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HOLOCENE COASTAL UPLIFT IN THE TAORMINA AREA, NORTHEASTERN SICILY: IMPLICATIONS FOR THE SOUTHERN PROLONGATION OF THE CALABRIAN SEISMOGENIC BELT

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Abstract—Elevated erosional notches and emergent marine deposits developed on limestone headlands along the Taormina coastline of northeastern Sicily testify to recent shoreline uplift. Although located at the southern prolongation of the Calabrian seismogenic belt, a zone of active extensional tectonics and rapid late Quaternary uplift, the study area lacks historical and instrumental evidence for significant earthquakes. A prominent notch level at an elevation of +4.5 and +5.0 m at Mazzaro and Capo Sant'Alessio, respectively, is dated by ^{14}C assay of associated marine boring molluscs (*Lithophaga*) to be coincident with the 5000 yr BP deceleration of global eustatic rise, the mid-Holocene quasi-stillstand. These first radiometric dates of Holocene emergence along the northeastern Sicily coast indicate time-averaged uplift rates of 1.1–1.8 mm/yr. Well-defined erosional notches postdating the mid-Holocene quasi-stillstand, however, imply coastal uplift was not gradual but instead involved occasional abrupt crustal movements, probably the result of large paleoseismic earthquakes along the coastal-bounding normal faults. The results support a need for a re-evaluation of the earthquake potential of the Sicilian sector of the Apenninic seismogenic belt. © 1997 Elsevier Science Ltd

INTRODUCTION

The Straits of Messina in southern Italy mark the mainland termination of a seismogenic belt located along and parallel to the Apenninic mountain chain. The belt, which has hosted numerous destructive earthquakes during historical times (Postpischl, 1985; Stucchi *et al.*, 1993; Guidoboni, 1994), comprises a segmented system of large normal faults accommodating 100°-directed regional extension (Fig. 1a) (Pantosti and Valensise, 1994). While considerable attention has been paid to the central and southern Apenninic sectors of the fault system (e.g. Pantosti *et al.*, 1993, 1996; Michetti *et al.*, 1996) and to its southwestward continuation into Calabria (e.g. Ghisetti, 1992; Tortorici *et al.*, 1986, 1995), the subsequent prolongation of this arcuate seismogenic belt into Sicily remains poorly understood. Some workers, for example, suggest that the belt continues to mimic the Apenninic trend by following normal faults along the northern shores of Sicily (e.g. Pantosti and Valensise, 1995), while others regard it as

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continuing south as the 'Siculo-Calabrian rift zone' (Monaco *et al.*, in press), bounding the eastern seaboard of Sicily and extending offshore as the Malta Escarpment (Tortorici *et al.*, 1986, 1995; Westaway, 1992; Mazzuoli *et al.*, 1995) (Fig. 1b).

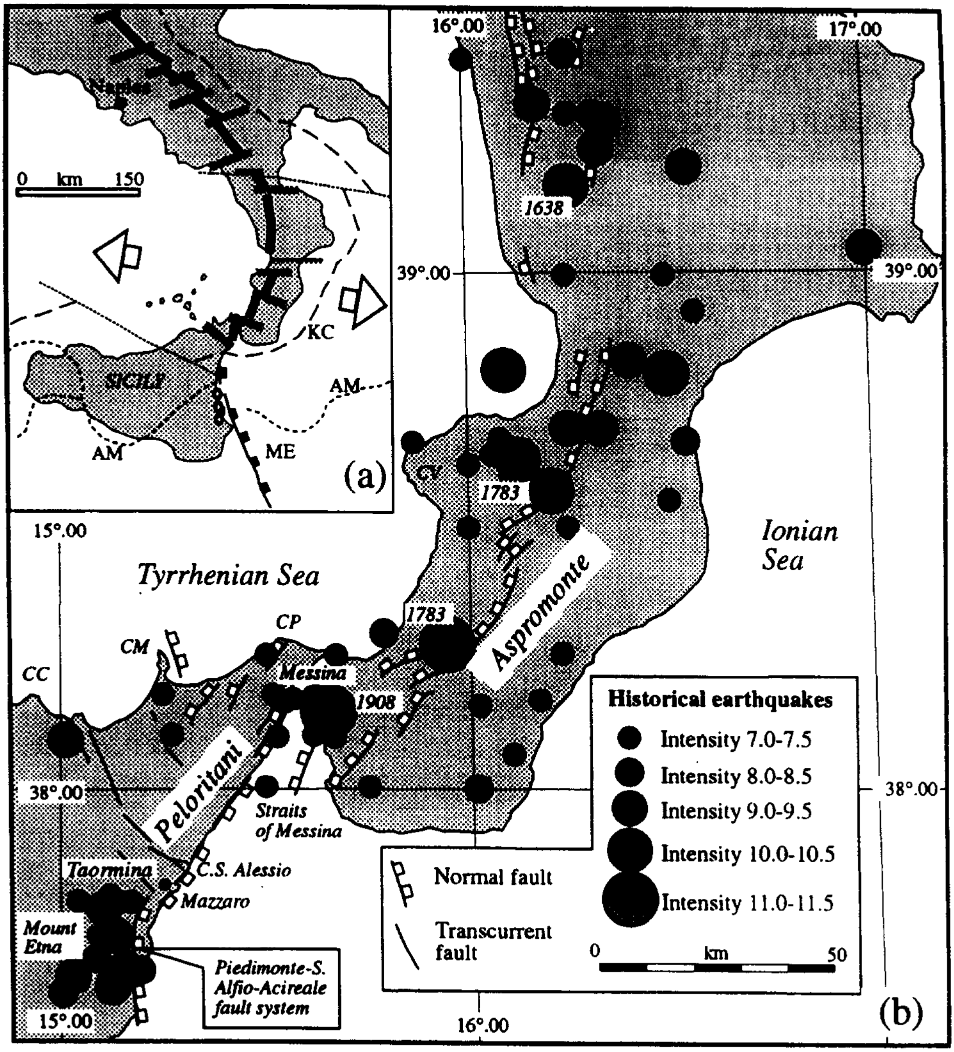

Fig. 1. (a) The regional tectonic framework of southern Italy; dashed lines represent the thrust fronts of the Apenninic-Maghrebian Chain (AM) and the Kabilo-Calabride (KC) chains which are cut by major transcurrent faults (dotted line); ME, Malta Escarpment (after Lentini *et al.*, 1995, Fig. 1). Thick lines denote normal-fault seismogenic zones within the Appeninic seismogenic belt which are segmented by weaker transverse structures (grey hatched bars) based on the scheme of Pantosti and Valensise (1995) (Fig. 4). Major normal faults in eastern Sicily shown by solid lines with solid box denoting downthrown side. Large open arrows show the direction of regional extension. (b) The seismotectonic setting of northeastern Sicily and western Calabria (modified from C.N.R.-P.F.G., 1987 and Tortorici *et al.*, 1995, Fig. 1), showing earthquake events between 1000 A.D. and 1980 A.D. based on the catalogue of Stucchi *et al.* (1993). CC, Capo Calavà; CP, Capo Peloro; CM, Capo Milazzo; CV, Capo Valentino.

These conflicting tectonic schemes pose contrasting seismotectonic implications for the heavily populated and urbanised coastal strip, here referred to as the Taormina coast, south of the zone affected by the 1908 (M=7) Straits of Messina earthquake, recently ascribed to reactivation of a low-angle, blind normal fault bounding the Sicilian coast (Ghisetti, 1992; Valensise and Pantosti, 1992). In one scheme, for example, the paucity of earthquakes south of the 1908 seismogenic zone reflects the switching of seismicity away from the Taormina coast, via a transcurrent fault system, to the northern Sicily seaboard where earthquakes are known from historical and archaeological records (Nikonov *et al.*, 1992; Pantosti and Valensise, 1995). Immediately south of Taormina, however, in the vicinity of Mount Etna, active fault movements and seismicity are associated with the Piedimonte–S. Alfio–Acireale normal fault zone (Fig. 1) (Stewart *et al.*, 1993; Monaco *et al.*, in press). Although here the shallow depth of seismicity and the widespread incidence of aseismic creep suggest that deformation is amplified by local volcano-tectonic or gravitational effects (Lo Giudice and Rasà, 1992; Rasà *et al.*, 1996), Monaco *et al.* (in press) have argued that the Etnean faults are important tectonic structures, being characterised by Late Pleistocene and Holocene slip rates equivalent to or greater than those reported along the central and southern Apenninic sectors of the belt. Moreover, the faults are linked directly with the offshore Malta Escarpment, which has been the possible site of important large historical earthquakes, most notably the destructive 1693 earthquakes which affected much of southeastern Sicily (Postpischl, 1985; Boschi *et al.*, 1995).

Determining whether the coast of Sicily south of the Straits of Messina is disconnected from the Apenninic seismogenic belt or is an area of anomalous seismic quiescence along an otherwise seismically active and through-going rift zone requires recourse to geological investigations in the Taormina sector. In this paper, we compare coastal uplift rates determined from radiocarbon dating of raised Holocene shoreline fauna along the Taormina coast with uplift rates for sections of the opposing Calabrian coast in the footwall of the seismogenic fault system. In addition, we use the detailed morphology of coastal sections to make inferences about whether coastal emergence in this part of northeastern Sicily was uniform or episodic.

COASTAL EVIDENCE FOR ACTIVE TECTONISM

Raised marine shorelines, extensively studied in the southern Italy area (Westaway (1993) and references therein), are valuable indicators of active tectonism because they are useful reference markers for detecting deformation and they generally provide deposits or fauna which permit deformation to be dated. Isolating the tectonic contribution to relative sea-level changes, however, requires a reliable understanding of background eustatic fluctuations. For the Holocene, the eustatic trend is reasonably well-constrained, with global sea-level rising rapidly in the early Holocene (due to ice-sheet melting) but decelerating sharply around 6000–5000 yr BP, after which there has been a slight sea-level rise (Fairbanks, 1989). Although some workers have proposed sea-levels higher than present during recent millennia for parts of the circum-Mediterranean coast (e.g. Flemming and Webb, 1986), the majority of sea-level studies in the region confirm the global tendency of rapidly rising sea-level up to a mid-Holocene quasi-stillstand followed by minimal change thereafter (Galili *et al.*, 1988; Pirazzoli, 1991; Dubar and Anthony, 1995). According to Miyauchi *et al.*, 1994, (p.20), for example, "no evidence of a sea level highstand higher than present is visible in the postglacial transgression around the southern Italian Peninsula". As a result, coasts in this region displaying emergent Holocene shorelines signify that net tectonic uplift has outpaced regional sea-level rise during this period.

Detailed surveys of fossil shorelines can also throw light on the nature of tectonic uplift along a coast. In particular, rapid or instantaneous emergence of a coastline during a large earthquake event can be revealed through a range of morphological and biological indicators (Laborel and Laborel-Deguen, 1994; Pirazzoli *et al.*, 1996). In the eastern Mediterranean Sea region, paleoseismic coastal indicators include well-defined tidal notches and *in situ* marine deposits which are preserved intact above the modern microtidal range where wave activity and bioerosion is concentrated (~ 0.5 m). Detailed measurement of the elevation of notches above modern mean sea-level biota (the 'biological mean sea-level' or BMSL — see Laborel and Laborel-Deguen, 1994), together with radiometric dating of associated marine deposits or shells, has elsewhere permitted chronologies of net coastal changes to be reconstructed and allowed calendar age ranges for discrete uplift events to be determined (e.g. Pirazzoli *et al.*, 1994; Stewart, 1996).

In this study, field surveys at two prominent coastal sites, here referred to as Mazzaro and Capo Sant'Alessio (Fig. 1), recorded the detailed form and elevation of tidal-notch levels (e.g. Pirazzoli, 1986) and collected samples of associated marine fauna for radiometric dating. Dating involved radiocarbon assay of a marine mollusc, *Lithophaga*, the upper limit of whose borings is a reliable marker of biological mean sea-level and whose elevated equivalent is often aligned with discrete notch levels. Samples of *Lithophaga* were mechanically cleaned and screened for contamination using X-ray diffraction. ^{14}C ages determined by Standard and Accelerator Mass Spectrometry (AMS) dating were calibrated based on the marine bicedal dataset in CALIB (Stuiver and Reimer, 1993), incorporating a reservoir effect of 320 years (Stiros *et al.*, 1992). Eustatic corrections were carried out based on the Holocene sea-level curve of Fairbanks (1989), a global eustatic curve broadly comparable to Mediterranean-based equivalents (Pirazzoli, 1991). The age data, together with the only previous radiometric date for this coast — a first-order ^{14}C age determination (Vita-Finzi, 1991) on a coral (*Cladocora caespitosa*) at Mazzaro (Firth *et al.*, 1996), are presented in Table 1.

Table 1. Conventional and Accelerator Mass Spectrometry (AMS) radiocarbon dates for *Lithophaga* samples collected from Mazzaro and Capo Sant'Alessio, listed alongside a first order ^{14}C age determination for a coral (*Cladocora caespitosa*) reported by Firth *et al.* (1996) from Mazzaro. Calibrated age after Stuiver and Reimer (1993), incorporating a reservoir effect of 320 years (Stiros *et al.*, 1992). Corrected elevation adds relative sea-level changes since the sample date, derived from the eustatic curve of Fairbanks (1989), to the present sample height above sea-level

Elevation (m)	^{14}C age (years $^{-1}$ BP)	Species	Lab No.*	$\delta^{13}C$ (‰)	Conventional ^{14}C age (years $^{-1}$ BP)	Calibrated age (cal years $^{-1}$ BP)	Corrected elevation (m)	Uplift rate (mm/yr)
Taormina								
3.4	4200±120	*C. caespitosa*	UCL-362	n.d.	4295±205	4288±528	6.7	>1.4
2.0	3000±210	*Lithophaga*	Beta-81859	3.2	3470±220	3238±510	4.3	1.15–1.6
1.5	5110±140	*Lithophaga*	Beta-81860	3.1	5570±150	5883±320	7.0	1.1–1.2
Capo Sant'Alessio								
4.9	4410±60	*Lithophaga*	Beta-81856*	3.3	4880±60	5058±190	9.0	1.7–1.8
4.5	4300±70	*Lithophaga*	Beta-81857*	3.8	4780±70	4995±210	8.5	1.6–1.75

*, AMS.

COASTAL ELEVATION CHANGES ALONG THE TAORMINA COAST

The Taormina coast of northeastern Sicily is flanked by the Peloritani Mountains, a sequence of stacked Hercynian crystalline thrust sheets and overlying Mesozoic–Cenozoic sedimentary units (Lentini *et al.*, 1995). The crystalline units are dominantly low and middle–high metamorphic-grade phyllites, micaschists and gneisses; Triassic to Paleogene carbonate units (limestones and dolomites) within the sedimentary cover crop out in the prominent coastal headlands of Mazzaro and Capo Sant'Alessio (Catalano *et al.*, 1995). According to Lentini *et al.* (1995), the Capo Sant'Alessio headland marks the eastern end of a NW-striking dextral fault system extending to Capo Calava on the north coast, interpreted by Pantosti and Valensise (1995) as a major transverse element within the Apenninic seismogenic belt. Despite the coastal sites lying outside the inferred Messina seismogenic zone, raised marine phenomena comparable to those described more widely from northern Sicily occur along the Taormina coast (Ottmann and Picard, 1954; Firth *et al.*, 1996).

Mazzaro

Immediately south of Giardini (Fig. 2), the coastline rises abruptly from a low-lying plain in the Etnean area into a steep, linear mountain front which extends north along the Taormina coast to the Messina area. This coastal escarpment, which is aligned with faults cutting the carbonate cover and metamorphic basement rocks, is planated at two broad structural levels in the Taormina area, both levels being capped in places by Pleistocene marine deposits. The hilltop town of Taormina is itself situated on a remnant of a c. 200 m high marine surface, while more extensive marine deposits lie at an elevation of 80–120 m. In addition to this evidence of late Pleistocene uplift, the limestone headlands of the Capo Sant'Andrea tectonic unit preserve evidence of more recent coastal changes. Thus at Mazzaro Bay and Isola Bella, steep limestone cliffs are incised by a well-defined, laterally continuous marine notch at ~+4.3–4.8 m above BMSL (Fig. 3a). Field surveys show that this notch is the highest and best developed of at least three distinct notch levels, with the others developed at elevations of +0.8 and +1.8 m above BMSL (Figs 2 and 3b). As illustrated in several notch profiles, the uppermost notch of this sequence corresponds to a composite feature, displaying a minor rock lip at +4.5 m above BMSL separating marked re-entrants at ~4.3 and ~4.8 m. The notch is associated with a band of *Lithophaga* borings at several localities but no *in situ* shells could be collected for dating.

A first-order ^{14}C age of 4295±205 yr BP was determined for a coral, *Cladocora caespitosa*, occupying a bench, +3.4 m above BMSL, in the floor of a broad rock overhang, the roof of which is incised by the double notch (Firth *et al.*, 1996). The broad depth range of the coral (0–50 m; Schiller, 1993) and its uncertain relation with the higher notch make it an unreliable paleosea-level marker, but the date places a maximum constraint on the timing of emergence. Of more use, however, is an age of 3470±220 yr BP determined for *Lithophaga* shells occupying surface borings in a prominent reef lip at +2.0 m, immediately below which is the +1.8 m high notch level developed on most cliff profiles (Figs 3b and 4). The age provides an upper age limit to the timing of notch development and its subsequent emergence. *Lithophaga* collected from an elevation 1.5 m above BMSL were dated at 5570±150 yr BP, providing a minimum estimate of relative sea-level fall. No datable elevated littoral fauna could be found in association with the lowest notch level, 0.8 m above BMSL.

In addition to indications of Holocene coastal emergence, the limestone headland of Capo Sant'Andrea preserves evidence of recent reactivation of an offshore fault. Here, a carbonate algal reef draping the northeastern face of the headland is cut by a series of minor normal faults.

The reef itself appears to have developed on a boulder field in the immediate hangingwall of an eroded limestone fault scarp, but both scarp and reef now lie uplifted and emergent in the footwall of the active fault plane, which is presumably immediately offshore. The strike of the minor faults, exposed vertically and horizontally for several metres to a few tens of metres, ranges between NNW–SSE and NNE–SSW, but all dip at roughly 45° eastward. Thus their trend is intermediate between that of the main coastal-bounding normal faults and the limestone headlands themselves. The reef carapace itself is incised by, and therefore predates, the +4.3–4.8 m high double-notch. A recent (Holocene?) age for surface faulting is inferred from the observation that one fault plane cutting the reef is associated with a metre-scale scarp which remains well preserved even though immediately above present-day sea-level.

Capo Sant'Alessio

The headland of Capo Sant'Alessio, 7 km northeast of Taormina, comprises a sequence of carbonate and metamorphic thrust slices, cut and bounded by prominent NW-striking normal

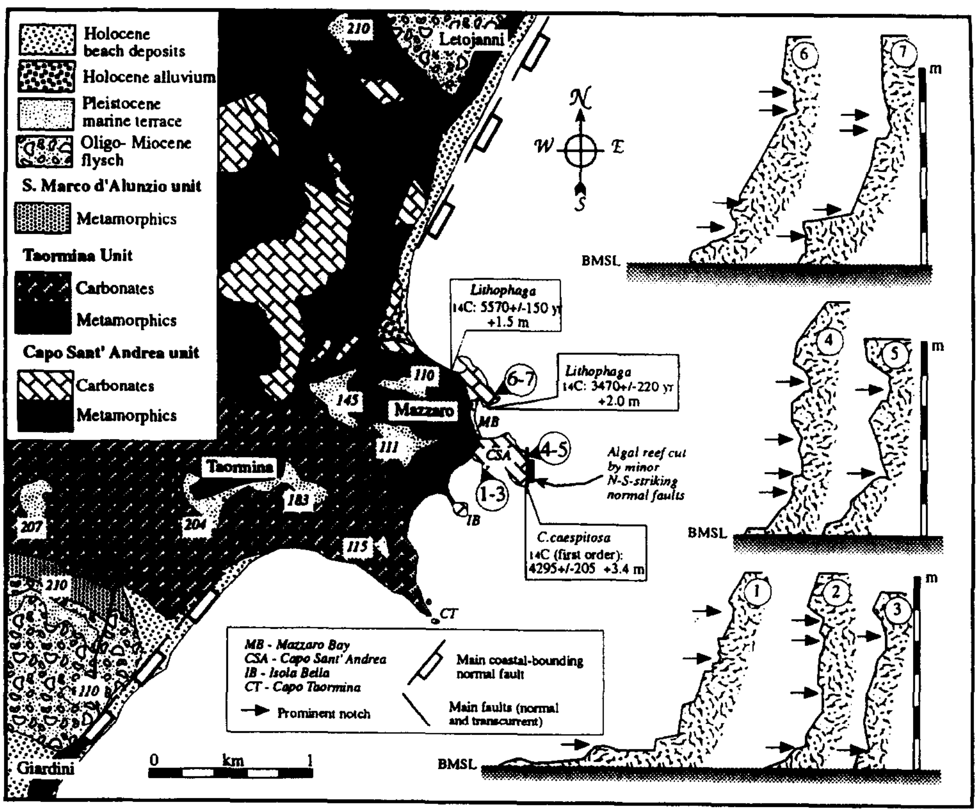

Fig. 2. Geology of the Taormina headland (simplified from Carbone *et al.*, 1994) (left) shown alongside coastal profiles surveyed in the Mazzaro area (right). Italicised numbers are elevation in metres of topographic spot heights, while circled numbers are locations of measurement stations for the corresponding coastal profiles (numbered on right). Note: the vertical and horizontal scale for the coastal profiles are the same. BMSL, Biological Mean Sea Level.

and transcurrent faults (Fig. 4) (Lentini *et al.*, 1995). Locally, however, NE-striking faults appear to be important, fragmenting the headland into a series of sharp, linear embayments and controlling the form of its eastern face. A distinct marine notch, ~+5.0 m above BMSL, can be found on near-vertical limestone cliffs on the southern, eastern and northern sides of the headland, though access is only possible to the northern and southern parts (Fig. 3c). The elevation of the notch above BMSL varies from +4.5–5.5 m (Fig. 4), generally being lower in more sheltered positions, but again in several places detailed observation shows that the main notch corresponds to a double incision with re-entrants spaced ~0.5 m apart. On both the northern and southern parts of the headland, a well-defined upper limit of *Lithophaga* perforations corresponds precisely to the elevation of the notch level (Fig. 3c). Samples of

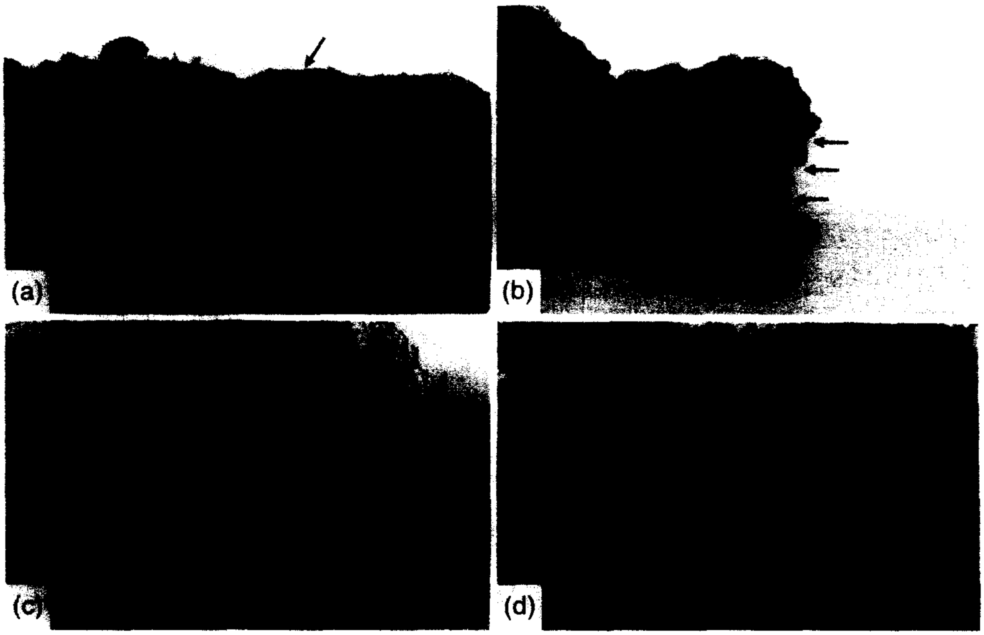

Fig. 3. (a) General view looking westward towards the Capo Sant'Andrea headland at Mazzaro where a well-defined notch is developed in the limestone bedrock at an elevation of +4.5 m. The arrow shows a higher planation surface at *c.* 100 m. (b) View of the limestone sea-cliff at Mazzaro Bay showing a sequence of well-defined notches (arrows). The uppermost notch (+4.5 m) is the most obvious but lower notches are also apparent. Patchy remnants of an indurated carbonate reef deposit (r) at an elevation of 2.0–2.5 m and apparently undercut by a +1.8-m high notch were radiocarbon dated at ~3230±510 yr BP on the basis of *in situ Lithophaga*. (c) General view of the +5.0-m notch developed on the southern side of the Capo Sant'Alessio limestone headland. *Lithophaga* collected from the uppermost level of borings (l) at an elevation of +4.5 m at this site yielded a conventional ^{14}C age range of 4780±70 yr BP. A comparable age of 4880±60 yr BP was obtained for *Lithophaga* at an elevation of +4.9 m on the north side of the headland. Lower notches are poorly developed at this cliff section, probably due to the burial of the lower part of the cliff under a previously more extensive indurated fanglomerate deposit (f). Figure shows approximate scale. (d) A limestone block located a few tens of metres in front of the Capo Sant'Alessio cliff section shown in (c) and preserving morphological evidence of two well-defined paleo-notches (1 and 2). The notches, at elevations of +0.8 and +1.8 m, retain well-defined roofs and floors indicating abrupt emergence consistent with coseismic coastal movements. The planated top of the block, at an elevation of +3.5 m, may represent a third prominent former sea-level. The cliff and fanglomerate deposit (f) shown in (c) are visible in the background. Figure shows approximate scale.

Lithophaga collected from the uppermost limit of borings at present-day elevations of +4.9 m and +4.6 m on the southern and northern sides, respectively, yielded similar AMS ages for this notch; 4880±60 yr BP on the southern side and 4780±70 yr BP on the northern side (Fig. 4 and Table 1).

Immediately below the upper notch on the northern side, a large algal reef carapace containing coral and *Lithophaga* fauna mantles the limestone cliff. The reef is absent on the southern side, where much of the cliff base is instead protected by remnants of an indurated conglomeratic fan. This reef and fan apron, together with the near-vertical attitude of the cliffs, make detailed profiling and measurement of the lower notches difficult. South of the main headland, however, large limestone blocks (1–10 m in size) shed from the adjacent cliffs are cut by clear-cut erosional notches at +0.5–0.9, +1.5–1.8 and, less distinct, at +2.2–2.3 m (Figs 3d and 4). The planated top of some blocks may correspond to a higher former sea-level now at +3.5 m, perhaps equivalent to the coral bench reported at Mazzaro. Although detailed profiles permit accurate determinations of the form and height of these levels, no datable material is associated with them.

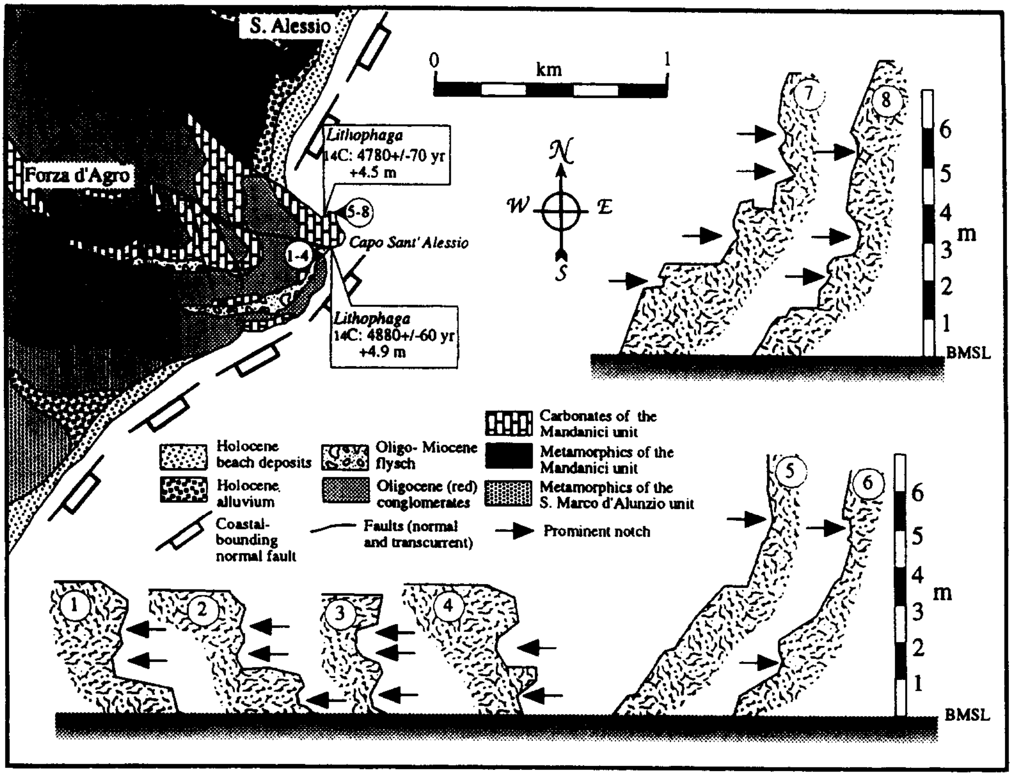

Fig. 4. Geology of the Capo Sant'Alessio headland (simplified from Carbone *et al.*, 1994) (left) shown alongside coastal profiles surveyed around the headland (right). Circled numbers are locations of measurement stations for the corresponding coastal profiles (numbered on right). Note: the vertical and horizontal scale for the coastal profiles are the same. BMSL, Biological Mean Sea Level.

HOLOCENE COASTAL UPLIFT RATES IN NORTHEASTERN SICILY

Notch sequences shown in Figs 2 and 4 demonstrate a broad similarity between coastal sections spaced less than 10 km apart. Inter- and intra-site variations in notch levels, where significant, are considered here to reflect profiling errors and contrasting positions on the headlands with respect to prevailing wind and wave directions. At both Mazzaro and Capo Sant'Alessio, the most prominent morphological feature is a well-defined double notch at ~+4.5 and +5.0 m. The similarity in form and elevation of these notches strongly suggest they conform to the same paleoshoreline, and thus the calibrated age of *c.* 5000 yr BP derived from ^{14}C dating of *Lithophaga* at Capo Sant'Alessio is here also assigned to the highest Mazzaro notch. This age, which effectively dates the abandonment of the notch by sea-level fall, is contemporaneous with the mid-Holocene switch from rapid to minimal sea-level rise (Dubar and Anthony, 1995), a short-lived period of relative sea-level stability during which well-defined erosional notches developed in other parts of the Mediterranean region (e.g. Pirazzoli *et al.*, 1991). Thus, the +4.5–5.0 m strandline recorded at Mazzaro and Capo Sant'Alessio is here interpreted as a shoreline corresponding to the mid-Holocene quasi-stillstand of *c.* 5000 yr BP. Corrected for global sea-level variations (Fairbanks, 1989), this elevated strandline indicates 7–9 m of uplift during the last 5000 years, an uplift rate of 1.6–1.8 mm/yr (Table 1).

The paucity of *Lithophaga* and other biota preserved in association with the lower notches at Mazzaro and Capo Sant'Alessio means that it is difficult to assign absolute ages to these shorelines. Nevertheless, the *c.* 3500 yr BP date determined from *Lithophaga* shells in a reef carapace undercut by the +1.8 m high notch at Mazzaro, serves as a useful maximum age for the inception of that intermediate notch. As with the higher shoreline, similarity with notch elevations and morphologies at Capo Sant'Alessio suggests that both the well-defined notches below +2.0 m at these two sites probably formed in the last 3500 years. Confirmation of this proposed shoreline chronology, however, awaits more extensive radiocarbon dating of the coastal sections, as well as U-series dating of corals collected from these localities. Regardless of the precise ages of specific paleoshorelines, however, the elevation of dated marine fauna above present-day sea-level can be used to establish time-averaged uplift rates for this part of northeastern Sicily (Table 1). The data indicate that mid–late Holocene uplift rates for the Mazzaro and Capo Sant'Alessio sites are comparable, falling in the range 1.1–1.8 mm/yr.

The elevations of raised Holocene shorelines along the Taormina coast are broadly consistent with equivalent features reported from the opposing Calabrian margin of the Straits of Messina, where Holocene strandlines lie within a few metres (typically +3.0–6.0 m) of present-day sea-level (Dumas *et al.*, 1987, 1993). In the absence of any radiometric dates on shoreline fauna or deposits, these features are generally correlated with the mid-Holocene transgressive maxima (~5000 yr BP) (e.g. Carobene and Dai Pra, 1991; Miyauchi *et al.*, 1994). Owing to the lack of Holocene data, however, uplift rates for the Calabrian margin have been based on late Pleistocene marine terrace sequences, largely correlated on the basis of stratigraphy and calibrated by reference to the oxygen-isotope record and some radiometric dating (e.g. Ghisetti, 1984; Dumas *et al.*, 1987, 1993; Carobene and Dai Pra, 1991; Westaway, 1993; Miyauchi *et al.*, 1994). The uplift rates for the Tyrhhenian coast of Calabria generally range between 1.5 and 3.5 mm/yr (Dumas *et al.*, 1993; Montenat *et al.*, 1991; Westaway, 1993), but the recognition by Westaway (1993) that much of the southern Italian Peninsula has experienced uplift of 1 mm/yr suggests that a strong regional uplift signal predominates. Nevertheless, higher uplift rates in the west coast of southern Calabria indicate that localised uplift in the footwall of active normal faults contributes an additional 0.67 mm/yr to regional upwarping (Westaway, 1993). The resulting uplift rate of 1.67 mm/yr is within the range of the Holocene uplift rates reported here for Sicily, but temporal variations in tectonism in many actively deforming coastal areas mean that Holocene uplift rates typically exceed equivalent late Pleistocene estimates (e.g. Pirazzoli *et al.*, 1994). Although the Pleistocene marine terraces at Taormina have not been studied, Late Pleistocene marine deposits found at Capo Milazzo and Capo Peloro at present-day elevations of 60 and 84 m, respectively (Hearty, 1986; Fois, 1990) and correlated with isotopic stage 5e (~125 ka) (Hearty, 1986), do indicate slower uplift rates (0.5–0.7 mm/yr). Closer to the study area, Westaway (1993) speculated that a sequence of marine terraces near Messina reflected a regional uplift component of 0.9 mm/yr, augmented by a >~0.2 mm/yr contribution from footwall uplift on the coastal-bounding normal fault. Thus, although directly equivalent comparisons are not possible, Holocene uplift rates for the footwall of coastal-bounding faults in the Taormina area are consistent with those determined from the footwalls of active faults in the Straits of Messina.

PALEOSEISMIC IMPLICATIONS

The pattern of notch development at both the Mazzaro and Capo Sant'Alessio sites indicates that gradual coastal uplift was disrupted by occasional abrupt emergence events. The composite-morphology of the mid-Holocene notch level, for example, suggests that notch development during this short-lived period of relative stability was interrupted by an increment of emergence which abruptly lowered the level of notch incision by ~0.5 m. More convincing evidence, however, is provided by the sharply defined notch levels at ~+0.8 and ~+1.8 elevations (Fig. 3d). Assuming the higher of these notches is equivalent to that incised into the 3500 yr old reef at Mazzaro, these notches developed during a period of minimal eustatic change and are therefore likely to represent abrupt emergence events consistent with those described from coseismic shoreline movements elsewhere in the circum-Mediterranean region (e.g. Laborel and Laborel-Deguen, 1994; Pirazzoli *et al.*, 1996). Although it is not possible to assign emergence to a specific seismogenic structure, it is most likely that these emergence events accompanied reactivation of coastal-bounding normal faults. Furthermore, the crude resolution of the coastal morphology and uplift chronology cannot constrain the number and timing of individual paleoseismic events. The observation that moderate- and large-magnitude normal-faulting earthquakes typically generate only a few decimetres of coastal uplift in the immediate footwall (Stewart and Vita-Finzi, 1996), suggests that the metre-scale spacing of notch levels at Mazzaro and Capo Sant'Alessio is unlikely to solely reflect repeated coseismic emergence. The extent to which the additional uplift component is partitioned between fault-localised coseismic and postseismic movements predicted by crustal modelling (e.g. King *et al.*, 1988; Ma and Kusznir, 1995) and field studies (Butler and Grasso, 1993), and broader regional geodynamics (e.g. Valensise and Pantosti, 1992; Westaway, 1993) remains unknown.

CONCLUSIONS

1. Emergent coastal phenomena, such as raised erosional notches and elevated marine fauna, indicate that the Taormina coast of northeastern Sicily has experienced mid–late Holocene uplift rates of 1.1–1.8 mm/yr. Such rates are comparable with Holocene and late Pleistocene uplift rates from the Calabrian margin of the Straits of Messina.
2. A useful marine strandline has been identified in the form of a prominent double-notch which has been dated at ~4800 yr BP by radiocarbon assay of associated marine fauna. The notch,

which is interpreted as the product of the mid-Holocene (*c.* 5000 yr BP) 'quasi-stillstand', is found at an elevation of ~+4.5 m at Mazzaro and ~+5.0 m at Capo Sant'Alessio. The recognition of proposed mid-Holocene shorelines at comparable elevations around parts of the Calabrian coast offers the possibility of utilising this strandline to reconstruct differential crustal movements at a regional scale during the Holocene.

3. The development of discrete shorelines testifies to abrupt vertical movements of the Taormina coast. Because the shoreline movements occurred during a period of minimal eustatic change, they are here interpreted as likely coseismic movements. Although the chronology and frequency of events cannot be determined from present data, at least two significant emergence events are considered to have occurred during the last 3500 years. It is likely, however, that cumulative coastal uplift along this coast was achieved by repeated coseismic movements superimposed on a general pattern of progressive marginal upwarping.
4. Coastal evidence that this fault segment has experienced abrupt emergence events during recent millenia suggests that a re-evaluation of the seismogenic potential of this southern prolongation of the Calabrian seismogenic belt is required. The anomalous absence of instrumental and historical seismicity in the Taormina-Capo Sant'Alessio zone contrasts with adjacent sectors of the Siculo-Calabrian rift zone, raising the possibility that this area is a prominent 'seismic gap'.

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