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Late Holocene relative sea level changes in SW Crete: evidence of an unusual earthquake cycle

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Abstract
Coastal changes in West Crete in the last 4000 years can be described as a series of 11 relatively small (25 cm on the average) land subsidences alternating with short (150-250 year long) relatively still stands of the sea level. At 1500 B.P. an up to 9 m episodic relative land uplift and tilting of this part of the island occurred, but since then no significant coastal changes have been identified. There is strong evidence that these Late Holocene coastal changes are not a product of fluctuations of sea level, but reflect palaeoseismic events. The sequence of the latter is at variance with models of seismic deformation deduced from a wide range of observations in different tectonic environments, including coastal uplifts near major trenches: according to these models, strain buildup and release through earthquakes is described as a cyclic and rather uniform process, the earthquake cycle. In this process, the permanent seismic deformation accumulates after each earthquake to produce geological features, while the long-term deformation rate is approximately equal to the short term one. Obviously this is not the case with West Crete. The unusual pattern of seismic deformation in this island has been observed in other cases as well, but its explanation is not easy. The juxtaposition of different earthquake cycles, variations in the source and rate of stress or internal deformation of the uplifted hanging wall of a thrust in the pre-seismic period are some possible explanations for this unusual pattern of earthquake cycle in Greece.

Key words *relative sea level changes – Holocene – Crete – earthquakes – uplift – subsidence – earthquake cycle – palaeoseismic event*

1. Introduction

Late Holocene raised beaches of West Crete were first identified more than 100 years ago (Spratt, 1865; Raulin, 1869), and since then have been a matter of study and debates. In recent years especially, Crete was recognized as one of the most quickly uplifting parts of the world (Lajoie, 1986), with rates probably similar to those of climatic sea level rise (*i.e.*, of the order of 10 mm/yr, van Andel and Shackleton, 1982). Yet, various detailed studies revealed that the situation is even more remarkable: while a series of about 11 earthquakes were associated with minor coastal subsidence, a subsequent great earthquake at around 1550 B.P. pushed a 200-km wide lithospheric block upwards, bringing the signs of the former transgressive shorelines to heights up to 9 m above the water (Pirazzoli, 1986a)!

This long and extraordinary uplift history is at variance with existing models of fault-related deformation: according to these models small movements caused by the reactivation of a fault are uni-directional (for instance, always uplift or always subsidence for a specific site) and accumulate through repetitive earthquakes to produce geological features (Shimazaki and Nakata, 1980; Thatcher, 1984; Schwarz and

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Coppersmith, 1984; Wallace, 1987; see fig. 1). The uplift history of Crete therefore raises two questions: can some of the relative sea-level changes observed be simply the result of fluctuations of the sea-level and not of bi-directional seismic movements? Can the observed fossil shorelines reflect not the seismic history of a specific fault (or fault segment), but the cumulative effect of the movement of different overlapping faults (or fault segment) with different uplift histories?

An answer to these two questions is necessary to document the palaeoseismic significance of the Holocene shorelines in SW Crete, and is the subject of this paper.

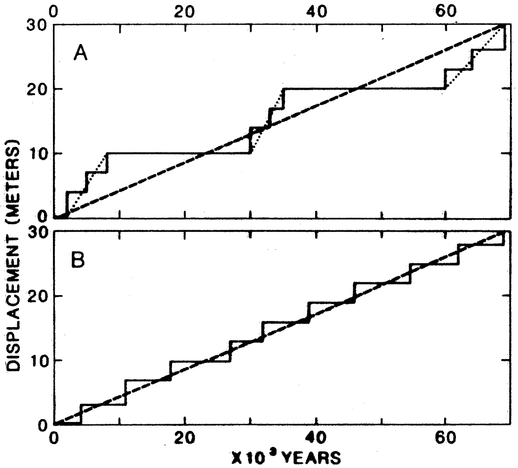

Fig. 1. Two different models for fault displacement versus time. a) Clustering of events separated by a quiescence period. b) Regular recurrence of slip events. A dashed line indicates the average slip rate over tens of thousands of years, a dotted line the average slip rate during clusters of events. In both models seismic slip is in one single direction, and short-term slip rate (measured between two events or two clusterings of events) equals the long-term, average slip rate (after Wallace, 1987). These models were inspired by the San Andreas Fault and intraplate faults in the Western United States. The pattern of permanent deformation in each earthquake cycle is, however, similar to that observed in other environments and other type of data (*e.g.*, coastal uplifts near major trenches; see Shimazaki and Nakata, 1980; Thatcher, 1984).

2. The uplift history of SW Crete

2.1. *Tectonic background*

Crete, especially its western part, lies close to the Hellenic Trench. More precisely, a more than 2 km deep bathymetric escarpment defining the northern margin of this Trench is about 30 km away from the Cretan coasts (fig. 2). This bathymetric escarpment probably indicates a major reverse fault zone (Angelier, 1979; Taymaz *et al.*, 1990) and is likely to control the geomorphological and tectonic evolution of the island. The most important aspect of this evolution is probably the tectonic uplift of the island, of the order of 2-3 km in the last 13 my. Uplift is still active, for Late Pleistocene sediments and fossil shorelines have been found at the height of a few tens of meters (Angelier, 1979; Pirazzoli, 1986a).

On land, normal faults dominate in the neotectonic period. The western part of the island, however, seems to behave as a rather rigid block (fig. 2); a result consistent with the pattern of Late Holocene uplifts in West Crete (see fig. 3).

2.2. *Fossil shorelines*

A number of fossil shorelines can be observed along the SW part of Crete (fig. 4). They reach the height of about 9 m in the SW corner of the island, but their elevation diminishes to the east, and disappears about 100 km away (fig. 3)

Since these fossil shorelines correlate with ancient ruins, they have been dated to the historical period (Spratt, 1865; Raulin, 1869; Flemming, 1978). Hafemann (1965) based on a number of radiocarbon dates estimated that the uplift of this part of the island occurred after 1685 B.P., while Flemming (1978), based on a study of notches and coastal archaeological remains, concluded that it can be analyzed to 14 uniformly distributed steps that occurred in the last 1500 years. On the contrary, other workers, including Keraudren (1971), interpreted the Holocene raised shorelines of SW Crete as remains of a mid-Holocene («Versilian») sea-

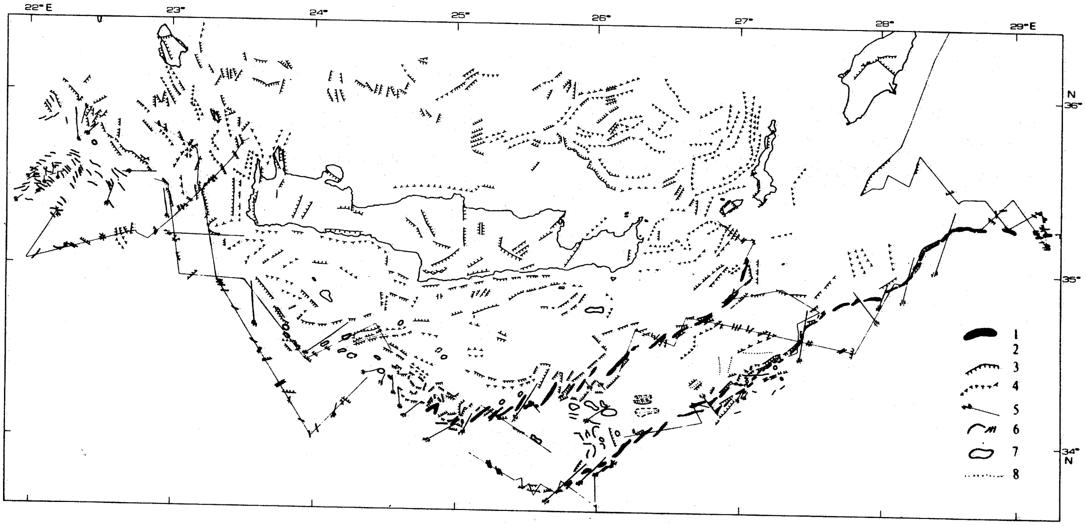

Fig. 2. Structural map of the area around Crete, simplified from Huchon *et al.* (1982). In echelon troughs (1) and normal faults, observed (3) or inferred (4) dominate, but the trench south of Crete is thought to reflect contractional tectonics. Note that the western part of the island seems to behave as a rigid block.

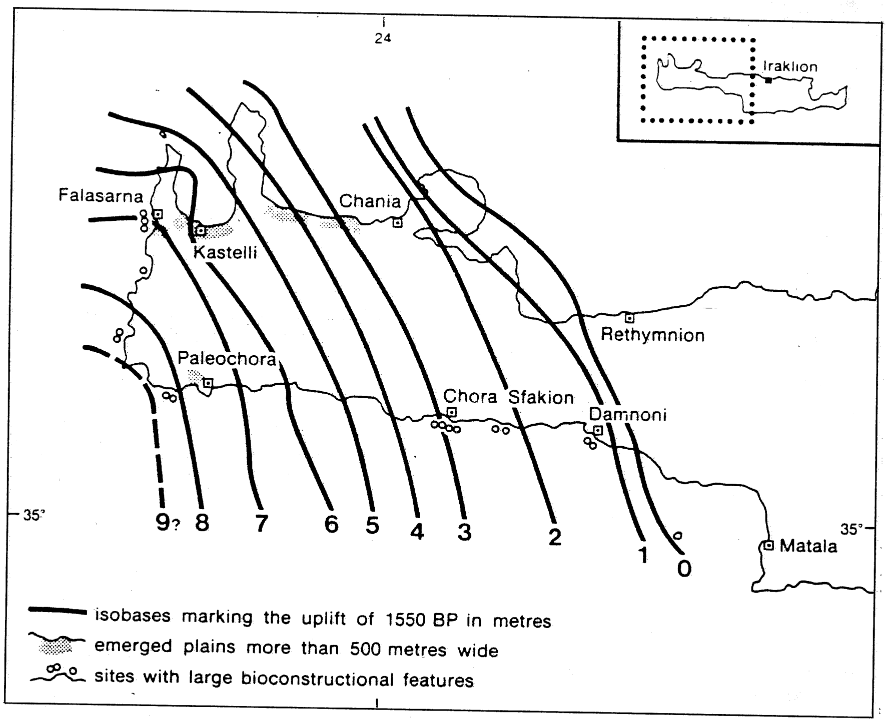

Fig. 3. Contours of the highest Holocene shoreline observed in West Crete, corresponding to the uplift at *ca.* 1550 B.P. (after Kelletat, 1991).

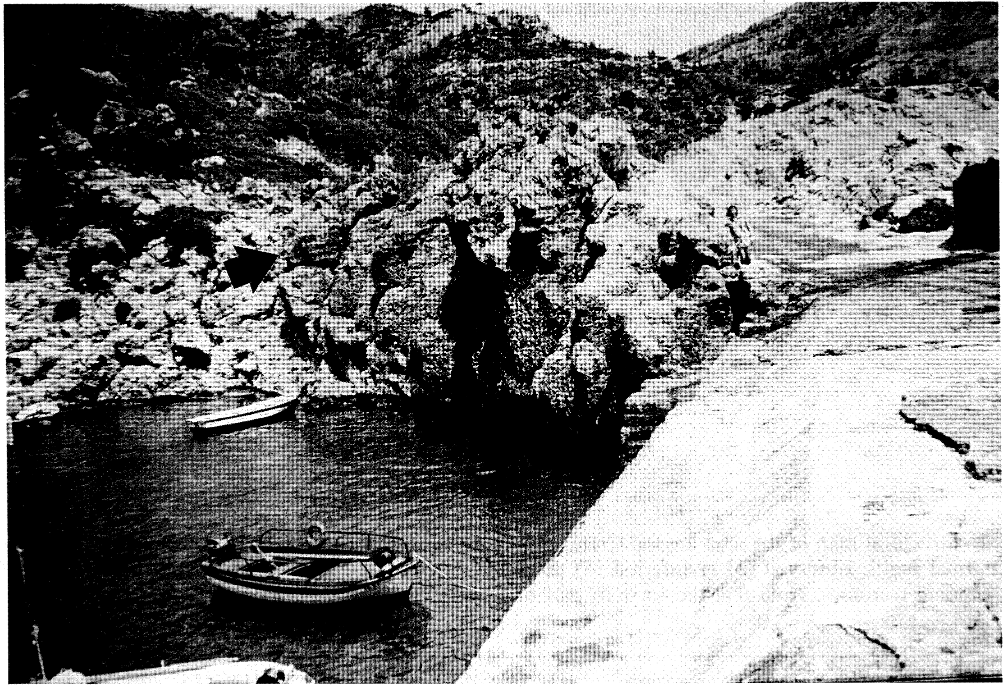

Fig. 4. Ripple notches at Sougia (the site where 6 m isolines of fig. 3 cut the south coast of Crete).

level highstand higher than present; an hypothesis, however, subsequently abandoned by most workers (Keraudren, 1979).

More recently, Thommeret *et al.* (1981), Pirazzoli *et al.* (1982; 1992; 1996a), Pirazzoli (1986a) and Kelletat (1991), based on integrated geomorphological and biological studies and numerous radiocarbon datings, showed that:

i) at least 11 raised parallel ripple notches (fig. 4), obviously relics of fossil shorelines, can be traced along the nearly tideless coast of the western part of Crete. These ripple notches are products of marine bio-erosion at sea level, and bear traces of marine erosion and deposition. From their dimensions (a few centimetres deep), it can be concluded that they were formed during periods of relative sea level stability, at least 100-150 years long (Pirazzoli, 1986b). This estimate is consistent with that deduced from the ratio of the length of the period during which the notches were formed and their number, *i.e.*, *ca.* 200-250 years;

ii) these fossil shorelines define a tilted band, about 2 m wide, which reaches its maximum height, about 9 m, at the SW edge of the island, and disappears about 100 km to the east (fig. 3);

iii) ripple notches are a product of marine bio-erosion at the time when sea level was at their middle. In the study area, signs of marine erosion and deposition can be observed even at their higher parts. These signs of bio-erosion postdate the notch formation and are more intense at the lowermost notches, but are absent in the uppermost notch. This most likely indicates that ripple notches in SW Crete were submerged after their formation for a period increasing in time as their elevation diminishes; a result confirmed by numerous, consistent radiometric datings showing that the uppermost shoreline is the youngest (*ca.* 1500 years old) and the lowermost one the oldest (*ca.* 4000 years old). The ages of the intermediate shorelines are roughly speaking uniformly distributed between these two dates, with an average spacing of approximately 250 years;

iv) the examined ripple notches are discontinuous, and only some of them (usually 3 to 4, but occasionally 2 to 9) can be observed in each site; they were probably formed and preserved where lithological conditions were favourable. However, from geomorphological and biological correlations and radiometric datings, these fossil shorelines seem to be laterally continuous along the whole coast of West Crete;

v) the sharp profile of ripple notches indicates that the passage from one notch to the other was rapid enough, otherwise their traces would have been obliterated (fig. 5a,b). Especially the last, major phase of uplift was extremely rapid, conspicuously seismic, so that some very fragile marine organisms of the infralittoral zone were not exposed to bio-erosion of the midlittoral zone, and have been preserved.

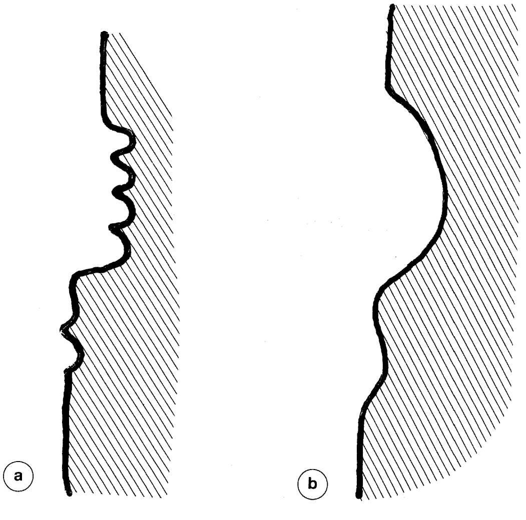

Fig. 5a,b. a) Ripple notches are formed when short periods of relative sea level stability alternate with episodic changes in the sea level. b) On the contrary, in the case of gradual relative change of the sea level the signs of individual shorelines are obliterated (after Pirazzoli, 1986b, simplified).

2.3. *Kinematic interpretation*

The available data and results discussed above can be used to reconstruct the sequence of relative sea level changes in SW Crete: between 4000 and 1550 B.P. about 11 small (25 cm on the average) relative subsidence movements following short (250 years on the average) (relative) stillstands of the sea level occurred; it is during these (relative) stillstands that the ripple notches were excavated. At around 1550 B.P., the part of the coast that was previously (relatively) subsiding was (relatively) uplifted by up to 9 m and tilted. Since then, no significant (relative) sea level changes have been identified.

This scenario is diagramatically shown in fig. 6, which summarizes the kinematic history of the oldest notch assuming a fixed sea level. Does this graph simply reflect sea level fluctuations, or it may also have a certain palaeoseismic significance? We try to provide an answer to this question in the following paragraph.

2.4. *Effect of possible sea level fluctuations*

Various lines of evidence indicate that the sea level was stabilized at approximately its present position by *ca.* 6000 B.P. (Chappel and Pollack, 1991; Flemming, 1978; Pirazzoli *et al.*, 1989; Ota *et al.*, 1993), and any climatic oscillations in the last 4000 years do not exceed the amount of a fraction of a meter, or the rate of 0.20 mm/yr. For instance, from the study of about 160 different sites in the Aegean, SW Turkey and Cyprus showing relative land subsidence, uplift or stability, Flemming (1978) estimated a rate of relative sealevel rise of 0.14 ± 1.05 mm/yr (see fig. 7). Since most of the observations of relative land subsidence come from margins of actively extending basins, it is quite reasonable to assign at least a major part of this small relative land subsidence to tectonic effects.

Consequently, the hypothesis of a nearly stable sea level during the last 4000 years assumed in fig. 6 is reasonable. Yet, a more detailed study

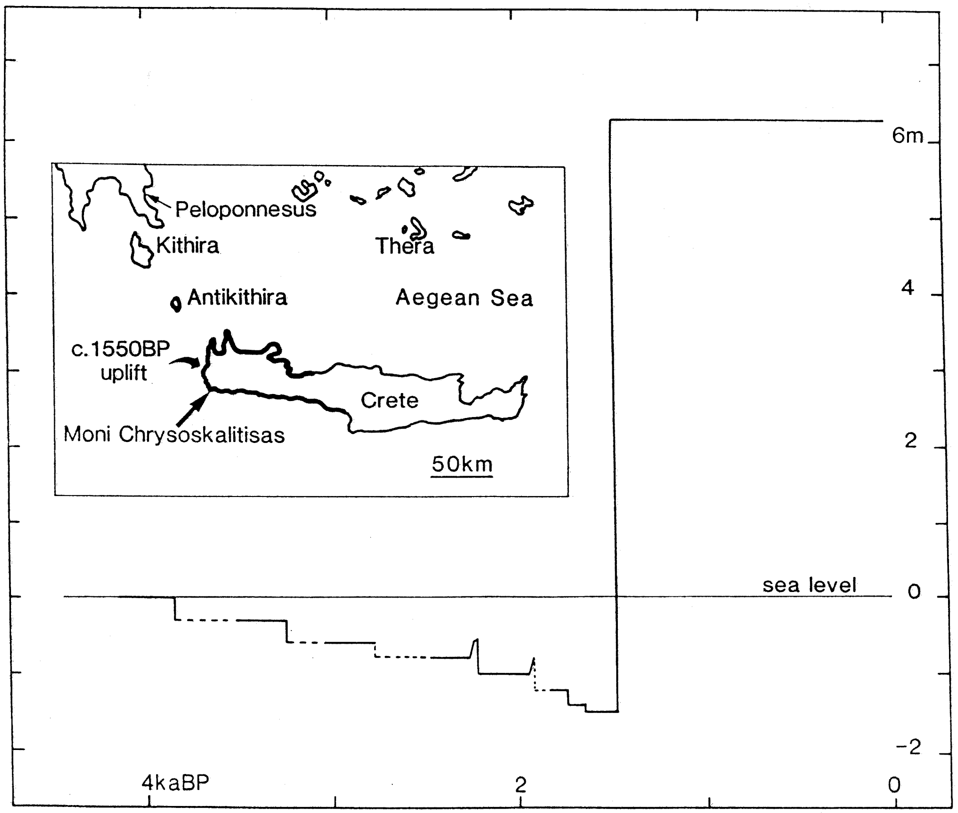

Fig. 6. Uplift history of the oldest (lowermost) notch at Moni Chrisoskalitisas, assuming a fixed sea-level. Based on data from Thommeret *et al.* (1981) and Pirazzoli *et al.* (1982).

of the impact of possible sea level fluctuations on the coastal evolution of Crete is necessary.

The best approach is to examine which possible sea level change models and under which circumstances could produce the graph of fig. 6. These models must be based on the assump-

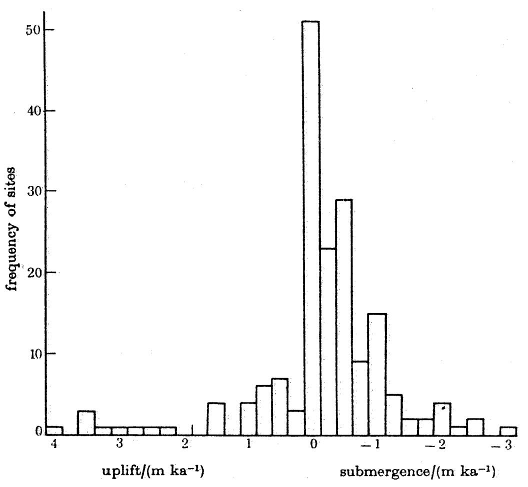

Fig. 7. Frequency of occurrence of sites showing rate of uplift or submergence relative to present sea level in the Aegean and and the Eastern Mediterranean, after Flemming (1978). Skewness of the histogram towards submergence is smaller than expected, for most sites are in an actively extending environment, where tectonic subsidence is expected. New data on Holocene sea level changes to be reported elsewhere support Flemming's conclusions.

tion that the short (150-250 years long) periods of relative sea level stability, necessary for the formation of notches, were uniformly distributed in time and were followed by periods of relative sea level rise, during which notches were drowned.

Two endpoint hypotheses for the sea level rise are examined herein. According to the first hypothesis, the rate of sea level rise was constant until 1550 B.P., and then sea level stabilized. The second one assumes that no tectonic movement between 4000 and 1550 B.P. occurred, and the observed ripple notches are simply an artifact of sea level fluctuations. For simplicity, these two alternative hypotheses are shown in graph form and for a period of 1000 years in figs. 8 and 9. Each figure shows hypothetical graphs of land uplift and sea level rise, the cumulative result of which is the graph of observed relative sea level changes. The variables in the graphs in both figures were calculated on the basis of the constraints analyzed above.

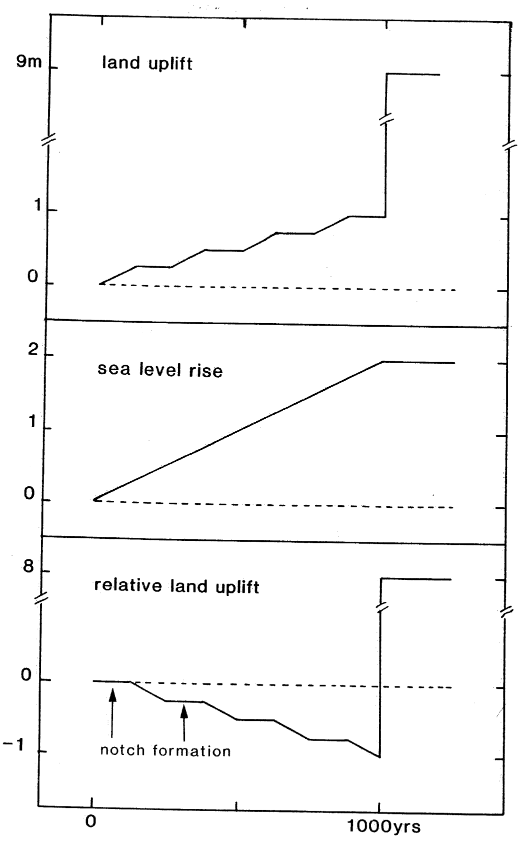

Fig. 8. A scenario for the explanation of the observed relative sea level changes in West Crete, based on the hypothesis of a constantly rising sea-level and an intermittently rising land. Four notches are formed during periods of relative sea level stability (land and sea level are both rising with the same rate), but during periods of no land uplift, the uppermost notch is submerged. Notches shown with an average spacing of 25 cm and 250 years, values similar to those in Crete.

Neither of these two endpoint hypotheses can explain the observed sea level changes: the first hypothesis (fig. 8) requires an unrealistic amplitude of sea level rise in the period 4000-1500 B.P. (5 m for 2500 years or 2 m every 1000 years), and it implies a complicated pattern of tectonic motions for which there is no easy reasonable explanation.

The second hypothesis also requires an unrealistic amplitude of sea level rise (2.5 m in 2500 years, or 1 m in 1000 years), and a pattern of sea level rise (fig. 9) for which no explanation can be proposed. Furthermore, both hypotheses assume a gradual, and not a rapid subsidence of the notches, and this is at variance with the notch profiles indicating rapid subsidences (fig. 5; Pirazzoli, 1986b; Pirazzoli *et al.*, 1996b). Consequently, both these two endpoint hypotheses, as well as any other combination between them should be excluded as a possible interpretation for the pattern of observed relative sea level changes in West Crete. Hence, we may conclude that the latter, as shown in fig. 6, primarily reflect tectonic movements. Since these movements were rapid, they conspicuously reflect palaeoseismic events.

2.5. *Individual seismic uplifts or overlapping uplifted segments?*

As has been mentioned above, notches in West Crete are discontinuous, and only some of them can be observed in each site. Further-

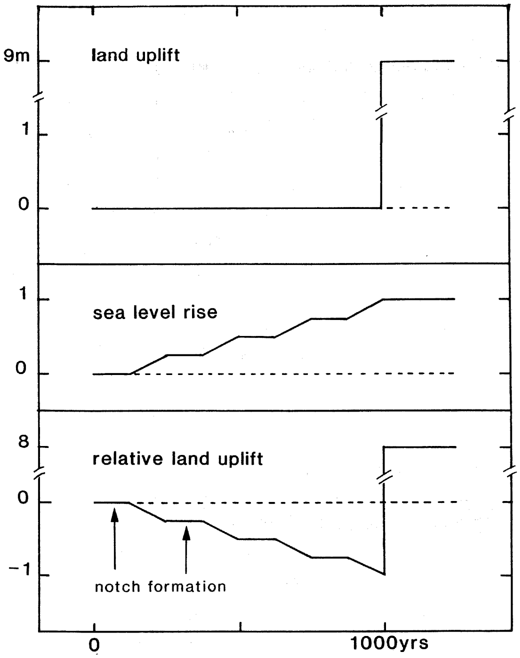

Fig. 9. A second scenario for the explanation of the uplift history of West Crete, based on the hypothesis of no land uplift and an intermittently rising sea level in the period of formation of four hypothetical notches.

more, since datable material can only rarely be identified, the available radiocarbon datings do not determine the precise uplift history of each coastal segment. Yet, based on geomorphological and biological criteria, a correlation between raised shorelines was made, and was confirmed by radiocarbon datings (Pirazzoli *et al.*, 1982, 1996a).

Hence, within the accuracy of numerous, carefully made radiocarbon analyses, the observed uplifted coastal segments seem to correspond to a number of events that affected the whole study area; this indicates that the possibility of each coastal segment having a different uplift history, and some of the observed fossil shorelines reflecting overlapping adjacent segments of uplifted shorelines should be rejected.

3. Palaeoseismic implications

The evidence discussed above indicates that tectonic motions responsible for the observed relative sea level changes in SW Crete were rapid, most likely seismic. Fossil shorelines in this part of the island can therefore be regarded as a record of at least 11 successive palaeoseismic events. Most of the latter were associated with small-amplitude vertical motions, 25 cm of coastal subsidence on the average, and seem to have affected only the southwestern part of the island, as well as the adjacent Antikythira island. The palaeoseismic event at around 1550 B.P., on the contrary, was associated with uplift with an amplitude varying between 0-9 m (fig. 3). This last event seems to correlate with seismic destruction observed in several archaeological sites in Crete in *ca.* A.D. 360 and some vague historical reports of a great earthquake in A.D. 365; it also correlates with events associated with coastal uplifts in an East Mediterranean-wide scale (Pirazzoli, 1986a; Pirazzoli *et al.*, 1996a).

The palaeoseismic events in Crete can therefore be divided into two different groups. A group of earthquakes producing relatively small subsidence was followed by a strong earthquake producing uplift and tilting, while subsequently, no earthquake producing coastal changes occurred. This seismic history is remarkable, and it recalls the theory of the earthquake cycle first documented by Fedotov (1968) for the great trench earthquakes in the western Pacific: a great earthquake is followed by a period of seismic quiescence, and then by a period of increased seismic activity to the time of the next great earthquake. Yet, the case of Crete is even more remarkable, as will be explained in the following.

4. Discussion

4.1. *The earthquake cycle in Crete and elsewhere*

Studies in different (plate boundaries-intraplate) environments reveal that if the source of stress is constant, the process of strain buildup and release through earthquakes is cyclic and repetitive, and is usually described as the *earthquake cycle.* Each individual cycle is associated with relatively small crustal deformations (fault offsets in a strike slip fault, coastal uplift in the vicinity of a trench, etc.; Shimazaki and Nakata, 1980; Thatcher, 1984; Schwarz and Coppersmith, 1984; Wallace, 1987) which accumulate after each earthquake to create geological structures (*e.g.*, Valensise and Ward, 1991).

According to one of the simplest and most popular models, major faults slip either at regular time intervals, or during clusterings of earthquakes separated by relatively long intervals of seismic quiescence (fig. 1). The basic characteristics of all these models are first, that the short-term deformation rate (rate between two successive major events, or clusterings of events) is constant and equal to the long-term deformation rate. Second, at any specific point seismic deformation is uni-directional (*e.g.*, always uplift).

For instance, in the *characteristic earthquake model*, originally developed in the San Andreas and the Wasatch Faults in the USA, at a point the amount of displacement during successive surface faulting earthquakes remains essentially constant (Schwarz and Coppersmith, 1984); in the *time-predictable model*, originally developed from observations of repeated coastal uplifts in Japan, the amount of vertical uplifts in each earthquake tends to correlate with the time that subsequently elapsed until the next event (Shimazaki and Nakata, 1980).

The uplift history of Crete discussed above (fig. 6) is certainly different from that described by the models of fig. 1 in two aspects.

First, it involves earthquakes that produce both seismic uplifts and subsidences.

Second, uplift rates are not constant: between 4000 B.P. and 1500 B.P. the trend differs from that after 1500 B.P., or the trend since 4000 B.P. (see fig. 6).

Certainly, the deformation pattern associated with earthquake cycles in single intraplate faults is rather simple, while near major trenches it is more complex; factors influencing it vary spatially and observations of slip are necessarily indirect. Consequently, in such cases, departure from the idealized behaviour sketched in fig. 1 is not atypical (Thatcher, 1984).

In the case of West Crete, however, the available data certainly do not permit a reconstruction of each earthquake cycle with much detail, but record the permanent deformation associated with each of the twelve seismic events. It is therefore clear that the case of Crete cannot be regarded as an «atypical departure from an idealized model», but a particular behaviour.

4.2. *Possible explanations*

The basic assumption for the idealized behaviour earthquake cycle of fig. 1 is that the rate of application and source of stress is constant. The deviation of West Crete from this idealized behaviour may therefore indicate that this assumption may not be valid. In an area with a complicated tectonic fabric and history such as Crete, this may be a possibility.

Another alternative explanation is that major thrusting events producing up to 9 m uplifts have long recurrence intervals, but during the interseismic (or better the preseismic) period, smaller earthquakes, reflecting internal deformation of the hanging wall (*i.e.*, the uplifting block) of the major thrust zone may produce small stepped subsidences (compare with Fedotov, 1968; Savage and Prescott, 1978).

A third alternative is that the observed pattern of uplift reflects the superimposition of two different earthquake cycles (see Savage and Prescott, 1978). Slip on a thrust fault results in uplift of its hanging wall and subsidence of its footwall. If a second parallel and homothetic thrust cutting through the hanging wall of this first fault moves, some subsidence is expected at the area that was uplifted during the first earthquake. This hypothesis, however, requires a clustering of earthquakes at one fault, separated by a rather long quiescence interval, the beginning of which coincides with the reactivation of a second, major fault.

However, for lack of data, all the above possible explanations for the particularities of the uplift history of Crete are only speculations.

4.3. *Parallels for the uplift of Crete*

The remaining question is: is the case of SW Crete unique, or do there exist other cases of seismic deformation, not consistent with the models of fig. 1? It is true that to date, no such information exists in the literature. Recently, however, K. Sieh *et al.*, based on the study of growth of corals, documented stepped uplifts and subsidences in Sipora Island (Sumatra, Indonesia) in a period of 200 years (K. Sieh, oral presentation, 1995).

It is therefore likely that the sequence of uplifts and subsidences in Crete, testifying to an unusual pattern of earthquake cycle in Greece, or simply of Crete, may not be a privilege of this area at all. For instance, the uplifted and submerged notches in the NE coast of Euboea, central Greece (Stiros *et al.*, 1992) may testify to a similar, still rather unexplained and complicated tectonic situation.

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REFERENCES

ANGELIER, J. (1979): Néotectonique de l'arc égéen, *Soc. Géol Nord*, Publ., No. 3, p. 418.

CHAPPELL, J. and H. POLACH (1991): Post-glacial sea-level rise from a coral record at Huon Peninsula, Papua, New Guinea, *Nature*, **349**, 147-149.

FEDOTOV, S. (1968): The seismic cycle, quantitative seismic zoning and long-term seismic forecasting, in *Seismic Zoning of the USSR*, edited by S. MEDVEDEV, (Nauka, Moscow).

FLEMMING, N. (1978): Holocene eustatic changes and coastal tectonics in the Northeast Mediterranean: implications for models of crustal consumption, *Trans. R. Soc. London*, **A 289**, 405-458.

HAFEMANN, D. (1965): Die Niveauveränderungen an den Küsten Kretas seit dem Altertum nebst einigen Bemerkungen über ältere Strandbildungen auf Westkreta, *Akad. Wiss. Lit. Mainz, Abh. Math.-Naturwiss. Klasse*, **12**, 607-688.

HUCHON, P., N. LYBERIS, J. ANGELIER, X. LE PICHON and V. RENARD (1982): Tectonics of the Hellenic trench: a synthesis of sea-beam and submersible observations, *Tectonophysics*, **86**, 69-112.

KELLETAT, D. (1991): The 1550 B.P. tectonic event in the Eastern Mediterranean as a basis for assessing the intensity of shore processes, *Z. Geomorphol. N.F. Suppl.*, **81**, 181-194.

KERAUDREN, B. (1971): Le Quaternaire marin de la Grèce, *Phd. Thesis*, University of Paris.

KERAUDREN, B. (1979): Le Plio-Pléistocène marin et oligohalin en Grèce: stratigraphie et paléogéographie, *Rev. Géol. Dyn. Géogr. Phys.*, **21**, 17-28.

LAJOIE, K. (1986): Coastal tectonics, in *Active Tectonics*, National Academic Press, 95-124.

OTA, Y., J. CHAPPELL, R. KELLEY, N. YONEKURA, E. MATSUMOTO, T. NISHIMURA and J. HEAD (1993): Holocene coral reef terraces and coseismic uplift of Huon Peninsula, Papua, New Guinea, *Quat. Res.*, **40**, 177-188.

PIRAZZOLI, P. (1986a): The Early Byzantine tectonic paroxysm, *Z. Geomorph. N.F. Suppl.*, **62**, 31-49.

PIRAZZOLI, P. (1986b): Marine notches, in *Sea-level Research: a Manual for the Collection and Evaluation of Data*, edited by O. VAN DER PLASSCHE (GeoBooks, Norwich), 361-399.

PIRAZZOLI, P., J. THOMMERET, Y. THOMMERET, J. LABOREL and L. MONTAGIONNI (1982): Crustal block movements from Holocene shorelines: Crete and Antikythira (Greece), *Tectonophysics*, **68**, 27-43.

PIRAZZOLI, P., L. MONTAGGIONI, J. SALIEGE, G. SEGONZAC, Y. THOMMERET and C. VERGNAUD-GRAZZINI (1989): Crustal block movements from Holocene shorelines: Rhodes Island (Greece), *Tectonophysics*, **170**, 89-114.

PIRAZZOLI, P., J. AUSSEIL-BADIE, P. GIRESSE, E. HADJIDAKI and M. ARNOLD (1992): Historical environmental changes at Phalasarna harbour, West Crete, *Geoarchaeology*, **7**, 371-392.

PIRAZZOLI, P., J. LABOREL and S. STIROS (1996a): Earthquake clustering in the Eastern Mediterranean during historical times, *J. Geophys. Res.*, **101** (B3), 6083-6097.

PIRAZZOLI, P., J. LABOREL and S. STIROS (1996b): Coastal indicators of rapid uplift and subsidence: examples from Crete and other Eastern Mediterranean sites, *Z. Geomorphol. Suppl.*, Bd. **102**, 21-35.

RAULIN, V. (1869): *Description Physique et Naturelle de l'Île de Crète* (A. Bertrand, Paris).

SAVAGE, J. and W. PRESCOTT (1978): Asthenosphere readjustment and the earthquake cycle, *J. Geophys. Res.*, **83**, 3369-3376.

SCHWARZ, D. and K. COPPERSMITH (1984): Fault behaviour and characteristic earthquakes: examples from the Wasatch and San Andreas Fault zones, *J. Geophys. Res.*, **89**, 5681-5698.

SHIMAZAKI, K. and T. NAKATA (1980): Time predictable recurrence model for large earthquakes, *Geophys. Res. Lett.*, **7**, 279-282.

SPRATT, T.A.B. (1865): *Travels and Researches in Crete* (J. van Voorst, London).

STIROS, S., M. ARNOLD, P. PIRAZZOLI, J. LABOREL, F. LABOREL and S. PAPAGEORGIOU (1992): Historical coseismic uplift on Euboea Island, Greece, *Earth Planet. Sci. Lett.*, **108**, 109-117.

TAYMAZ, T., J. JACKSON and R. WESTAWAY (1990): Earthquake mechanisms in the Hellenic Trench near Crete, *Geophys. J. Int.*, **102**, 695-731.

THATCHER, W. (1984). The earthquake deformation cycle, recurrence and the time predictable model, *J. Geophys. Res.*, **89**, 5674-5680.

THOMMERET, Y., Y. THOMMERET, J. LABOREL, L. MONTAGGIONI and P. PIRAZZOLI (1981): Late Holocene shoreline changes and seismotectonic displacements in western Crete (Greece), *Z. Geomorph. Suppl.*, **40**, 127-149.

VALENSISE, G. and S. WARD (1991): Long-term uplift of the Santa Cruz coastline in response to repeated earthquakes along the San Andeas Fault, *Bull. Seism. Soc. Am.*, **81**, 1694-1704.

VAN ANDEL, T. and J. SHACKLETON (1982): Late Paleolithic and Mesolithic coastlines of Greece and the Aegean, *J. Field Archeol.*, **9**, 445-454.

WALLACE, R. (1987): Grouping and migration of surface faulting and variations in slip rates on faults in the Great Basin province, *Bull. Seism. Soc. Am.*, **77**, 868-876.