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Geomorphic and archaeological - historical evidence for past earthquakes in Greece

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Abstract
Geomorphic observations focused on landforms of marine and fluvial origin such as notches, beachrocks, stream channel shifts, alluvial terraces and knickpoints, when combined with historical and archaeological information are able to date seismic events that took place in the past in some places of the Peloponnesus. At the Eastern Gulf of Corinth, a seismically active area, all the geomorphic observations fit quite well with the deformation field induced by the action of an offshore fault. At Mycenae, a seismically inactive area with no historical evidence of earthquakes, the archaeological information is the only evidence for past earthquakes while geomorphic data indicate the most probable activated fault. At Sparta, an area of low seismicity but with historical evidence of destructive earthquakes, the geomorphic evidence helps to identify the most likely ruptured fault. At Eliki, a seismically active area with well documented historical activity, the geomorphic data serve to define the causative fault.This paper shows that although historical and archaeological data provide evidence for the occurrence of past earthquakes and often their date, geomorphic observations must be used to identify the causative fault.

Key words *palaeoseismology – geomorphology – morphotectonics – archaeology – Greece*

1. Introduction

Greece is a tectonically active area in which frequent destructive earthquakes have left their imprints on both human and natural environments. The seismicity results mainly from rapid crustal extension expressed by the reactivation of normal faults (Jackson and McKenzie, 1988). In the area extending north of Central Peloponnesus the direction of the faults is nearly east-west (fig. 1), while south of it their direction is almost north-south (McKenzie, 1978; Angelier *et al.*, 1982; Armijo *et al.*, 1992).

The Peloponnesus is one of the most seismically active areas of Greece. Many destructive earthquakes have occurred in this region since ancient times. Information on such major seismic events is documented in historical reports which date as far back as 2500 years, and in archaeological remains going back several millennia. In the epicenter map of the Peloponnesus (fig. 2) of both instrumentally recorded (Makropoulos *et al.*, 1989; Ambraseys and Jackson, 1990) and historical earthquakes (Papazachos and Papazachou, 1989), it is apparent that there exist areas like the Gulf of Corinth with continuous seismic activity while others, *e.g.* Sparta, exhibit a low seismicity rate, or have been aseismic for the last hundred years (Argos-Mycenae). As the timespan of instru-

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mental-historical data in comparison to earthquake recurrence is limited, a combination of geomorphological observations and archaeological information is therefore considered essential for the determination and dating of the reactivation of active faults.

2. Geomorphological methods for the recognition of palaeoseismic events

Geomorphological approaches to the recognition of palaeoseismic events are mainly related to the study of depositional and erosional records associated with coseismically affected coasts, rivers and hillslopes.

Changes of the coastal zone resulting from seismogenic fault reactivation can be expressed in the form of raised marine depositional or erosional terraces or elevated eroded sea level markers such as tidal notches. In addition, the presence of raised or submerged beachrocks (an inter-tidal feature) along a coastline, provides an indication of negative or positive relative sea-level change. Such phenomena may be the only subaerial evidence of active faults

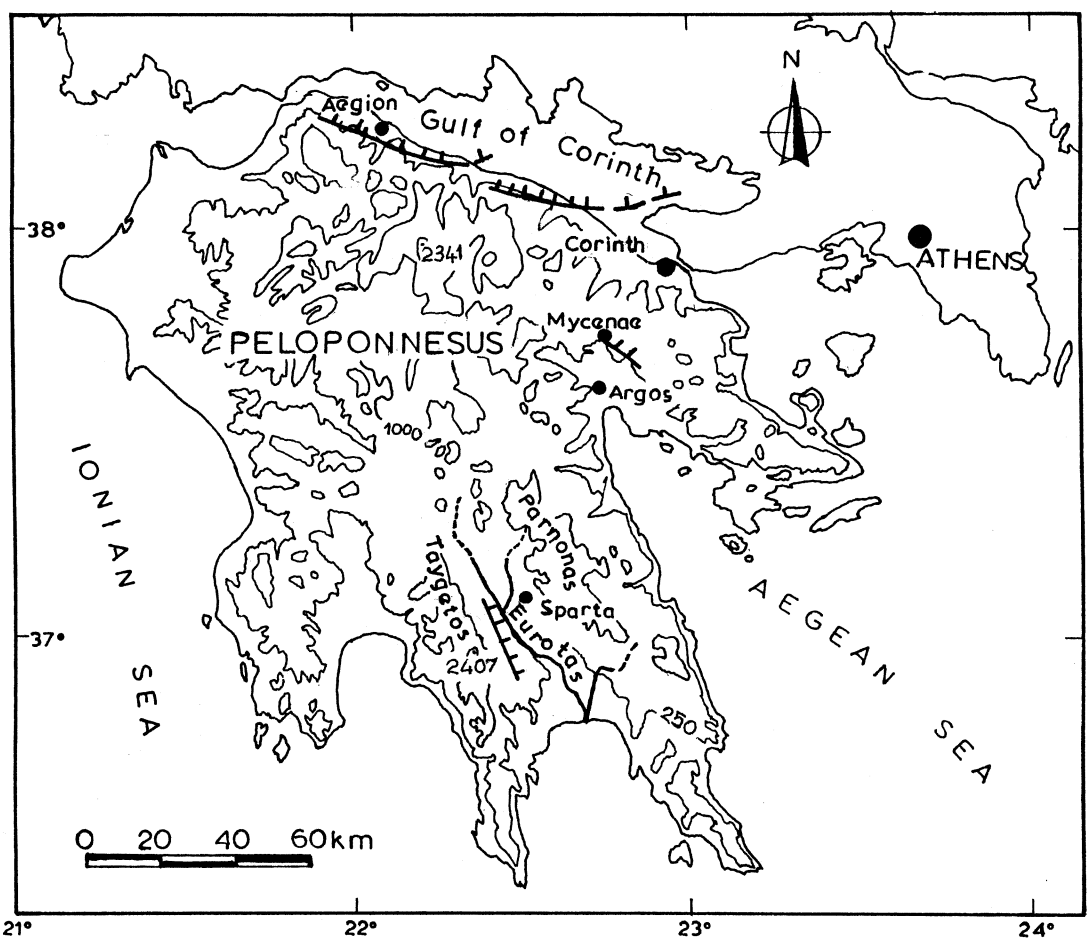

Fig. 1. Location map of the referred sites with the discussed faults.

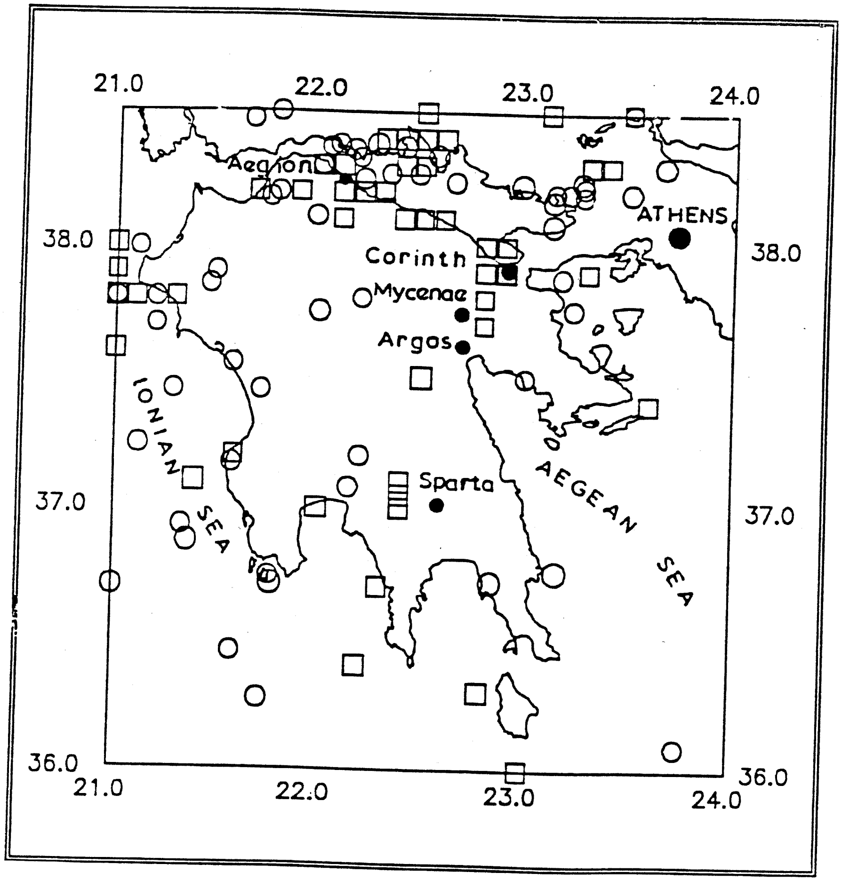

Fig. 2. Epicenter map of strong earthquakes ($M_s \geq 6.0$) of the Peloponnesus and the Gulf of Corinth. The historical earthquakes are denoted by squares while circles represent shallow earthquakes (depth down to 50 km) of the present century.

located offshore (Lajoie, 1986; Ota, 1986; Plafker, 1987; Pirazzoli, 1987; Laborel and Laborel-Deguen, 1994).

In the fluvial environment, abrupt changes in channel position, form or incision/aggradation rates could be evidence of recent fault reactivation, as could the development of sharp breaks or «knickpoints» in the longitudinal stream profile (Wallace, 1978; Hanks *et al.*, 1984; Mayer, 1984, 1986; Machette, 1986; Slemmons and De Polo, 1986; Zhang *et al.*, 1986; Martel *et al.*, 1987).

Linear, erosionally faceted mountain fronts are often topographic expressions of active faults which in turn are responsible for earthquakes. The presence of geomorphological features often permits the determination of fault activity. The existence of triangular and trapezoidal facets of some hundreds of meters separated by wine-glass canyons or gorges is an indication of cumulative displacement during the last hundreds of thousands of years. Moreover the presence of a fresh scarp at the base of the mountain front is often indisputable evidence for Holocene reactivation of the range-bounding fault. Degradation of the surface of the fault scarp may provide additional useful information about the timing and magnitude of reactivation (Wallace 1977, 1978; Colman and Watson, 1983; Andrews and Hanks, 1985; Mayer, 1986; Armijo *et al.*, 1986, 1989).

In palaeoseismological studies, historical and archaeological archives are often utilized to corroborate, identify and provide evidence for past seismic events. Surficial indications as well as *in situ* observations in the course of excavations of archaeological sites can reveal signs of ground rupture or shaking and provide useful information about the magnitudes and locations of prehistoric earthquakes while the dating of sherds can constrain the timing of an event to within a few decades. The location of beachrocks in relation to archaeological structures and the inclusion of sherds allow us to date them relatively. Therefore the corresponding tectonic movements postdate the formation of the beachrocks. Archaeological sites in the vicinity of active faults often provide information about the movement history of the fault such as where sites have undergone tectonic submergence or emergence. Greece, with a plethora of archaeological sites and a long historical record appears, well placed to develop a palaeoseismic approach to earthquake investigations. However the uneven distribution of such archaeological and historical sites within Greece, leads to some geographical limitations, making geomorphic evidence particularly important in areas outside them. The most promising areas lie in Southern Greece. Some examples from these areas are presented in this study (fig. 1).

3. Examples of geomorphological observations in relation to archaeological sites

3.1. *Eastern Gulf of Corinth*

The eastern end of the Gulf of Corinth is well known for the numerous archaeological finds, with many archaeological sites which date from the Neolithic period but the most important ones (Corinth, Lechaeon, Diolkos, Heraeon, Lake Vouliagmeni, Aegosthena) dating from Classical to Roman times (Benson, 1895; Payne, 1940; Fossey, 1969; Papahatzis, 1981).

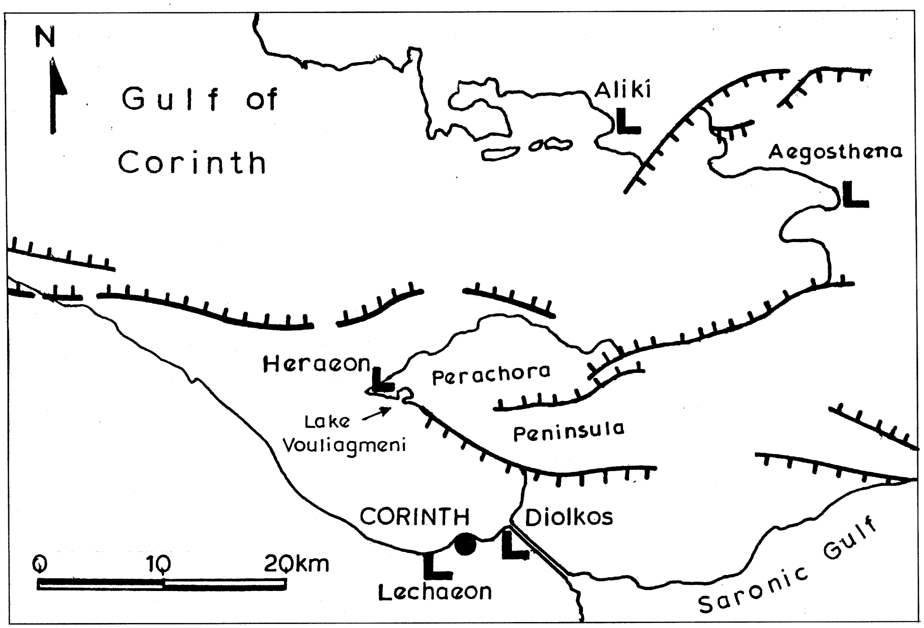

Fig. 3. Location map of the examined archaeological sites in the Corinth area and the offshore fault. The main faults of the area are also shown.

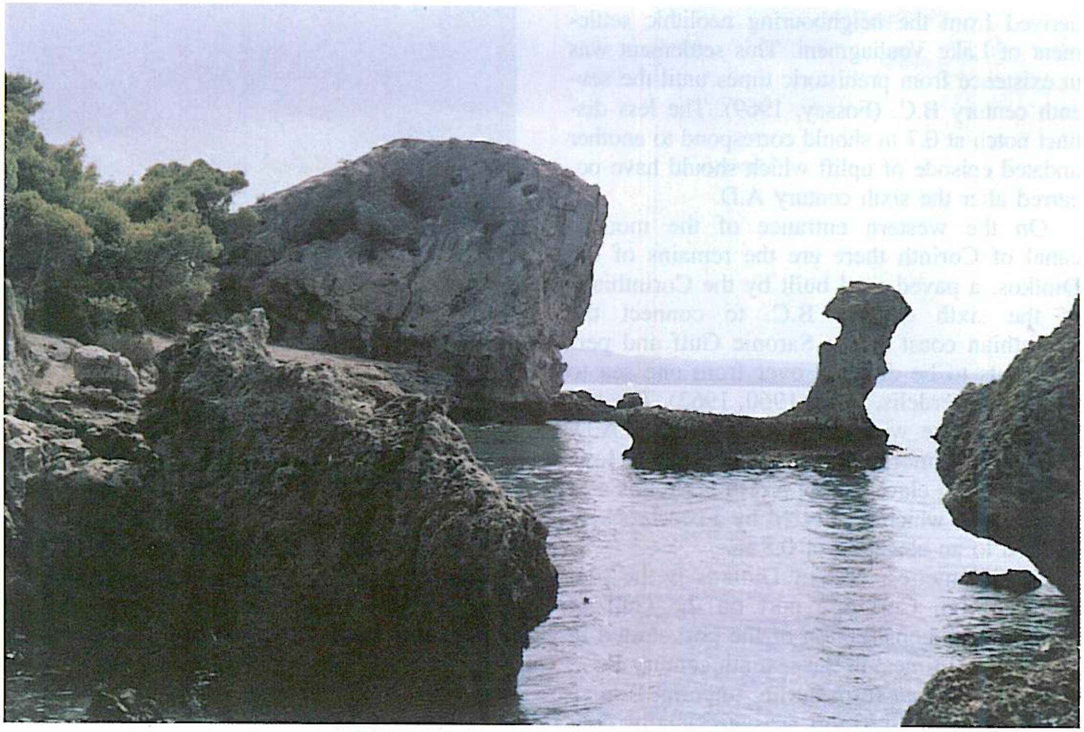

Fig. 4. Uplifted notches in the area of Skaloma east of Lake Vouliagmeni.

Despite the presence of many faults in this area, the great offshore fault located north and west of the Perachora peninsula (fig. 3) is believed to be responsible for the long term uplift of Northeast Peloponnesus (Armijo *et al.*, 1996). The presence of numerous coastal archaeological sites in the area provides an opportunity to correlate local relative sea-level changes with short term movements of this fault (Maroukian *et al.*, 1995a).

South of this fault many indications of recent uplift exist. At the western end of the Perachora peninsula there is the ancient harbour of Heraeon, where the ruins of the sanctuary of Hera are, which was in operation till the early Roman period. At the entrance of the harbour, distinct raised notches are present, at elevations of 1 m, 2 m and 3 m. There is however a less clear notch, below them, at an elevation of 0.7 m. On both sides of the entrance to Lake Vouliagmeni two distinct raised beachrocks were observed having elevations of 1 m and 2 m. It is important to note that the upper layer of the 2 m beachrock contains archaeological sherds. The lower beachrock is the wider and the clearest. In the western shores of Lake Vouliagmeni a prominent notch at the same level is also observed. East of Lake Vouliagmeni, at Skaloma, raised notches are observed at elevations of 1 m, 2 m and 3 m with corresponding beachrocks (fig. 4).

Vita-Finzi and King (1985) based on radiocarbon dating suggested that the area of Lake Vouliagmeni has been in emergence by more than 3 m for 7000 years while Pirazzoli *et al.* (1994) reported that the 2 m and 1 m notches at Heraeon correspond to two episodes of rapid uplift that probably occurred after 2440 years B.C. and between the third and sixth centuries A.D. respectively. Therefore the observed archaeological sherds included in the 2 m beachrock should be older than 2440 years B.C.

derived from the neighbouring neolithic settlement of Lake Vouliagmeni. This settlement was in existence from prehistoric times until the seventh century B.C. (Fossey, 1969). The less distinct notch at 0.7 m should correspond to another undated episode of uplift which should have occurred after the sixth century A.D.

On the western entrance of the modern canal of Corinth there are the remains of the Diolkos, a paved road built by the Corinthians in the sixth century B.C. to connect the Corinthian coast to the Saronic Gulf and permit boats to be dragged over from one sea to the other (Verdelis, 1956, 1960, 1962). The last mentioned use was in the ninth century A.D. The general morphology of this area is low, not exceeding elevations of 5 or 6 m. In this area the Diolkos, which is covered by a beachrock, is uplifted to an elevation of 0.8 m.

Six kilometres west of Diolkos is the port of Lechaeon, Corinth's port on the Gulf of Corinth. The construction of the port started in pre-classical times, in the seventh century B.C., and took its final form during imperial Roman times. Most of the port was artificially constructed, by excavation and dredging and was made up of an inner and an outer part (Paris, 1915). On the wall of the quay of the inner port there are borings of lithophaga organisms at an elevation of 0.70 m above present day sea-level. On the outer port beachrocks up to a height of 0.80 m cover an ancient structure of the port. These are indications of post Roman uplift of about 0.70 m. Next to the harbour there are ruins of a large early Christian basilica of the fifth century A.D. The church was destroyed by an earthquake and fire during the sixth century A.D. (Pallas, 1956, 1960, 1965). Such a seismic event in this area for this period is listed in the earthquake catalogue given by Papazachos and Papazachou (1989).

In contrast, the northern coast of the Gulf of Corinth shows clear evidence of coastal subsidence. The most impressive sites are located at Aegosthena and at Aliki (figs. 3 and 5) where ancient structures of the classical period (fourth century B.C.) are found submerged to depths of 1.5 m and 2 m respectively (Vita-Finzi and King, 1985).

Fig. 5. Submerged ancient constructions in the area of Aliki.

All this information supports our conclusion that the emergence of the coast of the south Gulf of Corinth and the consequent subsidence of the north coast is attributed to the repeated reactivations of the almost east-west trending offshore fault. The last two reactivations should have occurred between the third and sixth centuries A.D. and after the sixth century A.D. respectively.

3.2. *The Mycenae Fault*

Atop a limestone hill at the northeast corner of the Argive plain in Eastern Peloponnesus, the renowned Acropolis of Mycenae is located. This hill is separated from Mount Sara, to the southeast, by a deep gorge cut into limestones by the Havos stream (fig. 6).

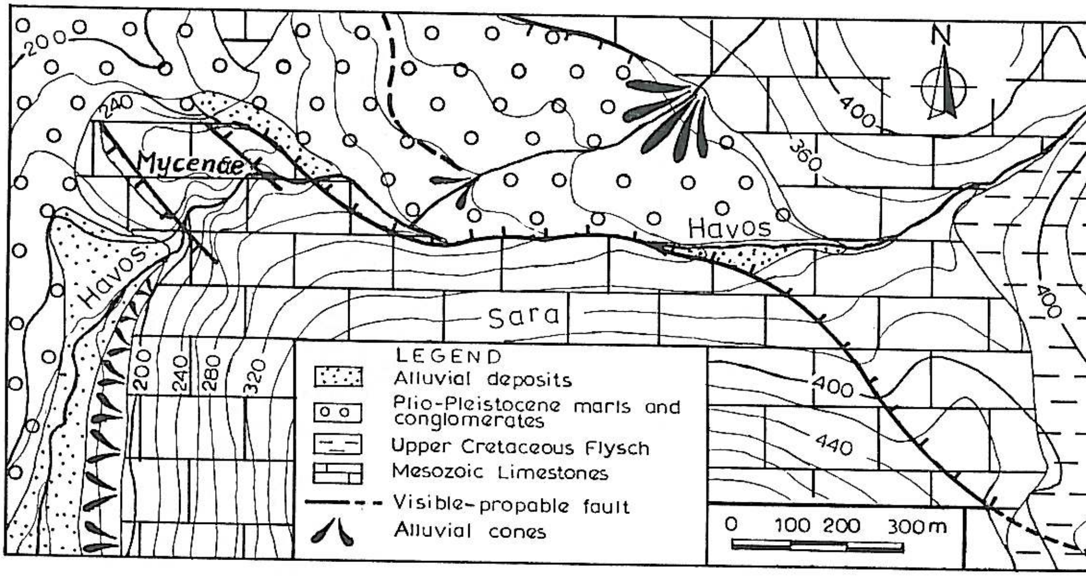

Fig. 6. Morphotectonic map of the area around the Acropolis of Mycenae (from Papanastassiou *et al.*, 1993).

Fig. 7. View from the northwest of the Mycenae Fault.

The hill of Mycenae is bounded on the east and west sides by antithetic normal faults with a NW-SE direction. The eastern segment, «the Mycenae Fault», is the longer and has the clearer morphotectonic expression. The fault trace starts from the northeast corner of the Acropolis, crossing the Havos stream and following the northern base of the Sara mountain along an E-W trend for almost 700 m. Then it turns to a N120° trend for more than 1 km (fig. 7) and continues into flysch formations and Quaternary deposits where it is difficult to follow. The total observed length of the fault, marked by a clear limestone scarp, is at least 2 km but it is assumed that it extends for at least another 3 km in the above mentioned erodable formations. This scarp east of Mount Sara reaches a height of almost 3 m. The upper 1.5 m is intensely weathered while the lower part remains relatively fresh (Papanastassiou *et al.*, 1993; Maroukian *et al.*, 1995b).

Papanastassiou *et al.* (1993) observed that a recent reactivation of the Mycenae Fault had disrupted the normal flow of the Havos stream by creating a natural dam. As a result, the stream periodically deposited sediments in the upstream section of the dammed channel elevating it to the point where it could overcome the fault scarp. This process was accompanied by a simultaneous shift of the channel further downstream. Fluvial deposits at this location were found to contain archaeological pot sherds that range in age from Mycenaean at depth to Roman at the top. As the first and oldest deposits include Mycenean sherds, they approximately date the last reactivation of the Mycenae Fault to the Mycenaean period that is early twelfth century B.C. and agrees well with the archaeological evidence (Mylonas, 1966; Shear-Mylonas, 1987) for an earthquake which destroyed the area of Mycenae in 1190 B.C.

3.3. *The Sparta Fault*

The city of Sparta, in the Southeast Peloponnesus (fig. 8), is located in an asymmetric tectonic depression, the Eurotas valley, bounded by the mountain masses of Taygetos on the west and Parnonas in the east.

This depression is filled by fluvio-torrential and lacustrine Plio-Pleistocene sediments eroded from the Parnonas highlands. These deposits are overlain, in the western margins by

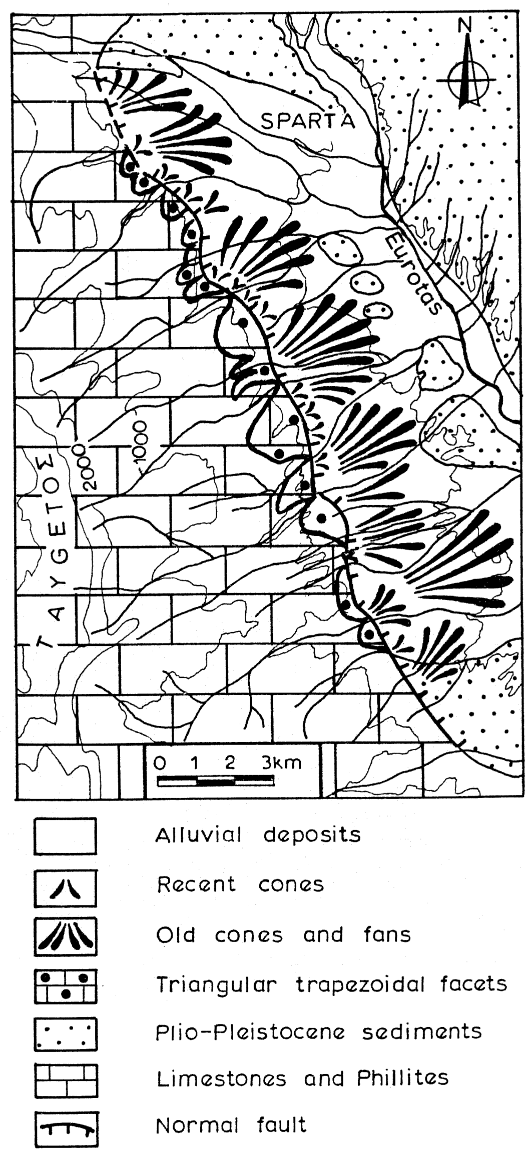

Fig. 8. Morphotectonic map of the Sparta Fault, based on Dufaure, 1975; Armijo *et al.*, 1991 and field observations.

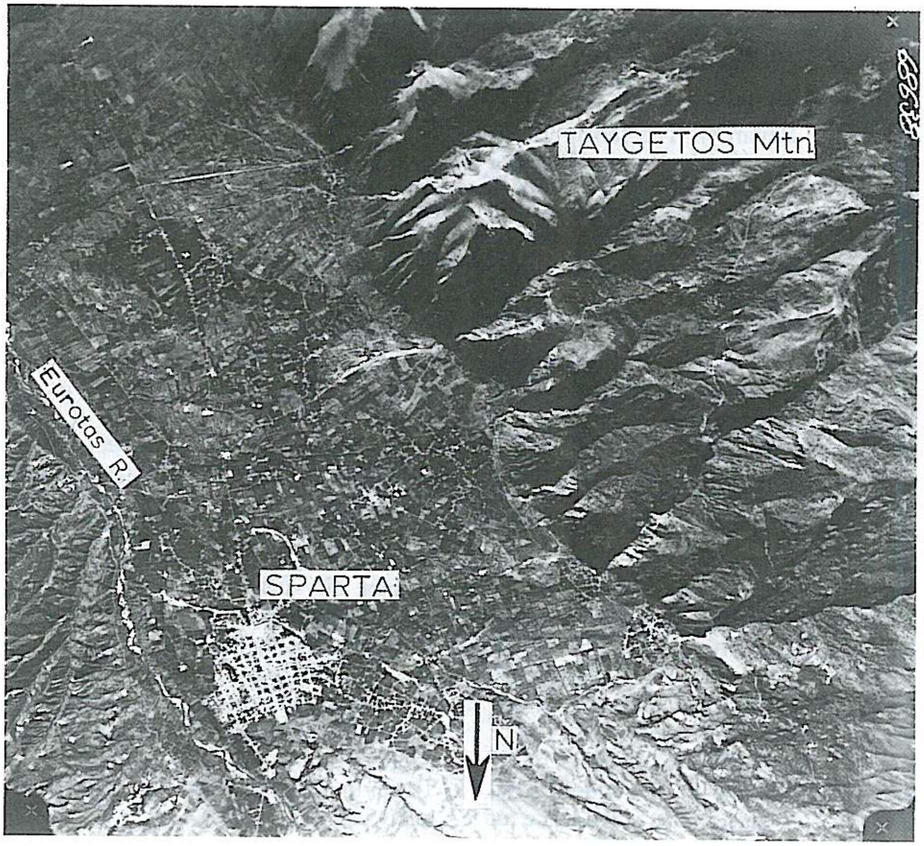

Fig. 9. Air-photo of the Taygetos Fault mountain front. The different generations of the triangular and the trapezoidal facets are clearly seen.

recent alluvial fans formed by streams issuing from the Taygetos mountain range. The shift in the flow of the Eurotas river towards the eastern part of the depression, the asymmetric cross-section of its channel with steeper relief on the eastern side indicate the active tectonics of its margin and especially the western one.

Immediately west of Sparta lies the Taygetos mountain whose eastern slopes are bounded by a large north-south trending normal fault, the Sparta Fault (figs. 8 and 9). According to Dufaure (1975) and Armijo *et al.* (1991), this fault segment has a scarp which is very clear and is easy to follow for more than 20 km. Along the central part of the Sparta Fault the scarp attains a height of 12 m. The Taygetos mountain front is incised by deep gorges and investigations of the streams issuing from the mountain show a steep gradient and the existence of knickpoints. Between these gorges prominent triangular and trapezoidal facets have formed. Different generations of alluvial cones and fans are observed also on the piedmont. In some places of the hanging wall a wedge of conglomerate debris lies against the bedrock. The wedge is also faulted and a smaller scarp remains visible. All these features suggest recent tectonic movement. In the seismic history of this region there is a period of intense seismic activity during the sixth and fifth centuries B.C. Destructive earthquakes affected the city of Sparta in the years 550 B.C., 496 B.C. and 464 B.C. and have been reported by various ancient historians (Thucydides, Pausanias, Ephorus, Diodorus of Sicily, Cicero, Strabo, Pliny and Plutarch). The most violent was that of 464 B.C., which destroyed Sparta not only physically but also created great social upheaval. Since then the seismicity of this area has remained low as is also shown by the instrumental data of the last one hundred years (fig. 1). Armijo *et al.* (1991) suggest that the 464 B.C. earthquake could be attributed to the most recent reactivation of the Sparta Fault and the corresponding maximum recurrence time for such large earthquakes would be of the order of more than 2500 years.

3.4. *The Eliki Fault*

East of Aegion in Northern Peloponnesus, exists another area which has been strongly affected by recent seismicity and tectonic movements. There exists the Eliki Fault, which has been studied by several researchers, among them Dufaure (1975); Mouyaris *et al.*, (1992); Poulimenos (1993) and Stewart (1996).

The reactivation of the E-W trending Eliki Fault (fig. 10) has caused the subsidence of the coast immediately north of it. Morphological observations between the Selinous and Vouraikos streams have noted intense downcutting, the development of knickpoints, truncated terraces, differential valley side slope morphology, changes in the form of alluvial cones and frequent channel shifts on active talus cones. In addition to these are characteristic trapezoidal and triangular facets (fig. 11) along the mountain front and the existence of a fault scarp of ~10 m height along the base indicate the recent activity of this fault. All these provide information on the evolution of the landscape and its response to recent movements of this fault.

In historical times the best known earthquakes, attributed to the reactivation of this fault, accompanied by significant vertical displacement, are those of 373 B.C. and 1861 A.D. That of 373 B.C. destroyed and sunk the ancient city-state of Eliki (Marinatos, 1960) and altered dramatically the landscape north of the fault. Besides Eliki, the neighbouring cities of Bura and Aigeira were also badly affected. Schmidt (1879) reported that the last reactivation of 1861 A.D. produced a rupture of 13 km length with a vertical displacement of 2 m. Traces of the scarp are still discernible, even today, in some places.

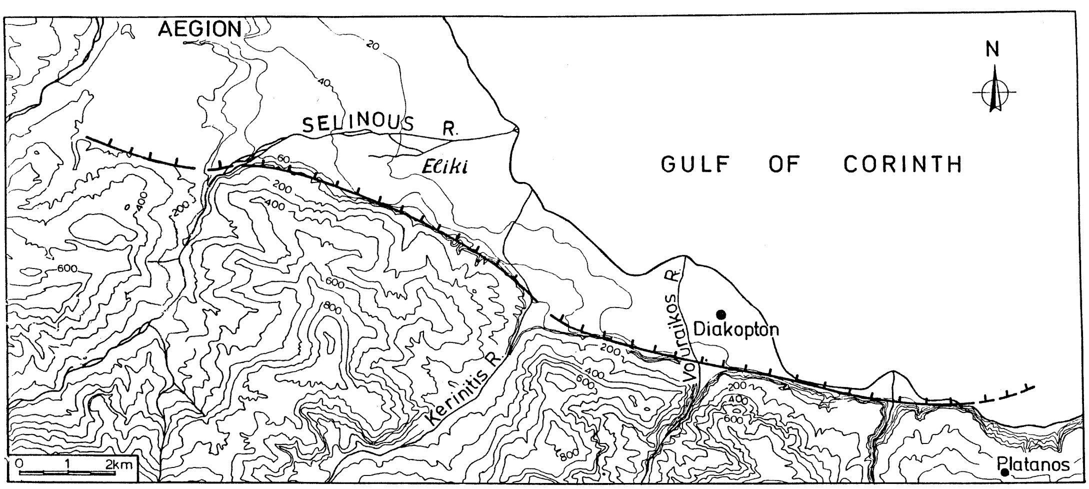

Fig. 10. The extent of the Eliki Fault in the Selinous-Vouraikos region.

Fig. 11. Panoramic view from the north of the Eliki Fault mountain front.

Recent morphologic studies and radiocarbon dating of raised marine features in the footwall, at the sites of Aigeira, Platanos and Diakopto located at the eastern extremity of the Eliki Fault, confirm the historical information and provide data to reconstruct previous movements (Mouyaris *et al.*, 1992; Papageorgiou *et al.*, 1993; Stewart, 1996). Between the well known historical events of 373 B.C. and 1861 A.D., Papageorgiou *et al.* (1993) recognized an earthquake around 900-1200 years A.D., while Stewart (1996) around the eighth and ninth centuries A.D. These events are not included in the historical catalogues of catastrophic events in this area although an earthquake is listed to have occurred in 1402 A.D. (Papazachos and Papazachou, 1989).

4. Conclusions

Through geomorphic and morphotectonic observations performed at coastal and inland archaeological sites combined with archaeological and historical information, an attempt was made to reconstruct the paleoseismic history of four areas in the Peloponnesus.

Thus, in the case of the Gulf of Corinth, contrary to the complicated tectonism, the plethora of archaeological sites submerged or uplifted on both sides of the gulf, helped in the identification of the fault that produced such a pattern of deformation as well as the dating of recent movements of this fault.

In the cases of Mycenae, Sparta and Eliki the archaeological data and/or the historical information readily correlated with great earthquakes which occurred in ancient times and with the help of morphotectonic observations we were able to identify the specific fault which ruptured in each case.

It becomes evident that geomorphological and morphotectonic investigations, in combination with archaeological evidence, lead to a better understanding and dating of past seismic events expressed by surface rupture. Such co-operative studies have become imperative in recent years. This is especially true in the case of Greece, where numerous archaeological sites exist.

REFERENCES

AMBRASEYS, N.N. and J.A. JACKSON (1990): Seismicity and associated strain of Central Greece between 1890 and 1988, *Geophys. J. Int.*, **101**, 663-708.

ANGELIER, J., N. LYBERIS, X. LE PICHON, E. BARRIER and P. HUCHON (1982): The tectonic development of the Hellenic arc and the sea of Crete: a synthesis, *Tectonophysics*, **86**, 159-196.

ANDREWS, D.J. and T.C. HANKS (1985): Scarp degraded by linear diffusion: inverse solution for age, *J. Geophys. Res.*, **90**, 10193-10208.

ARMIJO, R., P. TAPONNIER, J.L. MERCIER and HAN TONGLIN (1986): Quaternary extension in Southern Tibet: field observations and tectonic implications, *J. Geophys. Res.*, **91**, 13803-13872.

ARMIJO, R., P. TAPONNIER and HAN TONGLIN (1989): Late Cenozoic right-lateral strike-slip faulting in Southern Tibet, *J. Geophys. Res.*, **94**, 2787-2839.

ARMIJO, R., H. LYON-CAEN. and D. PAPANASTASSIOU (1991): A possible normal-fault rupture for the 464 B.C. Sparta earthquake, *Nature*, **351**, 137-139.

ARMIJO, R., H. LYON-CAEN and D. PAPANASTASSIOU (1992): East-west extension and Holocene normal-fault scarps in the Hellenic arc, *Geology*, **20**, 491-494.

ARMIJO, R., B. MEYER, G. KING, A. RIGO and D. PAPANASTASSIOU (1996): Quaternary evolution of the Corinth Rift and its implications for the Late Cenozoic evolution of the Aegean, *Geophys. J. Int.* (in press).

BENSON, E.F. (1895): Aegosthena, *J. Hell. Stud.*, **15**, 314-324.

COLMAN, S.N. and K. WATSON (1983): Age estimated from a diffusion fusion equation model for scarp degradation, *Science*, **221**, 263-265.

DUFAURE J.J., (1975): La relief du Peloponnese, *These*, Paris.

FOSSEY, J.M. (1969): The prehistoric settlement by lake Vouliagmeni, Perachora, *Ann. Br. Sch. Athens*, **64**, 53-69.

HANKS, T.C., R.C. BUCKNAM, K.R. LAJOIE and R.E. WALLACE (1984): Modification of wave-cut and fault-controlled landforms, *J. Geophys. Res.*, **89**, 5771-5790.

JACKSON, J.A. and D.P. MCKENZIE (1988): The relationship between plate motions and seismic tensors, and the rate of active deformation in the Mediterranean and Middle East, *Geophys. J. Int.*, **93**, 45-73.

LABOREL, J. and F. LABOREL-DEGUEN (1994): Biological indicators of relative sea-level variations and co-seismic displacements in the Mediterranean region, *J. Coastal Res.*, **10**, 395-415.

LAJOIE, K.R. (1986): Coastal tectonics, in *Studies in Geophysics: Active Tectonics*, National Academy Press, Washington, DC, 95-124.

MACHETTE, M.N. (1986): History of Quaternary offset and paleoseismicity along the La Jenca Fault, Central Rio Grande Rift, New Mexico, *Bull. Seism. Soc. Am.*, **76**, 259-272.

MAKROPOULOS, C., J. DRAKOPOULOS and J. LATOUSSAKIS (1989): A revised and extended earthquake catalogue for Greece since 1900, *Geophys. J. Int.*, **99**, 305-306.

MARINATOS, S. (1960): A submerged town of classical Greece, *Archaeology*, **113**, 186-193.

MAROUKIAN H., K. GAKI-PAPANASTASSIOU and D. PAPANASTASSIOU (1995a): Coastal changes in the broader area of Corinth, Greece, in *Proceedings of the Congress «Res Maritimae: Cyprus and the Eastern Mediterranean; Prehistory through the Roman Period, Cities on the Sea»*, 1994, Cyprus (in press).

MAROUKIAN H., K. GAKI-PAPANASTASSIOU and D. PAPANASTASSIOU (1995b): Geomorphic-seismotectonic observations in the area of Mycenae. Their relation to the catastrophes of Mycenae during Mycenaean times, in *Archaeoseismology*, edited by R. JONES and S. STIROS, paper No. 7 of the Fitch Laboratory (Oxbow Books, Oxford) (in press).

MARTEL, J.S., T.M. HARRISON and A.R. GILLESPIE (1987): Late Quaternary vertical displacement rate across the Fish Springs Fault, Owens Valley Fault zone, California, *Quat. Res*, **27**, 113-129.

MAYER, L. (1984): Dating fault scarps formed in alluvium using morphologic parameters, *Quat. Res.*, **22**, 300-313.

MAYER, L. (1986): Tectonic geomorphology of escarpments and mountain fronts, in *Studies in Geophysics: Active Tectonics*, National Academy Press, Washington, DC, 125-135.

MCKENZIE, D.P. (1978): Active tectonics of the Alpine-Himalayan belt: the Aegean sea and surrounding regions, *Geophys. J.R. Astron. Soc.*, **55**, 217-254.

MOUYARIS N. D. PAPASTAMATIOU and C. VITA-FINZI (1992): The Helice Fault, *Terra Nova*, **4**, 124-129.

MYLONAS, G. (1966): *Mycenae and the Mycenaean Age*, Princeton University Press, Princeton, NY, p. 214.

OTA, Y. (1986): Marine terraces as reference surfaces in Late Quaternary studies-examples from the Pacific Rim, *R. Soc. N.Z. Bull.*, **24**, 357-375.

PALLAS, D. (1956): The Excavation of the Basilika at Lechaeo, Praktika Arch. Soc., 164-178.

PALLAS, D. (1960): Excavation at Lechaeo, Praktika Arch. Soc. 144-170.

PALLAS, D. (1965): Excavation at Lechaeo, Praktika Arch. Soc. 137-166.

PAPAGEORGIOU, S., M. ARNOLD, J. LABOREL and S. STIROS (1993): Seismic uplift of the harbour of ancient Aigeira, Central Greece, *Int. J. Nautical Archaeology*, **22** (3), 275-281.

PAPAHATZIS, N. (1981): *Ancient Corinth*, Ekdotike Athenon.

PAPANASTASSIOU, D., H. MAROUKIAN and K. GAKI-PAPANASTASSIOU (1993): Morphotectonic and archaeological observations in the eastern Argive plain (Eastern Peloponnese, Greece), and their palaeoseismological implications, *Z. Geomorphol. Suppl.*, **94**, 95-105.

PAPAZACHOS, B.C. and C.B. PAPAZACHOU (1989): *The Earthquakes of Greece* (Ziti Publ., Thessaloniki), pp. 356 (in Greek).

PARIS, J. (1915): Contributions a l'etude de Ports antique du monde Grec, *B.C.H.*, 6-16.

PAYNE, H. (1940): *Perachora* (Clarendon Press, Oxford), vol. I.

PIRAZZOLI, P.A. (1987): Sea level changes in the Mediterraneen, in *Sea Level Changes*, edited by M. TOOLEY and I. SHENNAN (Blackwell, Oxford), 152-181.

PIRAZZOLI, P.A., S.C. STIROS, M. ARNOLD, J. LABOREL, F. LABOREL-DEGUEN and S. PAPAGEORGIOU (1994): Episodic uplift deduced from Holocene shorelines in the Perachora Peninsula, Corinth area, Greece, *Tectonophysics*, **229**, 201-209.

PLAFKER, G. (1987): Application of marine-terrace data to paleoseismic studies, in *Directions in Paleoseismology*, edited by A.J. CRONE and E.M. OMDAHL, U.S. Geol. Surv., Open-File Report, 87-673, 146-156.

POULIMENOS, G. (1993): Tectonics and sedimentation in the Western Corinth graben, *N.Jb. Geol. Palaeont. Mh.*, **10**, 607-630.

SCHMIDT, J. (1879): *Studien uber erdbeben*, Leipzig, 68-93.

SHEAR-MYLONAS, I. (1987): The Panagia houses at Mycenae, *University Museum Philadelphia Monograph*, No. 68, p. 171.

SLEMMONS, D.B. and C.M. DE POLO (1986): Evaluation of active faulting and related hazards, in *Studies in Geophysics: Active Tectonics*, National Academy Press, Washington, DC, 45-62.

STEWART, I. (1996): Holocene uplift and palaeoseismicity on the Eliki Fault, Western Gulf of Corinth, Greece, *Annali di Geofisica*, **39**, 575-588 (this volume).

VERDELIS, N. (1956): The Excavation of Diolkos, Arch. Ephimeris, 1-3.

VERDELIS, N. (1960): The Excavation of Diolkos, Praktika Arch. Soc., 136-143.

VERDELIS, N. (1962): The Excavation of Diolkos, Praktika Arch. Soc., 48-50.

VITA-FINZI, C. and G.C.P. KING (1985): The seismicity, geomorphology and structural evolution of the Corinth area of Greece, *Philos. Trans. R. Soc. London Ser. A*, **314**, 379-407.

WALLACE, R.E. (1977): Profiles and ages of young fault scarps, North-Central Nevada, *Geol. Soc. Am. Bull.*, **88**, 1267-1281.

WALLACE, R.E. (1978): Geometry and rates of change of fault-generated range fronts, North-Central Nevada, *J. Res. U.S. Geol. Surv.*, **6**, 637-650.

ZHANG, B., L. YUHUA, G. SHUNMIN, R.E. WALLACE, R.C. BUCKNAM and T.C. HANKS (1986): Fault scarps related to the 1739 earthquake and seismicity of the Yinchuan graben, Ningxia Huizu Zizhiqu, China, *Bull. Seism. Soc. Am.*, **76** (5), 1253-1287.