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Middle Pleistocene to Holocene Tectonic Activity along the Carmel Fault - Preliminary Results of a Paleoseismic Study

[1]Ezra Zilberman, [2]Noam Greenbaum, [1]Yoav Nahmias, [1]Naomi Porat, [1,2]Lana Ashqar

1- Geological Survey of Israel
2 - Haifa University

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1. Introduction

The Carmel fault runs along an ancient suture line that separate between two different geological provinces: The northern province, which includes northern Israel and Lebanon is characterized by a thin crust (about 23 km) while the southern province that includes the microplate of Israel and the Sinai peninsula (Salamon et al., 1996), has a thicker crust (more than 30 km) (Ginzburg and Folkman, 1980; Ben Avraham and Ginzburg,1990; Hofstteter et al, 1991).These two provinces differ in their structural character, seismic activity and style of topography (Achmon and Ben Avraham, 1997). This tectonic boundary is suggested to be a regional important structure since the Palaeozoic (Ben Avraham and Ginzburg, 1990), The Jurrasic (Derin, 1974), or Cretaceous (Kafri and Folkman, 1981).

The Carmel tectonic line shows a relatively high seismic activity (Ben Menhaem and Aboody, 1981; Shapira and Feldman, 1987, VanEck and Hofstteter, 1990), and is considered by De Sitter (1962), Freund, (1970), Garfunkel et al., (1981), and Hofstetter et al. (1996), among others, as a seismically active branch of the Dead Sea Transform (DST).

The origin and the age of the Carmel fault is a source of controversy. Some connected its origin to the Dead Sea Rift during the Middle Miocene and considered it as a left lateral strike slip that branches from the DST and transfers part of the sinistral movement to the Levant continental margin (De sitter, 1962, Fruend, 1970, Rotstein et al., 1993; Schattner et al., 2006). Others suggested that it predated the DST and was established during the opening of the Red Sea as part of the NW oriented "Erythrean" tectonic system (Picard, 1931; Picard and Kashai, 1958; Horowitz, 1979; Schattner, 2005).

The tectonic domain of the Carmel fault and its sense of displacement are also under debate. Ron (1984) and Ron and Eyal, (1985) concluded that the structure of the Galilee and the Carmel regions was developed under a Miocene stress field of E-W σ_{Hmax} and Pliocene to recent N-S extensional stress field. A later work (Ron et al., 1990) explained the Carmel structure as a result of a uniform stress field where σ_{Hmax} is in E-W direction.

Matmon et al., (2003) suggested that the structures of the Lower Galilee, Yizre'el Valley and the Carmel have developed since the Early Miocene under continuous extensional domain. This model is in contrast to the sinistral movement of some of 3-

4 km, which was estimated for the Carmel fault by Arad (1965), Fruend, (1970), and Rotstein et al., (1993), of which about 300 m are considered by Achmon (1986) as a young motion, which displaces stream channels.

Sinistral offset of alluvial fans and streams was described by Achmon (1986) and Gluck (2001) from the northeastern mountain front of the Carmel. A left lateral component also characterizes some of the recent earthquake epicenters detected along the northwestern segment of the Carmel tectonic line (Hofstteter et al., 1996). The focal plane solution of the present seismic activity of the fault is therefore in accord with the model suggested by De-Sitter (1962), Fruend (1970) and Schattner (2006) to the entire fault system along the Carmel Line and the Carmel Block. However, relocation of earthquakes epicenters that occurred in this seismogenic zone since 1984 by Shamir, (2006), found a diffuse distribution of the epicenters, with the moderate activity taking place mostly north-east of the mapped fault line.

The Carmel fault crosses the down town of Haifa, and runs just south of the chemical industry area of the Haifa bay, and therefore is a potentially source of a seismic hazard for this highly populated region..

The aim of the present research was to study the young (Pleistocene-Holocene) paleotectonic activity in selected sites along the Carmel fault system by conducting a paleoseismic analysis.

Two tectonic elements were analyzed in the present stage 1. The Nesher fault, which is a branch of the Carmel Fault and 2. The N-S oriented segment of the Carmel Fault running between Yoqneam and Jalame (Fig. 1).

In the first site we trenched a young alluvial fan that was deposited on the fault trace; in second site we dated sediments that were accumulated beyond a Shutter Ridge, which formed by a sinistral displacement along the Carmel Fault (Achmon, 1986; Ashqar et. al., 2006: Ashqar et al., in prep.).

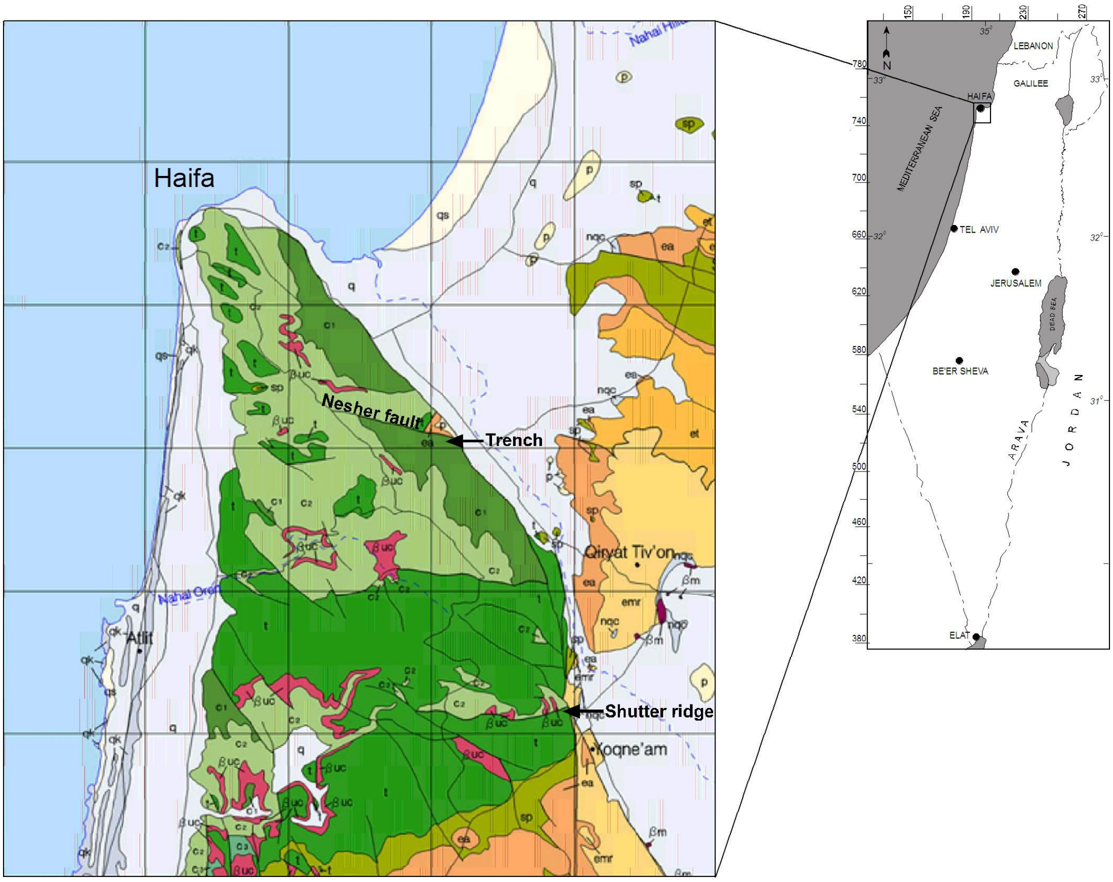

Fig. 1 – Location map of the study sites

2. The Nesher Fault

2.1 Geological background

The Nesher fault is a 5 km long, WNW (110^0) oriented normal fault, that diverges from the NW oriented Carmel (Yagur) fault between Kibbutz Yagur and the Nesher cement industry complex, and extends up to the water divide of the Carmel (Figs 1, 2). The fault was described by Picard (1931), Picard and Kashai (1958), Kashai, 1966, and was mapped by Karcz (1959).

The Nesher fault displaces the Early Eocene Adulam formation against the lower part of the Early Cretaceous Yagur Formation, a vertical offset of about 1000 m. The orientation of the Nesher fault is similar to a series of NW to WNW oriented normal faults that cross the Carmel block, of which the main ones are the Isefiya and the Muhraqa fault systems (Picard and Kashai, 1958, Kashai, 1966). A Pleistocene age was attributed, without field evidence, to the Nesher fault by Picard and Kashai (1958).

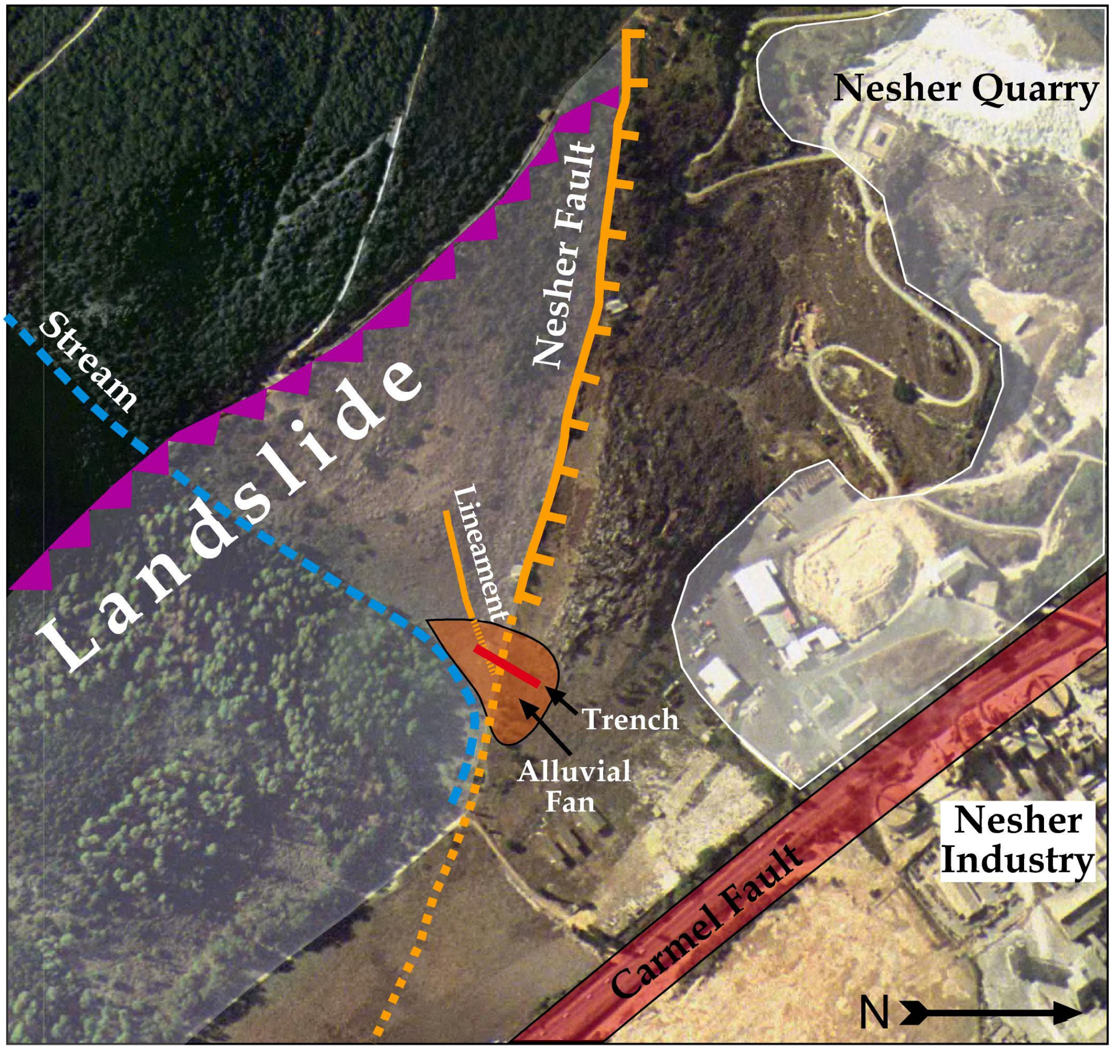

Fig. 2 – Tectonic and morphologic elements in the study area

The Nesher fault branches of the main Carmel fault, which runs in this area in NW direction under Bar Yehuda Road (Salamon, 2000), somewhere between Yagur and Nesher. The eastern part of the Nesher fault is hidden under young alluvial sediments and it is exposed in the study site near the Moslem cemetery of Nesher (coords. 2057574040). At this site the fault runs along the northern margins of a large landslide (Ashqar, in prep.) and displaces rocks of the Yagur Formation versus chalk and marly chalk of Latest Paleocene to Early Eocene Adulam Formation. The Paleocene-Eocene sequence is steeply tilted (60-75^0) to the north-north east (Azimuth 10-20^0). The rock trace is manifested in this area as a vertical smooth fault plain (Fig. 3) mantled by breccias.

At the western point of the exposed fault plain (coords. 2052574050), a colluvial apron, cemented by calcrete, faces the plane on its northern side. This colluvium is dissected by the fault near the fault plain and the hard top of the calcrete is tilted toward the fault (Fig. 4), a position which might reflects a small displacement. Small-scale horizontal slickensides were found on a slab of dissected colluvium near the fault plain (Fig. 5).

Fig. 3 – The Nesher fault plane west of the trench

Fig. 4 – Vertical displacement of calcrete crust by the Nesher fault (coords 2052574050)

Further to the west the fault is expressed as a wide shear zone, several tens of meters wide, associated with brecciated fragments of the Yagur dolomite. Near the western margins of the Nesher Quarry (cords 205023/740581), at altitude of 90-100 m, the fault deforms a well bedded Late Miocene to Pliocene marine sequence.

The fault was recently exposed in the upper Carmel (coords. 2018074140) in a foundation pit dug into the Shamir Chalk (Fig. 6). In this area the fault forms a shear zone about 30 m wide, but its vertical displacement is small (Karcz, 1959).

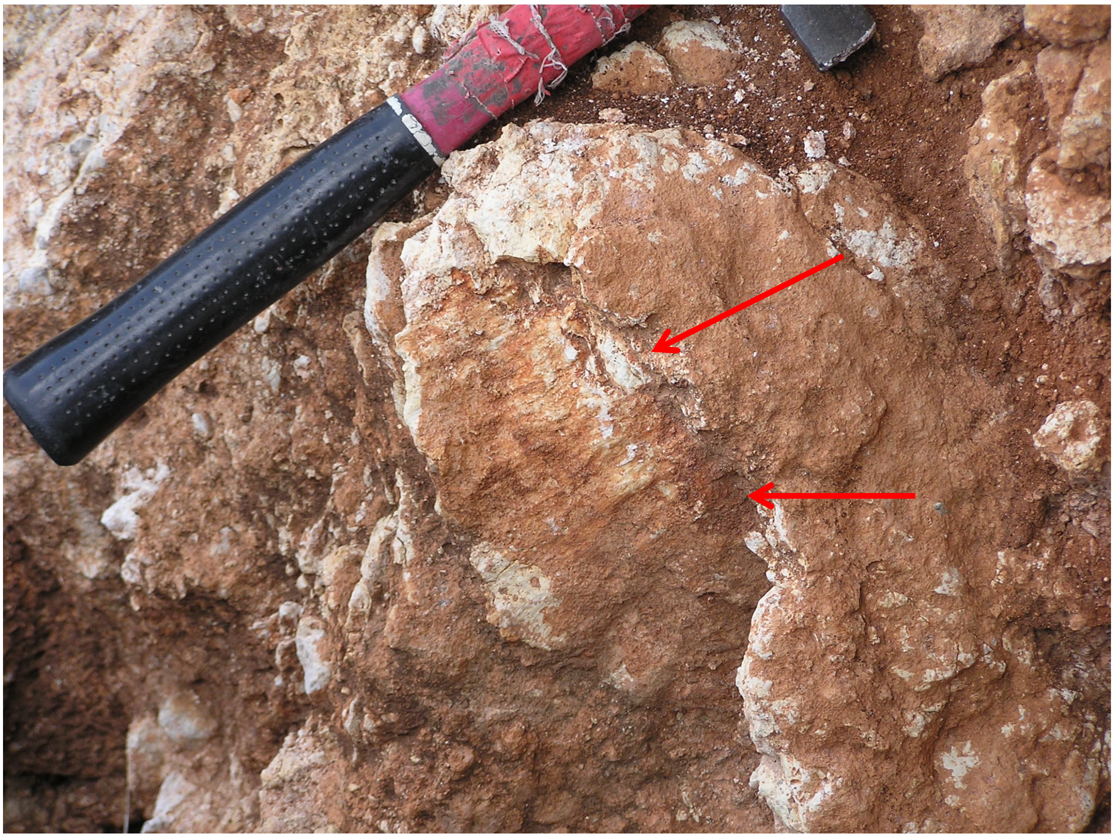

Fig. 5 – Subhorizontal slickensides on the fault plane of the Nesher fault (for location see fig. 4)

According to the map of Karcz (1959), the fault terminates near the Carmel water divide. However, this point requires further investigation since the wide shear zone in this area suggests that this is not necessarily the tip of the fault.

Since the Nesher Fault is considered a branch of the Carmel Fault (Kartcz, 1959; Picard and Kashai, 1966), it is believed that paleoseismic results obtained from this fault will also be relevant to the evaluation of the recent tectonic activity of the Carmel fault.

Fig. 6 – Exposure of the Nesher fault plane in a foundation pit of a building in the junction between Oskar Shindler road and Mendel Zinger St.

2.2 The Trench site

The study site is located at the northeastern foot of the Carmel Mt., where the Nesher fault is covered by a small abandoned alluvial fan (Figs. 2, 7). The alluvial fan was deposited by a small stream that drains the eastern slope of a large-size landslide that transported a thick sequence of the Yagur dolomite down the Carmel slope. At present the stream channel flows in a narrow channel incised along the southern margins of the alluvial fan.

The alluvial fan was cultivated during recent times and its surface was modified by artificial channels and terraces. Remnants of a Byzantine-Roman building were found on its northern part, but in most of the area only the uppermost part of the sequence (50-100 cm) was disturbed.

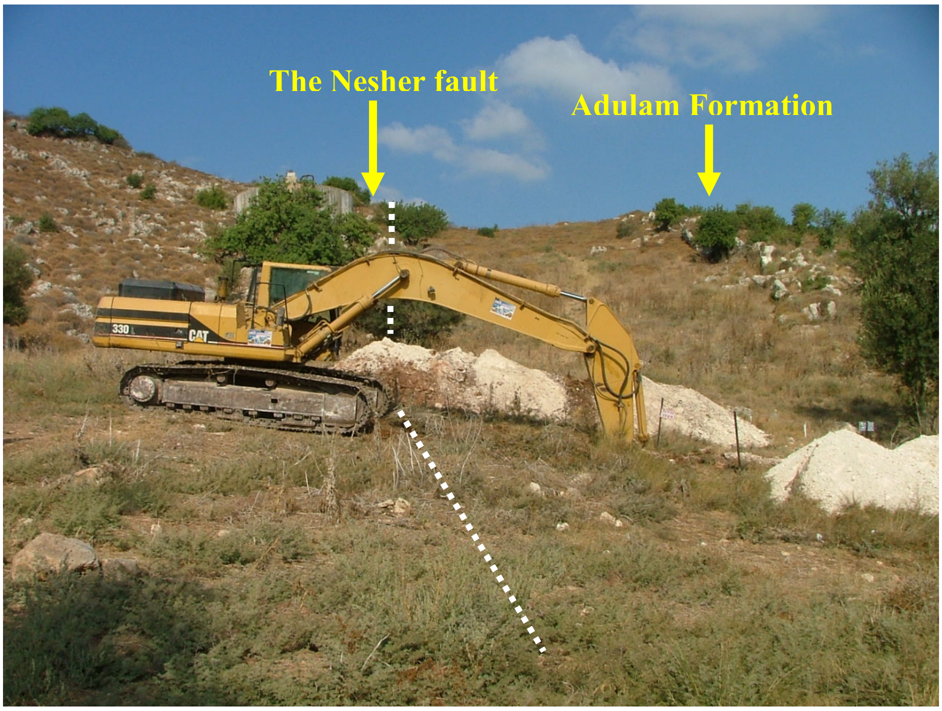

Fig. 7 – The Trench site. A view to the northwest

Two parallel trenches, each about 35 m long, were excavated a few meters apart perpendicular to the fault trace. Additional short trench was excavated in the eastern part of the study area. The two walls of the western trench were mapped at a scale of 1:20 (Figs. 9, 10), and the sedimentary units were described and sampled for dating in the GSI thermoluminiscence laboratory using the OSL method.

2.3 Unit description (Figs. 9, 10).

The sequence exposed in the trench can be divided into two main parts separated by the Nesher fault. North of the fault, young Holocene sediments overly directly a truncated chalk sequence of the Early Eocene Adulam Formation. South of the fault a thick (4-5 m) alluvial-colluvial sequence is exposed.

The OSL ages do not always match the stratigraphic order and therefore the present interpretation of the sequence should be considered preliminary until additional OSL ages are obtained.

The Eocene Bedrock

Rocks of the Late Paleocene to Early Eocene Adulam Formation are exposed in the northern part of the trench. Three facies can be distinguished in this sequence: In the north (33m-35m on the wall), the sequence consists of hard, white chalk, intensively fractured with black and reddish oxides staining on fracture planes. Chert layers and horizons of chert concretions (5-10 cm thick), are interbedded in the chalk, dipping 75-80^0 to the north (azimuth 90-100^0). The chert is generally intensively fractured and some horizons are offset by few cm horizontally. Reddish fine clastic materials and roots are penetrating along the crushed chert layers.

The middle part of the outcrop (33m-28m on the wall) consists of soft, white massive chalk. No fractures are observed in the chalk, but it contains intensively fractured layers of chert nodules, steeply tilted (60-70^0) to the north. Reddish fine clastic materials infiltrate along the fractured chert layers.

The southern part of the outcrop (28m-18m on the wall) is composed of fragments of white chalk mixed with marl. The chert layers are less developed dipping 70-75^0 to the north. Sub-vertical fractures, filled by reddish fine clastic sediments and roots, form a shear zone between 21m and 16m on the log.

The transition Zone and Unit 1

This unit is exposed in the lower part of the trench. Its contact with the Adulam Formation chalk is sub-vertical and it is located on the eastern extrapolation (azimuth 110^0) of the Nesher fault plane, exposed some 50 m to the west (Fig. 8).

The facies of this unit changes gradually southward away from its contact with the chalk of the Adulam Formation. Near the contact (14m-16m on the log of the western wall and 14.5m-12m on eastern wall) it is composed of matrix supported, angular clasts with frequent size of 1-3 cm. The clasts are composed of chalk, chert, bituminous-chalk, chalky limestone and in the upper part some dolomite. The amount of chalk fragments increases towards the bottom.

To the south, away from the contact with the Adulam Formation, the amount of clay increases and the unit gradually passes to a vertisol, which contains some floating rock gravels. The vertisol is composed of massive clay with blocky-prismatic structure (when dry). The dry color at the top - 2.5YR3/4 dark reddish brown and at the bottom – 5YR6/3 light reddish brown. It contains disorthic, gray to brown, hard calcic nodule (1-5 cm), which consists of series of concentric laminas with central void coated with calcite crystal forming a geode like structure. The carbonate also forms bridges and partial coatings on the bottoms of the clasts. The amount of carbonates nodules increases towards the bottom of the unit to form stage II-III. It contains also manganese and iron concretions up to 0.5 cm in size and small, 1-2 cm, clay mud-balls cemented by carbonates. The unit is compacted and hard when wet and friable to slightly hard when dry. The OSL age of the vertisol is 176±30 ka.

Interpretation - The unit may be a south-facing triangular colluvial wedge, which is related to an unclear, highly brecciated and weathered wide faulting zone located between 16m and 17 m on the western wall.

Fig. 8 – The transition zone (White color – Adulam Formation; Brown color – colluvial and alluvial sediments)

Unit 2

Unit 2 unconformably overlies unit 1 with a clear contact and is overlain by unit 3 with gradual undulating contact. It is 1-2 m thick, tilted southward and disappears under the trench bottom.

Unit 2 is poorly stratified, consisting of moderately sorted gravel, which forms clast supported gravel (composing 50-60% of the sequence) in its upper part, and matrix supported gravel, (composing 20-30% of the sequence) at the base of the unit. Most of the gravels are dolomite and some are limestone ranging from pebbles up to boulders of 80 cm in size; frequent size – 5-15 cm. Occasional local imbrications occur mainly at the base of the unit at the back of larger boulders.

The matrix is composed of dark brown clay (dry color – 2.5YR3/3 – dark reddish brown) with small rock fragments of sand to grit size. Small (1-2mm) rounded fragments of black manganese and iron oxides are scattered in the clay. It usually contains small carbonate nodules up to 0.5 cm in size and few larger disorthic nodules up to 2-3 cm; larger amounts of carbonates are disseminated in the matrix, forming stage III paleosol. The unit is very compact, but is slightly cemented. The clasts are coated by clay, which include carbonate concentrations. The OSL age of Unit 2 is 112±6 ka.

Interpretation – Unit 2 has characteristics of a debris-flow derived through the adjacent channel from the mountain slopes at the south. Unit 2 truncates unit 1 and is overlain by unit 3. The inclination of this unit to the south, opposite the flow direction, probably reflects a post deposition tectonic displacement. The northern end of the unit may have also been uplifted along the Nesher fault.

Unit 3

Unit 3 unconformably overlies unit 2 and is truncated in the western wall by unit 4 and in the eastern wall by units 4, 5 and 6. In the western wall and part of the eastern wall it is exposed on the surface where its upper part is weathered and disturbed.

Unit 3 consists of massive, reddish-brown (dry color – 5YR3/3 – dark reddish brown) clay unit, which contains up to 10-15% clasts up to 10 cm in size. The clasts are composed mostly of dolomite gravels and small reddish carbonate concretions. The clay has prismatic structure manifested by deep vertical cracks forming columnar structure, with slickensides on fracture planes. There are no clear pedogenic horizons in the sequence and it contains two types of calcic nodules: 1. hard brown disorthic, multiphase calcic concretions (5-6 cm) with variable shapes (from sub-rounded to flat), which show internal concentric laminar texture with central or peripheral voids coated by calcite crystals forming geode-like structure. The outer part of the nodules is reddish-brown and the concentric layers are paler from inside to outside. The external layers are grayish in color and are composed of the youngest carbonates.

Some of the concretions are already weathered by solution and form micro-speleothems within the void. This type of nodules is more common in the lower part of the sequence. 2. Orthic, soft, white calcic nodules (3-5 cm) disseminated in the clay, especially along cracks. These nodules show no internal structure and their number increases in the middle and upper part of the vertisol. Some clasts are partly coated by reddish and/or grayish carbonates. The clay contains also manganese and iron concretions up to 0.5 cm in size. The unit is compact but slightly cemented.

EpiPaleolithic chert microlites were found at point 10.5m on the log of the eastern wall, about 0.8 m below the top. This type of tools is typical to a prehistoric culture dated to 20-10ky BP (Ronen, A., pers. comm, 2006). It is not clear if these tools are found in situ or they were penetrated from the surface into the clay sequence through seasonal open fractures.

Three samples were taken for OSL dating from the eastern wall between 5.5m and 6.5 m on the wall, where the unit thickness is maximum: sample No. 13 at the base of the unit yielded an age of 137ka ±19; sample No. 14 at the middle part of the unit, yielded an age of 69ka ±7; sample No. 15 at the top of the unit, yielded an age of 48ka ±4.
Three samples were taken from the western wall. The Lower most sample (No 19), yielded an age of 73ka ±4; sample No 20 form the middle part of the sequence, yielded an age of 52ka±2; sample No. 21 from the upper most sequence yielded an age of 27ka±1.The age of the vertisol that underlies unit 4 in the western wall (sample 17), is 75ka±4ka.

Interpretation – Unit 3 is an alluvial-colluvial clay unit that filled a slowly subsiding structural depression and developed into a cumulic Vertisol with carbonate nodules. The tectonic depression was developed south of the Nesher fault due to the southward tilting of unit 1, toward the southern fault. The accumulation of this unit terminated when the subsidence stopped and therefore, the age of its upper indicates end of the tectonic activity along the Nesher fault.

Unit 4

Unit 4 unconformable overlies unit 3 with a clear contact and is overlain by unit 5 with gradual undulating contact in the western wall and is truncated by unit 5 in the eastern wall. It is up to 2 m thick, horizontal, and appears only south of 3 m on the log. In the western wall it terminates abruptly, forming a 2 m high vertical contact with unit 3.

Unit 4 has the same lithological characteristics as unit 2. It is poorly stratified, consisting of moderately sorted gravel, which forms clast-supported gravel (composing 50-60% of the sequence). Most of the gravels are dolomite ranging in size up to 60 cm. The gravels are coated with clay and very little carbonates.

The matrix is composed of dark brown clay (dry color – 5YR3/3 dark reddish brown) with small rock fragments of sand to grit size. It contains little carbonates and few small carbonate nodules, and small manganese and iron concretions. The unit is very compact, but slightly cemented. The OSL age of Unit 4 is 41ka±2.

Interpretation – Unit 4 has characteristics of a debris-flow derived through the adjacent channel from the mountain slopes at the south. However, its morphological position in relation to Unit 3 is not entirely clear. It might represents a fill of a channel entrenched in the clay of Unit 3, although the vertical contact with this unit can not be easily understood through this interpretation.

Unit 4a *(The western wall)*

Unit 4a overlies unit 4 with a gradual contact. It consists of gravel floating in clay and silt matrix. This unit disappears near the southern edge of the trench (0 on the western wall) and its thickness increases toward 3 m on the wall, where it terminates abruptly, forming a vertical contact with unit 3. It is not clear if this is the upper part of Unit 4 or a separated unit.

Unit 5

Unit 5 is exposed in the southern part of the trench between 0 and 3 m on the western wall and between 0 to 9 m on the eastern wall, where it overlies a clear truncation surface. The unit is 0.3-1.2 m thick consisting of angular dolomite gravel up to 30 cm in size (frequent size 6-7 cm.), in clast-supported or matrix supported structure.

A stage II-III calcic horizon about 40 cm thick developed above the lower contact. Clay and silt matrix with granular texture fills the voids between the coarse gravel (dry color – 7.5 YR4/4 dark brown). The matrix contains increasing amounts of carbonates towards the base of the unit where a stage II-III carbonate soil developed. This calcic horizon includes 40% gray angular nodules 2-3 cm in size, carbonate bridges and carbonate coatings are found at the bottoms of clasts. The unit is compact and slightly cemented. In the western wall the upper part (50-60 cm) is disturbed.
The OSL age of this unit in the eastern wall (sample 16) is 78 ka ±8.

Interpretation – Unit 5 is a coarse alluvial unit probably derived through channel from the mountain slopes at the south. The stage II-III carbonate soil at the base of the unit indicates relatively longer exposure time and no significant deposition. The age of this unit is older than that of the underlying units 4 and 3, and therefore it should be treated carefully. Such inverse order of ages can be explained by a deposition of debris flow, which delivered older colluvial materials from the nearby slopes, or caused by a problem in choosing the sampling site within the unit.

Unit 6 *(The eastern wall)*
This is a small gravel lens, which accumulated near a north facing step in the chalk of the Adulam Formation (between 29m and 33 m on the eastern wall).

Unit *7 - The upper cover*
Young colluvial sediments overly the sequence of the trench (units 1-6), as well as the truncated chalk of the Adulam Formation. This unit is mantled by a dark-brown horizon of an undeveloped brown (moist color – 5YR3/3 dark reddish brown) soil consisting mainly of clay, silt, organic materials and dense root framework. This organic rich horizon is 10-50 cm thick with granular texture, and it is mostly disturbed. In the northern part of the trench this unit contains pieces of pottery.
In the western wall the upper cover is undivided while in the eastern wall it was subdivided to three units.

Subunit 7a(The eastern wall)

Subunit 7a is exposed in the southern part of the trench. It is 0.6-1 m thick and overlies unconformable units 5 and 3 in the eastern wall with clear and wavy contact, probably associated with slight truncation.

It is consists of poorly stratified and sorted, matrix supported coarse gravel (40-50% of the sequence) up to boulders of 50 cm, with occasional imbrications. The gravels are composed mainly of dolomite.

The silty-clay brown (moist color – 5YR4/4 reddish brown) matrix contains disseminated carbonates, carbonate nodules up to 1 cm in size and partial carbonate coatings at the bottom of some gravels (stage I+) at the base of the unit. At the uppermost 70 cm the unit is disturbed by human activity and contains roots. The unit is compacted at the lower part and is slightly cemented and friable at the upper part.

Interpretation – The structure of this coarse unit may suggest debris flow, probably derived through the channel from the mountain slopes at the south.

Subunit 7b (The eastern wall

This unit is exposed in the central part of the eastern wall of the channel. It overlies with clear contact the truncated chalk of the Adulam Formation (from 25-26 m and from 29-33 m on the wall) and is overlain by unit 7c.

Subunit 7b is consists of 0.2-0.5 m thick, poorly stratified and moderately sorted, matrix supported gravel up to 8 cm in size (composing 20-30% of the sequence). The gravels are composed of dolomite, limestone, chert and chalk.

The clay loamy matrix is brownish (moist color – 7.5YR4/4 dark brown) and contains large amounts of disseminated carbonates and carbonate concentrations in the form of miceliae. The amount of carbonate increases towards the bottom of the unit near the relatively impermeable bedrock. The unit is slightly cemented.

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Interpretation – The unit fills rectangular depressions which were excavated in the bedrock and are related to the Roman-Byzantine period. A Roman-Byzantine structure was found at the northern end of the eastern trench.

Subunit 7c (The eastern wall)

The unit is 0.4-1 m thick and extends from 29-35 m on the log. It unconformably overlies unit 7b and the truncated chalk of the Adulam Formation with clear contact. At few places a thin calcareous crust (Calcrete?) coats the contact with the chalk.

It is poorly stratified, moderately sorted, matrix supported, 10-20% gravel up to 6-7 cm in size. The gravels are composed of dolomite, chert, limestone and chalk floating in a friable-slightly cemented, loamy clay matrix, The unit contains plenty of pottery fragments and some prehistoric chert tools.

Interpretation – This is a colluvial unit, which was probably deposited during the Roman-Byzantine period.

2.4 Discussion

Two different sequences are exposed in the walls of the trench, separated by the Transition Zone, which is located on the extrapolated trace of the Nesher fault. A truncated, northward tilted sequence of the Early Eocene Adulam Formation builds the walls of the trench north of the Transition Zone and a southward slightly tilted alluvial-colluvial sequence is exposed on its southern side.

The northward tilted sequence of the Adulam Formation is truncated and covered by young soil and gravel, which contains pottery fragments. This sequence is not disturbed by the fault.

The deformation of the Adulam Formation increases toward the Transition Zone. In the southern part of the trench the Adulam Formation is densely fractured and lateral offset of few tens centimeters were observed in the Hard chalk. Near the transition zone all the chert layers and chert nodules are intensively crushed and a few meters wide zone of composed of breccias of chert and marl is attached to the contact with the alluvial sediments. We interpret the Transition Zone as a shear zone which marks the trace of the Nesher fault although no clear fault plane is observed, probably due to the soft marl and chalk lithology.

The gradual transition from colluvial-like sediment near the transition zone to a vertisol further southward (unit 1), suggests that a small depression developed near the fault during its deposition. This subsiding small basin served as a local sedimentary trap for fine clastic sediments, which transported by runoff from the near slope, and also for wind blown dust.

Unit 2 is a debris flow that originated from a colluvium that was accumulated on the nearby Carmel slope, which is built of dolomite of the Yagur Formation. It was deposited in a single event on the alluvial fan forming a 1-2 m thick gravel layer. Its lower contact manifests a flat surface of the alluvial fan during its deposition, indicating that the previous tectonic depression south of the fault was filled by sediments.

The tectonic activity was renewed after the deposition of unit 2. Unit 3 was accumulated in a slowly subsiding depression, which developed south of the Nesher fault. The southern boundary of this depression is not exposed in the trench.

According to the OSL ages obtained from unit 3, it was accumulated during the Late Pleistocene, starting about 40ky after the deposition of the 112 ka old unit 2. The upper time limit for the deposition of unit 3 is not clear. The OSL age of its top (27ka) and the EpiPaleolithic tools found in its upper part (10ka-20 ka old) are younger that the OSL age of the overlying units 4 (41 ky old) and unit 5 (78ky old). The reasons for the inverse order of ages are not yet well understood and therefore, we prefer to rely on the vertisol ages for our tectonic interpretation.

However, units 4 and 5 are horizontal, and therefore are considered as post tectonic sediments forming the upper time-limit to the slow subsidence represented by unit 3.

Since we are not certain that the Paleolithic tools in unit 3 found in situ, we consider the OSL age of the upper part of unit 3 as the time limit for the tectonic activity along the Nesher fault.

The slow rate of deformation and the lack of small-scale stratigraphic markers in the vertisol of unit 3 do not allow to distinguish between distinct earthquake-related faulting events. However, the results suggest that the Nesher fault was active during most of the Late Pleistocene. Since it is only a short fault, which branches from the main regional system, it represents the timing of the tectonic activity along the Carmel fault rather than earthquake magnitude or recurrence interval.

2.5 Conclusions

Two periods of tectonic activity, accompanied by surface deformation were identified along the Nesher fault. 1. Subsidence of a small basin south of the main fault occurred before the deposition of unit 2. This is evident by colluvium that was accumulated

south of the fault trace and the clay that accumulated in a small depression further to the south.
2. A slow subsidence of a small basin occurred south of the Nesher fault after the deposition of unit 2. This continuous subsidence resulted in southward tilting of unit 2 and accumulation of unit 3 in the developing depression. This stage lasted for almost 50ky and was terminated towards the end of the Pleistocene at about 27ka..

It is assumed that these two periods of activity represent the timing of seismic activity along the entire western segment of the Carmel fault (Between Jalame and the Mediterranean). Yet, since this paleoseismic data is related only to a small branch of the fault it can not represent the magnitude of the seismic events on the main fault. Hence, the timing of the activity periods, as well as the accumulated displacement (which is a proxy of the earthquake magnitude) should be considered as minimum values in assessing the seismic hazards in this region.

3. The Shutter Ridge

3.1 Introduction

A shutter ridge is a barrier formed across a stream-valley by tectonic activity, which blocks the downstream flow (Burbank and Anderson, 2001). The barrier can be formed by vertical (normal or reverse) or lateral displacement. The blocked stream can change its course and flow around the barrier or it can fill the reservoir formed behind the tectonic dam by sediments that accumulate up to the top of the barrier and then overflow it.

Two sites in streams that were blocked by shutter ridges were found along the Carmel fault (Fig. 1), both located along the N-S oriented segment that extends between Yoqneam and Jalame (Achmon, 1986, 1991; Ashqar, 2006). This segment was considered by Achmon (1986) a restraining bend, associated with intensive deformation and block rotation. He estimated that the shutter ridges were formed due to young lateral offset of about 300 m.

The shutter ridge selected for the present study is located at an outlet of a small stream, about two km long (coords. 20950/23205). It separates between the upper reach of the stream channel that incised in the steep northeast-facing slopes of the Carmel and its alluvial fan, which was deposited north of the slope margins (Fig. 11).

3.2 Geological Background

The northeastern slope of the Carmel Mt. is composed in the study area of a NE tilted Turonian sequence. This sequence builds unstable slopes with abundant landslides, and in fact it is difficult to find a slope that was not disturbed by some kind of mass-movement.

The Carmel fault crosses the eastern margins of the Carmel, forming a shear zone several hundreds meters wide (Achmon, 1986). The Shutter ridge is composed of eastward tilted bedded limestone, which forms a narrow ridge that extends several hundreds meters to the south of the stream (Fig. 11). A flat alluvial terrace covered by colluvium and soils, developed along the western backside of the ridge (Fig. 12). In the west this terrace is bounded by a fault that runs along the Carmel slope (Fig. 13). Additional faults occur further to the west on the steep slopes.

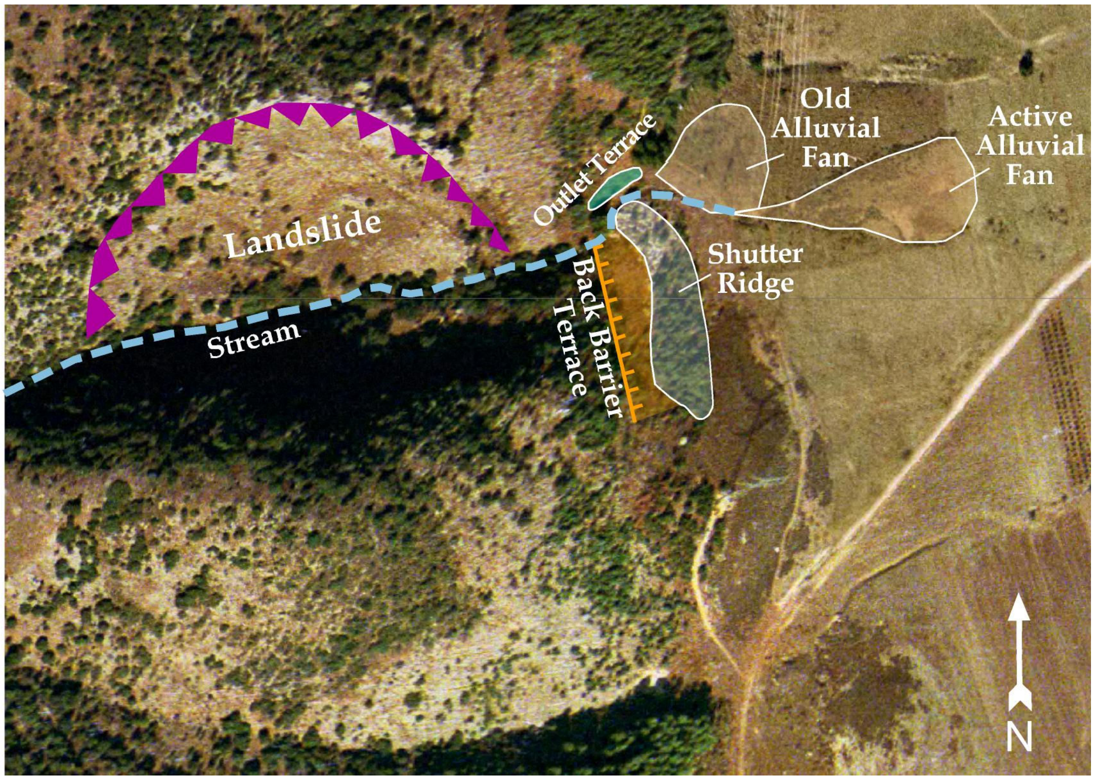

Fig. 11 – Tectonic and morphologic elements in the study area

A large morphological cirque was formed by landslide scar between altitude 200 and 300m in the upper stream valley (Fig. 11). This landslide blocked the stream channel and formed a series of knick points expressed as dry waterfalls. This barrier also prevented alluvial materials from reaching the down stream channel and therefore enhanced an incision regime near the stream outlet.

3.3 Morpho-alluvial units

Several morpho-alluvial units are distinguished in the lower reach of the stream (Fig. 11).

1. An *abandoned alluvial fan*, incised at present by the narrow active stream-channel. This alluvial fan consists of coarse gravel, which forms a typical conic shape sedimentary body. The apex of the ancient alluvial fan is located few tens of meters north of the shutter ridge. The gradient of the alluvial fan is greater than that of the present channel (Fig 14) and its surface is modified by man-made terraces, which were used for agriculture.

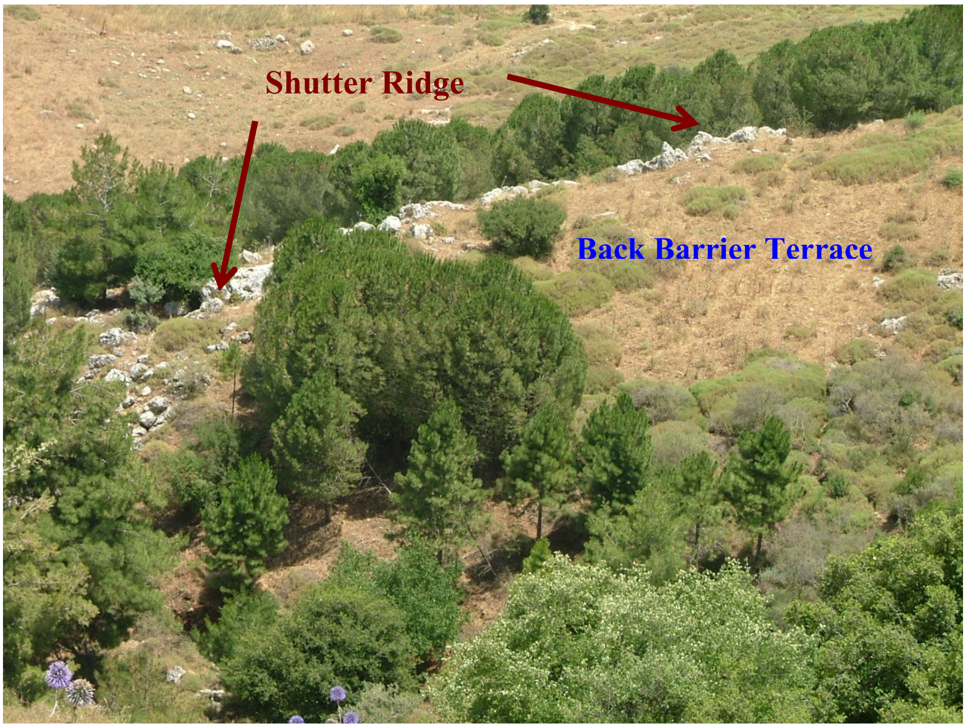

Fig. 12 – The back-barrier terrace south of the stream valley

Fig. 13 – The fault plane that forms the western boundary of the Back Barrier Terrace

2. The *present alluvial fan*, which has a lower gradient and is narrower than the older one. Its apex is located near the northeast margins of the abandoned fan and it seems that there is not much accumulation of sediments along its rout.
3. The *Stream Outlet Terrace* is a coarse gravel terrace, located along the western side of the present stream opposite the Shutter ridge. Its top is elevated 4.5m above the present stream channel and it is connected to the colluvial apron of the nearby slope. The upper part of the terrace is capped by fine-clastic sediments (sand, silt and clay) and small gravels. This terrace reflects the bottom of a stream valley that surrounded the shutter ridge.
4. The *Back barrier Terrace* is a remnant of an alluvial sequence 7-10 m thick (Fig. 15) that was accumulated beyond the shatter ridge. The top of this sequence forms a flat terrace, which extends southward, bounded by the shutter ridge in the northeast and a fault plain in the southeast (Fig 12). This sequence was the target of the present study.

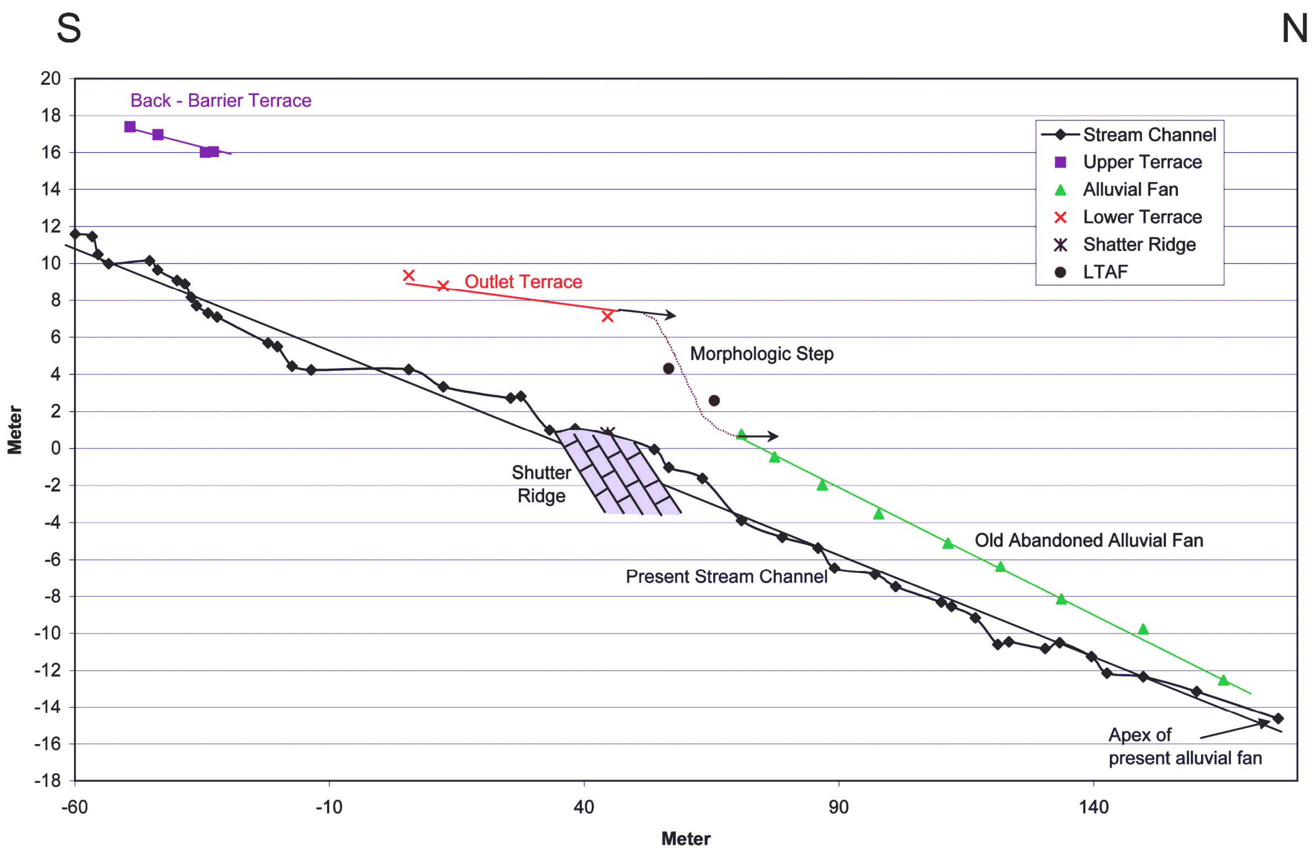

Fig. 14 – EDM profile of the shutter ridge stream channel and the fluvial terraces

3.4 The sequence of the Back Barrier Terrace

The sequence of the alluvial fill, which accumulated beyond the shutter ridge, is exposed along the eastern bank of the stream.

Two types of sediments were found in this outcrop, both exposed in the lower part of the sequence. The upper part is covered by thick colluvial materials and was not excavated during the present study.

Unit 1

Unit 1 is exposed in the western part of the outcrop. It is 2.5 m thick, its base is not exposed and it is unconformably overlain by unit 2. It consists of poorly stratified, poorly sorted, matrix supported gravel (composing 10-20 % of the sequence) up to 10 cm in size. The gravels are sub-angular, shattered and weathered and composed mostly of basalt and tuff, dolomite, limestone, chalk and marl. Clay matrix contains about 40% disseminated carbonates. Moist color – 2.5YR3/4 dark reddish brown.

The unit is compacted and moderately cemented.

Four samples were taken from this unit for OSL dating (see appendix and Figs 16, 17). The age of the lower part is 146ka ± 20; and of the upper part is 24.5ka ± 2.5. Sample Car- 2a (16.1ka ± 1.9) seems to be too young, probably due to infiltration of young silt into the sequence.

Unit 1 is covered by sediments consisting mainly of reworked Terra Rossa soil and small gravel (Unit 2). We do not know if these two parts of the sequence were accumulated continuously or they represent two different events, as suggested by the abrupt lithological change

<u>Interpretation</u> – Unit 1 is an alluvial unit derived from a drainage basin where basalts and tuffs are exposed. Although it was slowly accumulated during more than 120 ky, it does not show any clear paleosol profile.

Unit 2

The lower part of unit 2 is exposed near the Shutter ridge. It is composed of poorly sorted, poorly stratified, imbricated, clast-supported coarse gravel (composing 50-

70% of the sequence), up to boulders of 50 cm in size (frequent size 7 cm) (Figs 15, 17). The gravels are sub-rounded and are composed mainly of limestone and dolomite. This coarse facies is overlain by stratified, well sorted clast-supported fine gravel up to 7 cm in size. The matrix consists of brown clay and silt (Moist color – 2.5YR3/4 dark reddish brown) and contains disseminated carbonates. The unit is compacted and slightly cemented.
Two OSL ages were obtained for the lower coarse part of the sequence (Fig 17). Its base is 3.5 ± 0.4 ka BP; and the age of the overlying finer bedded sequence (2.5 m above the stream channel) is 2.3 ka± 0.4.

A similar lithological facies overlies unit 1 about 20 m upstream. Here it consists of massive, matrix supported loamy clay which includes increasing amounts of clasts up section from 5% at the base of the unit up to 30% at the top of the unit. The clasts are moderately sorted, angular, up to 2 cm in size at the base of the unit and becomes poorly sorted, 3-15 cm in size with a frequent size of 5 cm towards the top of the unit. The clasts are composed of limestone, dolomite, chalk and bituminous chalk.

The matrix is reddish loamy clay (moist color – from 2.5 YR3/4 dark reddish brown at the base of the unit to 7.5YR/3/4 dark brown at the top), and contains decreasing amount of carbonates up section from about 12% at the bottom of the unit to about 8% at the top. The unit is compacted and slightly cemented at the base and friable at the top.

Interpretation – Unit 2 consists mainly of fast accumulated alluvial-colluvial sediments, which represents the present weathered materials of the nearby Carmel slope and the rocks exposed in the drainage basin of the stream. The matrix is basically a reworked Terra Rossa soil and probably also some brown Rendizna. The similar lithological character of this unit near the shutter ridge and above unit 1 further upstream, may reflects a continuous accumulation. However, this point must be clarified by additional dating from the upper part of the sequence.

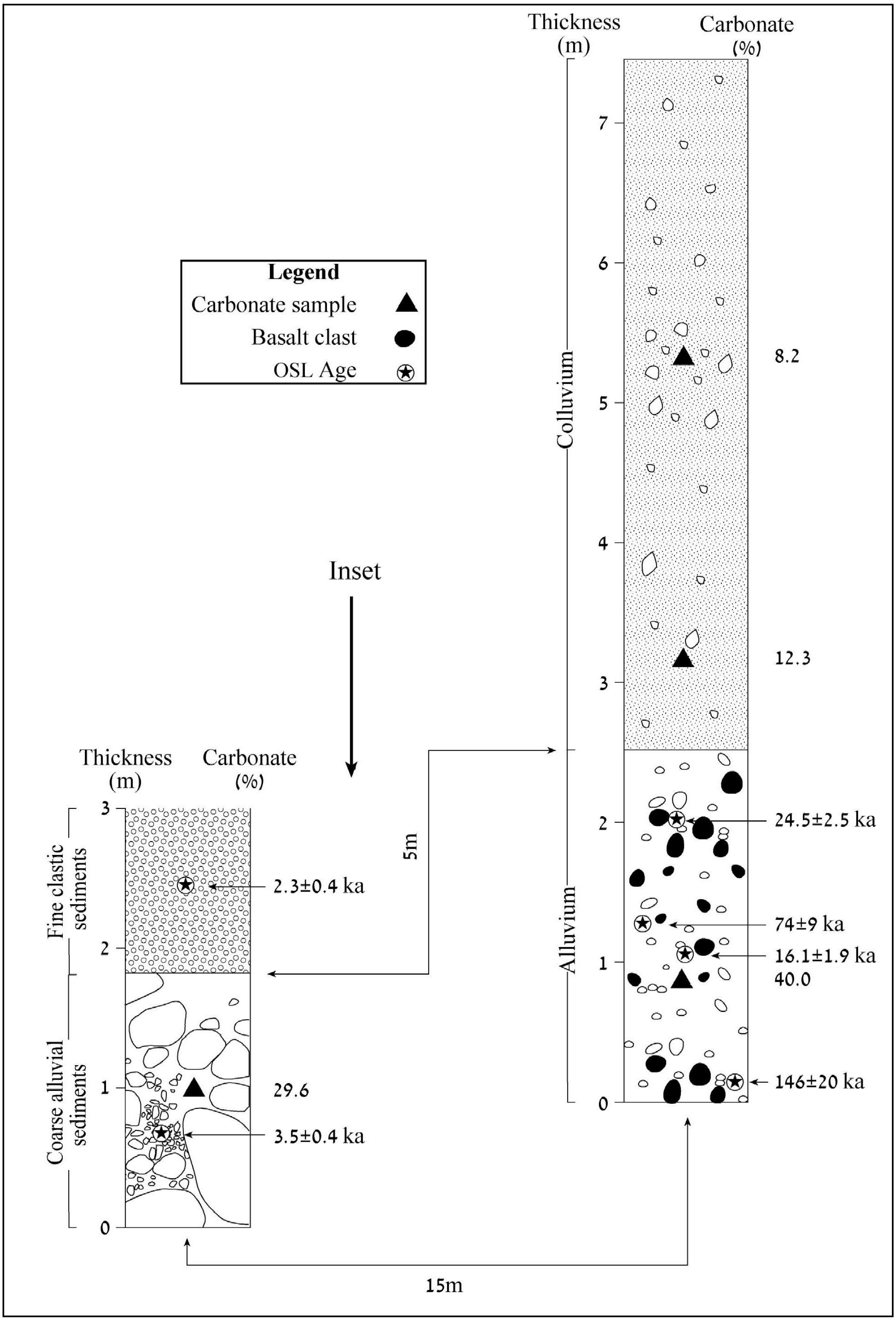

Fig. 15 – Columnar sections of the Back-Barrier Terrace (From Ashqar et al in prep.)

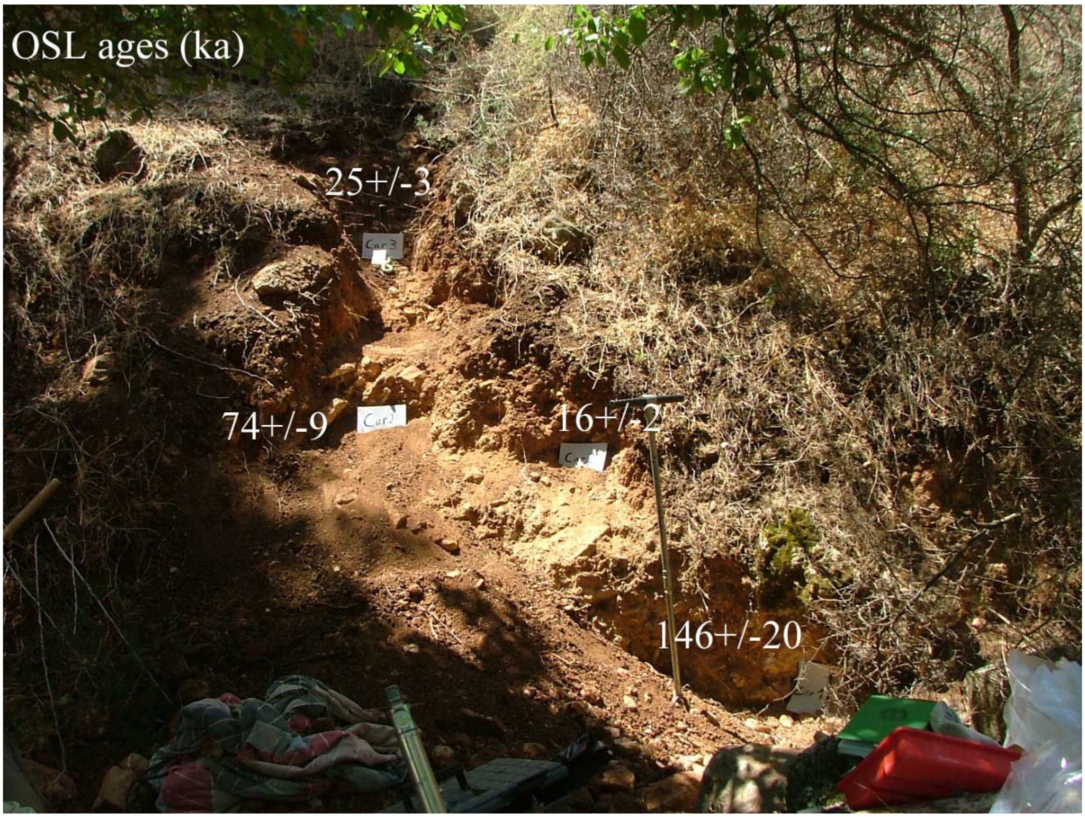

Fig. 16 – The sites and ages of OSL samples 1-3 in Unit 1

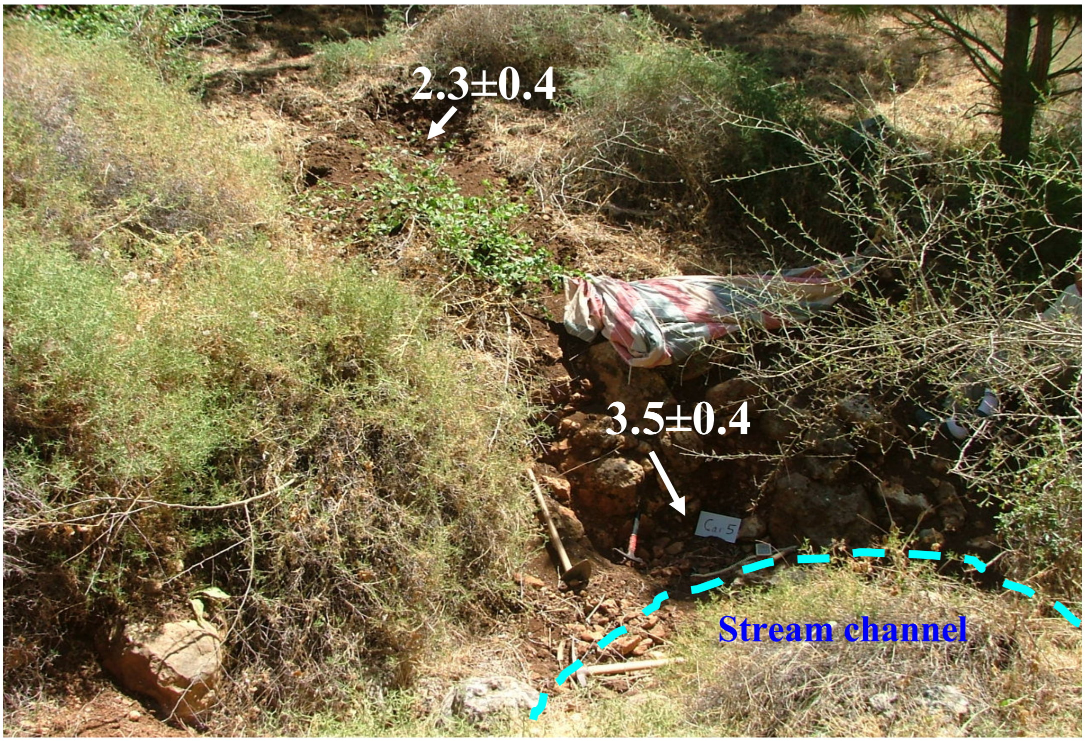

Fig. 17 – The sites and ages of OSL samples 4-5 in the lower part of Unit 2

3.5 Discussion

In order to examine the possibility of tectonic activity along the Carmel fault, the thick sequence, which was accumulated beyond the shutter ridge, must be explained.

It might be argued that this accumulation is not necessarily a result of stream blockage, but it may also reflect a negative balance between water discharge and sediment yield (Low water/sediment ratio) from the drainage basin (Schumm, 1977). Such situation could be related to a climatic deterioration or anthropogenic activity resulted in destroying the forest and intensive slopes erosion. However, in such case a similar sediment accumulation should have been found also in other streams along the Carmel Mt. and so far such accumulation along other streams, is not known.

Hence, the basic hypothesis in our interpretation is that in order to accumulate such a thick sequence of alluvium in a high gradient stream (about 11%), we must assume some disturbance to the down stream transport of the alluvial sediments.

We did not find any clear evidence to a morphological-sedimentological barrier such as debris flow or landslide near the outlet of the stream, and so the rocky shutter ridge is left as the only possible barrier.

The stratigraphic sequence of the higher terrace reflects two different sediment sources: The older part is composed of materials derived mainly from exposures of soft rocks and pyroclstic units. The younger sequence is composed mainly of reworked Terra Rossa soil with some gravel derived mainly from hard carbonate rocks (dolomite and limestone).

The age of these two alluvial-colluvial units and their field relations, indicate two different periods of accumulation separated by an incision event. The older unit was accumulated slowly during more than 100ky, starting before some 146ky and continued until 22ka-27ka. This period was terminated by incision of the stream up to the present level of the stream channel, so the accumulation of the younger unit started before some 3.5 ky from the same level as unit 1. The second accumulation phase was short and terminated before 2.3 ky.

The volcanic gravels found in unit1 raise a question concerning their source, because there are no exposures of volcanic rock mapped so far in the drainage basin of the studied stream (Segev in prep.). Such rocks are exposed in a drainage basin of an adjacent stream further to the south. Hence, the existence of such gravel in the study site can be explained in several ways: 1. volcanic rocks were exposed in the past in the drainage system of the studied stream but were covered later by landslides. 2. Unit 1 was tectonically displaced to its present site from an alluvial fan in the south. 3. The gravels were transported to their present site by a north flowing stream that drained volcanic outcrops in the south. So far we do not have enough data to decide which hypothesis should be adopted and additional field work is required in order to clarify this problem.

The incision event that separates between the depositions of the two alluvial units reflects a major change in the hydrology of the stream, which prevented alluvial materials from the upper drainage basin to reach its outlet. It is suggested that this change is related to a large landslide that formed a barrier and a high waterfall a few hundreds of meters upstream. The age of this landslide should be younger than the age of the top of the older unit, e.g. 23.5ka.

Hence, we suggest that the thick sequence (8 m) found behind the shutter ridge reflects two episodes of stream blockage, due to a northward displacement of the shutter ridge.

The barrier which was formed in the younger episodes (e.g. about 4ky BP) was several meters high and triggered rapid accumulation of alluvial and colluvial sediments. The stream broke through the shutter ridge not earlier than 2.3 ka and incised rapidly to its present level.

Additional evidence for young tectonic activity is manifested by the Stream Outlet Terrace, which reflects accumulation of coarse alluvium in a stream valley that surrounded the shutter ridge. This terrace, which has a sub horizontal upper surface, indicates a low-relief valley bottom, which is not in accord with the downstream abandoned steep alluvial fan. There is a sharp gradient change between the terrace and the ancient abundant alluvial fan further to the east and it seems that it is hanging above it. Such relations could have been formed by uplift of the terrace in relation to the eastern margins of the Carmel ridge. We do not know yet what is the age of this terrace but, it is clear that it supplies time-constraint on the stream blocking.

The morphological relations between the old and the present alluvial fans of the stream are also typical to an uplifting terrain. The apex of the present active alluvial fan is located at the margins of the old fan, indicating a migration of the base level to the north as a result of uplift of the old fan together with the mountain front (Denny, 1967; Bull., 1977).

3.6 Conclusions

Two groups of evidence are presented here for young tectonic activity along the Yoqneam-Jalame segment of the Carmel Fault.

1. Young uplift of the mountain front is manifested by the hanging position of the Outlet Terrace in relation to the old alluvial fan of the stream, and the development of recent telescopic alluvial fan in the northern margin of the old abandoned one
2. Two periods of stream blockage, probably by horizontal displacement of a rock slab along the Carmel Fault, were identified so far. The first period is associated with slow accumulation of sediments beyond the shutter ridge, which lasted between 146 ka and 24.5ka. The second period was associated with fast accumulation, which lasted between 3.5 ka and 2.3 ka. A period of stream incision separated between these two periods of sedimentation.

If we relate the deposition/incision processes in this small stream to tectonics alone, we may reach the conclusion that the stream was blocked in the first time at the beginning of the late Pleistocene and again in the Late Holocene. For our purpose it is more important to evaluate the tectonic origin of the second young event and to eliminate other causes that might result in a similar reaction of the fluvial system.

In order to achieve this goal we must date the entire sequence of the Inner Terrace, the sequence of the Outlet Terrace and the abandoned alluvial fan. We also have to conduct a more regional research in order to find if accumulation of thick alluvium also occurred in other streams, which drain the northern mountain front of the Carmel.

4. Summary

The present study show evidence for continuous tectonic activity along the Nesher fault during the Late Pleistocene, but it seems that during the Holocene this branch of the Carmel fault was stable. Tectonic activity also occurred during the Late Pleistocene along the Yoqneam-Jalama segment of the Carmel fault but here there are also indications for Middle to Late Holocene activity.

We intend to continue our study in the two sites in order to collect additional data that we hope will clarify the tectonic picture. We will date the upper part of the sequence of the Back-Barrier Terrace and will try to establish a better chronosequence in this site. We will trench the southern part of the alluvial fan in the Nesher fault site in order to clarify the relations between the fault and the various sedimentary units, and will try to obtain a better age constrain on the tectonic activity.

References

Achmon, M., 1986. The Carmel border fault between Yoqneam and Nesher. M.Sc thesis, the Hebrew University of Jerusalem (in Hebrew, English abstract), 56 pp.

Achmon, M., 1998. Paleomagnetic and geophysical research of the Carmel Fault Zone. Ph.D thesis, Tel Aviv University, 124 pp.

Achmon, M., and Ben Avraham, Z.,1997. The deep structure of the Carmel Fault Zone, northern Israel, from gravity field study. Tectonics, 16:563-569.

Arad, A., 1965. Geological outlines of the Ramot Menashe region (northern Israel). Isr. J. of Earth Sci., 14:18-32.

Ashqar, L., Greenbaum, N., Salamon, A., Zilberman, E., 2006. Morphologic and morphotectonic elements along the eastern and northeastern Carmel Mountain front – evidence for young tectonic activity. Isr. Geol. Soc. Ann. Meet. Bet Shean, abstract, p. 6.

Ben Avraham, Z., and Ginzburg, A., 1990. Displaced terrains and crustal evolution of the Levant and Eastern Mediterranean. Tectonics, 9:613-622.

Ben Menhaem, A., and Aboody, E.,1981. Micro and macroseismicity of the Dead Sea Rift and off coast eastern Mediterranean. Tectonophysics, 80:1139-1142.

Bull, W., B., 1977. The alluvial fan environments, Progress in physical geography 1: 70-222.

Burbank, D.W., and Anderson, R.S., 2001. Tectonic Geomorphology. Blackwell Science Ltd, UK.

Denny, C., S., 1967. Fans and pediments. American J. of Science. 265: 81-105.

Derin, B., 1974. The Jurrasic of central and northern Israel. Ph.D. thesis, Hebrew Univ., Jerusalem (in Hebrew, English abstract), 152 pp.

De–Sitter, L. U., 1962. Structural development of the Arabian Shield in Palestine. Geology en. Mijnb., 45:116-124.

Freund, R., 1970a. The geometry of faulting in the Galilee. Isr. J. of Earth Sci., 19:114-140.

Garfunkel, Z., 1981. Internal structure of the Dead Sea leaky transform (rift) in relation to plate kinematics. Tectonophysics, 80:81-108.

Ginzburg, A. Folkman, Y., 1980. The crustal structure between the Dead Sea Rift and the Mediterranean Sea. Earth and Planetary Science Letters. 51;1: 181-188. 1980.

Hofstteter, A., Feldman, L., Rotstein, Y., 1991. Crustal structure of Israel: constraints from teleseismic and gravity data. Geoph. J. Inter., 104:371-379.

Hofstetter, A., van Eck, T., Shapira, A., 1996. Seismic activity along fault branches of the Dead Sea-Jordan Transform: the Carmel-Tirza fault system. Tectonophysics, 267:317-330.

Horowitz, 1979. The Quaternary of Israel. Academic Press, 394pp.

Kafri, U., Folkman, Y., 1981. Multiphase reverse vertical tectonic displacement across major faults in northern Israel. Earth Plan. Sci. Let., 53:343-348.

Karcz, Y., 1959. The structure of the northern Carmel. Bull. Res. Counc. Isr., 8G:119-130.

Kashai, E., 1966. The geology of the eastern and south-western Carmel. Ph.D Thesis, The Heb. Univ. Jerusalem (in Hebrew, English abstract) 129 pp.

Gluck, D., 2001. Landscape evolution in the southwestern Dead Sea basin, and paleoseismic study of tectonic activity in the Late Pleistocene and Holocene along the southwestern marginal fault of the Dead Sea basin and the Carmel Fault. M.Sc thesis, Hebrew Univ. of Jerusalem, 86 pp. (in Hebrew, English abst.).

Matmon, A., Wdowinski, S.,Hall, J.K., 2003. Morphological and structural relations in the Galilee extensional domain, northern Israel. Tectonophysics, 371:223-241.

Picard, L., Kashai, E., 1958.On the lithostratigraphy and tectonics of the Carmel. Bull. Res. Coun. Isr., 7G: 1-18.

Ron, H., 1984. Paleomagnetic investigation of the fault structure of theGalilee– northern Israel. Ph.D thesis. The Heb. Univ. Jerusalem (in Hebrew, English abstract) 102pp.

Ron, H., Eyal, Y., 1985. Intraplate deformation by block rotation and mesostructures along the Dead Sea Transform. Tectonics, 4:85-105.

Ron, H., Nur, A., Hofstetter, A., 1990. Late Cenozoic and recent strike slip tectonics in Mt. Carmel, northern Israel. Ann. Tectonicae, 4:70-80.

Rotstein, Y., Bruner, I., Kafri, U., 1993. High resolution seismic imaging of the Carmel fault and its implications for the structure of the Carmel. Isr. J. Earth Sci., 42:55-69.

Rotstein, Y., Shaliv, G., Rybakov, M., 2004. Active tectonics of the Yizre'el valley, Israel, using high-resolution seismic reflection data, Tectonophysics, 382:31-50.

Salamon, A., 2000. Seismic hazards in the "Dry Line", Nesher industry – Haifa. 18 pp.

Salamon, A., Hofstetter, A., Garfunkel, Z., Ron, H., 1996. Seismicity of the eastern Mediterranean region: Perspective from the Sinai Sub-plate. Tectonophysics, 263:293-305.

Schattner, U., Ben-Avraham, Z., Lazar, M., Huebscher, C., 2006. Tectonic isolation of the Levant basin offshore Galilee-Lebanon – effects of the Dead Sea fault plate boundary on the Levant continental margin, eastern Mediterranean. J. of structural Geology, 1-18.

Schattner, U., Ben-Avraham, Z., Reshef, M., Bar-Am, G., Lazar, M., 2006. Oligocene-Miocene formation of the Haifa basin: Qishon-Sirhan rifting coeval with the Red Sea-Suez rift system. Tectonophysics, 419:1-12.

Shamir, G., 2006. Scattering of earthquake epicenters along the Gilbo'a Tirza faults. A report submitted to the Steering Committee for Earthquake Readiness in Israel.

Shapira, A., Feldman, L., 1987, Microseismicity of three locations along the Jordan Rift. Tectonophysics, 141:89-94.

Schumm, S., A., 1977. The fluvial system. New York: John Wiley.

Van Eck, T., Hofstteter, U., 1990. Fault geometry and spatial clustering of microearthquakes along the Dead Sea-Jordan rift fault zone. Tectonophysics, 180: 15-27.

Appendix =- OSL results

Table 1: Carmel fault Nesher Trench luminescence dating results

Lab No.	Depth (m)	Unit	Grain Size (μm)	K (%)	U (ppm)	Th (ppm)	Ext. α (μGy/a)	Ext. β (μGy/a)	Ext. γ (μGy/a)	Cosmic (μGy/a)	Total dose (μGy/a)	Aliquots used	De (Gy)	Age (ka)
CAR-11	3.2	Lower vertisol	74-125	0.27	1.1	4.3	6	394	394	142	896±35	5/5	157±26	**176±30***
CAR-12	2.0	Debris flow	74-125	0.50	1.9	5.8	9	3666	550	164	1389±39	5/6	156±8	**112±6**
CAR-13	3.95	Base main vertisol	88-125	0.83	0.8	2.7	4	674	378	129	1185±35	6/6	162±23	**137±19**
CAR-14	2.9	Middle main vertisol	88-125	0.95	1.9	6.3	9	958	669	147	1783±36	6/6	124±12	**69±7**
CAR-15	1.9	Top main vertisol	88-125	1.08	1.9	8.8	11	1094	804	166	2075±40	6/6	100±7	**48±4**
CAR-16	1.2	Upper debris	88-125	0.62	2.1	5.4	9	754	579	181	1522±31	6/6	121±12	**78±8**
CAR-17	3.0	Lower vertisol	74-125	1.25	1.7	7.9	10	1162	783	145	2099±56	6/6	155±12	**74±6***
CAR-18	1.8	Debris flow	74-125	1.25	1.8	8.6	11	1189	823	168	2190±54	6/6	89±4	**41±2**
CAR-19	3.2	Base main vertisol	74-125	1.00	2.2	7.6	11	1056	766	142	1975±53	5/5	150±9	**76±5***
CAR-20	1.95	Middle main vertisol	74-125	1.16	1.9	7.4	10	1117	762	165	2054±41	6/6	107±4	**52±2**
CAR-21	1.0	Top main vertisol	88-125	1.25	1.8	7.8	10	1167	789	185	2151±39	5/6	59±2	**27±1**

Gamma was calculated from the concentrations of the radioelements and cosmic dose estimated from burial depth. Water contents estimated at 10±3%.

Quartz was etched by concentrated HF for 40 minutes. De was obtained using the single aliquot regeneration (SAR), using preheats of 10 s at 200-260°C and cut heats of 5 s @ 20° < preheat. Samples have recycling ratios within 5% of 1.0 and negligible IR signals.

*preliminary ages

Table 2: Carmel fault shutter ridge luminescence dating results

Lab No.	Depth (m)	Grain Size (µm)	K (%)	U (ppm)	Th (ppm)	Ext. α (µGy/a)	Ext. β (µGy/a)	Ext. γ + cosmic (µGy/a)	Total dose (µGy/a)	Aliquots used	De (Gy)	Age (ka)
CAR-1		74-125	1.03	1.2	1.8	4	830	667	1501±72	13/14	219±28	**146±20**
CAR-2a		88-125	0.95	1.0	2.4	4	767	678	1449±75	10/14	23.3±2.5	**16.1±1.9**
CAR-2b		74-125	0.76	1.1	1.5	4	641	678	1323±74	11/14	98±11	**74±9**
CAR-3		88-125	1.11	1.3	2.7	5	909	644	1558±74	7/14	38.1±3.5	**24.5±2.5**
CAR-4		88-125	0.56	1.4	4.7	7	619	711	1337±77	11/14	3.1±0.5	**2.3±0.4**
CAR-5		88-125	0.71	1.4	6.1	8	744	591	1342±67	10/14	4.7±0.4	**3.5±0.4**

Gamma +cosmic dose rates were measured in the field using a portable gamma spectrometer. Water contents estimated at 10±3%.

Quartz was etched by concentrated HF for 40 minutes. De was obtained using the single aliquot regeneration (SAR), using preheats of 10 s at 200-260°C and cut heats of 5 s @ 20° < preheat.

Samples have recycling ratios within 5% of 1.0 and negligible IR signals.

תקציר

במסגרת המחקרים הפלאוסייסמיים בעמק זבולון ושולי הכרמל נבדקו שני אתרים לאורך העתק הכרמל. 1. העתק נשר, המתפצל מהעתק הכרמל בין יגור למפעל המלט של נשר ונמשך למערב-צפון-מערב אל מרכז העיר חיפה. 2. מחסום טקטוני של אפיק המנקז את המורדות הצפוניים של הכרמל, שנוצר על ידי תזוזה אופקית שמאלית לאורך הקטע של העתק הכרמל בין יוקנעם וג'למה.

בתעלה שנחפרה בניצב להעתק נשר נמצאו עדויות לשתי תקופות של פעילות טקטונית: האחת בסוף הפלייסטוקן התיכון (לפני כ- 176,000 שנה), והשניה בתקופת הפלייסטוקן המאוחר (75,000-27,000 שנה לפני זמננו). לא נמצאו עדויות להעתקה הולוקנית (10,000 השנים האחרונות).

בתקופות הפעילות של העתק נשר חלה השתפלות איטית של צדו הדרומי ונוצר שקע בו הצטברו סדימנטים חרסיתיים בהם התפתחו פאלאוסולים. עובי החתך שהצטבר בפלייסטוקן התיכון אינו ידוע, אך בפלייסטוקן המאוחר הצטבר חתך חרסיתי בעובי של כ- 3-4 מ, המשקף את סך ההסטה המצטברת על ההעתק.

כמה מאות מטרים ממערב לתעלה נמצא קרום קלקריט המצפה את פני השטח, כשהוא מוסט בשעור של מספר עשרות סנטימטרים על ידי ההעתק. בנקודה זאת נמצאו סימני החלקה תת-אופקיים על מישור השבר.

העדויות מהעתק נשר אינן מאפשרות לקבוע גיל ומגניטודה של ארועים סייסמיים, אך הן מהוות סמן לפעילות על ההעתק הכרמל. עם זאת, מאחר שמדובר בהעתק משני, העדויות שנאספו ממנו מייצגות ככל הנראה רק חלק מהפעילות שהתרחשה על ההעתק העיקרי .

יש לציין שהחל מאמצע תקופת ההולוקן היה אזור המחקר נתון לפעילות אנושית שלא אפשרה לסדימנטים להצטבר בצורה טבעית ולשמר עדויות לפעילות טקטונית.

בעורף המחסום הטקטוני נמצאו עדויות לשתי תקופות של הצטברות סדימנטים פלוביאליים כשביניהם מפרידה תקופת התחתרות: הצטברות איטית התרחשה במשך כ- 100,000 שנים בפלייסטוקן המאוחר, עד לפני כ- 26,000 שנה. הצטברות מהירה החלה לפני כ- 3,500 שנה והסתיימה לפניכ-2,300 שנה. ניתן לייחס הצטברויות אלה לחסימה זמנית של האפיק עקב תזוזה שמאלית של המחסום הטקטוני, אך נושא זה טעון מחקר נוסף על מנת לשלול אפשרויות אחרות.

שתי עדויות להרמה של הכרמל ביחס לעמק שמצפונו נמצאו באזור המחסום הטקטוני. 1. במוצא הנחל החסום, נמצאה טרסה "תלויה" המורמת מטרים אחדים מעל מניפת סחף נטושה הנמצאת מצפון לה. 2. מניפת הסחף הנוכחית של האפיק התפתחה מהמשוליים הצפוניים של המניפה הקודמת הנטושה ונוצרה "מניפה טלסקופית", תופעה המאפיינת חזיתות הרים הנמצאים בתהליך התרוממות. עדיין אין נתונים על גיל ההרמה.

מהעדויות שנאספו משני האתרים עולה שההעתק הכרמל היה פעיל לסרוגין בסוף תקופת הפלייסטוקן התיכון ולאורך רוב תקופת הפלייסטוקן המאוחר ויתכן שגם בחלק מתקופת ההולוקן. העתק נשר היה פעיל בסוף תקופת הפלייסטוקן התיכון וחלק ניכר מהפלייסטוקן המאוחר, אך אין עדויות לפעילותו בתקופת ההולוקן.