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PALEOSEISMIC EVENTS RECORDED IN PLEISTOCENE SEDIMENTS IN THE AREA OF KALAMATA (PELOPONNESSOS, GREECE)

I. MARIOLAKOS, I. FOUNTOULIS and H. KRANIS

University of Athens, Department of Geology, Dynamic Tectonic Applied Geology Division, Panepistimiopolis Zografou, GR-157 84 Athens, Greece

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Abstract—Two localities of sedimentary deformation in the Kato Messinia sub-graben (Kalamata area) are examined. In both cases Early (or Middle) Pleistocene sedimentation was disrupted possibly by earthquakes. A comparison is also made between tectonic activity at the eastern margin and within the Kato Messinia graben. The study of these two cases shows that the current tectonic regime has been established at least since Early Pleistocene. © 1997 Elsevier Science Ltd

INTRODUCTION

It is well known that earthquakes cause rockfalls, landslides, tsunamis and other disturbances at or near the Earth's surface. These distubances are, in some cases, imprinted on the sedimentary record as an abrupt change in the appearance, or characteristics, of associated deposits, as well as in sedimentary structures diagnostic of synsedimentary deformation. Consequently, a seismic event can be recorded in the surficial deposits of a seismically active area in a specific time frame. In this paper, evidence of some paleoearthquakes that occurred most probably during the Early Pleistocene in the Kalamata area, Greece, is presented. It should be noted that, although numerous researchers have worked on the neotectonics and the seismicity of the region [Fig. 1(A)] (e.g. Galanopoulos, 1947, 1963; Berchemer and Kowalzyk, 1978; Kowalzyk and Winter, 1979; Mariolakos and Papanikolaou, 1987), no paleoseismological study has until now been undertaken.

The south-western Peloponnessos, being very close to the Hellenic Trench, is one of the most active areas in Greece. At a regional scale, some neotectonic first-order structures may be distinguished (Mariolakos *et al.*, 1989, 1994) [Fig. 1(B)]. These are, from east to west: (1) the Parnon Mt. horst; (2) the Sparti graben; (3) the Taygetos Mt. horst; (4) the Kyparissia–Kalamata graben; (5) the Kyparissia Mts composite morphotectonic structure (Mariolakos and Fountoulis, 1991; Fountoulis, 1994); and (6) the Gargaliani–Filiatra horst.

Within, or at the margins of these neotectonic zones, macrostructures of second and third order occur. Within the major Kyparissia–Kalamata graben is, for example, the Kato Messinia sub-graben [Fig. 1(C)], which is seismically active and many destructive earthquakes are known to have affected this area during historical times (Galanopoulos, 1947; Mariolakos *et al.*, 1989).

The most recent destructive seismic event (M=6.0 R) took place on 13 September 1986 and caused considerable damage to the buildings of Kalamata and some villages close to it, as well

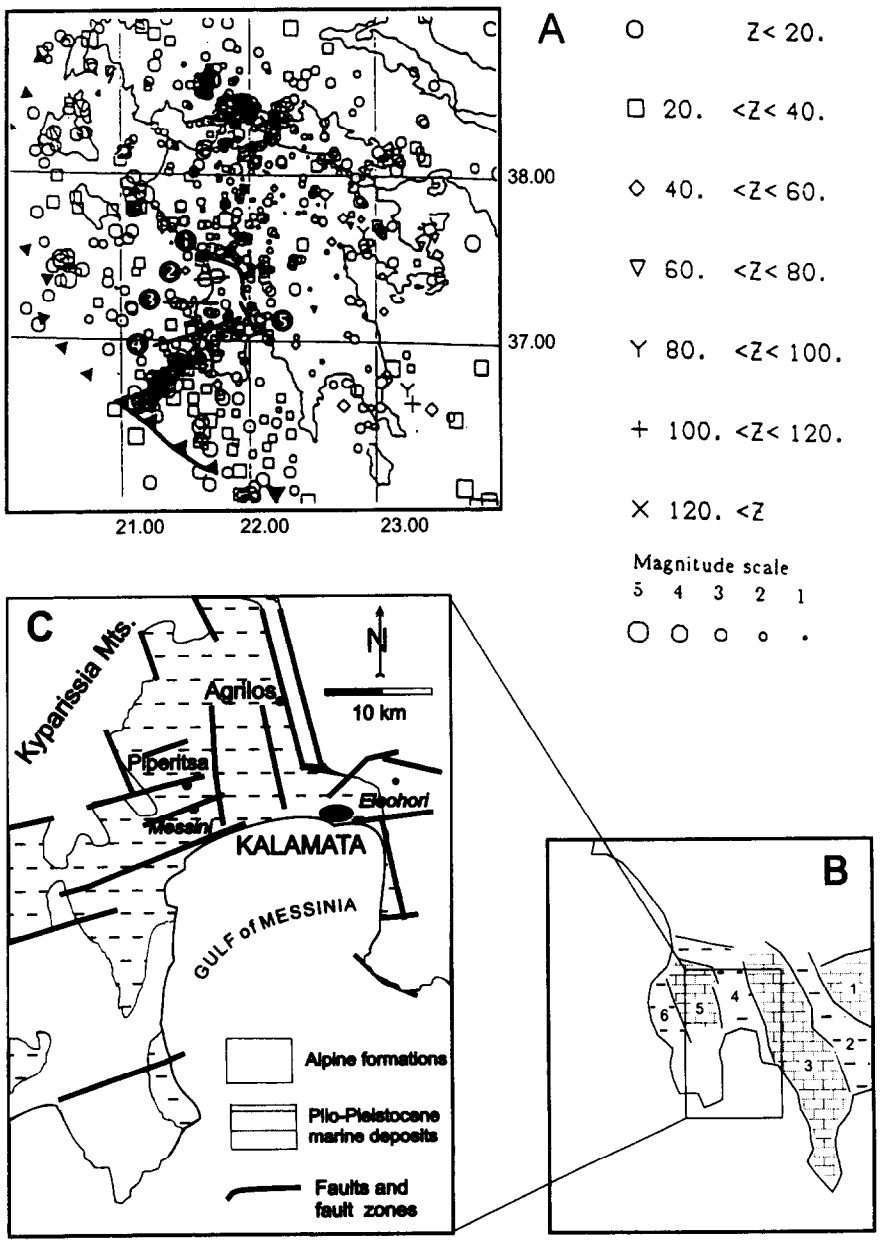

Fig. 1. (A) Earthquake epicentre map of Peloponnessos after Hatzfeld *et al.* (1990). Numbers in black circles indicate interpreted tectonic lineations by Fountoulis (1994). (B) First-order neotectonic macrostructures of the Southern Peloponnessos. The numbers correspond to the neotectonic macrostructures described in the text. (C) The neotectonic sub-graben of Kato Messinia and its dominant tectonic structures.

as rockfalls; 20 people lost their lives. The Kato Messinia sub-graben is filled mainly with shallow marine deposits of Early Pleistocene age bearing the fossil *Hyalinea balthica* (Marcopoulou-Diakantoni *et al.*, 1989, 1991), which gives an age of at least 1.6 Ma BP and more recent (Late Pleistocene–Holocene) terrestrial deposits, such as red-coloured siliclastic formations and alluvial deposits. All these post-Alpine sediments have been deposited on the well-formed paleorelief of Alpine formations of the Tripolis and Pindos geotectonic units.

In the Kato Messinia neotectonic sub-graben, two well-exposed sedimentary sections in Quaternary deposits were studied: the first (Piperitsa sand quarry) in the central part of the graben, and the second (Agrilos) at the eastern margin of the graben, between Agrilos and Velanidia villages. These two localities were chosen for study because they display certain peculiarities in the sedimentary record and they provide the opportunity for comparison of neotectonic activity between the centre and margins of the graben.

PIPERITSA SAND QUARRY

In the central part of the Kato Messinia graben, an excavated section within the Piperitsa sand quarry, about 2 km north of Messini, provided an opportunity to study sedimentary as well as tectonic structures. The sand quarry was developed in mainly Early Pleistocene shallow-marine deposits, which display the following sequence from bottom to top [Fig. 2(A)]: at the base of the section, sands and yellowish, locally laminated marls are predominant over an exposed thickness of about 4 m. They are covered by a layer of oligomictic conglomerates, ~1 m thick, consisting of siliceous pebbles and red silt matrix and characterized by a complete absence of any carbonate rocks. A layer, about 2 m thick, consisting of silts, sands and pebbles (carbonate and siliceous) overlies the conglomerate. This basal sequence is truncated by a prominent unconformity, which is visible across the whole section [Fig. 3(A) and (B)]. The beds immediately above the unconformity consist of polymictic conglomerate bringing into contact the lower part of the section with the overlying shallow-marine yellow sands and silts bearing macrofossils as well as limestone pebbles. At the top of the section, a continental red-coloured siliceous clastic sediment has been deposited on the paleorelief that was formed after the area had been uplifted above sea level (Mariolakos *et al.*, 1994). In the same section, the following typical structures were observed: at the southern end of the section and within the lowermost laminated marls, small-scale folds occur. These folds are localized, bounded at the top and the bottom by sediment layers typical of a low-energy depositional environment. In the central part of the section and within the lower shallow-marine layers, small listric [LF In Fig. 3(B)] faults occur, indicative of synsedimentary slumping. Here, a normal fault [MF in Fig. 3(B)], which cuts the lower shallow-marine layers, as well as the lower part of a conglomeratic horizon, has a vertical throw of about 90 cm across the displaced oligomictic conglomeratic horizon, and about 15 cm across the displaced unconformity [Fig. 3(A) and (B)]. This fault is accompanied by smaller ones, all of which seem to terminate below or at the unconformity, the throw on which is much smaller, from 2 to 15 cm.

AGRILOS

At the eastern margin of the Kalamata–Kyparissia graben, a section in a road cutting located on the left side of the road connecting the villages of Arfara and Velanidia and after the junction to Agrilos village, displays evidence of sedimentary deformation. The characteristic of this site is the occurrence of red soils, formed on a paleorelief of 'Alpine' bedrock that are in turn

overlain by Early Pleistocene shallow marine deposits (Fig. 2). The bedrock consists of Eocene neritic carbonates, which have experienced intensive karstification since at least the late Pliocene. Karstic hollows of different sizes and shapes created by these dissolution processes are commonly filled by red soil (terra rossa) up to a thickness of more than 10 cm. These paleosols unconformably overlain by a marine conglomerate of early Pleistocene and probably Middle Pleistocene age, bearing *Ostrea* sp. The great size of the pebbles (from 10 to 70 cm in diameter) as well as the presence of *Ostrea* sp., which is a large gastropod with thick, resistant walls, indicate a marine paleoenvironment of high energy. There are no faults or fractures cutting the marine and the terrestrial formations, the outcrop of which is limited to the area around the village of Agrilos.

DISCUSSION AND CONCLUSIONS

The sand quarry at Piperitsa displays several synsedimentary deformation features that can be attributed to earthquake activity. For example, the gradual decrease of the throw of the fault towards the younger horizons indicates repeated faulting during sedimentation, faulting here

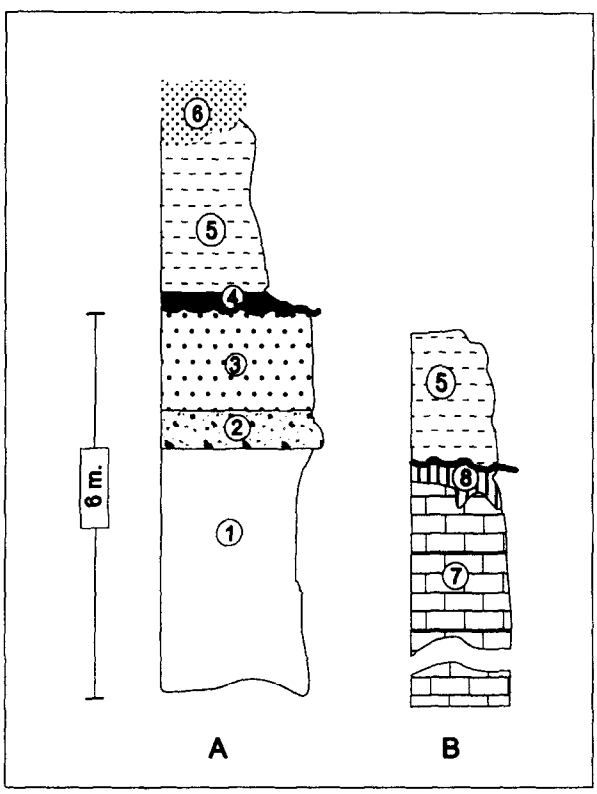

Fig. 2. Lithostratigraphic columns for the two localities. (A) Piperitsa sand quarry. (B) Agrilos road-cut section. 1: sands and marls, 2: oligomictic conglomerate, 3: silt, sand and pebbles, 4: polymictic conglomerate, 5: sand and silt, 6: red-coloured siliclastic formation (terrestrial), 7: neritic limestones, 8: paleosols.

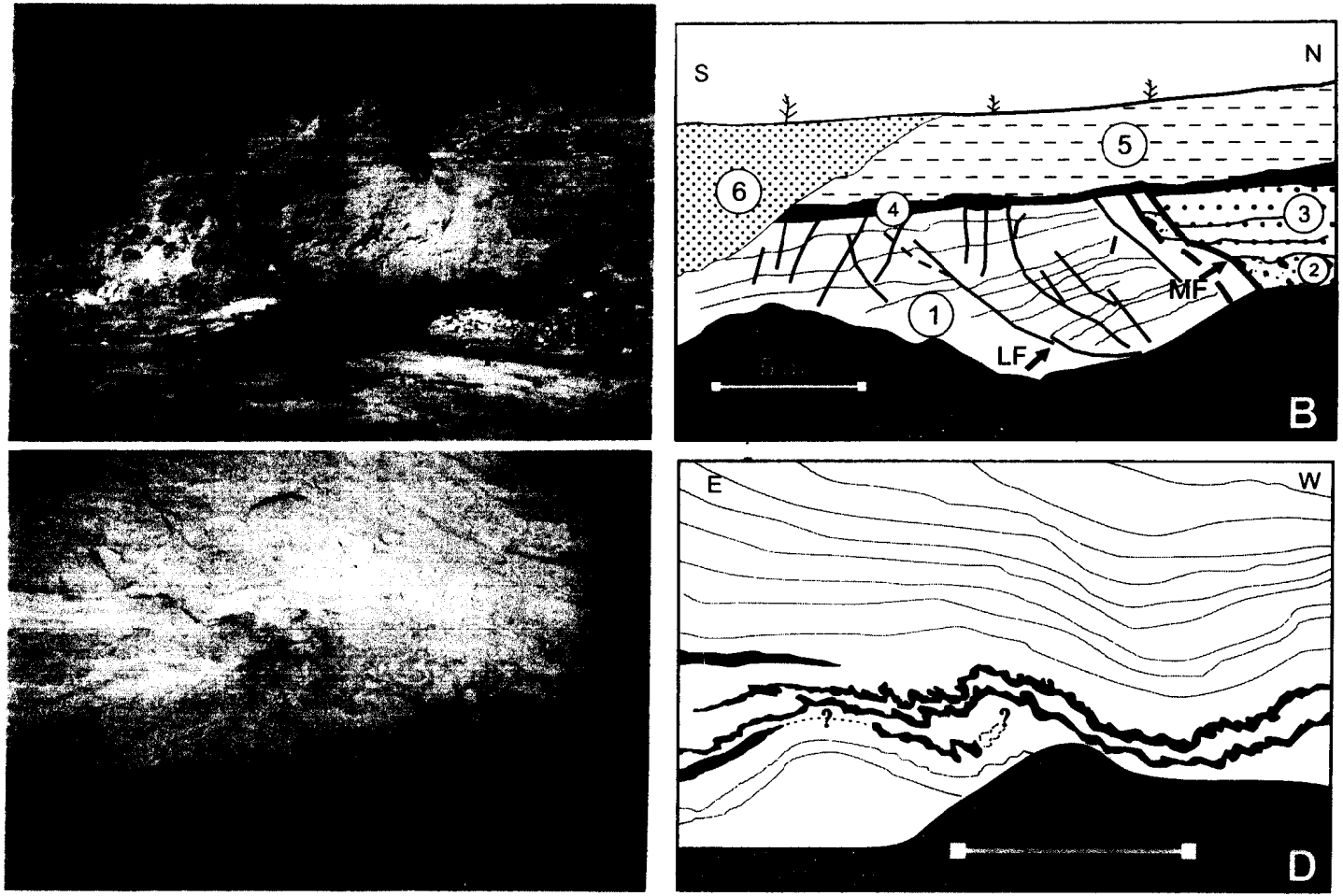

Fig. 3. Photographs (A, C) and corresponding sketches (B, D) from the Piperitsa sand quarry. Section A(B) is normal to C(D). MF: main fault; LF: listric fault. Refer to Fig. 2 for legend. The thin lines within the lower marine marls indicate bedding.

presumed to be of tectonic origin. Also, small-scale listric faults have also accommodated some of this deformation. Disturbance to the tranquility of the depositional environment is also expressed in the folding of the laminated marls at the base of the section. Similar presumed paleoseismic cases of disturbance of the depositional environment (in a different geotectonic regime) have been described by Sims (1975) from the Hood Canal. It is also noteworthy that the earthquake of 1986 in Kalamata caused listric faulting in the sediments of Kalamata bay (Papanikolaou *et al.*, 1988).

In the Agrilos road-cut section the change between shallow-marine sediments and red paleosol is abrupt, with no transitional layers. On the other hand, the rate of subsidence of the Kato Messinia graben during the Pleistocene has been estimated to be about 0.3 mm/year (Mariolakos *et al.*, 1994). Under such low subsidence and high-energy conditions, it is to be expected that the red paleosol would have been eroded. Here we suggest that erosion could have been avoided if the whole area had suffered abrupt subsidence, possibly during an earthquake. Abrupt vertical movements connected with earthquakes are very common in the Hellenic Arc; for example, during a recent earthquake sequence (February–March 1981) shoreline subsidence of 0.8–1.0 m was observed in the area of Strava (eastern coast of the Corinthian Gulf) (Mariolakos *et al.*, 1981).

Taking into account all the above inferences, the following summary can be made.

(1) Two localities suspected of the exhibiting paleoseismic deformation occur inside the Kato Messinia graben. One of them, the Agrilos road-cut, is located on the eastern margin of the Kato Messinia graben whereas the other one, Piperitsa sand quarry, lies in the central part of the graben.

(2) These observations suggest that the graben was seismically active during Early (or Middle) Pleistocene times, when shallow-marine sedimentation was taking place.

(3) Comparing the pattern of seismic activity (paleoearthquakes) on the eastern margin with that in the central part of the Kato Messinia graben, it is concluded that the latter was very active, as many minor events were recorded in the sediments of the Piperitsa sand quarry whereas there are significantly fewer on the eastern margin at Agrilos, where only one event was identified.

Thus, it is evident that in the area of the Kato Messinia graben, recent seismic activity started close to the Pliocene–Pleistocene boundary and has continued until the present day, with many earthquakes having occurred during historical times, the most recent one affecting the city of Kalamata (13 September 1986).

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