



THE MINISTRY OF NATIONAL INFRASTRUCTURES  
GEOLOGICAL SURVEY OF ISRAEL

**The evolution of the Northern Shutter Ridge, Mt. Carmel,  
and its implications on the tectonic activity along the Yagur fault**

**Ezra Zilberman, Noam Greenbaum, Yoav Nahmias, Neomi Porat**



Submitted to the Inter-ministerial Steering Committee for Earthquake Preparedness

Contract No. 29-02-014b

Report No. GSI/14/2011

Jerusalem, September 2011





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## **Abstract**

The present study examined the Northern Shutter Ridge (NSR) that developed along the south eastern segment of the Yagur fault, which extends between Yoqneam and Jalame. This shutter ridge represents a left lateral strike slip movement of about 100 m. An additional 400-500 m left lateral displacement can be deduced from the offset of the first order streams that drain towards it.

The alluvial-colluvial sequence, which accumulated between the shutter ridge and the north-eastern slope of Mt. Carmel, was trenched to a depth of 7-8 m (its base was not exposed).

This sequence, which dated between 200 ka and 100 ka, overlies a hard well cemented gravel unit that paves the trench bottom and the nearby Carmel slope. It is assumed that this gravel unit was deposited on the bottom of a channel that flowed along the rock barrier to the north. A change in the depositional environments triggered a slow accumulation of colluvial-alluvial clay-rich sediments beyond the shutter ridge. The slow accumulation process was interrupted by sporadic debris flow events that transported coarse gravel from remote slopes to the small dammed basin.

There is no evidence for young deformation in the sedimentary fill of the small basin, however, the lithological nature of this clay-rich sediment can prevent the preservation of any sedimentary or tectonic structure.

We conclude that the shutter ridge developed during the end of the Middle Pleistocene or the early late Pleistocene and gradually filled during the late Pleistocene, until the rock barrier was breached.

The results of the present study were combined with additional data obtained from previous studies carried out along the Yagur fault to conclude that it was continuously active throughout the late Pleistocene. Circumstantial evidence for Holocene activity were found so far only in the Southern Shutter Ridge, but it must be noted that most of the Holocene sequence along the fault trace is disturbed by anthropologic activity and therefore, if there was evidence for young activity it was probably obliterated.

Based on general geological consideration as well as new data obtained from paleoseismic and other studies, we recommend treating the Yagur fault as an active fault.



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## **1. Introduction**

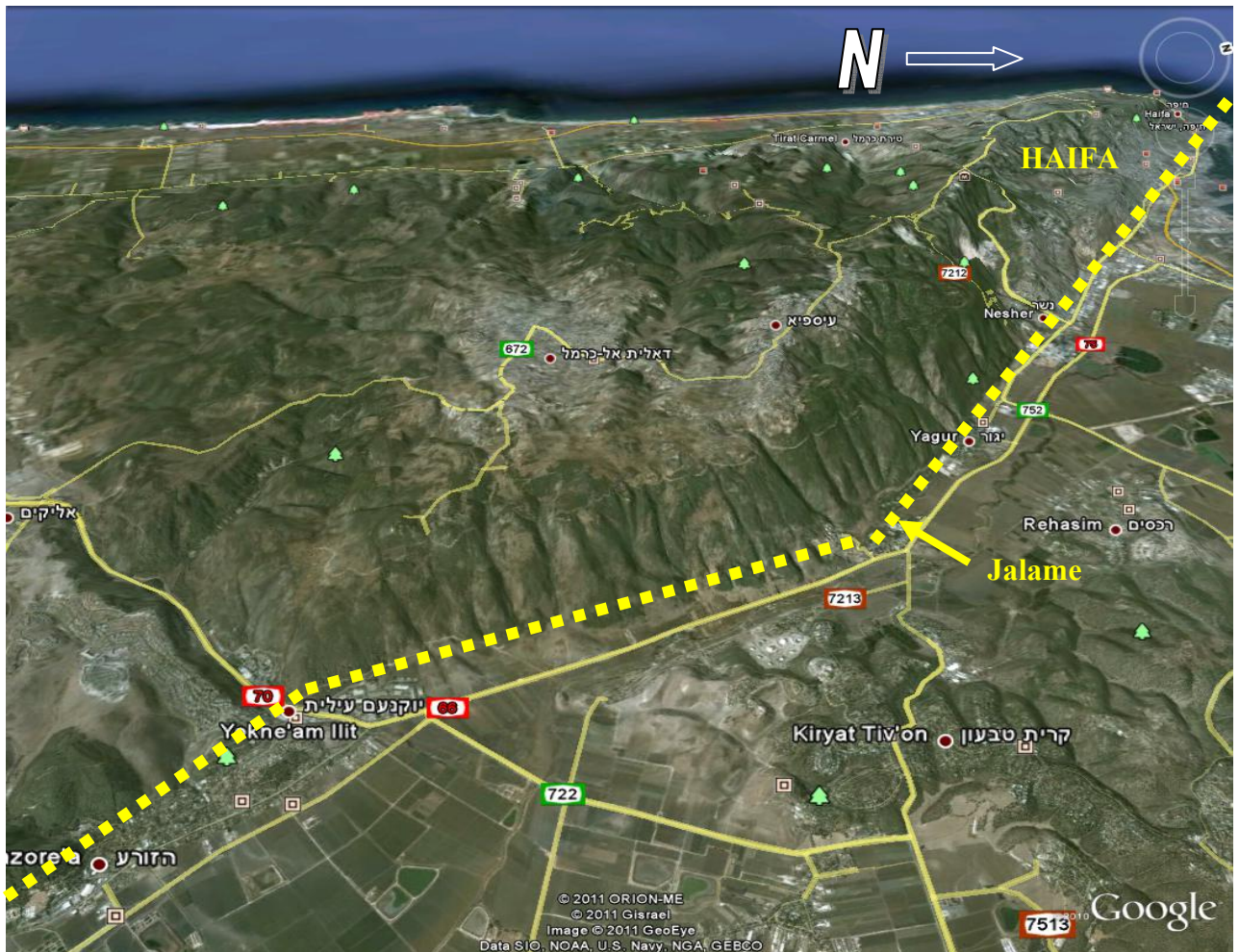
The present study is a part of an ongoing research that is being carried out along the Yagur fault (also termed Carmel Fault) since 2005. The past tectonic activity along the Yagur fault has been investigated so far at three sites: The "Southern Shutter Ridge" (Zilberman et al., 2006; Ashkar-Halak, 2009), the Neshar Fault (Zilberman et al., 2006, 2008), and the Neshar Quarry (Zilberman et al., 2010). The topic of the present research is the "Northern Shutter Ridge (NSR)" located some 2.5 km north of the Southern Shutter Ridge.

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 (usually reversed) or lateral displacement. The blocked stream can change its course and flow around the barrier or it can fill the natural reservoir formed beyond the tectonic dam with sediments that accumulate up to the top of the barrier and then overflow.

Two streams that had been blocked by shutter ridges are found along the Carmel fault (Ashkar-Halak, 2006, 2009; Fig. 1). These sites are located along the N-S oriented wide shear zone of the Yagur fault that extends between Yoqneam and Jalame (Achmon, 1986, 1991). This segment (Fig. 1) was considered by Achmon (1986) to be a restraining bend, associated with intensive deformation and block rotation. Based on offset stream channels, he estimated a horizontal displacement of about 300 m along this segment

The shutter ridge selected for the present study is located south of Hirbet Qle'a at an outlet of a displaced stream (coords. 20950/73405) (Figs 1, 2).

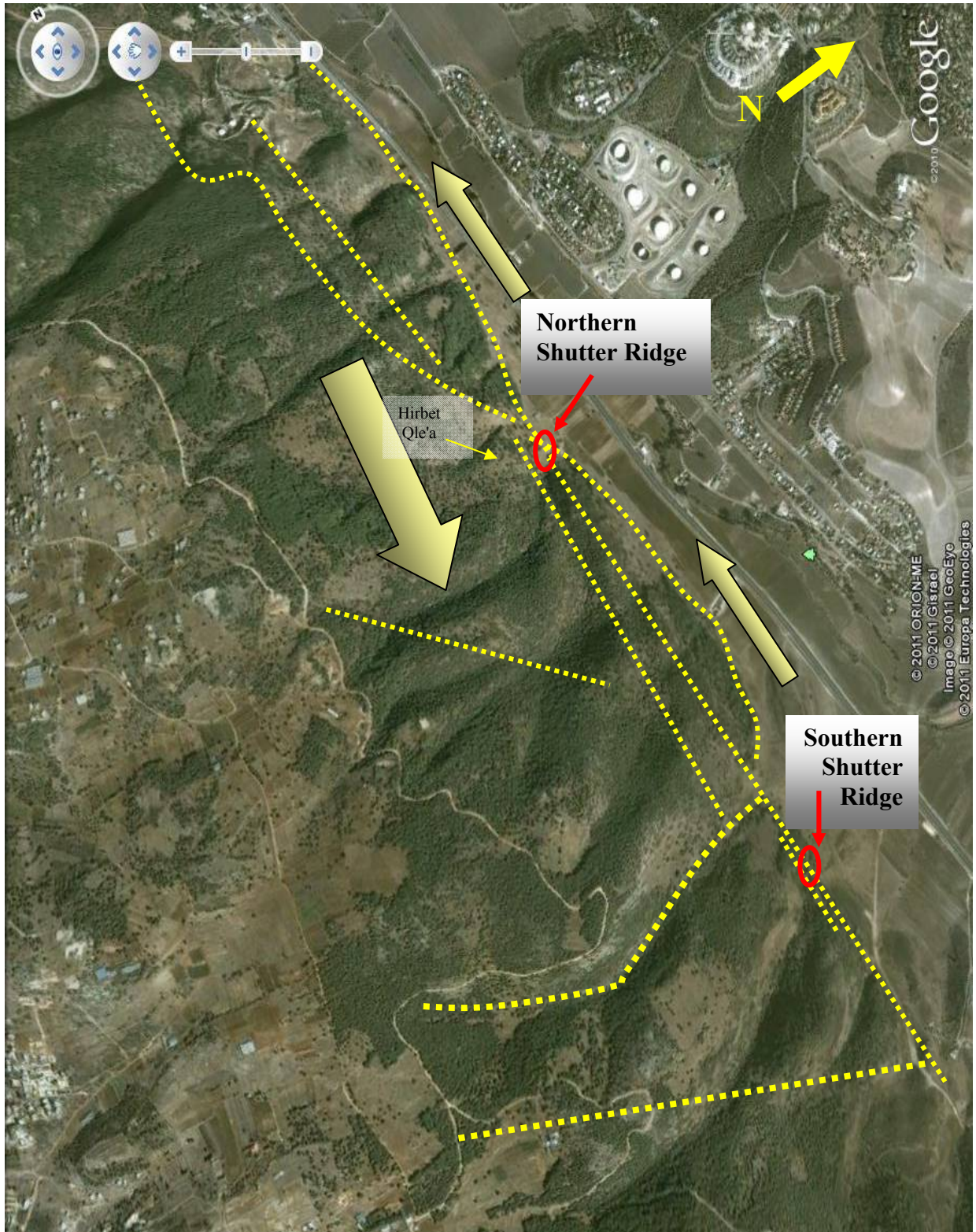
This report presents the results of the last study, and discusses the implications of the entire information achieved during the investigation of the Yagur fault on our understanding of its young tectonic activity.



*Fig. 1 - The trace of the Yagur fault between Yoqneam and the Mediterranean.*

## 2. Geographic setting

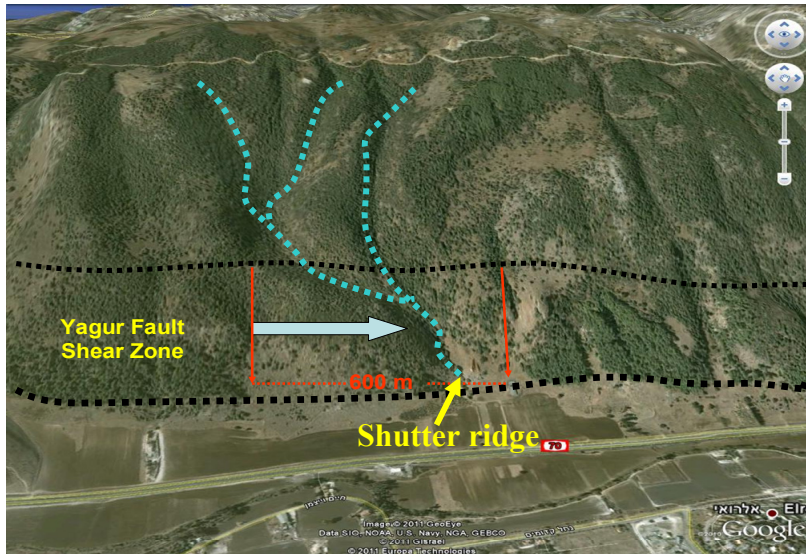
The North Shutter Ridge (NSR) is located in the outlet of a small second order stream, some 2.5 km north of the Southern Shutter Ridge (SSR) (Zilberman et al., 2006; Ashkar-Halak, 2009). The blocking ridge is some 100 m long, built of a northward-tilted Turonian limestone sequence. The southern edge of the ridge was breached by the stream forming a V-shaped outlet with a shallow alluvial fan stretching to the north. The tributaries upstream of the blocked channels show a westward deflection from a straight northward flowing course as expected on the steep northern slopes of Mt. Carmel.



**Fig 2** - The location of the two studied shutter ridges (marked by red ellipses). The main faults are marked by yellow dotted lines and the direction of the lateral displacement is marked by yellowish arrows.

This deflected course is attributed to the left lateral displacement by the Yagur fault (Achmon, 1986, Gluck, 2002, Ashkar-Halak, 2009). The offset decreases from about 500 m in the eastern tributary, to about 150 m in the western tributary.

The shutter ridge is a part of a 300-400 m wide shear zone, characterized by shattered rocks and dense vertical fracture system (Fig. 2). It rises some 20 m above the alluvial plain that extends from its foot northward toward the Qishon River (fig. 3).



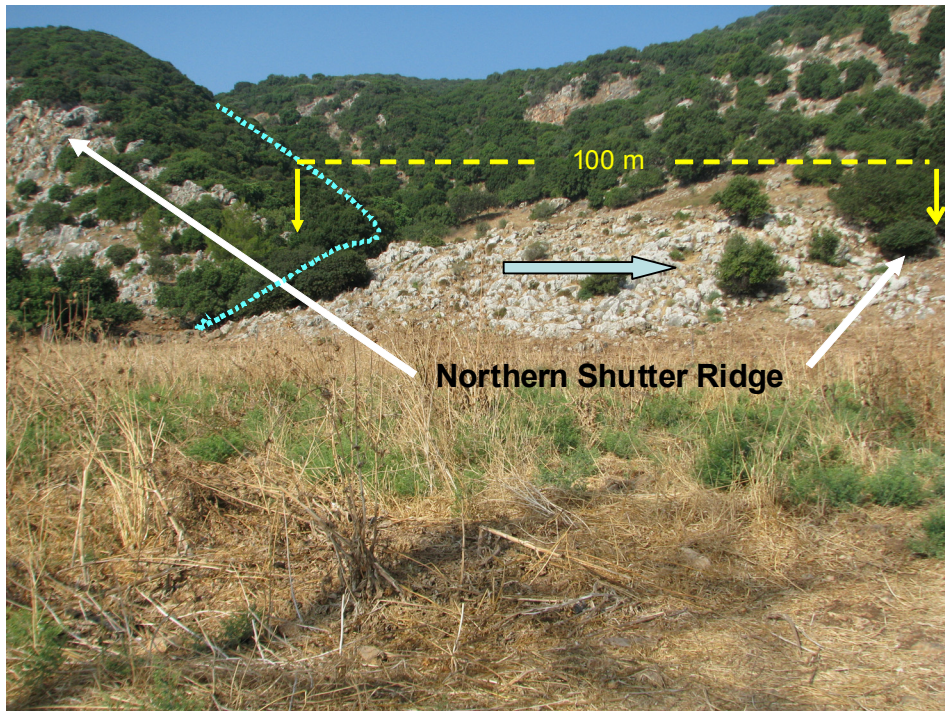
**Fig 3** - A southward view at Mt. Carmel showing the blocked and displaced fluvial system. The shear zone of the Yagur fault is marked by two black dotted lines. The outlet of the main channel is offset by ~500 m in relation to the confluence point of its southern tributaries. The shutter ridge reflects an additional offset of ~100 m.

### 3. Geological Background

The northeastern slope of the Carmel Mt. is bounded by the Yagur fault, which is part of the Carmel fault system that connects the Dead Sea Transform with the eastern Mediterranean basin (De-Sitter, 1962; Freund, 1970; Hofstetter et al., 1996).

Two segments compose the Yagur fault: a S-N oriented fault that runs between Yoqneam and Jalame, and a NW oriented segment the runs from Jalame towards the Haifa bay (Fig. 1).

In the study area the slopes of Mt. Carmel are built of north tilted strata of hard carbonate rocks, mainly limestone of the Turonian age. This sequence builds unstable slopes with abundant landslides, and other types of mass-movement.



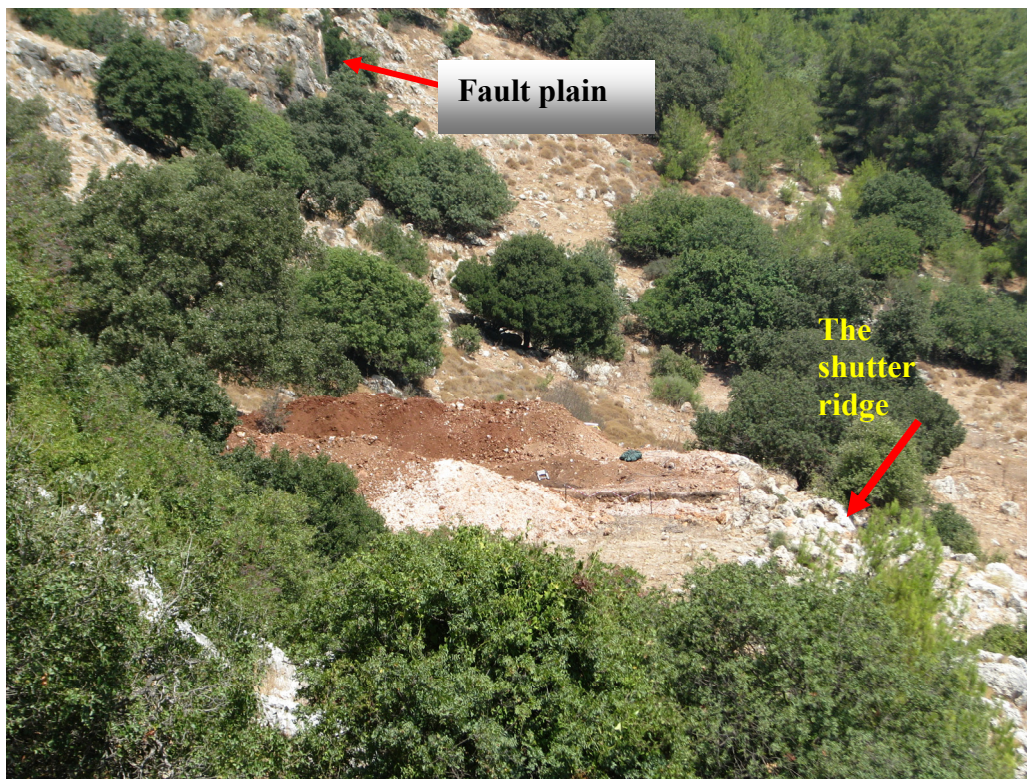
**Fig. 4** - The North Shutter Ridge . The blocked stream is marked by a blue line. The outlet of the stream, which is incised in the southern margin of the ridge, is hidden by the vegetation.



**Fig 5** - Shattered rocks built of cemented breccia. The exposed surface is a north- facing fault plain of the Yagur fault shear zone.

Between Yoqneam and Jalame, the Yagur fault crosses the lower slopes of the Carmel, forming a shear zone several hundred meters wide (Achmon, 1986), characterized by densely shattered rocks (Fig. 4).

The shutter ridge is displaced several meters eastward by a small, left lateral east-west oriented strike slip fault. The fault plain is exposed along the southern wall of the V-shape outlet of the stream entrenches in the shutter ridge. Along the western backside of the ridge there is a flat alluvial terrace covered by colluvium and soils (**Fig. 6**).



***Fig. 6** - A westward view of the trench excavated across the flat terrace that accumulated between the shutter ridge and the slopes of Mt. Carmel.*

#### **4. Methods**

A N-S trench, 7 m deep and 40 m long, was excavated between the shutter ridge and the slope of Mt. Carmel across the back-barrier terrace (Figs. 6, 7, 8). The trench exposed an alluvial/colluvial sequence, which is more than 7 m thick. The base of the trench was not exposed. Because of the short transport distance the gravel is angular and it is not possible to distinguish between alluvial and colluvial gravel according to their roundness.

The exposed sequence was described and its stratigraphy was determined. 10 OSL samples were taken from the sedimentary sequence and analyzed at the GSI luminescence laboratory.

The trench was logged using EDM.

## **5. Description of Sedimentary Units**

As aforementioned, the trenched alluvial-colluvial fill is more than 7 m. The base of the trench is mantled by an indurated coarse gravel unit in the form of a calcrete that could not be trenched. This strongly cemented unit is continuous with the colluvium that covers the slope of Mt. Carmel and the trench facing wall of the shutter ridge, forming a hard base for the overlying friable fill. The configuration of this hard unit illustrates a wide channel that flowed sub-parallel to the blocking shutter ridge (Fig. 6). Most of this channel was filled by a thick alluvial/colluvial sequence rich in clay, covered by a younger colluvial unit (Fig. 7). The shutter ridge is composed of intensively shattered limestone, sometimes with a chalky appearance, crossed by many sub-vertical fractures.

### **5.1 Unit 1**

Unit 1 is a massive colluvial unit, which overlies the south-facing wall of the shutter ridge. It consists of matrix supported angular to subangular rock fragments (40%) up to 8 cm in size, probably detached from the underlying cemented gravel. The matrix is mainly massive silt cemented by disseminated carbonate.

The unit is overtopped by a stage III carbonate soil: the clasts are coated with a carbonate crust and the matrix contains carbonate nodules up to 2-3 cm in size. The top of the unit is enriched with brownish clay from the overlying unit. ABK peds, moderately cemented, developed at the upper part of this unit.

The lower boundary, with the brecciated limestone of the shutter ridge, is abrupt.

Dry color: 7.5YR 5/3-6/3 – brown-light brown.

The lowermost part of this unit appears to be crossed by one of the small faults that displace the underlying cemented gravel.

## **5.2 Unit 2**

Unit 2 is a colluvial gravel unit, which overlies unit 1. The lower contact with unit 1 is gradual, clear and wavy.

Unit 2 consists of clast-supported, subangular gravel (50-60%) in a clay matrix. The clasts are mainly limestone and weathered, hard cemented brecciated rocks. The average size of the clasts is 5 cm, but the size of the coarse clasts is up to 25 cm. Some of the clasts were eroded from rock-units that are not exposed near the trench. The matrix is brownish clay (Dry color: 7.5 YR 4/4 – dark brown) with blocky peds, and contains iron and manganese concretions, and small (<1cm) carbonate nodules. The matrix contains large relict disorthic carbonate nodules – 4-5 cm in size and weathered relicts of carbonate coatings. The amount of disorthic carbonate nodules increases upward. Some of the limestone clasts have a partial coating. A moderately cemented, stage II-III clastic soil has developed in this unit.

The OSL age of this unit is  $154 \pm 9$  ka.

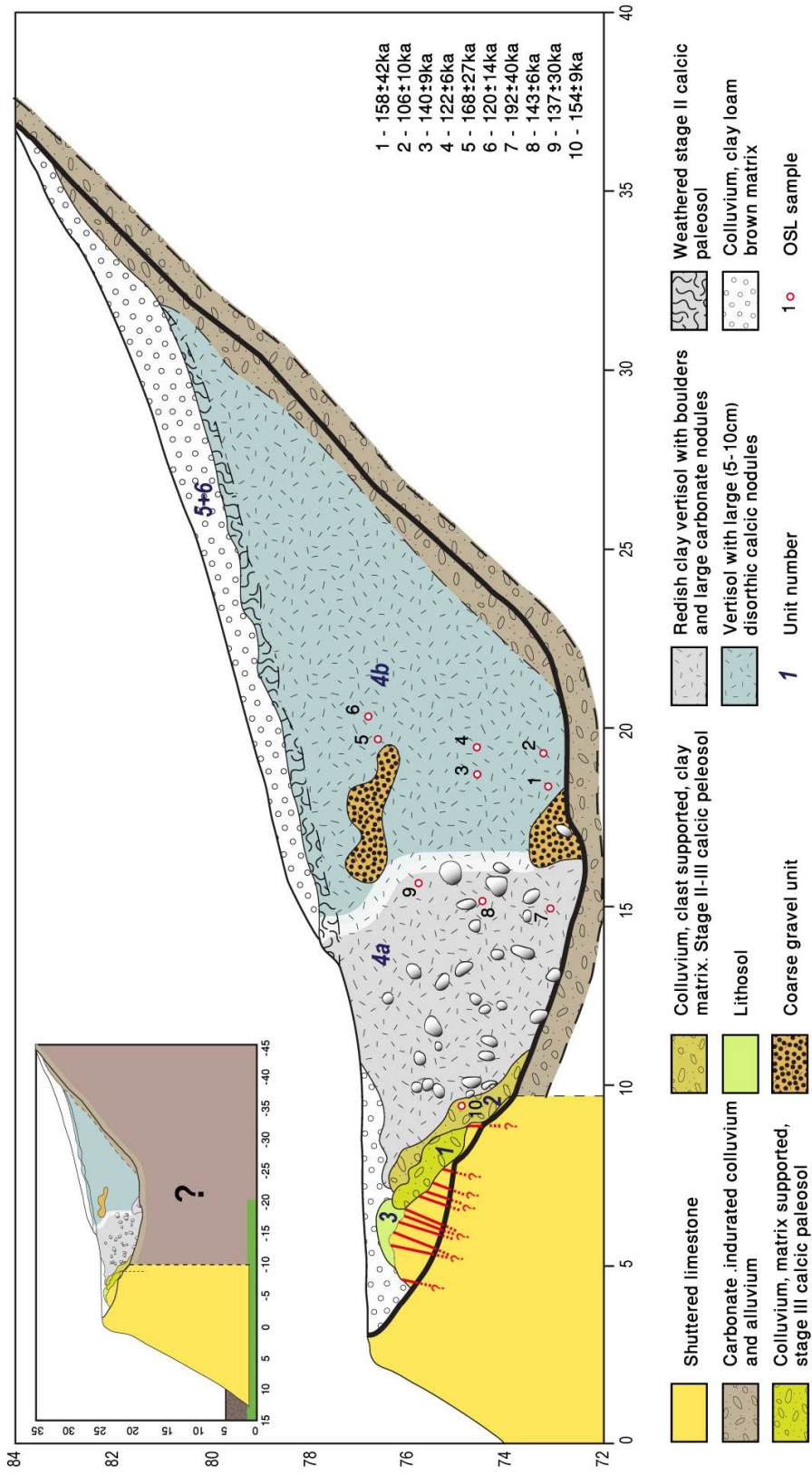
## **5.3 Unit 3**

Unit 3 is a remnant of a lithosol, which has been preserved in a small depression over the shattered limestone of the ridge and unit 1, at the northern part of the trench. It is composed of weathered rocks grounded into silt with a few rock fragments at the bottom and massive silt at the upper part. The silt contains up to 20% angular clasts up to 10 cm in size. The unit is slightly-moderately cemented. Its lower contact with bedrock is gradual but clear and wavy. Dry color: 7.5YR 5/6 – dark brown.

## **5.4 Unit 4**

Unit 4 forms the main fill of the back-shutter ridge channel. It is up to 6 m thick and overlies the lower hard cemented gravel unit that covers the bottom and the slopes of the channel, except for the northern edge where it overlies the colluvial unit 3.

Unit 4 consists of two facies: a northern, coarse clastic facies (unit 4a) and a southern, fine clastic facies (unit 4b). The two facies are separated by a sub-vertical wavy boundary (Figs. 6, 7).



**Fig. 7 - The log of the trench excavated across the back-barrier terrace of the NSR**



*Fig. 8 - A southward view at the trench. In the front – the white shutter ridge. Most of the fill is the reddish-brown unit 4, covered by dark brown younger colluvium. The white boulders (marked by the arrow) are part of the coarse facies of unit 4.*

**The Coarse facies** (unit 4a) is a massive, matrix supported boulder unit, with 40% angular boulders up to 70 cm in size (Fig. 9), composed of brecciated dolomite, limestone, sandy dolomite (yellowish or white) and fragments of reworked slope calcrete. Some of the boulders – mainly the sandy-dolomites, are highly weathered. The matrix is reddish clay with a very hard blocky or prismatic structure, localized between large boulders. It also contains small lithoclasts and disorthic carbonate nodules. At the lower part, the matrix is redder (Dry color at the base of the unit: 5YR 4/4 reddish brown) and contains also manganese and iron concretions. At the upper part the matrix is paler (At the top of the unit – 5YR 4/6 yellowish red) and contains more carbonates.

Some boulders have partial carbonate coatings. Some coatings cover grayish mud balls. Carbonates also form thin films between clay blocks and clay prisms. The unit is compacted and very hard.

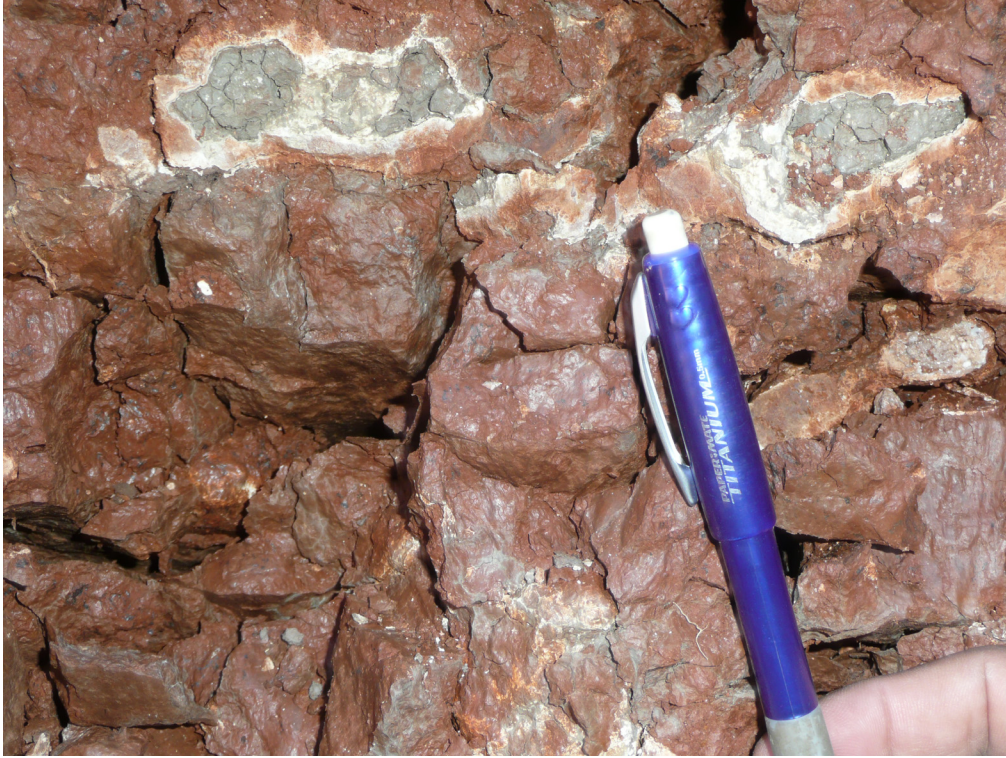
The lower contact with the hard cemented gravel unit is clear. At the lower part, near the contact with the southern fine-clastic facies (unit 4a), there is a lens-shaped unit of clast-supported, well sorted gravel (1-5 cm) unit, probably of fluvial origin.



**Fig. 9** - *The coarse facies of unit 4. The size of the boulders (marked in yellow color) is up to 70 cm and they are mostly matrix supported*

**The fine-clastic facies** (unit 4b) is a reddish (Dry color: 5YR 4/4 – reddish brown; at the base – 2.5YR 3/4 – dark red) massive clay vertisol with 10% angular limestone and calcrete clasts up to 15 cm in size. The clay has well developed hard peds, prisms or blocky structures (up to 10 cm in size) with slickensides on the joints surfaces. In places, fine gravel lenses (alluvial?) up to 2 m long and 0.5 m thick occur within the unit.

Most clasts have complete, pinkish white carbonate coatings up to 2-3 cm thick. The clay contains large iron and manganese concretions. Grey clay is abundant along joints indicating localized reduction environments along joints and macropores (Fig. 10). Grey clay also appears in a form of angular clay peds coated by a thin carbonate crust. However, there are no significant differences between the composition of the reddish and the grey clay minerals (A. Sandler pers. com.).



*Fig. 10 - The vertisol of unit 4b. Grey fragments of clay coated by calcite. Grey clay also form thin films on the fractures walls*

A large fraction of the clasts are actually elongated, very large (5-10 cm), hard, disorthic, amorphous carbonate nodules (Fig. 11), which developed within the vertisol. Most of the nodules have a concentric structure with a solution void at the center that is coated by secondary carbonate precipitation in a form of micro-speleotems. Some of the concretions are probably elongated rhyzoliths. The lower contact with unit 3 is abrupt.

A stage II calcic soil, developed at the upper part of Unit 4 (Upper soil color – 7.5 YR 4/4 – reddish brown). The carbonate nodules form a mottling of about 30%. The soil also contains large (5-6 cm), pinkish carbonate nodules with karstic features similar to those scattered in the entire sequence of unit 4. This mixture of two types of carbonate concretions indicates that the soil is a polygenetic calcic soil, in which a younger (stage II) calcic soil has developed into a weathered, well-developed, much-older calcic soil profile.

### 5.4.1 dating

Nine samples for OSL dating were collected from unit 4: Samples 1-6 from the fine clastic sequence (two parallel series were taken) and samples 6-9, from the coarse clastic unit (Fig. 7; Table 1).

**Table 1** - Results of OSL dating in the trench.

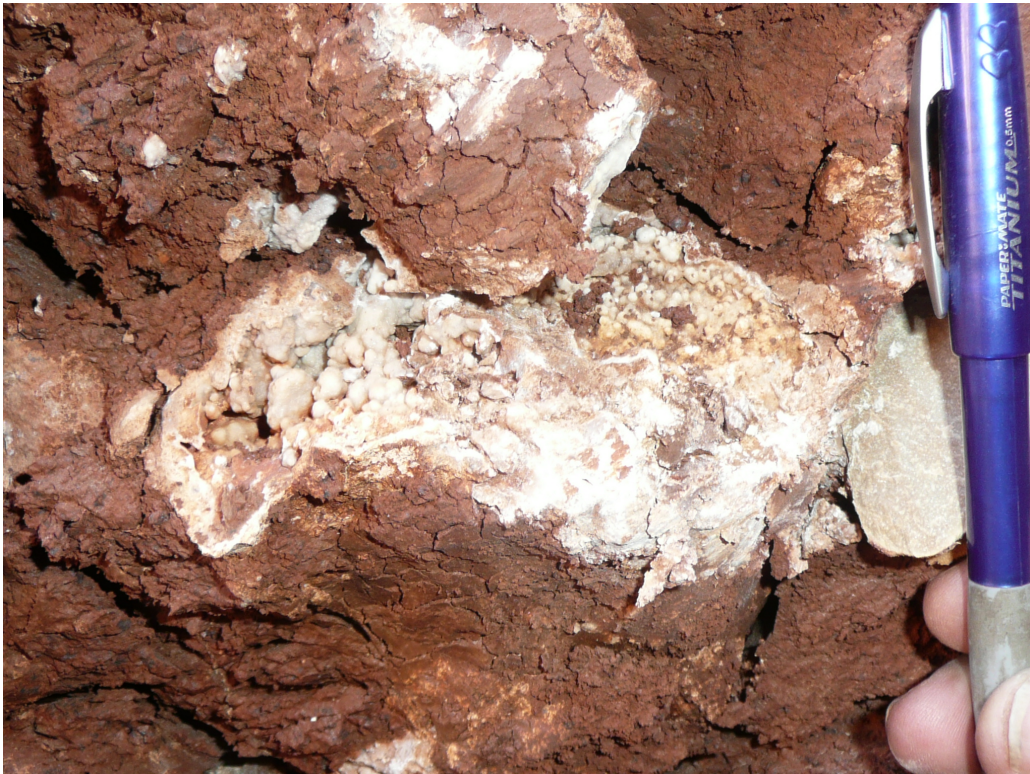
Lab. No.	Depth (m)	Field gamma & cosmic ( $\mu\text{Gy/a}$ )	K (%)	U (ppm)	Th (ppm)	Ext. $\alpha$ ( $\mu\text{Gy/a}$ )	Ext. $\beta$ ( $\mu\text{Gy/a}$ )	Dose rate ( $\mu\text{Gy/a}$ )	No. of discs	De (Gy)	Age (ka)
CAR-31	6	699	1.0	1.7	10.8	12	1068	1778 $\pm$ 73	6/6	282 $\pm$ 73	158 $\pm$ 42
CAR-32	6	716	0.83	1.7	10.1	11	945	1672 $\pm$ 80	2	177 $\pm$ 15	106 $\pm$ 10
CAR-33	4	603	1.0	1.6	8.3	11	1001	1614 $\pm$ 72	2	226 $\pm$ 11	140 $\pm$ 9
CAR-34	4	605	0.91	1.9	9.6	12	1008	1625 $\pm$ 72	2	197 $\pm$ 5	122 $\pm$ 6
CAR-35	2	628	1.0	1.2	6.8	8	921	1557 $\pm$ 71	5/6	261 $\pm$ 41	168 $\pm$ 27
CAR-36	2	592	1.0	1.7	9.9	11	1048	1651 $\pm$ 65	2	199 $\pm$ 21	120 $\pm$ 14
CAR-37	6	345	0.83	1.6	7.6	9	878	1232 $\pm$ 47	6/6	237 $\pm$ 49	192 $\pm$ 40
CAR-38	4	456	0.83	1.7	8.3	10	905	1372 $\pm$ 55	2	196 $\pm$ 3	143 $\pm$ 6
CAR-39	2	605	1.08	2.1	11.4	13	1178	1797 $\pm$ 75	7/8	246 $\pm$ 57	137 $\pm$ 30
CAR-40	2-3	308	0.78	1.6	8.1	10	858	1176 $\pm$ 47	2	180 $\pm$ 8	154 $\pm$ 9

Time-averaged moisture contents estimated at 10 $\pm$ 3%. Grain size: 75-125  $\mu\text{m}$ . Samples in **bold** were measured on 6-8 discs. All other samples were averaged on 2 measurements only and are preliminary. All ages should be considered as minimum, as samples are close to saturation.

Not all the ages are in stratigraphic order: in the coarse clastic facies the lower sample is 192 $\pm$ 40 ky old, the middle sample is 143 $\pm$ 6 ky old and the upper sample is 137 $\pm$ 30 ky old. In the fine clastic facies the northern samples series are always older than the southern samples series and the ages range between 168 $\pm$ 20 ka and 106 $\pm$ 10 ka. The age distribution in the vertisol is probably caused by infiltration of young eolian quartz silt from the surface into the clay sequence via open fractures, which formed during dry seasons. Such a process could have occurred during the deposition of this unit or during the time of the exposure and the development of the upper calcic soil. The coarse facies was less sensitive to the fracturing process and therefore, its dating maybe more reliable. This contamination process was terminated when unit 4 was covered by the coarse colluvium of unit 5.

### 5.5 Unit 5

Unit 5 is a coarse clastic unit, in which 40% is gravel. It composed of layers with subangular –subrounded fine gravel, weakly stratified alternating with coarser gravel layers, moderately bedded with gravel up to 10 cm in size (recurrent size 1-4 cm). The gravel is composed of limestone and sandy dolomite. The matrix is reddish clay (Dry color – 2.5YR 3/4 – dark red), which includes small clasts, manganese and iron concretions, and a few carbonate nodules. Thin carbonate crusts partially coat the bottom of some clasts.



*Fig. 10 - Disorthic carbonate concretion, with small speleothems in its leached core.*

### 5.6 Unit 6

Unit 6 is a gravel unit, which truncates and cuts into the topsoil of unit 5 and forms a multi-channel pattern. It contains limestone clasts 3-10 cm in size. The matrix is clay-loam massive and friable colluvial brown soil. The lower contact is abrupt. Dry color – 7.5YR 3/2 – dark brown.

## **6. The northern Shutter Ridge - Summary and discussion**

The tectonic activity represented by the NSR, reflects only part of the left-lateral displacement along the Yagur fault. The amount of lateral displacement at this site is at least 100 m (the length of the shutter ridge), but this amount should be added to the 500 m offset of the southern first order channel of the drainage system that was blocked by the Shutter ridge (Achmon, 1986; Ashkar-Halak, 2009). The offset represented by the three streams that drained toward the shutter ridge seems to decline northward (Fig 2). This change can be attributed to the width of the shear zone in this area (almost 400 m), which raises the possibility that the lateral movement splits between several branches of the Yagur fault.

The tectonic phase that established the NSR predated the deposition of units 1- 4 that fill the channel, meaning that it is older than 200 ka. This alluvial/colluvial sequence fills a paleo-channel that flows northward between the slopes of Mt. Carmel in the west and the rock barrier of the shutter ridge in the east. The total thickness of the alluvial-colluvial fill is unknown since the buried bed rock was not exposed in the trench. However, the lower indurate gravel unit, which underlies unit 4, might represent the gravel pavement of the paleo-channel bottom. Therefore, the thickness of the alluvial/colluvial fill can be estimated as 7-8 m.

The indurate gravel unit at the base of the trench is separated from the overlying friable fill of unit 4 by a clear contact, which suggests a depositional hiatus associated with a major change in depositional environments.

Most of the channel is filled by unit 4, which is dominated by clay. The age of this unit ranges between 200 ka and 100 ka, reflecting a slow accumulation rate, which lasted several tens of thousands years. The massive structure and the lack of stratigraphic features might be a result of a low sedimentation rate accompanied by intensive bioturbation. Nevertheless, it might also be related to the annual reaction (shrinking and swelling) of the clay to wet and dry seasons, which can erase any evidence of a sedimentary structure in the sequence.

The two facies of unit 4 (4a and 4b), which are separated by a sub-vertical unclear boundary, reflect two different sediment sources. The western fine-clastic vertisol facies was probably contributed by the near slope of Mt. Carmel. The rare coarse gravel in this unit suggests stable slopes, probably mantled with reddish-brown soils and covered by dense vegetation. The large disorthic, leached carbonate nodules scattered among this

sequence are remnants of calcic soils that were disrupted by the continuous shrinking-swelling process of the clay.

The northern coarse facies (unit 4a) is dominated by very coarse gravel (up to 70 cm), embedded in a clay matrix, which points to a possible debris flow and/or alluvial mass transport events as the main sedimentary agents. The lithology of the coarse gravel, especially the yellow and white sandy dolomites gravel, suggests a source that is not the near slopes of the Carmel. Therefore, it is assumed that the sediment fluxes originated from colluvium aprons on remote slopes of the Carmel. This coarse sediment was transported to the shutter ridge barrier by the north and northwest flowing first order streams that converge near the shutter ridge. The sediment fluxes were deflected northward by the rock barrier, which forced them towards and along the western wall of the barrier, and therefore, they were deposited near the shutter ridge. The similar ages of the coarse and the fine-clastic facies of unit 4 delineate the contiguous deposition of the two facies across the back-barrier channel.

Although there is no evidence for syn or post-depositional deformation in unit 4, it should be emphasized that in such clay dominated sediments tectonic features are rarely preserved.

The polygenetic soil at the top of unit 4, which includes a stage II calcic soil and relicts of older, well-developed calcic soil, indicates a long period of stability of the surface of the terrace combined with pedogenesis and minor erosion. This surface was later covered by the younger colluvial units 5 and 6.

It is not clear what the paleogeographic change that caused the transition from a continuous fluvial activity in open channel to slow accumulation of the slope sediments of unit 4 was. However, this process led to a complete filling of the back-barrier channel and incision of a new outlet by the stream at the southern margins of the back-barrier terrace. The small, W-E oriented right lateral strike slip fault that bounds the new outlet might suggest the involvement of tectonic activity in determining its location. The eroded surface at the top of unit 4 was probably established when the stream returned to an eastward course by breaching the barrier. Therefore, it represents a time gap that lasted until a new colluvial apron from units 5 and 6 were deposited on the abandoned terrace. Unit 5 covers all of back-barrier terraces, forming a continuous, un-deformed colluvial apron. There is no absolute age for this unit, but it is clear that it post-dates unit 4, which

is at least 100 ka old. However, there is no clear soil profile in this unit, indicating that it is probably of late Pleistocene age.

In summary, the main tectonic phase that formed the NSR is of Late-Middle Pleistocene or early Late Pleistocene age. If there was any tectonic activity during the deposition of unit 4, its evidence was erased by the clay shrinking-swelling process. The young colluvial unit seems to be un-deformed.

## **7. Is the Yagur fault active?**

According to building codes in Israel, an active fault is a fault that was a source for at least one earthquake during the last 13,000 years. Since the historic reliable seismic record of earthquakes in the region is limited to the last 2-3 millenia (Ambraseys, 2009, and ref. therein), most of the Holocene seismic record is based on paleoseismic research. Moreover, although the historic record gives a lot of information about the date and the radius of destruction caused by each earthquake, the location of the epicenter is still not always known and depends on paleoseismic records obtained from other paleoseismic studies. However, paleoseismic methods applied to active faults can detect only seismic events that were associated with surface rupture, which is generally induced by earthquakes with a magnitude of  $M \geq 6$  (Wells and Coppersmith, 1994). Therefore, the lack of evidence for a young surface rupture along a fault trace cannot eliminate the possibility that a fault is active but only gives an upper limit to the magnitude of the earthquakes it produced.

In this chapter we will present a synthesis of the results obtained by our previous studies along the Yagur fault with additional data regarding seismic activity in the Carmel region that has been published in the last years.

### **7.1 – Previous results of neotectonic studies along the Yagur fault system**

Three sites were investigated along the Yagur fault in the last years. The depositional history of sediments that accumulated beyond two shutter ridges were analyzed in order to reconstruct their tectonic history, and a paleoseismic study was carried out in a trench excavated across the trace of the Nesher fault, a branch of the Yagur fault (Zilberman et al., 2006, 2009). The young (post Miocene) vertical uplift of Mt. Carmel was investigated in the Nesher Quarry (Zilberman, 2010). The main results of the previous studies are presented below.

**7.1.1 The Nesher fault** is a short, E-W oriented branch of the Yagur fault, which splits from the main stem south of Nesher. The vertical displacement of this fault declines from 1000 m near the splitting point from the Yagur fault in the east to a few meters in the water divide of Mt. Carmel, some 5 km to the west (Kcartz, 1959). Most of the vertical offset predated the Pliocene (Zilberman et al., 2010), and the young tectonic activity is dominated by a strike-slip movement (Zilberman et al., 2006; 2008).

The paleoseismic study was performed near the splitting point of the Nesher fault from the Yagur fault, assuming that each major seismic event that occurred along the Yagur fault reactivated the Nesher fault. This means that the paleoseismic record of the Nesher fault represents only major seismic events on the Yagur fault and not all of the tectonic activity.

This paleoseismic research found evidence for tectonic subsidence of a small depression south of the fault trace. The subsidence is at least  $178 \pm 20$  ky old (the base of the alluvial fill was not exposed) and it continued to subside slowly up to almost 20 ka. Discrete seismic events could not be detected in the sequence attached to the fault, but it is clear that this fault was episodically reactivated during the entire late Pleistocene. The upper time-limit for the tectonic activity was determined at 20-27ka because the younger upper part of the sequence was disturbed by anthropogenic activity.

**7.1.2 The Southern Shutter Ridge** developed along the N-S oriented segment of the Yagur fault that extends between Yoqneam in the south and the A'amaqim Junction (Jalame) in the north (Ashkar-Halak, 2009). The sequence that was accumulated beyond the barrier was analyzed by Zilberman et al., (2006, 2008). Two periods of sediment accumulation were identified in this sequence: A slow deposition of an alluvial unit rich in weathered pyroclastic fragments (from unknown outcrops of volcanic rocks) started  $140 \pm 20$  ky ago, and terminated before 25 ka, when the barrier was probably breached and the stream incised at least to its present level. This incision was followed by a rapid accumulation of an almost 8 m thick alluvial and colluvial sequence of middle Holocene ( $\geq 5000$  Y.B.P.) age, consisting of eroded soils and carbonate gravels of local origin with no volcanic components. The present incision of the stream in this young fill is younger than 2000 Y.

The accumulation of sediments in this steep gradient stream is attributed to a complete or partial blocking of the stream outlet. This process might be related to the left lateral

offset of the shutter ridge, and thus reflects a phase of intensive tectonic activity. Another option, which cannot be ignored, is that there was a massive debris flow that blocked the stream outlet, or a climatic change impacted the balance between the contribution of run off and sediments to the stream. However, no evidence to such events was found in the study site.

The analysis of this shutter ridge sequence indicates continuous, but slow tectonic activity that lasted during most of the late Pleistocene and maybe also a short but intensive tectonic phase that occurred during the Middle Holocene.

### **7.1.3 The Northern Shutter Ridge**

Reflects a late middle Pleistocene to early late Pleistocene tectonic activity (see above).

### **7.1.4 The Neshar Quarry**

The Neshar Quarry, exploited by the cement industry, is a submarine channel filled by a sub-horizontal sequence of marine gravity mass-flow sediments. The sequence, more than 60 m thick, was deposited in the margins of the Zevulun Valley during the Messinian and the lower Pliocene at a depth of at least 300 m. It was uplifted to the present altitude (20-90 m) after the lower Pliocene (Zilberman et al., 2010a).

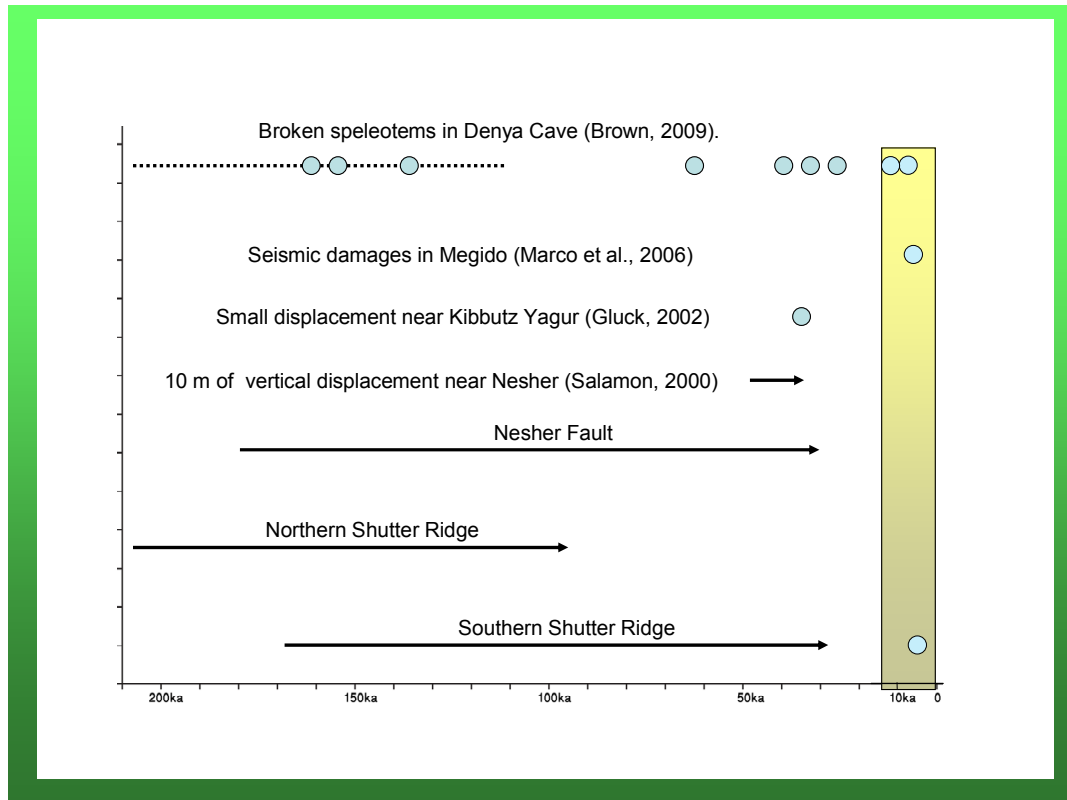
The post Early Pliocene vertical uplift of the Carmel was not induced by tectonic activity along the Yagur fault, but it is part of a regional uplift of the entire mountainous back bone of Israel extending between the Be'er Sheva Valley in the south and the Yisrael Valley in the north. The Yagur fault only serves as a tectonic boundary that enabled this uplift by separating between the southern mountainous block and the northern densely faulted tectonic province of the Yizre'el and Zevulun valleys and the Lower Galilee (Zilberman et al., 2010b).

## **7.2 Additional data**

Several studies suggesting Pleistocene and Holocene tectonic activity along the Yagur fault have been published in the last years (Fig. 11).

1. A vertical displacement of about ten meters was detected in the subsurface trace of the Yagur fault near Neshar. The displaced units are about 50 ky old (Salamon, 2000)
2. A small displacement of a 30 ka alluvial unit was described by Gluck (2002) in a small alluvial fan that covers the Yagur fault trace near Kibbutz Yagur.

3. Several episodes of destruction, some of them are assumed to have been induced by earthquakes, were described from Megido ruins by Marco et al., (2006). It was suggested (although with no clear evidence) that some of these seismic events originated at the Yagur fault.



**Fig. 11** - Evidence for tectonic activity along the Yagur fault during the late Pleistocene and the Holocene. The last 13 ka are marked in yellow.

4. A study of clusters of broken speleotems in Denya Cave, located only 4 km from the Yagur fault (Braun, 2009), suggest that each of them is related to a strong ground acceleration induced by a seismic event. Two of these clusters were dated to the Holocene circa 10ka and 5ka.

Although the sources of the seismic events that produced the ground acceleration that broke the speleotems were not determined, it is worth noting that all the strong earthquakes that occurred along the Dead Sea Rift Valley in the last 5000 yrs (up to M=7.4-7.6; Ambraseys, 2009 and refer. therein; Kagan et al., 2011; and refer. therein), did not cause any damage in the cave. This might suggest that remote earthquakes,

although very strong, can not produce ground acceleration strong enough to break the speleotems in this area and the damages in the cave represent mainly earthquakes with close epicenters located on the Yagur fault.

### **7.3 Tectonic activity along the Yagur Fault - Summary and Conclusions**

The origin and age of the Carmel fault system are a source of controversy. It was interpreted as a Paleozoic suture line (Ben Avraham and Ginzburg, 1990), a Mesozoic tectonic line associated with large gravity anomalies and volcanic activity (Folkman, 1976; Ben-Avraham and Hall, 1977; Dvorkin and Kohn, 1989), the southern boundary of a Miocene half graben of the Yizre'el Valley (Matmon and Widowsky, 2003), a branch of the Dead Sea Transform that accommodates a small part of the sinistral strike slip displacement since the Middle Miocene (De Sitter, 1962; Freund, 1965, 1970; Rotstein et al., 1993; Hofstetter, 1996); The southern boundary of the west moving Galilee block under an E-W compression stress field (Schattner et al., 2006).

However, all the models accept the idea that there is a tectonic connection between the DST and the Carmel Fault system, and therefore, under the present active plate tectonic regime the Yagur fault and the entire Carmel fault system, extending between the northern Jordan Valley and the Mediterranean, should be considered active.

This assumption is supported by the present study. The Paleoseismic, archaeoseismic and geological data collected so far about young tectonic activity along the Yagur fault, indicates continuous activity during the entire late Pleistocene. However, evidence for Holocene activity is rare, for two main reasons: 1. The upper part of the sedimentary sequence along the fault trace, which represents the Holocene, is mostly disturbed by several millennia of intensive anthropogenic activity. Therefore, if there was any surface rupture during this period its morphological impression was not preserved. 2. The displacement associated with young tectonic activity is small and characterized by almost pure lateral movements (Achmon, 1986; Rotstein et al., 1993; Zilberman et al., 2006). Therefore, it is very difficult to detect surface morphological evidence such as fault scarps or Holocene displaced morphological elements. The lack of significant vertical displacement also raises difficulties in identifying subsurface deformation using geophysical methods or drill holes analysis. So far the only site where circumstantial evidence for Holocene tectonic activity was found is the Southern Shutter Ridge.

Although discrete seismic events could not be distinguished among the study sites, the field evidence for surface ruptures suggests that some of the earthquakes produced by the

fault were of Magnitude 6 or higher (Well and Coppersmith, 1994). The lack of detailed records about magnitudes and recurrence intervals of earthquakes originated by the Yagur fault, raise obstacles in assessing accurate seismic hazards in this region.

Although most of the evidence on young tectonics in the present study is indirect, in our view, based on general tectonic considerations and the new findings, this fault should be treated as an active fault according to the present Building Code of Israel.

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שאינן עדויות לכך שחל שינוי משמעותי במערך ובקצב של תנועת הלוחות באזורנו לפחות מאז תחילת הפלייסטוקן, ניתן להעריך שהממצאים שנאספו לגבי אופי וקצב הפעילות הטקטונית של מערכת זאת בפלייסטוקן המאוחר מייצגים גם את תקופת ההולוקן וניתן להקיש מהם לגבי מידת הסיכון הסייסמי הטמונה בהעתקים המהווים חלק ממערכת זאת.

לכן, לאור העדויות לרציפות הפעילות הטקטונית בפלייסטוקן המאוחר לאורך טרנספורם ים המלח והעתק יגור המהווה אחד מסעיפיו, אנו ממליצים להתייחס אל העתק זה כפעיל.

לא נמצאו עדויות לדפורמציה ביחידת הקולוביום העליונה המכסה את המיזרון הנוכחי ולא ביחידת הוורטיסול. עם זאת יש לציין שהטקסטורה של יחידה 4 נשלטת על ידי תהליכי יבוש (והתכווצות) והרטבה (והתרחבות) של החרסית הבונה אותה, המטשטשים כל עדות לדפורמציה טקטונית. היחידה התחתונה המצפה את התעלה נחצית על ידי העתק קטן במקום בו היא מצפה את מדרונות הרכס החוסם, אך לא נצפתה הסטה משמעותית לאורך העתקים אלה.

תוצאות המחקר מראות שהמחסום הטקטוני הצפוני נוצר לפני למעלה מ-200.000 שנה עקב תנועה שמאלית בשיעור של כ-100 מ' על העתק יגור. תזוזה זאת הנה השלב הסופי בהסטה שממדיה המצטברים עולים על 500 מ' שהסיטה את מערכת האפיקים המתנקזת אל הרכס החוסם. בשלב ראשון לאחר החסימה הוסט האפיק צפונה וזרם לאורך קיר המחסום. בשלב זה הורבדה היחידה התחתונה הקשה המצפה את בסיס התעלה. לאחר מכן, חל שינוי באנרגיית הזרימה והחלה הצטברות איטית של סדימנט בתוך התעלה שנמשכה כ-100.000 שנה. בקרבת המיזרון הצטברו בעיקר חרסיות שמקורן בסחיפת קרקעות מדרוניות, כמעט ללא מרכיבים גסים, הרכב המצביע על מידרונות יציבים המכוסים צמחיה. ארועים של זרימות בלית שמקורן במעלה האגן הובילו סדימנטים גסים במורד האפיקים, אך זרימות אלה נתקלו ברכס החוסם והורבדו בקרבתו ויצרו את חלקה המזרחי של יחידה 4.

כאשר המילוי של האגן הגיע אל שפת הרכס החוסם, פרץ הנחל נתיב חדש וקצר בקצהו הדרומי ויצר מפל שבחלקו נשמר גם כיום. הטרסה ננטשה, חלקה העליון נסחף והתפתחה בה קרקע גירנית. לאחר מכן כוסתה הטרסה בקולוביום גס שמקורו במדרונות הסמוכים. אין עדויות לפעילות טקטונית החל מתחילת שלב המילוי של התעלה, אך כפי שצויין למעלה, האופי החרסיתי של מילוי התעלה אינו מאפשר שימור של עדויות לפעילות טקטונית.

הנתונים שנאספו במסגרת הנוכחית של מחקרי הכרמל מארבעה אתרים – שני מחסומים טקטוניים, העתק נשר ומחצבת נשר, בצרוף נתונים שמקורם במחקרים נוספים שנעשו לאורך העתק יגור (ראה איור 12), מצביעים על פעילות טקטונית של העתק יגור לאורך כל תקופת הפלייסטוקן המאוחר ואף בהולוקן (במחסום הטקטוני הדרומי). נראה שמקטעים שונים של ההעתק פעלו בנפרד, אך איכות הנתונים אינה מאפשרת לבצע קורלציה בין ארועים טקטוניים לאורך כל מקטעי ההעתק.

לא כל העדויות לפעילות טקטונית הן ישירות והנתונים הקיימים בשטח אינם מאפשרים לקבל תמונה מהימנה של תדירות רעידות האדמה והמגניטודה שלהן. עם זאת, מאחר שיש עדויות לכך שההעתק הגיע לפני השטח, ניתן להניח שחלק מרעידות האדמה היו במגניטודה של 6.

הנתונים לגבי הפעילות הטקטונית המתמשכת של העתק יגור בפלייסטוקן העליון, משתלבים עם הידע הגיאולוגי הקיים לגבי טרנספורם ים המלח שהוא המערכת הטקטונית הפעילה העיקרית באזורנו. מערכת ההעתקים של עמקי בית שאן, יזרעאל והכרמל, שאחד מענפיה הבולטים הוא העתק יגור, מסתעפת מטרנספורם ים המלח ומעבירים חלק קטן מהתנועה האופקית עליו אל מדף היבשה של הים התיכון. מאחר

## תקציר מורחב

במסגרת מחקר הפעילות הטקטונית הצעירה לאורך העתק יגור והאגף הצפון מזרחי של בלוק הכרמל, נבדק רכס חוסם (הרכס החוסם הצפוני) שנוצר עקב תנועה שמאלית אופקית לאורך המקטע של העתק יגור הנמשך בכוון צפון-דרום בין יוקנעם לצומת העמקים.

המחסום הטקטוני של הרכס החוסם הצפוני נוצר במקום בו יוצר העתק הכרמל רצועת גזירה ברוחב של כ- 400 מ' לאורך שולי רכס הכרמל וגורמת לריסוק סלעי חבורת יהודה הבונים כאן פלקסורה הנטויה לצפון. המחסום הטקטוני שנבדק במחקר הנוכחי נמצא כשני קילומטרים צפונית למחסום נוסף (המחסום הדרומי) שנבדק במחקר קודם.

אורכו של המחסום הטקטוני הצפוני כ- 100 מ' והוא חסם את המוצא של מערכת ניקוז המוסטת צפונה לאורך רצועת הגזירה של העתק יגור בשעורים המשתנים בין כ- 500 מ' ביובל הדרומי לכ- 150 מ' ביובל הצפוני. עקב חסימת אפיק הנחל על ידי קיר הבנוי מסלעי גיר קשים של גג חבורת יהודה, הצטבר מאחורי המחסום חתך של סדימנטים מדרוניים ונחליים שיצרו טרסה שטוחה בינו לבין מדרונות הכרמל. גגה הטרסה נמצא כ- 20-25 מ' מעל קרקעית העמק הצר המשתרע בין רמת טבעון לכרמל ובו זורם נחל קישון. פתח הניקוז הנוכחי של הנחל נמצא בקצה הדרומי של המחסום, שם הוא יצר מפער צר החתור בתוך קיר המחסום. פתח הניקוז התחתון לאורך העתק קצר שכוונו מזרח-מערב, שלאורכו חלה תזוזה אופקית ימנית שהסיטה את קיר המחסום צפונה ביחס לשולי הכרמל שמדרום לו.

תעלה שנחפרה בניצב לטרסה, בין המחסום במזרח לשולי הכרמל במערב, חשפה חתך של סדימנטים מדרוניים ונחליים בעובי של כ- 7-8 מ', אך לא הגיעה לבסיסו של המילוי שהצטבר מאחורי המחסום (ראה איור 7).

בבסיס התעלה נמצאה שכבה קשה של סדימנטים קלסטים גסים מלוכדים על ידי קרבונט, המתלכדים עם הקולוביום המצפה את מדרונות הכרמל ועם הקולוביום המצפה את הדופן המערבית של הרכס החוסם. נראה כי יחידה זאת מצפה את קרקעיתו של אפיק קדום של הנחל שזרם צפונה לאורך הרכס החוסם. מעל יחידה זאת מונחת במגע חד יחידה רכה (יחידה 4) של סדימנטים מדרוניים-נחליים המהווה את רוב המילוי של התעלה. בשולי הרכס החוסם היא מונחת על יחידות קולוביאיות (יחידות 1-2) שהורבדו על הדופן המערבית של המחסום. החלק המערבי של יחידה 4 הנו חרסיתי ומורכב מוורטיסול עם תצבירי קרבונט דיסאורטיים ואורטיים ואילו חלקה המזרחי מורכב מבלדרים בממדים של עד 70 ס"מ הצפים במטריקס חרסיתי של וורטיסול הדומה לזה שהתפתח בחלקה המערבי. מקור הסדימנט בחלק המערבי של התעלה הנו מדרוני בעוד שחלקה המזרחי הורבד בתהליך בו היו מעורבות זרימות בלית (Debris Flow) שמקורן במעלה האגנים של מערכת הניקוז החסומה. טווח הזמן (נקבע בשיטת OSL) בו הורבדה יחידה זאת הנו 200.000 עד 100.000 שנה לפני זמננו.

החלק העליון של יחידה 4 עבר תהליכי סחיפה והתפתח בו פרופיל של קרקע גירית. מעליו הורבדה שכבה של סדימנטים מדרוניים בהם התפתח פרופיל של קרקע גירית בדרגה II (יחידות 5-6).





משרד התשתיות הלאומיות  
המכון הגיאולוגי

## שילבי התפתחות הרכס החוסם הצפוני בכרמל ומשמעותם לגבי הפעילות הטקטונית של העתק יגור

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הזמנה מס' 29-02-014 ב