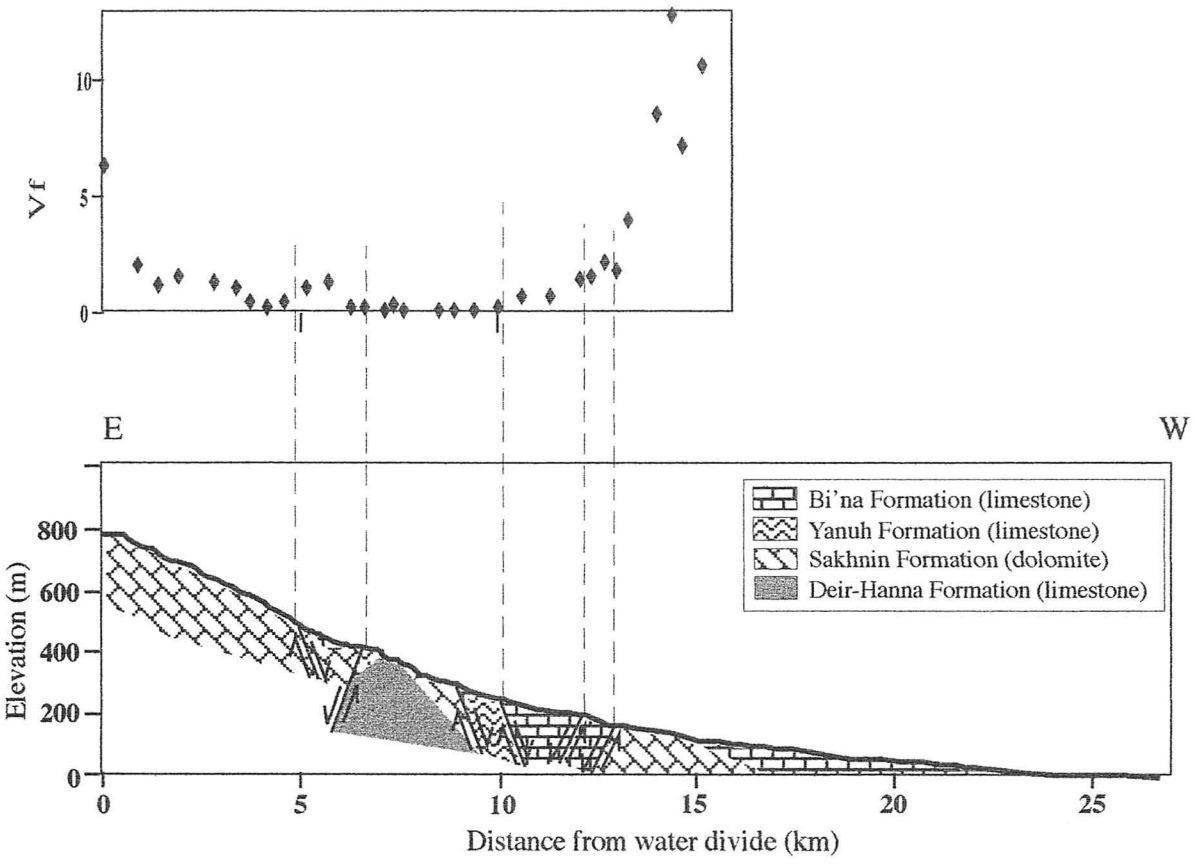


Fig. 4 - Topographic profile of Nahal Bet-Ha'Emeq. Notice the correlation between the steep sections of the drainage system, the location of uplifted blocks it crosses and the Vf low values. Lithology does not seem to influence the Vf value. All rock units are hard carbonates (geology after Kafri, 1972).

Longitudinal profile of Nahal Bet-Ha'Emeq.

The headwaters of Nahal Bet-Ha'Emeq are located in a series of abandoned valleys on the Kisra block which is uplifted by the Sumi fault (point 1 in Fig. 1b; Fig. 5). Quartz geodes were found at the headwaters of Nahal Bet-Ha'Emeq. The only possible source for these geodes is the Deir-Hanna Formation (Eliezri, 1965), exposed on the Bet-Jann uplifted block, east of the Peqi'in Valley (Fig. 1b). This block is currently drained into the Peqi'in Valley, and is disconnected from the Bet-Ha'Emeq drainage system by the uplifted block of the Sumi fault.

Longitudinal profiles of main westward-flowing streams in the Upper and Lower Galilee were constructed (Fig. 6). Two important observations are drawn from the comparison of the stream profiles: 1) The Upper Galilee streams are steeper than the Lower Galilee streams, and 2) Three Upper Galilee stream profiles are similar with the upper reach of Nahal Bet-Ha'Emeq being anomalously steeper than the other

Upper Galilee streams. These observations may reflect two tectonic phases that took place in the area:

1) The Lower and Upper Galilee are uplifted due to arching of the west margins of the Dead-Sea Transform valley (Matmon et al., 1999). However, the Lower Galilee has been subsiding during the Late Cenozoic due to the extension process that formed the basin and range structure of the area (Freund, 1970; Ron et al., 1984). The steep profiles of the Upper Galilee reflect the arching while the gentle profiles of the Lower Galilee reflect the subsidence of the Lower Galilee.
2) The relative steepness of the upper reach of the Nahal Bet-Ha'Emeq reflects the uplift of the Kisra block, and points at the disequilibrium state of Nahal Bet-Ha'Emeq in relation to the relief formed by activity of the Sumi fault. This observation and the existence of the quartz geodes at the head waters of Nahal Bet-Ha'Emeq suggest that prior to the formation of the Kisra ridge by the activity of the Sumi fault the headwaters of Nahal Bet-Ha'Emeq were located in the Bet-Jann block. Vertical displacement along the Kisra and Peqi'in faults diverted the headwaters of Nahal Bet-Ha'Emeq into the subsiding Peqi'in Valley and over-steepened the current head-waters of Nahal Bet-Ha'Emeq relative to other Upper Galilee streams.

The preservation of the Senonian sequence

A Senonian sequence of chalk and marl is preserved in the Bet-Ha'Emeq graben (Figs. 1b and 7; Kafri, 1972). The existence of the Senonian rocks in the graben helps put constrains on the relations between regional denudation and faulting in the area. To further the discussion on the implications of the occurrence of these Senonian rocks we provide a short review of the geological history of the region from the late Eocene to the middle Miocene. The Eocene sequence of limestone and chalk was deposited on the preexisting truncated folds of the Syrian Arch that began forming as early as the late Turonian (Flexer, 1964, 1968; Flexer et al., 1970). The regression of the Tethys Ocean at the end of the Eocene and the slow uplift of the land left behind a flat continental platform covered by Eocene carbonate units (Fig. 8A), which was drained westward by a regional drainage stystem (Picard, 1943, 1951; Garfunkel and Horowitz, 1966; Nir, 1970; Garfunkel, 1988; Avni, 1990, 1991).

North South

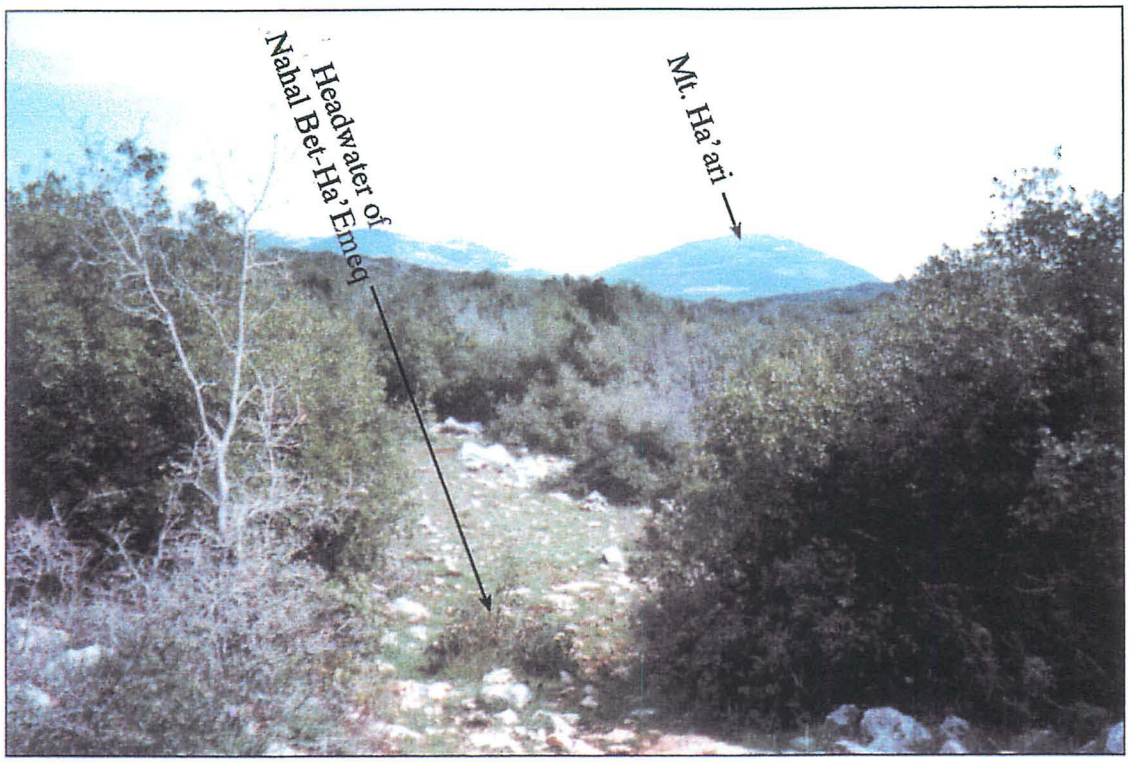


Fig. 5 – The abandoned saddle at the present head-waters of Nahal Bet-Ha'Emeq. Quartz geodes were found on the saddle. The most likely source of the geodes is Bet-Jann block which can be seen in the background. Presently, the Bet-Jann block does not drain into the Bet-Ha'Emeq drainage system.

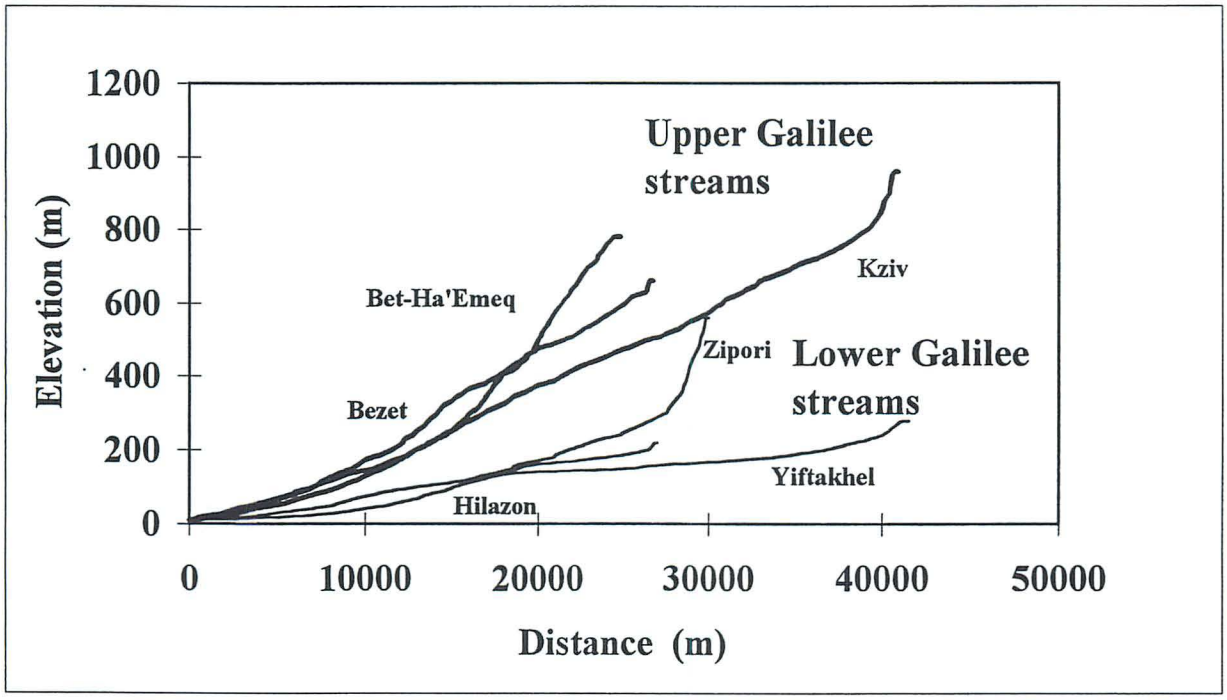


Fig. 6 – Stream profiles of some of the major drainage systems in the Galilee. The Upper Galilee streams are significantly steeper than the Lower Galilee streams. Zilberman, 1992; Garfunkel and Ben-Avraham, 1996; Begin and Zilberman, 1997).

This drainage system eroded the uplifted terrain and exposed differentially rocks of the Judea Group, while the Senonian, and sometimes the Eocene sequence was preserved in the synclines (Fig 8C). The rate of uplift and erosion during the Oligocene and the Miocene are not well known. The abundant gravel of Eocene source in the Miocene conglomerates, even in areas where the Eocene sequence has been eroded, suggests that Eocene cover was still wide-spread during the Early Miocene and that erosion was limited during the Oligocene (Garfunkel, 1970; Garfunkel, 1978).

The preservation of the Senonian sequence in the Bet-Ha'Emeq graben, as well as along other fault-controlled structural lows in the Galilee, demands that the structure already existed in the Miocene. This implies that vertical displacement of the Bet-Ha'Emeq fault system began early enough in the history of denudation, while Senonian rocks were still on the surface (Fig. 8B or 8D). This type of preserving mechanism of young stratigraphic units has been suggested as responsible for a) the existence of the Upper Mesozoic sequence in the grabens of Yotam and Netafim in the Elat area, b) the preservation of the Hazeva Formation in the Karkom and Abu-Treifa grabens in the central Negev and c) the preservation of Maastrichtian-Neogene sequence along the boundary of the Dead Sea basin (e.g. Garfunkel, 1970; Agnon, 1982; Zilberman, 1993).

Ongoing erosion on the upper blocks and preservation of young sequence on the lower blocks requires that the rate of vertical displacement is lower than the rate of denudation. Fast vertical displacements will trigger rapid incision of the drainage network and, in turn, the abandonment of the top of the uplifted block and a significant decrease in erosion on the isolated high ridges (Matmon et al., 1998; Fig. 8B). In such a case Senonian units are expected to be preserved on, or near the summits of the uplifted isolated blocks. In places, such as Mt. Zefat or Nazareth Mountains, the summits, which are at the same elevation as neighboring summits, are built of Senonian and Eocene units. Nevertheless, this is not the case in the Galilee in general and in the Bet-Ha'Emeq area in particular. The complete erosion of the Senonian sequence from the uplifted block along with the preservation of the Senonian sequence on the down faulted block could be achieved provided the Senonian sequence was removed from the uplifted block prior to the formation of the present topography (Fig. 8D). This topography was formed only at a later stage (Fig. 8E).

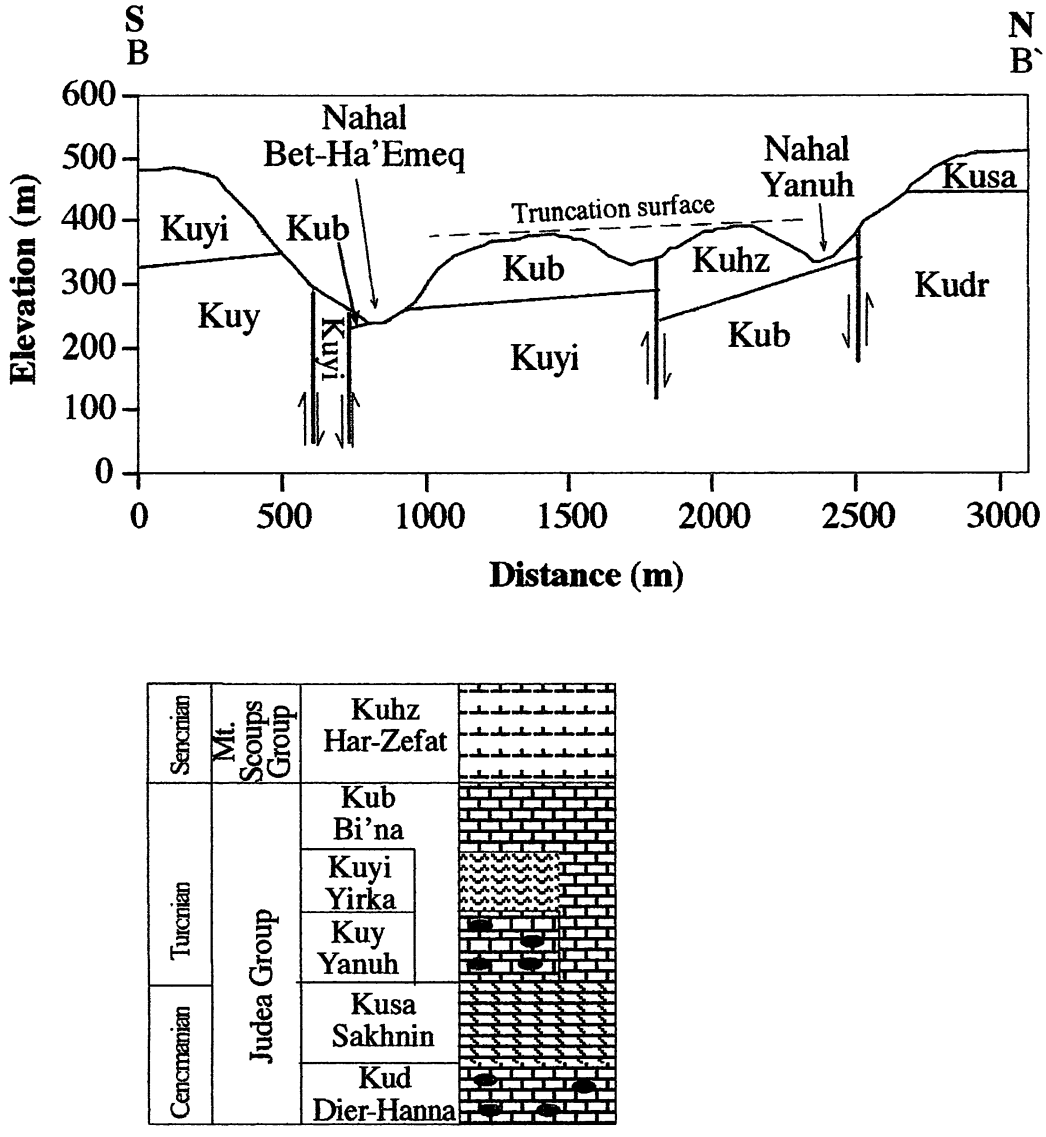


Fig. 7 – Topographic and geologic cross section across Nahal Bet-Ha'Emeq in an area of preserved Senonian units in the down-faulted block. For location of cross section see Fig. 1b. The down faulted block has been incised by the Bet-Ha'Emeq stream and its tributaries. Notice the upper surface of the remnant hills in the down faulted blocks. Modified after Kafri (1972).

Remnants of the low-relief terrain which pre-dated the present topography are observed in the Bet-Ha'Emeq graben. The summits of the rounded hills which developed in the soft Senonian units form a flat level that does not correspond to the dip of the beds but truncates them (Fig. 7).

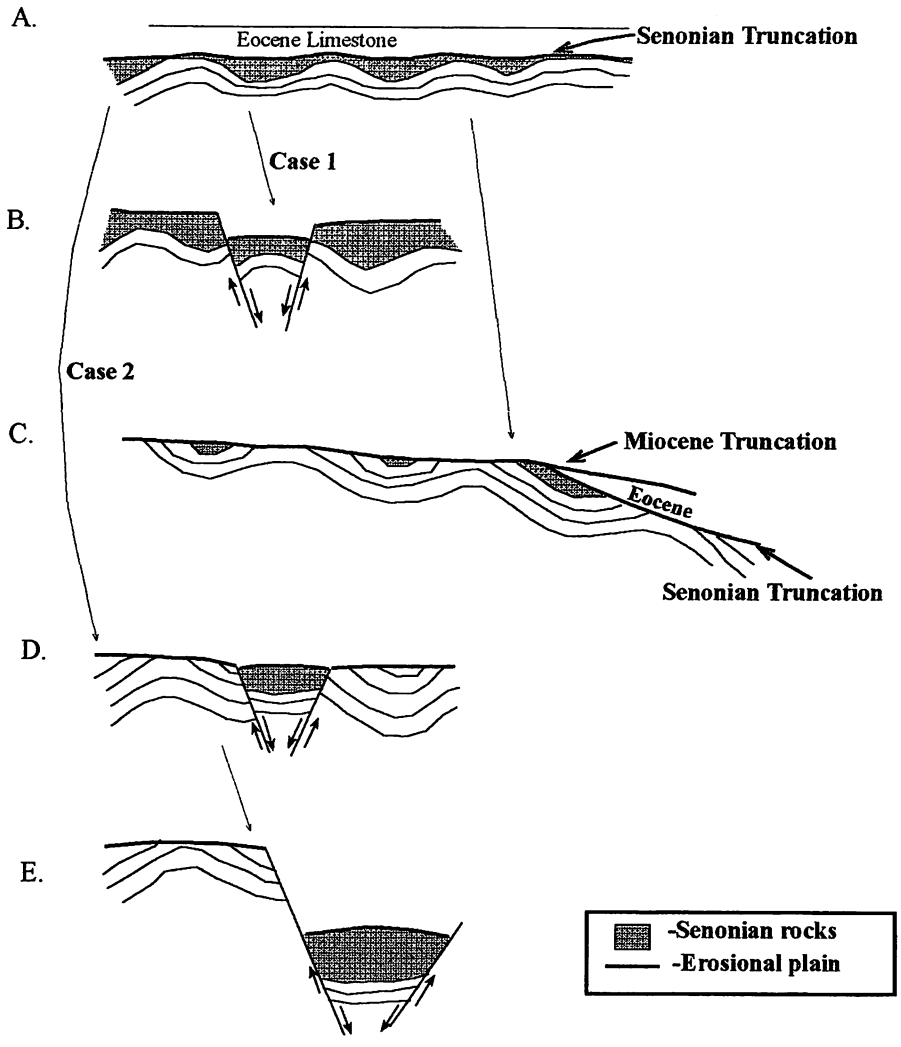


Fig. 8 – Cartoon showing the mechanism for Senonian rock preservation. A. Initial situation after the regression of the Tethys ocean. Eocene carbonate sediments were deposited over an erosional surface that developed after the deposition of the Senonian sequence. B. Case 1: Faulting and relief forming during early stages of Miocene truncation. In this case the Senonian sequence is preserved both on the uplifted and down faulted blocks. This situation does not occur in the Bet-Ha'Emeq graben indicating that faulting was not accompanied by relief. C. Ongoing truncation with no faulting. In this case the Senonian sequence is preserved only in the synclines of the pre-Eocene structure. D. Faulting during the early stages of truncation. The faulting is not associated with topography. This situation allows the on going truncation on the uplifted blocks while preserving the Senonian sequence on the down faulted block. This situation occurs when the rate of vertical displacement is equal to the rate of truncation and it agrees with field observations in the Bet-Ha'Emeq area. E. Final stage of uplifting forms the present topography.

Alluvial terraces

Alluvial terraces are rare along the slopes on both sides of the Bet-Ha'Emeq graben, which expose Upper Cretaceous rocks coated in places with calcrete. The scarcity of alluvial terraces might be related to: (a) the flow level of the drainage system occupied the surface of the graben as it was down faulted and there was no major incision phase, (b) incision phases were rapid and alluvial and rock-cut terraces were not formed, and (c) terraces that were formed were eroded from the slopes of the graben.

The terraces in the graben are confined to its western part (Fig. 9) and are situated 10 to 30 meters above the present streambed. The terraces contain well-rounded limestone, dolomite, chalk and chert pebbles and angular chert fragments. The pebbles are embedded in a highly developed calcrete coating that is currently eroding due to karst processes (Fig. 10). The thickness of the alluvium does not exceed several meters and it is deposited on benches incised into Senonian chalk at the margins of the valley (Fig. 11). The alluvial terraces probably experienced a

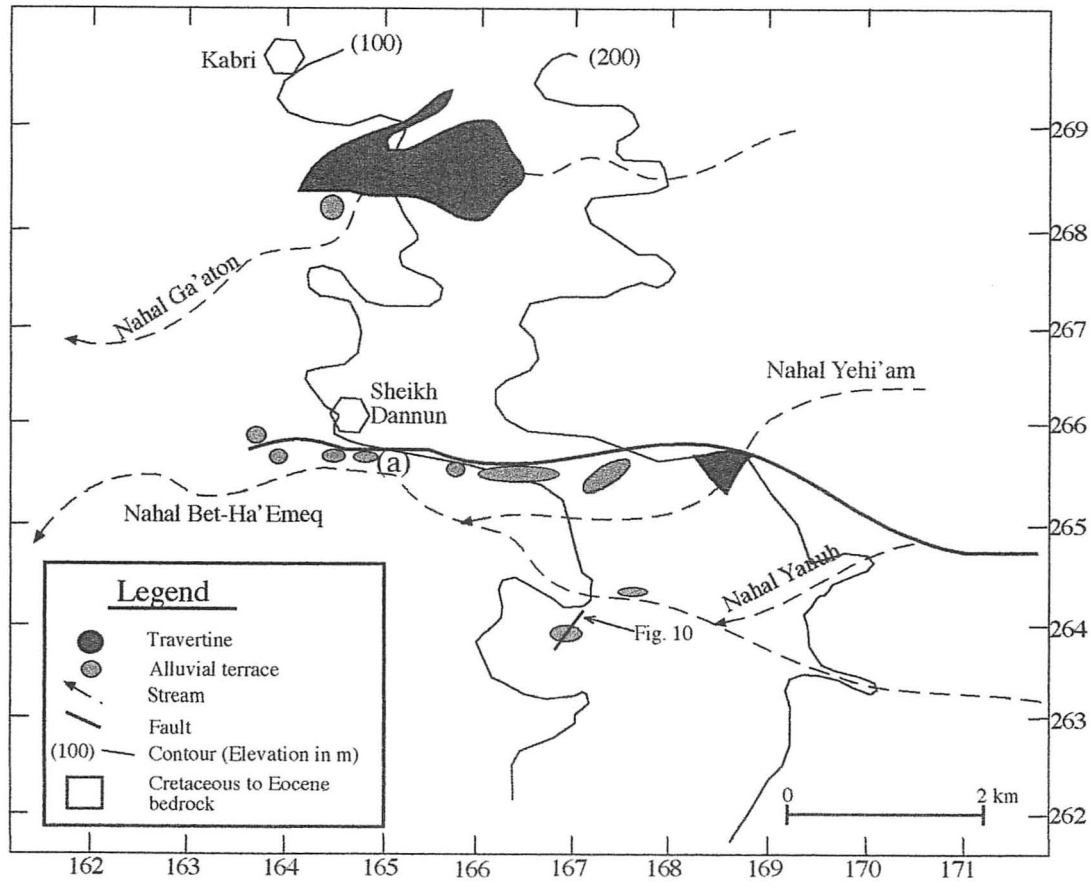


Fig. 9 – Detailed map of travertine units and alluvial terraces in the western part of Nahal Bet-Ha'Emeq.



Fig. 10 – Typical appearance of the alluvium in the terraces. The pebbles are cemented in a hard calcrete matrix. It can be seen that presently, the calcrete is disintegrating, and pebbles are being washed back to the active drainage system.

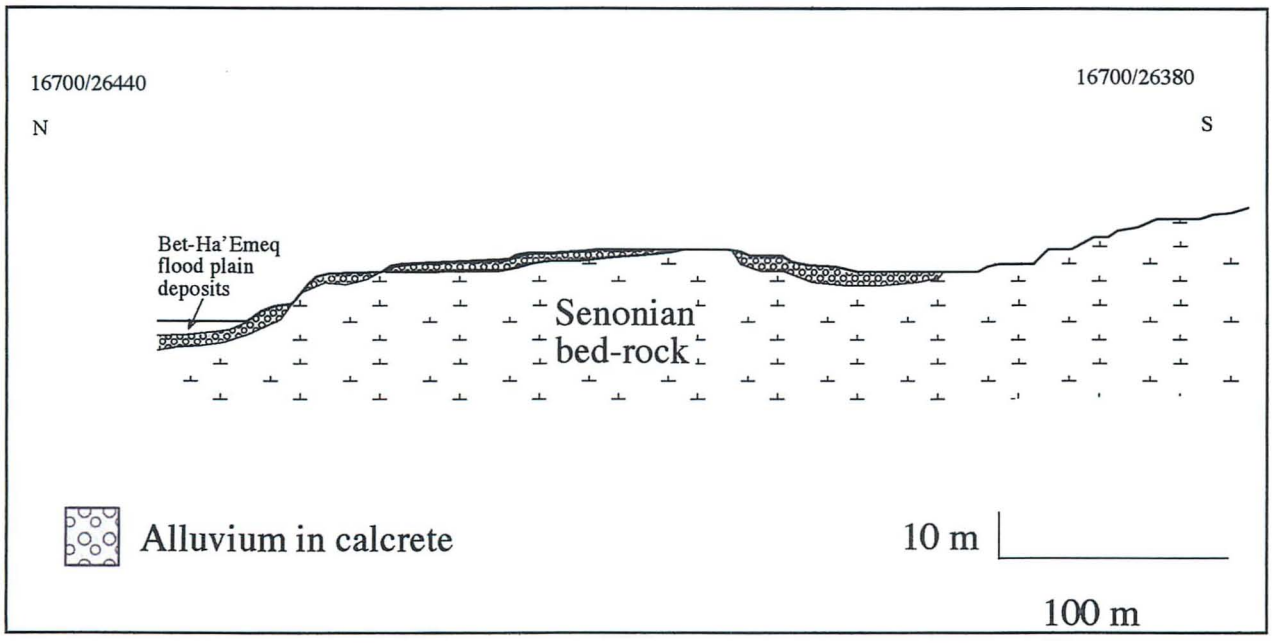


Fig. 11 – A detailed cross section of an alluvial terrace on the southern margin of the Bet-Ha'Emeq Valley. The underlying chalk is exposed at different levels of the terrace indicating that the thickness of the alluvium is only several meters, and that it is deposited on benches in the Senonian chalk.

long period of pedogenic process resulting in the development of Stage VI calcretes (Machette, 1985). In comparison to calcrete horizons in the southwestern United States, the age of the these calcrete horizons, and therefore the terraces, is at least 400 Ka (Birkeland, 1984; Machette, 1985; Birkeland et al., 1991). At site (a) in Fig. 9 (coordinates. 16540/26580 Israel Grid) the terrace leans on a relatively fresh fault scarp (Fig. 12) displacing the Upper Cretaceous Sakhnin Formation Dolomite. The freshness of the fault scarp that caused surface displacement suggests that displacement took place during the Late Pleistocene or Holocene (Gran et al., 1999) whereas the maturity of the calcrete suggests a much older age for the terrace. It should be emphasized that there is no direct field evidence to whether the conglomerate was deposited along the fault scarp or was displaced by it. Alluvial terraces, similar in texture and composition to the alluvial terraces of Nahal Bet-Ha'Emeq, are found near Nahal Ga'aton about 10 km north of Nahal Bet-Ha'Emeq (Figs. 1b and 9), about 20 meters above the Ga'aton stream bed and 10-20 meters above the Yitzhar channel bed, approximately 10 km south of Nahal Bet-Ha'Emeq.

A travertine unit, tens of meters thick, was deposited at the mouth of Nahal Yehi'am (Figs. 1b, 9; Baida, 1963; Kafri, 1972). At present, the channel Ye'hiam is incising into the travertine slowly eroding it away. The gradient of the channel in the area of the travertine beds is 5%. Similar relations between travertine units and incising channels can be seen at the mouth of Nahal Ga'aton (Fig. 9).

Discussion and Conclusions

The drainage pattern in the Bet-Ha'Emeq Valley and the preservation of a Senonian sequence on the down faulted block indicate that the activity of the Bet-Ha'Emeq faults started early in the faulting history of the region and probably earlier than most of the other normal faults in the Galilee. The tectonic and erosional evolution of the Bet-Ha'Emeq structure and the development of the drainage system in the Bet-Ha'Emeq Valley can be divided into three stages, and the rates of tectonic and erosional phases are estimated below.

Stage 1 - The beginning of denudation

The denudation of the region began sometimes after the regression of the



Fig. 12 – Alluvial material against a fresh fault scarp built of dolomite of the Sakhnin Formation. For location see point (a) in Fig. 9.

Tethys in the Late Eocene. Begin and Zilberman (1997) estimated denudation rates of the mountainous backbone of Israel from the Oligocene to the Pleistocene. They calculated a typical denudation value of 20 meters in a million years for an average relief of 100 meters (which represents the landscape in the region during the Oligocene and Miocene). The Senonian and Eocene sequence in the Galilee is 150-250 meters thick (Kafri 1972). Therefore, it would take no more than 7.5 to 12.5 million years to erode the Eocene and Senonian sequence. Regional denudation during the Oligocene was probably very limited. Evidence for initial relief and significant stripping of sediments is represented in continental sediments found along the margins of the Samaria, Judea and Negev and dated to Upper Oligocene and Lower Miocene (~ 23 Ma) (Shaliv et al., 1991; Zilberman, 1992; Buchbinder and Zilberman, 1997). Therefore, the lower part of the Senonian sequence could be exposed only in the middle Miocene, 7.5-12.5 million years after beginning of significant denudation. We shall state that our time estimates for the activity of tectonic and erosional phases in the area are minimum estimates.

Stage 2 - Normal faulting at denudation rates

As mentioned earlier, the preservation of Senonian sequence in the Bet-Ha'Emeq graben required that faulting start before the Senonian sequence was totally eroded and that the rate of faulting was compatible with the rate of denudation resulting in low-relief terrain. Therefore, faulting must have started no later than Middle Miocene probably 7.5-12.5 Myr after denudation has begun. The occurrence of Late Eocene and Early Oligocene units at the western end of the Bet-Ha'Emeq Valley indicate that it subsided and trapped sediments while the rest of the region was under erosion. The absence of Senonian units on the uplifted blocks indicates that denudation continued on the uplifted blocks south and north of the Bet-Ha'Emeq low structure after its initial subsidence. Matmon et al. (1998) demonstrated that the formation of tectonic relief in the Galilee caused a profound reduction in the denudation rates along the interfluves that established on the uplifted blocks. If substantial relief were to develop, the reduced denudation rates that would follow it would allow the preservation of Senonian rocks on the uplifted blocks. Since this sequence is totally absent from the uplifted blocks, it must be concluded that the rate of normal faulting during this tectonic phase was equal to the rate of denudation of the uplifted blocks. The drainage system of Nahal Bet-Ha'Emeq, that occupied the shallow valley at this stage, incised through the uplifting secondary blocks that developed in the Bet-Ha'Emeq low structure.

The stratigraphic displacement between the Senonian units preserved in the valley and the Cenomanian rocks exposed at the top of the uplifted blocks reaches in some places 400 meters (Kafri, 1972). Since only one third of the stratigraphic displacement is expressed by topography, it appears that about two thirds of the displacement occurred before the last tectonic phase that formed the present relief. Assuming vertical displacement rates that are compatible to denudation rates (20-25 m/Myr; Begin and Zilberman, 1997) the period dominated by low-rate displacement without forming topography lasted 10-11 million years. This calculation is subjected to several uncertain parameters: (1) The changes in rates of denudation. Begin and Zilberman (1997) estimate rates of denudation between 10-60 m/Myr since the Miocene. This range can result in much shorter or longer periods of time needed to erode the sequence missing on top of the uplifted blocks. The rate of 20 m/Myr used above is the average rate calculated by Begin and Zilberman (1997) and it is a reasonable rate for an average relief of 100 m. (2) Uncertainty of the thickness of

sediments that were removed. The thickness of the eroded section ranges between 200-400 m (Baida, 1963; Kafri, 1972). This range could shorten or extend the period of denudation by 20-25%. A thickness of 260 m of the eroded section was assumed based on structural data of the area (Kafri, 1972).

Stage 3 - The development of the present topography

The present topographic expression of the Bet-Ha'Emeq graben was formed by a tectonic phase associated with high rates of vertical displacement. Considering that denudation started ~23 Ma and lasted 7.5-12.5 Myr in stable conditions and additional 10-11 Myr under slow rate displacement, topography was formed by high rate vertical displacement within the last 5.5 Ma. This estimate agrees with the results of topographic analysis by Matmon et al. (1998) that show that most of the morphotectonic features in the Galilee began forming about 4 Ma. It should be stated again that these estimates are minimum ones and that all three stages might have occurred earlier if substantial denudation began earlier than ~23 ma.

The activity on the Bet-Ha'Emeq fault system continued through the Quaternary as indicated by the fresh fault scarp in the Sakhnin Dolomite (point a in Fig. 9), evidence for shearing in the calcrete of the Sheikh-Dannun exposure (in preparation) and a knick point where the Ye'hiam channel crosses the Bet-Ha'Emeq - Yanuh fault (Fig. 13). These observations agree with the Quaternary displacement inferred by Sivan (1996).

The correlation between the different terraces observed in the lower Bet-Ha'Emeq Valley is not certain although they are very similar in composition and texture. Whether these terraces are of the same age or not, the incision of approximately 20 meters below the terraces by the recent drainage systems (Bet-Ha'Emeq, Ga'aton, Yitzhar) indicates a response to a regional change in base level and is not directly related to local activity of the Bet-Ha'Emeq fault system. The incision into these terraces reflects a regional tectonic phase such as the ongoing arching of the Galilee (Matmon et al., 1999) or a fall of sea level.

The travertine at the intersection of the streams of Nahal Ye'hiam and Nahal Bet-Ha'Emeq (Baida, 1963; Kafri, 1972; Fig. 9) could not be deposited in a drainage configuration similar to the present one because of the steep gradient. At this gradient the fast flowing floodwaters of the ephemeral channel cannot precipitate $CaCO_3$ and accumulate the travertine (Heimann, 1985). A gentler gradient, which could be

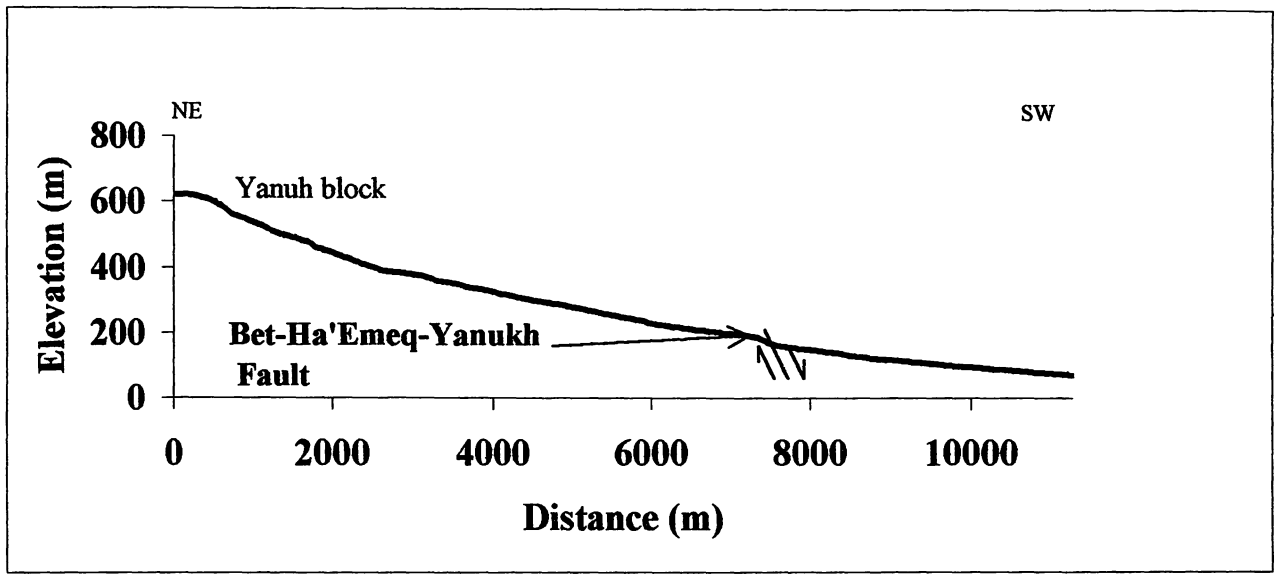


Fig. 13 – Topographic cross section of the Ye'hiam stream. A nick-point occurs where the northern normal Bet-Ha'Emeq - Yanuh fault crosses the stream.

achieved by a higher base level would result in a lower gradient of Nahal Yehi'am and allow slower flow and enable the deposition of the travertine unit. This higher base level could have existed before Nahal Bet-Ha'Emeq incised to its present level, possibly as a result of regional uplift. Similar relations between travertine units and incising channels are described in the northern Hula Valley (Heimann, 1985) and observed at the mouth of Nahal Ga'aton to the coastal plain and in the eastern Bet-Kerem Valley.

The elevation of the alluvial terraces along the western part of the Bet-Ha'Emeq Valley increases from 65 meters above sea level in the west to 115 meters above sea level in the east resulting in a gradient of 1.4%. This gradient is similar to the gradient of the active channel in this area (Fig. 14). The similarity in gradients indicates that the amount of uplift along the western part of the Bet-Ha'Emeq structure is uniform and that the axis of uplift is not located in or close to the part of Nahal Bet-Ha'Emeq where the alluvial terraces are but farther to the east.

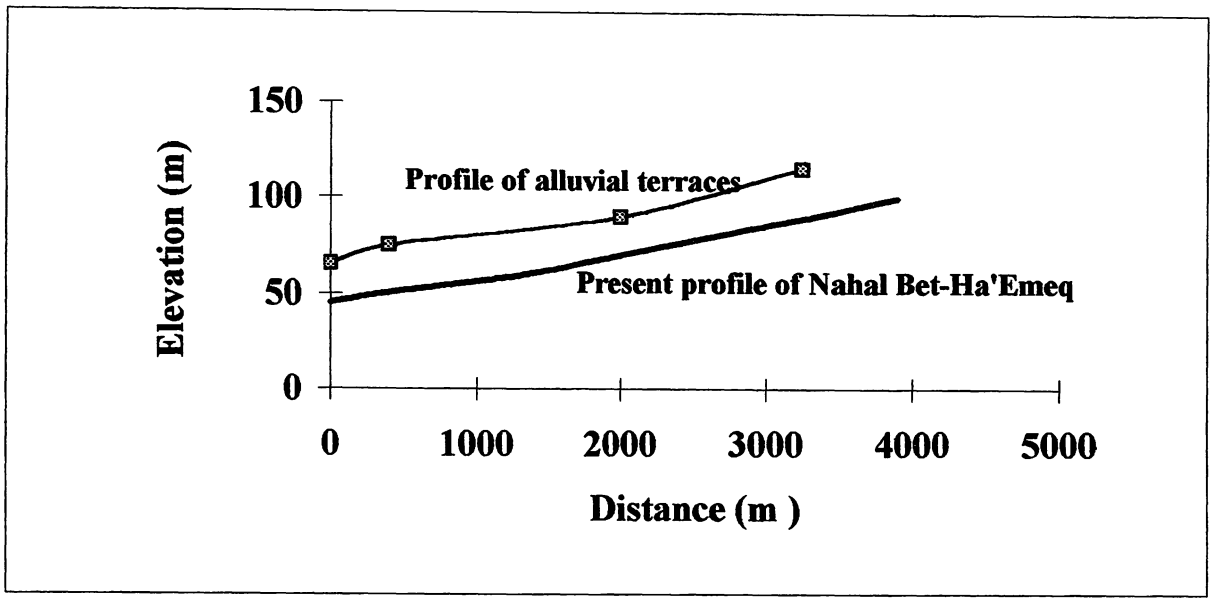


Fig. 14 – Comparison of the gradient of the western part of the present Nahal Bet-Ha'Emeq with the reconstructed gradient of alluvial terraces above Nahal Bet-Ha'Emeq.

Summary

The Bet-Ha'Emeq Valley is bounded by escarpments formed by normal faults and is a dominant topographic feature in the western Upper Galilee. The topographic relief of the Bet-Ha'Emeq normal faults is unique in the Upper Galilee where most of the faults have no topographic expression. The geometry of Nahal Bet-Ha'Emeq is controlled by previous and recent tectonic structures related to the Bet-Ha'Emeq fault system. The primary subsidence along the Bet-Ha'Emeq fault system probably initiated prior to the formation of the Bet-Kerem Valley and the tilting of the Upper Galilee. The preservation of Senonian units on the down faulted block in the central Bet-Ha'Emeq Valley and Late Eocene to Early Oligocene sediments at the western end of the valley suggest that subsidence began in the Middle Miocene (~15 Ma) and maybe even earlier, before these units were completely eroded from the area. The drainage system that occupied the Bet-Ha'Emeq Valley incised through the uplifted blocks that developed within the Bet-Ha'Emeq low structure. The ancient headwaters

of the Nahal Bet-Ha'Emeq drainage system are located in the uplifted block of Bet-Jann. They were disconnected from the rest of the drainage system due the activity of the Peqi'in and Sumi faults and the formation of the Peqi'in Valley. The vertical displacement along the Bet-Ha'Emeq- Yanuh fault appears to have continued through the Quaternary. Even though this activity cannot be precisely dated it is evident by a fresh fault scarp in the Sakhnin dolomite close to the western end of the Bet-Ha'Emeq Valley (Fig. 12) and by the knick-point of Nahal Ye'hiam in the Pleistocene travertine units (Fig. 13; Kafri, 1972).

Incision into alluvial terraces at the western reach of the Nahal Bet-Ha'Emeq as well in other adjacent drainage systems may indicate the response of the fluvial systems to the regional uplift of the Upper Galilee platform. The uplift is manifested in the steep gradient of the Upper Galilee streams.

In spite of the scarcity of Neogene and Quaternary sediments in the Bet-Ha'Emeq drainage system, morphometric analysis enables the detection of tectonic activity and increases the understanding of the relation between tectonic activity and surface processes.

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