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ARCHAEOSEISMOLOGICAL EVIDENCE OF HISTORICAL ACTIVITY OF THE WADI ARABA-JORDAN VALLEY TRANSFORM FAULT

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RIASSUNTO - *Indizi archeosismici dell'attività storica della faglia trasforme del Wadi Arba-Valle del Giordano* - Il Quaternario *Italian Journal of Quaternary Sciences,* **10**(2), 1997, 401-406 - Lungo il *rift* del Mar Morto, dal Golfo di Aqaba al Lago di Tiberiade, è presente senza soluzione di continuità una delle faglie trasformi più importanti ma meno studiate del mondo, la Wadi Araba-Jordan Valle Fault (AJF). Lungo questa questa faglia, attiva per tutto l'Olocene, sorgono diversi insediamenti storici che, in maniera diversa, hanno risentito dei movimenti della faglia. Lo studio delle deformazioni indotte sui manufatti ha permesso, in maniera speditiva, di definire alcune caratteristiche del comportamento della faglia, i tempi di attivazione e lo *slip-rate.*

Keywords: Archeoseismology, active tectonics, Dead Sea Rift
Parole chiave: Archeosismologia, tettonica attiva, *Rift* del Mar Morto

1. INTRODUCTION

The Wadi Araba-Jordan River Fault (AJF) is the sinistral transform fault separating the Sinai-African plate from the Arabian Plate (Fig. 1A). According to Quennel (1959), Freund *et al.* (1970) and Girdler (1991) the offset of 107 km between the two sides of the fault occurred mainly in the last 15 million years. The surface trace of the AJF can be followed for hundreds of kilometres from the Gulf of Aqaba to the Lebanon mountains (Figs. 1-2). The fault runs mainly in Jordan, very close to the border with Israel.

A survey along AJF, from the Aqaba Gulf to the northern Galilee, has allowed to recognise many archaeological sites located close to the fault plane, which record the deformation induced by coseismic slips, and give information about the age and the amount of the movement. Among these sites, at least five — namely, from S to N, the ancient town of Ayla, the Roman reservoir of Qasir el Telah, a nearby Roman (?) aqueduct, the calcolithic settlement of Teleilat Ghassul, the one of Deir Alla and a crusaider castle near the Jakob ford, in Israel — are cut by the fault, showing displacements of the masonry structure and/or of the foundation deposits.

In a region rich of archaeological remains, archeoseismology may represent an additional tool to constrain seismic events both in space and time.

2. SOUTHERN ARABIA

Whitcomb (1987) directed attention to the presence of a ENE-WSW fault, which caused a displacement of ~1.5 m in the SW wall of Ayla, a town on the Aqaba Gulf, a few kilometres to the W of the AJF (Fig. 1).

New excavations (March, 1996) across the presumed fault, exposed masonry structures and virgin soils with no traces of displacement. Although, the surrounding NW and SW walls display deformations which are consistent with a NS dextral shear zone (the NW wall is composed of three segments, right-shifted to one another; Fig. 3).

Other decimetric deformations affect both the foundation deposits and the masonry structures discovered outside the Egyptian Gate. Muslim Ayla reached the peak of its prosperity in the period between the 9th-11th Century, during the Abbasid era; historical and archaeological data testify that the town, by the 11th Century, started to deteriorate and finally to collapse. The relatively abrupt abandonment of the city was probably contemporary to or occurred shortly after the age of deformations in the walls (which appear not restored) and in their foundations. The common cause may be the earthquake which would have struck this area in 1068 (Abou Karaki, 1987) and that probably occurred along the AJF.

3. NORTHERN ARABIA

South of Dead Sea, close to the AJF scarp, the ruins of the square water reservoir of Qasir el Telah crop out (Fig. 1). They may be linked to the Roman Toloana, which is known to have had a military garrison in the 4th Century A.D. (Khouri, 1988). The eastern wall of the reservoir is cut into the bedrock, the remaining structure being constructed with cemented and plastered sandstone blocks, with foundations carved into cemented gravels and counterforts on the southwestern side. The southeastern wall, a well preserved and rectilinear structure striking N60°E, is tilted counterclockwise (1.5° 35 cm/14 m) starting from a vent at half of its length. Part of the southwestern wall is tilted, as well. The W corner (a tower ?) is vertically tilted to E and is separated from the surrounding wall by a N10°W fracture (0.5-1 m large). The fracture is aligned to the AJF scarp (Figg. 4-5). The corner and its foundations are shifted southward, stricking out of some decimetres with respect to the S wall. The deformation can be asso-

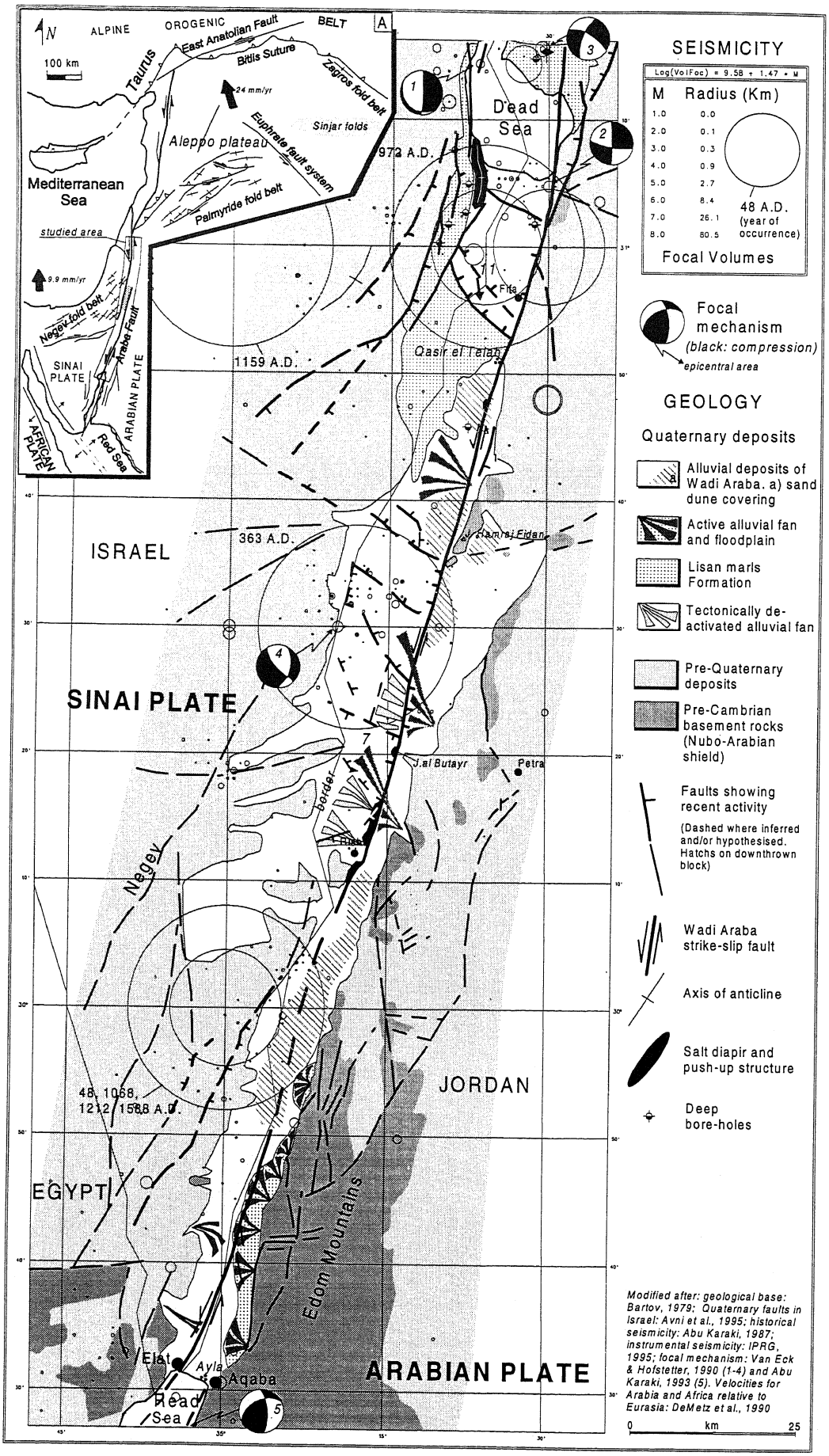

N
ALPINE
OROGENIC
BELT
A
East Anatolian Fault
Bitlis Suture
Zagros fold belt
Taurus
100 km
24 mm/yr
Aleppo plateau
Euphrate fault system
Sinjar folds
Palmyride fold belt
Mediterranean Sea
studied area
9.9 mm/yr
Negev fold belt
Arabia Fault
SINAI PLATE
ARABIAN PLATE
AFRICAN PLATE
Red Sea
Dead Sea
972 A.D.
1159 A.D.
363 A.D.
48, 1068, 1212, 1588 A.D.
Fifa
Qasr el Tafan
Hamrat Fidan
ISRAEL
SINAI PLATE
Negev
border
Jal Butayr
Petra
JORDAN
EGYPT
Edom Mountains
Elat
Ayla
Aqaba
Read Sea
ARABIAN PLATE
SEISMICITY
Log(Vol Foc) = 9.58 + 1.47 * M
M
Radius (Km)
1.0 0.0
2.0 0.1
3.0 0.3
4.0 0.9
5.0 2.7
6.0 8.4
7.0 26.1
8.0 80.5
48 A.D. (year of occurrence)
Focal Volumes
Focal mechanism
(black: compression)
epicentral area
GEOLOGY
Quaternary deposits
Alluvial deposits of Wadi Araba. a) sand dune covering
Active alluvial fan and floodplain
Lisan marls Formation
Tectonically de-activated alluvial fan
Pre-Quaternary deposits
Pre-Cambrian basement rocks (Nubo-Arabian shield)
Faults showing recent activity
(Dashed where inferred and/or hypothesised. Hatchs on downthrown block)
Wadi Araba strike-slip fault
Axis of anticline
Salt diapir and push-up structure
Deep bore-holes
Modified after: geological base: Bartov, 1979; Quaternary faults in Israel: Avni et al., 1995; historical seismicity: Abu Karaki, 1987; instrumental seismicity: IPRG, 1995; focal mechanism: Van Eck & Hofstetter, 1990 (1-4) and Abu Karaki, 1993 (5). Velocities for Arabia and Africa relative to Eurasia: DeMetz et al., 1990
0 km 25

Fig. 1 - Seismotectonic sketch of the Wadi Araba region. Inset A: Regional tectonics of the Dead Sea Rift.

Schema sismotettonico della regione del Wadi Araba. Nell'inserto A è riportto l'inquadramento tettonico regionale.

ciated to the wrenching occurred during the left-lateral movement of the AJF.

The NW wall of the Qasir el Telah reservoir, which is partly convex toward the reservoir (W side), forms an high angle (70°) with the fault, but is badly preserved, especially close to the fault itself. Thus, with respect to the W corner, an evaluation of the horizontal displacement is not easy. However, if the W corner bulging (about 80 cm, partly due to vertical tilting) and the low angle of incidence between the fault and the SW wall (about 20°) are taken into consideration, the horizontal displacement might be about 1.5-2 m. Since some restorations in the western wall seem to be contemporary to the construction, a first earthquake could have damaged the reservoir during or shortly after the period of the Roman domain in the region (*e.g.* the event of 363 A.D. responsible for serious damages in Holy Land and in the close town of Petra (Hammond, 1980; Russel, 1980), followed by another earthquake that caused the displacements which would have not been restored (*e.g.* the 972 A.D. earthquake; Abu Karaki, 1987).

Farther north (Wadi Khunaizir gorge), a NNW-SSE splay of the AJF displaces an aqueduct, with a 2 m right-lateral step. The aqueduct, probably of the same age of Qasir el Telah, is partly built of masonry with a standing archway and is party entrenched in the hill-slope.

A few metres away, another branch of the AJF cuts the aqueduct, some masonry stones being trapped in the fault plane.

4. JORDAN VALLEY

At Telleilat Ghassul, a calcolithic settlement near the NE corner of the Dead Sea (Fig. 2), Hennesey (1969) hypothesised the occurrence of many earthquakes that contributed to the abandonment of the town (3600 B.P.).

There are evidence of surface faulting all along the entire historical stratigraphical sequence, the fault system being composed by N50°E subvertical reverse faults with decimetric vertical throw, E-W undefined faults and NNW-SSE subvertical reverse faults (Fig. 6). On a photo published by Hennessey (1969; pl. III) a normal fault of unknown strike, displacing the whole historical sequence of about 0.5 m, can be observed. The site lies on a roughly NNW-SSE fault system, with evidence of right-lateral slip affecting some stream entrenched in the Lisan Formation top surface (Early Holocene: Galli, 1997, submitted to J. Geophys. Res.).

In the past, some of these faults could have been activated during some of the strong earthquakes occurred along the AJF, producing surface faulting and thus contributing to the abandonment of the calcolithic settlement of Ghassul.

Surface faulting is also visible in the historical strata at the top of "Tell Deir Alla" (at the mouth of Zarqa River; Fig. 2). The "Tell" emerges from the alluvial plain about 4 km to the east of the Jordan Valley Fault. This "Tell" was used almost continuously throughout a period spanning from around 3600 to 2400 B.P. According to the literature (see Khouri, 1988), the site was seriously damaged by an earthquake around 3200 B.P., and suffered other catastrophic events later on.

The last site studied regards the segment of the AJF to the north of Lake Tiberias, in Israel.

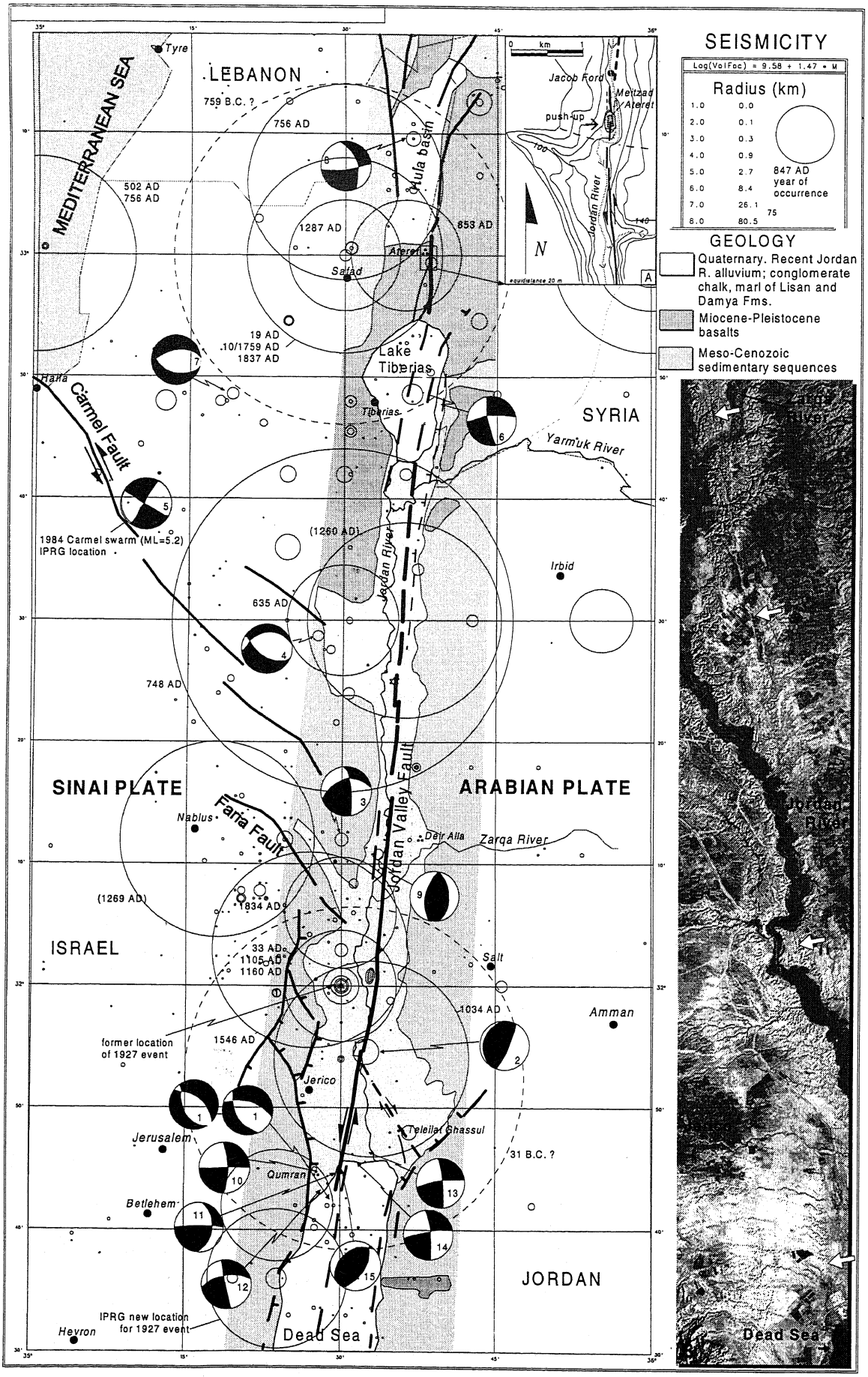
In 1178, King Baldwin IV, built a fortress near the Jacob's ford, on the W bank of Jordan River. The castle, Meitzad Ateret (Fig. 2), was destroyed in 1179 by Saladin and never rebuilt (Runciman, 1954). Abandoned for four centuries, it was partly reutilized during the Ottoman period (16th Century) and then was again abandoned and was covered by debris.

On the top of a small elongated hill, recent archaeological excavations discovered the remains of the 160 m long and 55 wide surrounding walls of the castle. The hill raises abruptly from the valley bottom of the Jordan River, north of a right bend of the stream. The river runs there in a straight gorge carved into basaltic rocks, along the AJF line. At the river bend, the fault has a right step. The shape of the hill is consistent with an asymmetrical anticline, gently dipping westwards and with a steep wing towards the east produced by the transpressive component of the fault.

On the southern side of the castle, a few metres right away from the threshold, the masonry shows an almost pure horizontal deformation of at least 2.5 m, due to the left-lateral slip that occurred during one or more strong earthquakes (Fig. 7). The deformation may be described as a warping with no neat rupture of the wall, whereas, at a more detailed scale, each block has been tilted and shifted of 5-30 cm with respect to the neighbours. Spaces amongst blocks are empty or partially occupied by basaltic stones coming from the infilling material and from the overlying masonry of the Turkish settlement. Awaiting the constraints that might derive from the archaeological dating, this latter circumstance allows to hypothesise that the last deformation of the wall might be related to a relatively recent earthquake (1759, Oct. 30 and Nov. 25; 1837, Jan. 1) rather than to an old one (1202, May 20).

5. CONCLUSION

The observations carried out in the archaeological sites located across the AJF testify the historical activity of the fault. The fault seems to have been mobilised several times (*e.g.* , from south to the north: in 1064 A.D.; in the period from 363 A.D. to 972 A.D.; in the period from 3600 to 3200 years B.P.; in the18th-19th Century A.D.) and along different segments, from the Gulf of Aqaba to the Tiberias Lake region. The deformations recorded by the archaeological structures are consistent with the 1mm/a slip-rate which was deduced on the basis of field observations (Galli, 1997 submitted to


SEISMICITY
Log(VolFoc) = 9.58 + 1.47 • M
Radius (km)
1.0 0.0
2.0 0.1
3.0 0.3
4.0 0.9
5.0 2.7
6.0 8.4
7.0 26.1
8.0 80.5
847 AD
year of occurrence
GEOLOGY
Quaternary. Recent Jordan R. alluvium; conglomerate chalk, marl of Lisan and Damya Fms.
Miocene-Pleistocene basalts
Meso-Cenozoic sedimentary sequences
MEDITERRANEAN SEA
LEBANON
SYRIA
ISRAEL
JORDAN
SINAI PLATE
ARABIAN PLATE
Tyre
759 B.C. ?
756 AD
502 AD
756 AD
1287 AD
853 AD
Safad
Ateret
Hula basin
Jacob Ford
Meitzad Ateret
push-up
Jordan River
equidistance 20 m
19 AD
.10/1759 AD
1837 AD
Lake Tiberias
Haifa
Carmel Fault
Tiberias
Yarm'uk River
1984 Carmel swarm (ML=5.2)
IPRG location
(1260 AD)
Jordan River
Irbid
635 AD
748 AD
Nablus
Faria Fault
Jordan Valley Fault
Deir Alla
Zarqa River
(1269 AD)
1834 AD
33 AD
1105 AD
1160 AD
Salt
1034 AD
Amman
former location of 1927 event
1546 AD
Jerico
Jerusalem
Qumran
Teleilat Ghassul
31 B.C. ?
Betlehem
Hevron
IPRG new location for 1927 event
Dead Sea
Jordan River
Dead Sea

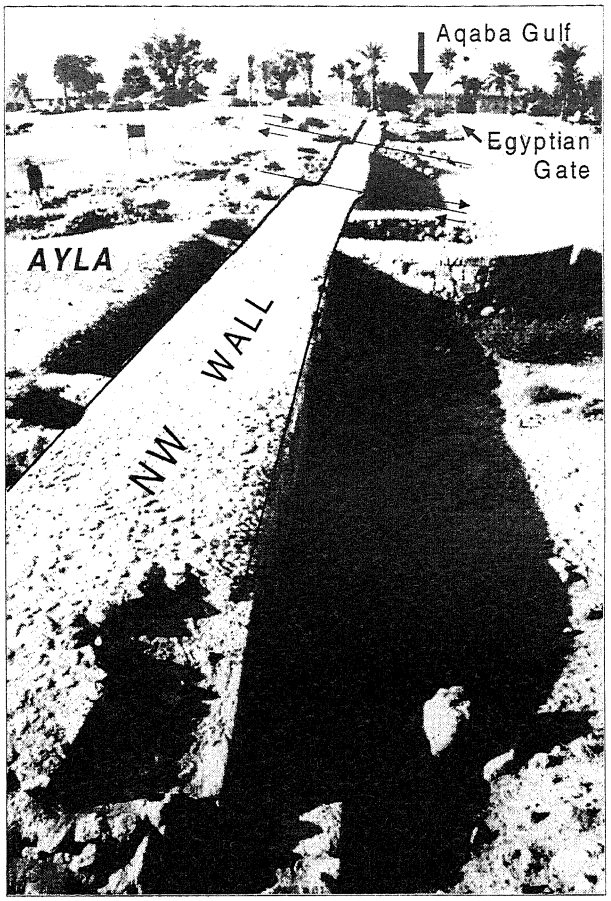


Fig. 3 - View of the NW wall of the ancient town of Ayla, on the Aqaba Gulf. The wall is deformed by a NS dextral fault system, evidence of which were observed in the foundation deposits during archaeological excavations outside the Egyptian Gate.

Vista del muro nord-occidentale dell'antica città di Ayla, sul Golfo di Aqaba. Il muro è deformato da faglie destre ad andamento NS di cui sono state osservate delle testimonianze nei terreni di fondazione durante degli scavi al di fuori della Porta Egiziana.

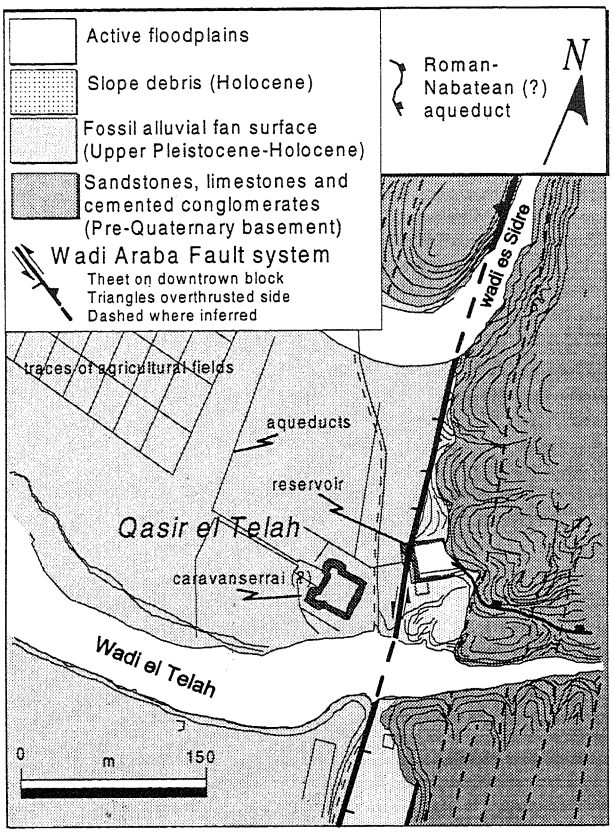


Fig. 4 - Geological sketch of the Qasir el Telah area, on the northern extremity of the Wadi Araba Fault.

Schema geologico della zona di Qasir el Telah, al limite settentrionale della Faglia del Wadi Araba.

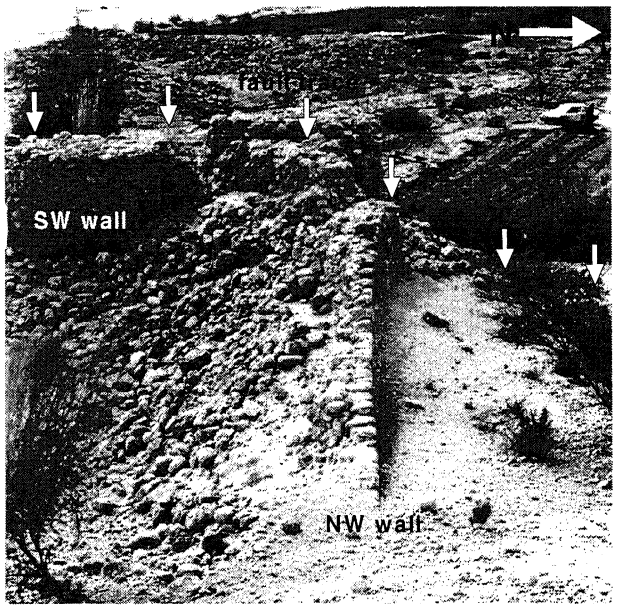


Fig. 5 - Northern Wadi Araba. Ruins of the Roma reservoir of Qasir el Telah. In this portion of the Rift, the fault runs at the foot of the slope. The reservoir lies just above the fault plane and was affected by the movements occurred in the last 15-16 centuries.

Wadi Araba settentrionale. Rovine del serbatoio romano di Qasir el Telah. In questa parte del Rift, *la faglia borda il piede del versante. Il serbatoio è fondato proprio al di sopra del piano di faglia ed è stato dislocato dai movimenti avvenuti negli ultimi 15-16 secoli.*

Geophys. Res.) and global plate motion programs (De Metz, 1990).

These few indications highlight the potential of archeoseismology for the understanding of the seismogenetic behaviour of the AJF and the need of future paleoseismological analyses in this (by now) desert region.

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Fig. 2 - Seismotectonic sketch of the Jordan Valley region and satellite view (Landsat-spot combination from an original 1:150,000 image) of the AJF area. In inset A, a particular of the Jacob Ford area is shown.

Schema sismotettonico della regione della Valle del Giordano e immagine da satellite dell'area della AJF (da una combinazione Landsat-spot *alla scala 1:150.000). Nel riquadro A, è riportato un particolare dell'area del Jacob Ford.*

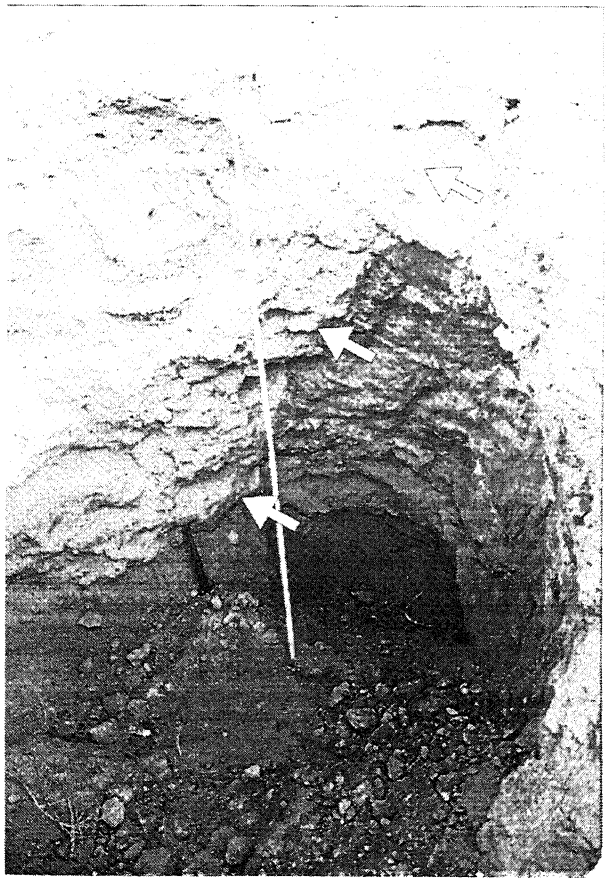

Fig. 6 - Trench at Teleilat Ghassul, near the Dead Sea north-eastern coast. Faulted historical deposits (ash and camp floor deposits, 3600 years BC).

Trincea a Teleilat Ghassul sulla costa nord-orientale del Mar Morto. Depositi storici fagliati (cenere e terreno di calpestio, 3600 anni BC).

Fig. 7 - Northern Jordan River Valley. A few kilometres N of Lake Tiberias, there are the impressive ruins of a crusader's castle — Meitzad Ateret, the *chatelet* — built by Baldwin the 4th in 1178 on the top of a hill close to the Jacob Ford. The hill is a push-up to the west of the Jordan Valley Fault. During a strong earthquake (in 1202 or in 1759 or, most probably, in 1834) the movement along the fault plane warped the castle powerful wall for more than 2 m. The photo shows part of the displacement of the southern wall, immediately east of the threshold (the camera axis is parallel to the underformed western wall).

Parte settentrionale della Valle del Giordano. Pochi chilometri a N del Lago Tiberiade, si trovano le rovine del castello crociato di Meitzad Ateret, lo chatelet, *costruito da Baldovino IV in cima ad una collina vicino a Jacob Ford nel 1178. La collina è una* push-up *a W della Faglia della Valle del Giordano. Durante uno dei forti terremoti occorsi nella zona (nel 1202 o nel 1759 o, molto più probabilmente, nel1834) il movimento lungo il piano di faglia ha deformato le poderose mura del castello di oltre 2 m. La foto mostra lo spostamento del muro meridionale subito ad est dell'ingresso (la macchina fotografica è in asse alla parte occidentale del muro non deformata).*

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