STRIKE-SLIP FAULT MORPHOLOGY AND RECONSTRUCTION OF OFFSETS ALONG THE QANA'IM FAULT ZONE, JUDEAN DESERT.

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STRUCTURAL FRAMEWORK

This paper delineates structural and morphological features and the history of movements along the Qana'im fault zone, one of the largest (>100 km) fault zones of the Dead Sea transform system. Its main N-S trending fault transects the prevailingly NE Syrian Arc (Krenkel, 1924) thrust-folded mesostructures 8 to 10 km west of the Dead Sea cliffs (Fig. 1). The poly-stage movement along the transform, which is a dominant wrench fault with left lateral displacement of about 100 km (Quennell, 1959, Freund, 1965), accomodating the Red Sea spreading and the northward movement of the Arabian Plate relative to the African, produced a system of rift-type depressions (grabens) in the Levant, including the Gulf of Elat and the Dead Sea graben. These develop inside the generally north-south oriented shear-zone of the transform (~30 to ~90 km wide). Contrary to most parts of this zone, the southern part is not camouflaged by Phanerozoic sediments, and is clearly visible on satellite images and on the geological map (Bartov, 1990). Sinistral faults belonging to this zone have been studied west of the Gulf of Aqaba, with the general conclusion that the movements took place during the last 20 m.y. (Bartov et al., 1980). Further north and west of the Dead Sea, in the Judean Desert, the total thickness of Phanerozoic sedimentary cover reaches 3-4 km, and the reflection of strike-slip movements on the surface is inferior to that in the eastern Sinai.

The pre-Santonian main Proto-Qana'im fault subdivides the southern part of the desert into two different geological regions, which have a different Late Cretaceous - Neogene geological history; these are reflected by the Late Santonian-Early Campanian "Double-Chert" and the development of numerous circular dolomite bodies during the Miocene - Pliocene, both phenomena occurring only in the eastern region (Qana'im Valley fault, Gilat and Honigstein, 1981; Gilat et al., 1978). In some of the fault segments, which comprise a main fault and its branches, the limestone and even the chalky rock sequence have been massively dolomitized in the faults' vicinity by hydrothermal - metasomatic processes, probably in the Pliocene (Gilat, 1992a).

The main Qana'im Fault runs parallel to the major western Dead Sea fault from the area of Hamakhtesh Haqatan in the south to Biq'at Hureqanya and farther to the north, where it sinistrally displaces and is dextrally displaced by the dextral Samia fault (Begin, 1973). Farther north it passes along the Auja monocline (Blake, 1928); its NNW trending branches are 3-15 (or more) km long, crossing the entire Judean Desert and parts of the horst-anticlines of the Judean and Shomeron Mountains. (Fig. 1). The faults show alternating sides of both normal and thrust throws. They also form flexures, V-shaped synclines and shear zones with horizontal slickensides. Vertical displacements of up to 0.3 km and sinistral offsets of 0.1-1.3 km were observed.

Many fault segments are superposed on pre-existing structures: in the Adasha Valley the younger (Plio-Pleistocene) fault is about 100 m west and is parallel to the Pre-Santonian fault; near Mt. Holed it passes through a long and narrow graben, above which the Senonian sequence is much thinner, suggesting a horst development during that period (Gilat and Honigstein, 1981).

The western region of the Judean Desert is a large structural terrace forming since the earliest Santonian (Flexer et al., 1989), comprised of different N-S and NE-SW trending anticlinal flexures, deformed by a well-developed and still active system of faults related to the Dead Sea transform. In conjunction with activated faults of the northeastern trend, these faults form the structural frame (Fig. 1), which reflects the northward movements of the blocks.

Between the main fault of the Qana'im zone and the main Dead Sea cliff there are at least three more N-S trending sinistral strike-slip faults of more than 20 km length and a system of E-W trending dextral strike-slip shear zones up to 1 km wide, solely responsible for the development of oversized U-shaped box canyons in the easternmost Judean Desert area. Present-day structures in the area illustrate the idealized scheme of sinistral faults causing counterclockwise rotation of domains nested between sub-perpendicular dextral faults; even the triangular gaps (crumbled sections, Gilat, 1992a, fig. 2) along domain boundaries are well preserved, and arc-systems of tensional fractures, separating southeastern

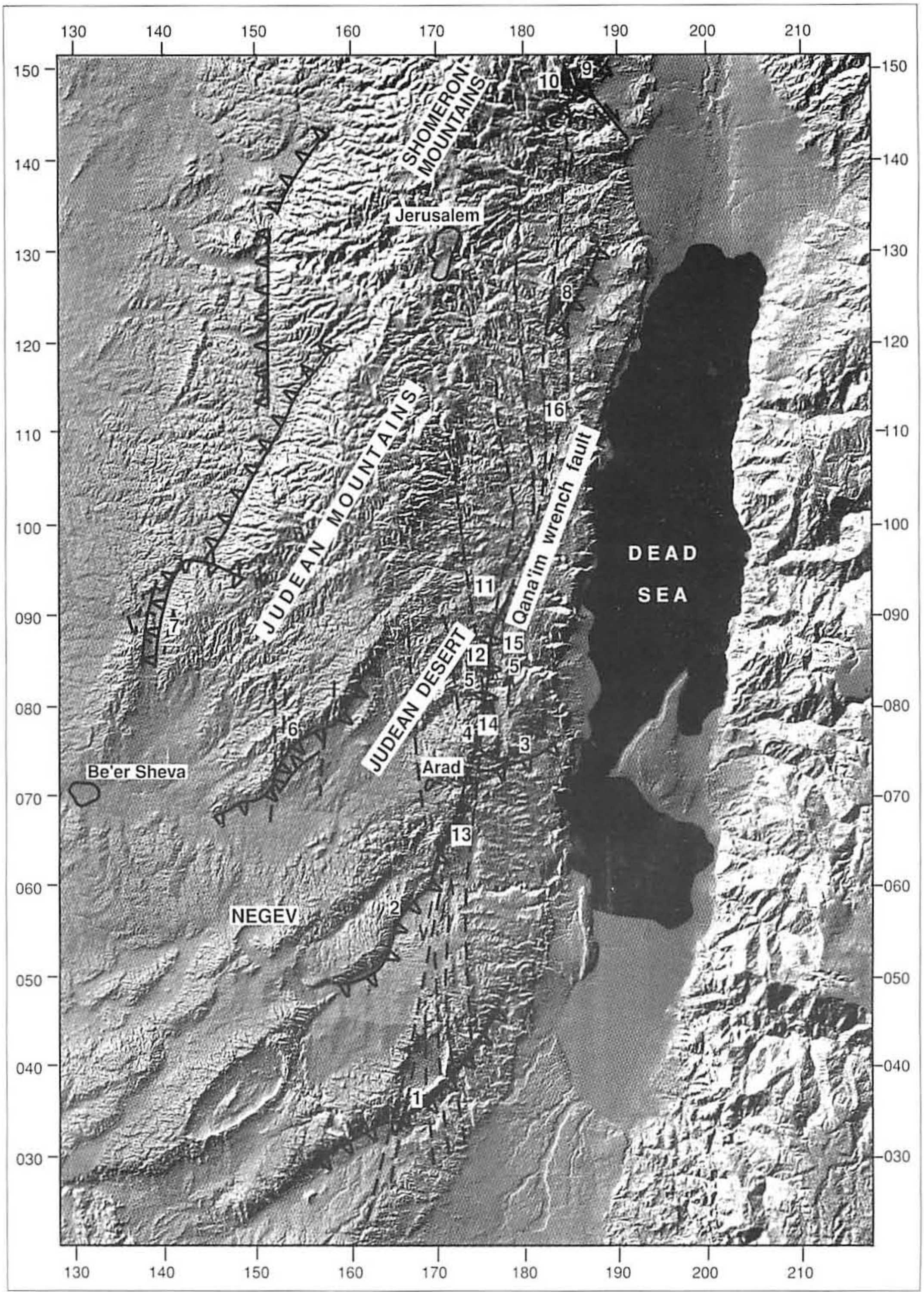

Figure 1. Location map of the Qana'im wrench fault shown on the digital shaded-relief map of Israel and environs (Hall, 1997). 1. strike-slip fault; 2. strike-slip fault, locality inferred; 3. flexure, arrows show downdip; 4. V-syncline; 5. V-syncline vertically displaced. Numbers on the map show the localities of flexures: 1 - Makhtesh Hazera; 2 - Dimona-Zohar; 3 - N. Rahaf; 4 - Biq'at Qana'im; 5 - N. Ze'elim; 6 - eastern flexure of the Judean Mts.; 7 - western flexure of the Judean Mts.; 8 - Biq'at Hureqanya; 9 - Auja; 10 - Samia fault strip; Additional localities: 11 - Mt. Holed; 12 - N. Adasha; 13 - Hatrurim basin; 14 - Har-Menahem; 15 - Har-Namer;16 - N. Darga.

block-edges, protruding (as a result of rotation) into the few kilometers deep Dead Sea graben, are clearly visible even on aerial photographs (Gilat, 1992a, fig. 4).

The study area is composed of Cenomanian to Recent sedimentary rock (Fig. 2). Block-rotation and development of huge canyons (a result of intensive shearing caused by repeated reversals in the sense of rotation of adjacent domains, which dramatically increased sheet-erosion and mass-wasting of valley slopes, multiplying valley bed-load), occurred in the Late Pliocene-early Late Pleistocene following massive dolomitization (Gilat, 1992b), and preceded the Lisan Lake sedimentation (about 100,000 BP).

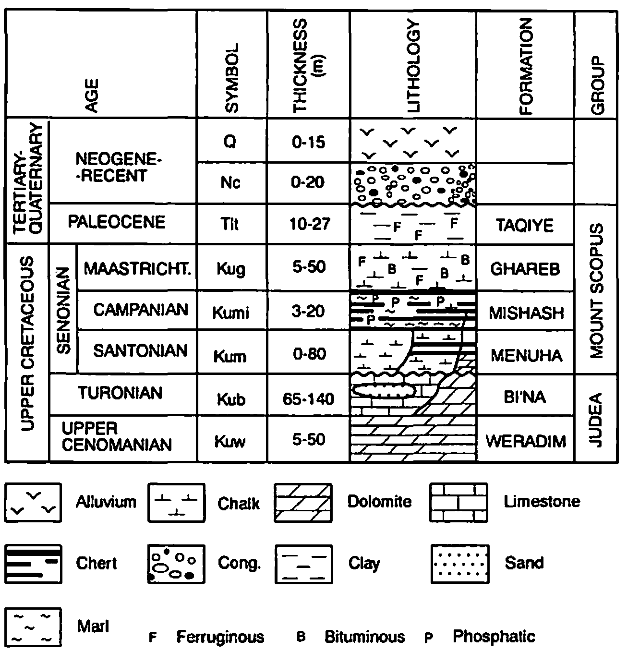

Figure 2. Generalized stratigraphic section of the Judean Mountains - Judean Desert region.

GEOMORPHOLOGY OF THE MAIN QANA'IM FAULT

Fault morphology is shown in Figure 3. Near the Arad - Mezada road crossing Biq'at Qana'im, an intricate structure of an *en echelon* system of branch-faults, 5-15 km long, cuts the western flexure of the Qana'im Fault. This flexure is composed of faulted east-dipping blocks. The eastern part of the structure in that area comprises a west-dipping up-thrusted block. The vertical displacement on the eastern fault is about 120 m. On its southern extension (coord. 1775/0749) are horizontal slickensides. The whole structure shown in section I (Fig. 3), can be defined as an "up-thrusted flexure - opposite flexure". The fault inferred beneath the alluvial cover is indicated by the Har-Menahem anticlinal structure steeply dipping to the west and east.

Some 2 km north of section I (coord. 1763/0822, II, Fig. 3), there is no vertical displacement on the Qana'im Fault but a "narrow syncline" (V-syncline), formed by the simple western flexure of Har-Namer from the east juxtaposed against the complex western flexure of the Qana'im Valley. Further north, the western flexure steeply dips northward toward the Ze'elim Valley (from coord. 1760/0822 to coord. 1760/0829), from a structural height of 340 m to 220 m, and even lower. On the uplifted block to the east of the main fault, 2-3 fault planes developed parallel to the main fault, and the thickness of the overlying Senonian section is some 30% less than that in the down-faulted block. One of these faults crosses the Ze'elim canyon escarpment, and has the appearance of a reverse fault.

Further north an additional lowering of the base of the east-dipping flexure west of the main fault took place. On this segment the main fault plane dips 100° and the vertical displacement is ~100 m, and horizontal slickensides are found on the fault plane. The beds of the uplifted eastern block dip westward (Fig. 3, section IV). On the exposed main fault large (up to 10 m long), open concave fractures trending parallel to it and slickolites (coord. 1763/0837) are visible. The dominant structure along the main fault is a "westward dipping uplifted eastern flexure - opposite a down faulted western flexure dipping eastward, both flexures separated by the strike-slip fault".

The eastern block of the Qana'im Fault dips to the north (1763/0845). On the fault segment situated between coords. 1763/0844 and 1763/0856 (Fig. 3, section V, center) its graben-like structure can be defined as a ramp-structure (produced by thrust-fault), only 50 m wide, infilled by shale and clay of the Taqiye Formation. This ramp separates the western flexure from the uplifted eastern block.

Along its farther northern segment, up to coord. 1764/0885, the main fault subdivides into at least five concave faults (surface manifestation of vertical flower structure?). Four of these have vertical displacements of only a few meters, but one produces a V-syncline, vertically displaced by about 80 m (Fig. 3, section VI).

On the next segment to the north the Mt. Holed dome structure is cut by the Qana'im Fault, which produced another ramp-structure, ~300 m wide, developed since

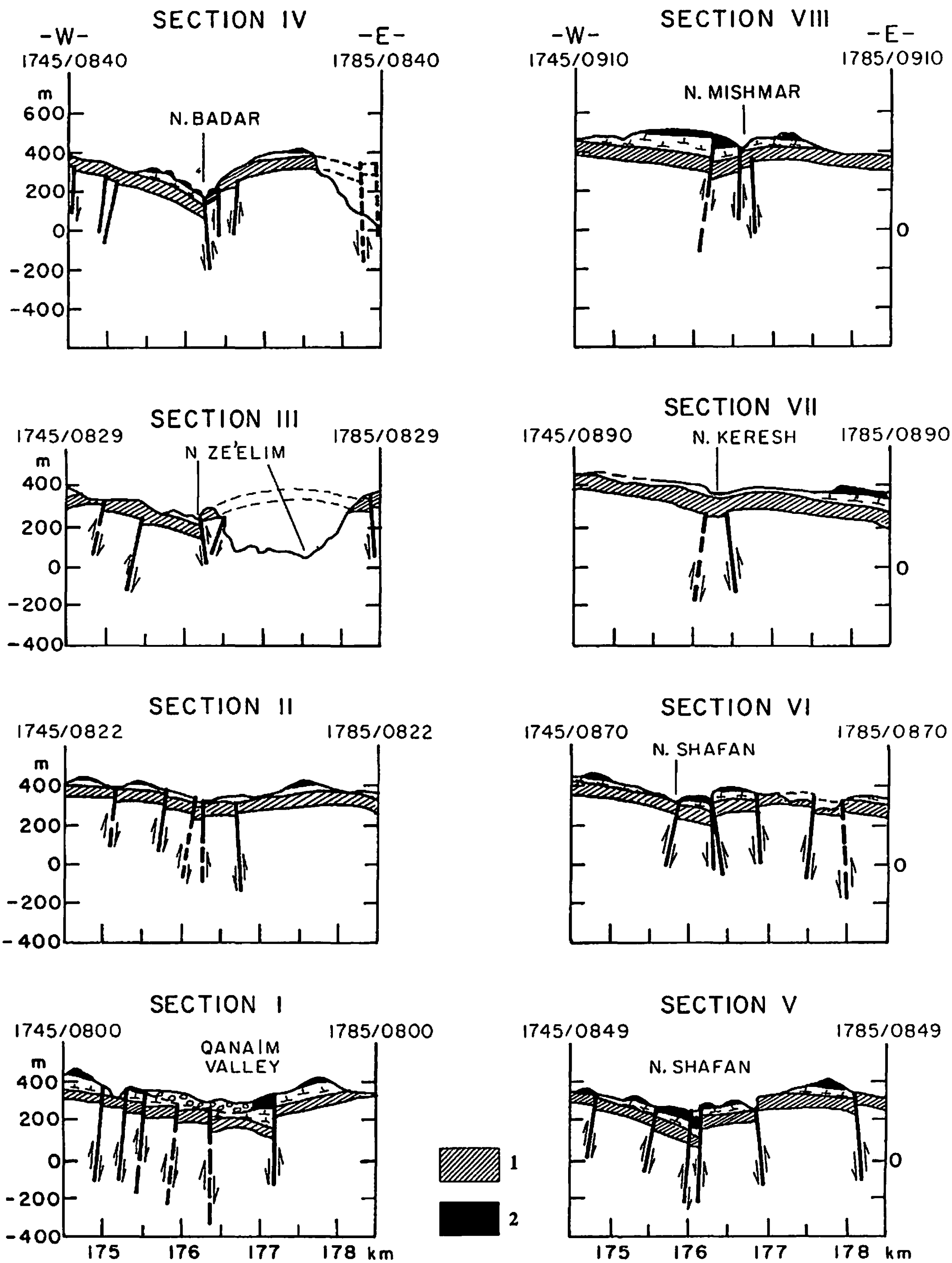

Figure 3. Geological cross-sections along the N-S trending Qana'im wrench fault. Restoration of vertical displacements yields a simple V-syncline. 1. Turonian sequence; 2. Senonian chert.

pre-Senonian, as shown by ostracode assemblage zone analysis (Gilat and Honigstein, 1981). Its probably younger horizontal slickensides can be found in the ramp near coord. 1765/0895. Development of this structure northward can be seen on sections VII - VIII in Figure 3.

North of Mt. Holed within the Qana'im Fault, a half-brachysyncline (center near coord. 1765/0936) is developed. Further northward, up to the northern boundary of the Har Hezron sheet, the main fault of the Qana'im Valley fault system continues as a shear zone characterized by small (less than 20 m) vertical displacements "scissoring" from west to east.

RECONSTRUCTION OF SINISTRAL OFFSETS ALONG THE QANA'IM VALLEY MAIN FAULT

There is no evidence of stike-slip movements along the older, Pre-Pliocene Qana'im Valley fault, which preceded development of the generally W-E oriented hydrographic network.

The 75 km-long NW-trending Dimona-Zohar-Rahaf flexure and the 5 km-long W-E trending Nahal Ze'elim flexure, are cut by the main Qana'im Fault (Fig. 1); the only other monocline in its way both south and north of the detailed study area, the Makhtesh Hazera monocline, is deformed by at least four middle-size faults, producing narrow north and north-northwest trending V-synclines, which join together farther north, comprising the main Qana'im Fault. Both the Dimona-Zohar-Rahaf (from coord. 1740/0717 to coord. 1740/0730) and the Ze'elim Valley (from coord. 1763/0828 to coord. 1763/0842) flexures are sinistrally displaced by this fault by ~1.3 km.

The W-E valleys in the Judean Desert often turn N-S and then, once again, east ("dog-leg bends"), while intersecting the Qana'im Fault or its branches, indicating balance disruption: e.g., intersecting it, the east-trending well-developed canyon of Nahal Zefira changes into a shallow channel (Figs. 4, 5), turns north, approaching (near coord. 1765/0827) the 300 m deep Ze'elim Valley canyon. Instead of entering it, the coulie turns west, then north, along the main fault, and joins the Ze'elim Valley before it becomes a major canyon (Figs. 4, 5).

On its N-S segment along the main fault, Nahal Shafan enters a ramp, its floor comprised of the Taqiye Formation. Instead of continuing its way south through soft clay, the valley abruptly turns east (near coord. 1763/0851, Figs. 4, 5), producing a 15 m deep canyon in the Main Chert Member of the Mishash Formation (!), and only after a 0.5 km-long bend joins the Qana'im Fault again (near coord. 1762/0847).

Cross-sections along the Zefira, Ze'elim and Adasha valleys (Fig. 6) show points of sudden incision where they intersect the Qana'im Fault. Sections across the Zefira and Ze'elim valleys, before and after they intersect the Qana'im Fault, clearly show that their segments beneath the fault are many times smaller than those above it (Fig. 7), the only possible explanation being a sinistral displacement of the valley segments along the fault.

An experiment has been made in reconstructing the river-network according to different stages of movement, both on an aerial photograph and on the 50,000 scale map of the Har Hezron sheet. The results are shown in Figures 4 and 5. The total sinistral displacement of the Dimona-Zohar-Rahaf and Ze'elim flexures is 1.3 km. The backward dextral displacement of the hydrographic network over the 1.3 km yields a reconstruction of an earlier arrangement of the older valleys (of order 5 and 6; valleys order after Horton, 1945); the dextral displacement over 0.7 km (intermediate stage, 0.7 km is the distance between N. Adasha and the northern end of the above described N. Shafan bend) yields a reconstruction of an intermediate system of younger and older valleys (of order 3-6). The same type of reconstruction is also suggested for the the valleys which cross the Qana'im Fault in the Hatrurim basin.

BRANCH-FAULTS OF THE QANA'IM MAIN FAULT

Comparatively small NNW-striking faults that branch from the Qana'im main fault produce parallel fracturing (shearing), steps and local secondary flexures on the western flexure of the Qana'im Valley and cross the southern and eastern parts of the Judean Desert (Fig. 1). These faults change their throw direction, with vertical displacement on some reaching 60 m. Among the geomorphological forms they produce are all the major combinations characteristic for the main Qana'im faults, including graben-like (ramp) structures, horsts, vertically displaced V-synclines and flexures opposite up-lifted blocks; locally horizontal slickensides can be found. In places they follow older Turonian-Senonian faults, which appear as normal, but were formed as compressional and not as tensional features.

Additional NNW-striking faults can be traced on the satellite maps branching from the main Qana'im Fault north of N. Ze'elim, and south of N. Darga (Fig. 1).

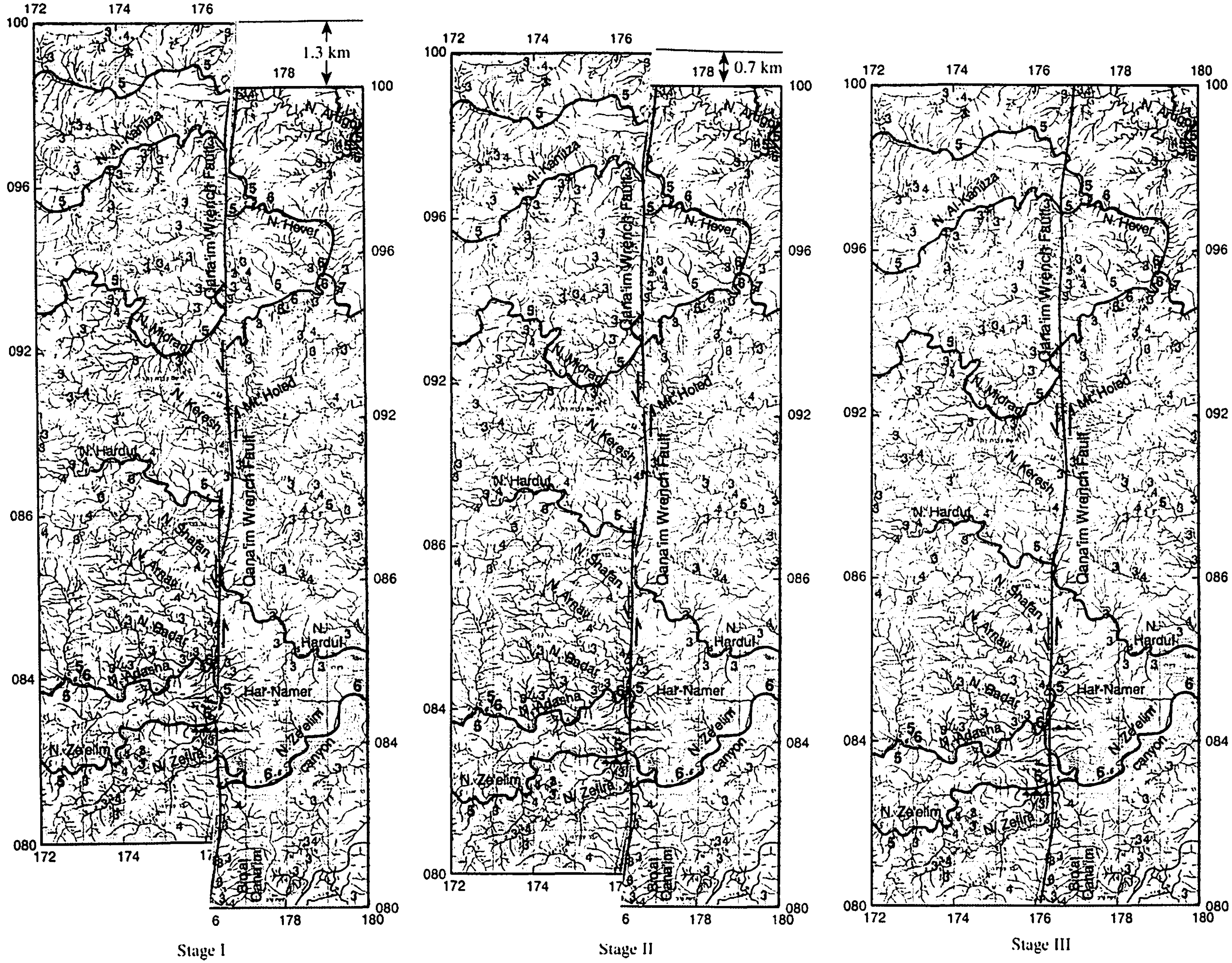

Figure 4. Proposed stages of drainage displacement on sheet 15-II, Har Hezron 1:50,000 map by the main Qana'im wrench fault. Stage I Pre-Pliocene; completion of the Dimona-Zohar - Rahaf and Ze'elim monoclines (location on Fig. 1); valleys of order 5 - 6 are already well developed (valley orders after Horton, 1945). Stage II Pre-Pleistocene; following syn-dolomitization sinistral displacement of 0.6 km. of flexures and older river valleys. Stage III Present stage; following Early Pleistocene to Acheulean phase of additional 0.6 km of sinistral displacement of 3-4th order valleys to their present position.

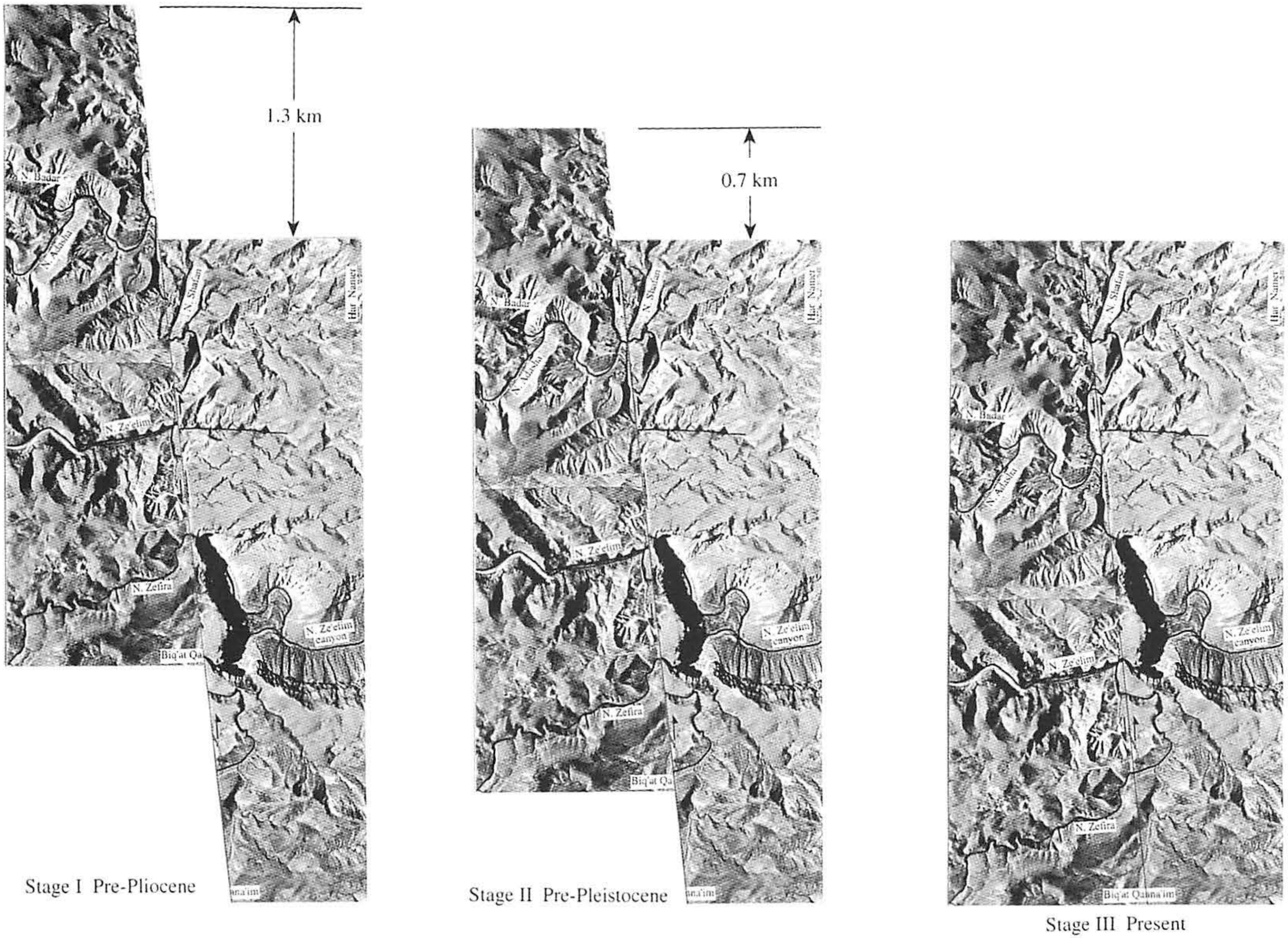

Figure 5. Proposed stages of displacement of the main tributaries in the Ze'elim Valley bythe main Qana'im Fault, shown on the aerial photograph.

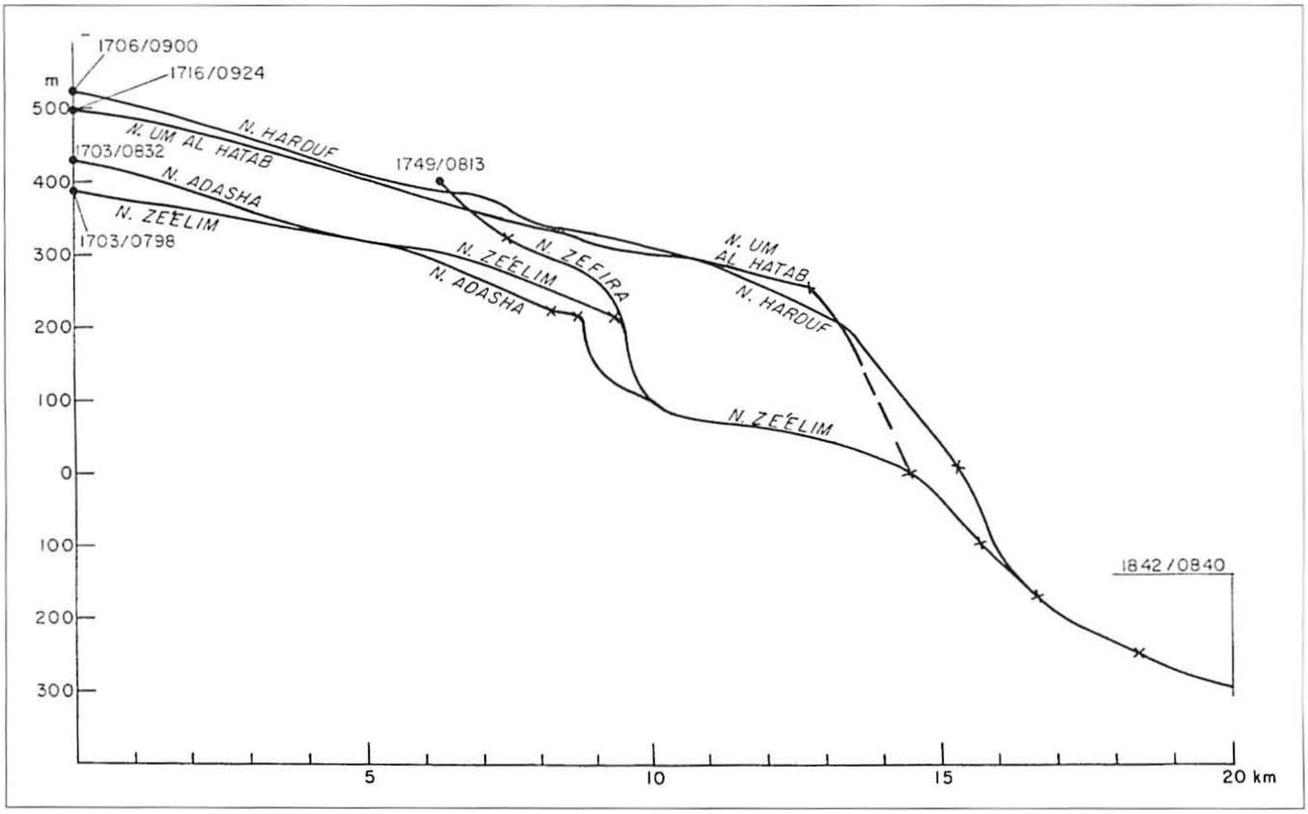

Figure 6. Profiles along the southern Judean Desert valleys latitudenally crossing the longitudenal main Qana'im wrench fault and some of its branches (localities on Fig. 4). x – locality of the main fault – valley intersection.

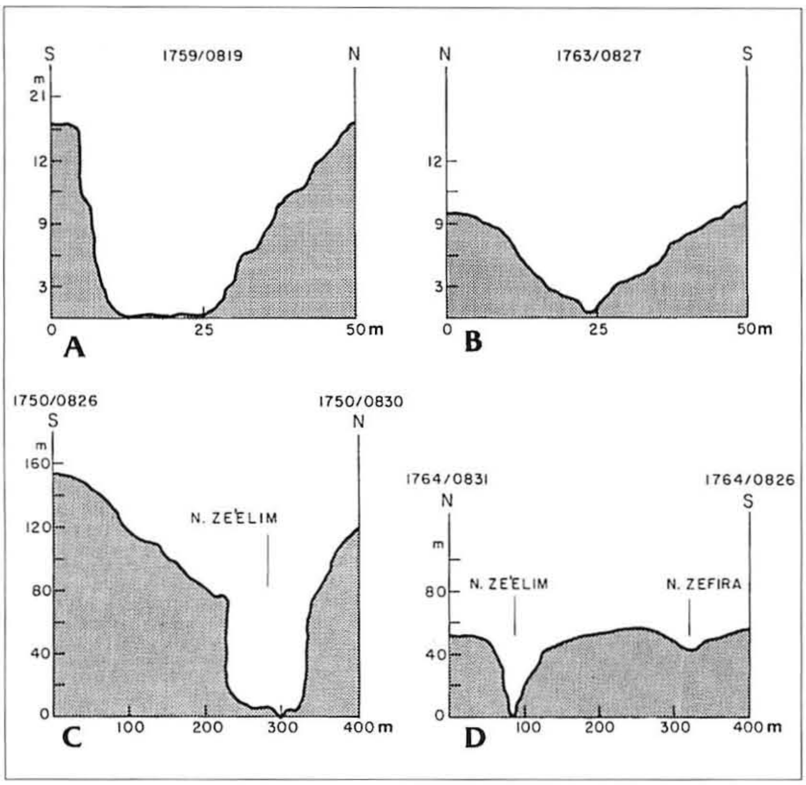

Figure 7. Transformations of valley profiles by strike-slip move-ments along the Qana'im wrench fault:

1. N. Zefira profiles before (A) and after (B) crossing the main Qana'im Fault;
2. N. Ze'elim profiles before (C) and after (D) crossing the main Qana'im Fault (localities on Fig. 4).

Most of the branch faults are sinistral, but some of them displaced older structures dextrally (near coord. 1730/0833, 1736/0833, Gilat, 1987) by 50 to 300 m. Some of them caused temporal closure of the Ze'elim, Adasha and Harduf valleys and accumulation of alluvial material in terraces up to 18 m high; at the base of one of these, in N. Adasha, flint tools of probably Acheulean culture were found (Gilat, 1992b).

DISCUSSION AND CONCLUSIONS.

Large scale lineaments crossing the Negev, the Judean Desert, the Judean and the Shomeron mountain areas of Israel are seen on satellite images and on the digital shaded relief map (Fig. 1). The better reflected among these are flexures with NNE-SSW and NE-SW trends which belong to the Syrian Arc system. The western flexure of the Judean Mountains is dextrally displaced; its eastern flexure is deformed by numerous lineaments of N-S and NNW trends. Some of these are branch faults which belong to the Qana'im fault system (Fig. 1). A morphological analysis of kinematics of the main Qana'im Fault could be an important tool for understanding the nature and distinguishing strike-slip faults reflected through the few kilometers thick sedimentary cover.

In the Qana'im Fault zone, four main morphological forms of fault profiles, which recur so often, may typify strike-slip faults. These are (Fig. 3): (a) V-syncline (flexure opposite flexure); (b) V-syncline vertically displaced; (c) shear zone; (d) straightening monocline or flexure. Usually it was possible to find on a typical cross-section not one, but a few sub-vertical faults (probably, flower-structure). With the exception of one (d), which is typical also for reverse faults, all the other types can result only from strike-slip movements.

Strike-slip faults younger than the hydrographic network displace valleys and produce typical sharp bends in the valley course ("dog-leg bends"). These, together with dome and "half-dome" structures and short brachysynclines along the lineaments, give sufficient indications for determining the nature of a given lineament even though harder evidence is absent.

To explain the typical (for strike-slip) V-syncline morphology, the process known as the reduction of vertical displacements of faults in the chalky-marly sequence (Mimran and Michaeli, 1986) must be taken into account. Thus, an addition of a few hundred meters of a soft carbonate section would reduce vertical displacement on a strike-slip fault cross-section to near zero, at the same time retaining flexures produced by compression on both sides of the fault.

The strike-slip movement in the Qana'im Fault occurred in two-stages, in the Pliocene (a period of massive dolomitization) and in the Lower Pleistocene (as indicated by Acheulean tools found buried in the base of a displaced river terrace).

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