Holocene sea-level change in Sicily and its implications for tectonic models: new data from the Taormina area, northeast Sicily

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Abstract

The northeast coast of Sicily shows emergent marine features that have been uplifting during the Holocene along the footwalls of two major regional fault systems, the Malta Escarpment and Messina fault system. Previously, uplift rates were interpreted as up to about 1.8 mm/mm a⁻¹. New dates on shelly remains, collected close to sea-level, from the Taormina area north of Mount Etna, and amended sea-level curves, are used to show that uplift over the past 6000 years has been proceeding at a slower rate of about 1.4 mm a⁻¹. However, over a longer time period, from the Tyrrhenian Oxygen Isotope Stage 5.5 (about 125 ka) to the present day, the uplift rate has been yet slower, at about 1 mm a⁻¹. Northeast Sicily lies in a complex plate boundary region whereas, in contrast, the rest of Sicily appears to have been stable throughout the later Quaternary. Further comparisons show that the French Mediterranean coast [Lambeck, Bard (2000) Earth Planet. Sci. Lett., 175, 202–222] is a region of crustal stability, where movement is dominated by subsidence of the outer portion of the proglacial forebulge of the last glaciation. There the coastline has been progressively submerged during the Holocene, and sea level has never been higher than at present. Northeastern Sicily uplift is therefore more likely controlled by plate processes that mask most of the effects of glacio-hydro-isostatic adjustment.

Keywords: uplift; Quaternary; Holocene; sea-level change; Taormina; Sicily

1. Introduction

Sicily occupies a complex tectonic setting at the boundary of the European and African plates (Figs. 1 and 2), a situation reflected by active patterns of differential uplift and subsidence. In particular, the coastal region between Capo Peloro, on the north coast, and Catania, in the east, lies on the upthrown side of two regional-scale structures, the Malta Escarpment and the Messina fault system (Fig. 3). Uplifted marine terraces and notches document recent activity on
these structures, and general patterns have been interpreted by previous workers (Firth et al., 1996; Stewart et al., 1997; Monaco et al., 1997; Bordoni and Valensise, 1998; Rust and Kershaw, 2000). However, these results are based on a relatively small dataset, and can be usefully augmented by two additional sources of information: (1) comprehensive dating of uplifted organic remains to constrain uplift rates for different parts of the coast, and (2) information from below present sea level that is important in developing a complete picture of the relative sea-level changes in the Quaternary.

This paper is part of an ongoing study to refine and test previously published interpretations by selecting important sites where datable material is plentiful. Here we focus on a key section of the coastline, at Taormina, where several limestone promontories, on the upthrown side of the Messina fault system, record abundant evidence of sea-level change. The Taormina area (Fig. 4) is of particular interest because its coast-
line is: (1) composed of well-cemented limestones that form a suitable substrate for marine notch and terrace formation, indicators of former sea-level positions, and (2) colonised by a range of critical sea-level indicator organisms that have left datable remains. Thus the data presented in this study, together with recent sea-level curves (Alessio et al., 1998; Morhange et al., 2001), have allowed us to calculate the amended uplift rates for the region; the information is then discussed in relation to possible controlling models.

2. Previous work

A well-developed marine terrace is present throughout northeast Sicily, which has an inner margin that varies in altitude between 110 and 170 m above present sea level. This terrace is attributed to the Oxygen Isotope Stage (OIS) 5.5 highstand (also called the Tyrrhenian), due to the presence of *Strombus bubonius* (Bonfiglio, 1991). At Capo Peloro this distinctive fossil occurs at an altitude of 86 m. Other research on marine deposits and features in the Taormina
area at an altitude of 90–140 m also suggests correlation with OIS 5.5 (Bonfiglio and Violanti, 1983; Antonioli et al. (2002)). In the vicinity of Catania a terrace at 170 m was also related to OIS 5.5, taking into account the age of lava into which the terrace was carved (Monaco et al., 2000). Instead, south of Catania town the OIS 5.5 highstand shows its lowest altitude, reaching only 15 m in the Augusta area (Di Grande and Neri, 1988; Fig. 3). These observations and interpretations indicate differences in uplift rates from locality to locality along the coast.

Work on sea-level indicators (marine notches and dated shells) closer to modern sea level at a number of locations along the coastline (Firth et al., 1996; Stewart et al., 1997; Rust and Kershaw, 2000; Kershaw, 2000) shows that differential uplift has also operated in the Holocene. Examples are: Augusta on the Iblean block; Aci Trezza on early Etnean basalts adjacent to the Malta Escarpment; Taormina and Capo St. Alessio adjacent to the Messina fault system, and Capo Milazzo, a fault-bounded block on the north Sicily coast. Data from marine notches and organic rims, now uplifted to approximately 5 m above present sea level in the Taormina area, allowed uplift rates to be calculated, taking into account the sea level of the period considered from the calibrated dating, using the sea-level curve of Fairbanks (1989).

3. Taormina localities and dated materials

3.1. Objectives

The Mesozoic limestone promontory of Isola-bella lies NE from the centre of Taormina (Fig. 4), and is joined to the mainland by a small isthmus which is irregularly flooded by the sea (Fig. 5). Isola-bella consists of a central main island, together with several large limestone blocks (20—
30 m long and 10 m high). The main island and all the blocks show a prominent marine notch, located, as shown by Fig. 5, at essentially the same height above sea level throughout (about 4.7–4.9 ± 0.10 m). This notch was formed during a time when the rate of sea-level rise matched the rate of tectonic uplift, creating a period of sea-level stability sufficiently long for this prominent notch and its distinctive roof to be produced (Rust and Kershaw, 2000). The consistent height of the notch through all the blocks (Figs. 6 and 7) near site 4 (Fig. 4) provides confirmation that the blocks have not moved (relative to each other) in the last 5000 cal years BP. Sampling here was carried out on two different vermetid gastropod crusts, at 2.8 and 1.5 m, one *Lithophaga* shell at 2.1 m, and other shells forming part of an association from present sea level up to 1.5 m. The sampling site lies on the west side of Isolabella, close to the isthmus (Fig. 5). Information from this site is used here to recalculate Holocene uplift rates in this area with reduced margins of error, and in order to achieve this the following measures were undertaken:

1. Sampling and 14C dating of encrusting shelly fossils at levels between 0 and 3 m above present sea level.

2. Sketching and photographing the subsurface bedrock profile, with two purposes: (a) to provide a complete view of the notch profiles both above and below the surface (not done in previous studies of this area), and (b) to calculate the maximum error for fossils that are not limited to intertidal growth positions. At Isolabella the seafloor is a few metres beneath the water surface, in contrast to the steeply descending submarine cliff which lies a few tens of metres further offshore from the protected embayment in which Isolabella lies (Fig. 6). A large area of shallow water therefore extends from the shoreline seawards to the submarine escarpment of the Messina Fault on the outer edge of the bay, and provides a habitat suitable for the shallow marine biotas in the bay. However, that habitat does not exist in neighbouring locations where the sea cliff descends steeply into the water, so that the shallow seafloor provides a local maximum depth to which the biota can survive.
(3) In order to more precisely estimate the uplift rate, we have taken into consideration the sea-level curves published from Marseilles (France) and the Tyrhenian Sea (Italy) by Morhange et al. (2001) and Alessio et al. (1998), respectively.

3.2. Samples

The palaeontological content of the encrusting fauna was examined, confirming that most material is in place and that the amount of bioclastic debris is low. Between present sea level and +1.5 m, three samples of gastropods were obtained, which have evidently endured a considerable degree of wave abrasion. In the fossil beach a shell of *Bolma rugosa* was sampled and dated (Table 1), but some important ecological characteristics (such as species characteristic of the biocoenosis of a lower mesolittoral setting) are better seen in the unsampled material. The first gastropod present is *Osilinus turbinatus* (Born, 1780), a species characteristic of the biocoenosis of an inferior mesolittoral cliff subject to regular periods of immersion (RMI; Peres and Picard, 1964). A second gastropod is *Hesaplex trunculus* (Linné, 1758), a species occurring frequently with photophyl algae. This biocoenosis is still present and extends along the infrashoreline zone around the outcrops. Very close to the biocoenosis described above, at an altitude of 2.1 m, a *Lithophaga* in living position was sampled where large presently living specimens, and their borings, can also be found. At altitudes of 1.9 and 2.8 m, some metres landward of the Isolabella outcrops previously described (site 4; Figs. 4 and 5), vermetid ledges (Fig. 8), characteristic of lower intertidal environments, were also sampled. Here the fossiliferous association comprised species dominantly from intertidal to infralittoral zones.

3.3. Scuba-aided transects

All sampled locations at Isolabella have been further studied underwater (including the sites studied by Stewart et al., 1997), and interesting morphologies and deposits were observed.
Sketches of sea-floor features (Figs. 4 and 9), together with seabed profiles, provide an outline of the depth and morphology of the seabed. In fact, taking the maximum depth of the sea bottom immediately below the dated fossils allows us to assume that the fossils, when alive, had a maximum depth limit. This gives a maximum depth error for fossils that are not intertidal organisms.

Nearly all the transects (Fig. 9) cross zones that lack sand and gravel cover; therefore we assume there has been equal modification of the subsurface seafloor morphology over the last 5 ka in the areas of all transects.

In transect 1a (Figs. 4 and 9A) coastal subaerial erosion is illustrated, with formation of small isolated sea stacks (Fig. 10). An abrasion notch was recognised at −16 m, but no marine dissolution notches were identified.

Transect 1b (Figs. 4 and 9B), close to transect 1a, shows a large marine cave, probably developed on an exposed submarine fault plane.

Transects 2a–d (Figs. 4 and 9C) were measured immediately under the vertical submerged wall of the little promontory of Mazzaro; transect c is under the Lithophaga dated by Stewart et al. (1997). Bedrock morphology appears to be due to continuously active subsurface abrasion, with abrasion occurring at differing heights because of variations in abrasion and because the ledges which store abrasive material occur at different heights above the seafloor (Fig. 11).

Transect 3 (Figs. 4 and 9D) shows seafloor morphology and the presence of a few centimetres of sediment below the sampling point of Stewart et al. (1997). The maximum error of the Lithophaga is 2 m.

Transect 4 (Figs. 4 and 9E) is the location of samples collected for this study at Isolabella, where the maximum depth of the sea bottom (near the site of the dated shells) does not exceed 1 m, and the altitude of 5 ka marine notches lies between +4.7 and +4.8 m. During scuba dive re-
search we found living Lithophaga up to 3.12 m, and old encrusting faunas (Balanids) at 3.9 m (Fig. 12).

3.4. Sea-level curve

In order to study sea-level change in the study area during the last 5000 yr cal BP, we have used the sea-level curve of Morhange et al. (2001). In order to estimate the oldest sea level we have also used the Italian curve constructed by Alessio et al. (1998) which is based on dated serpulids, sampled on flooded speleothems, and archaeological data.

We argue that it is possible to use two different curves (Fig. 13) obtained in different areas, for the following reasons.

First, the surveying methodologies are similar, employing dated marine shells and archaeological remains from tecotonically stable zones; second, the analytical techniques and calibrations are the same (AMS 14C using Stuiver et al., 1998 calibration); and third, the rebound due to glacio-hydro-isostasy should be similar.

In a strict sense, any sea-level marker indicates a relative level, which can be different from the global eustatic sea-level, the difference being linked to glacio-hydro-isostasy (see Lambeck and Chappell, 2001 for a recent review). However, at mid-and low-latitude sites (so-called intermediate and far-field sites), the difference between global and local sea level is relatively small, on the order of several metres. Furthermore, these second-order effects can be evaluated using geophysical models. Recently, Lambek and Bard (2000, Fig. 10) showed that the isostatic of predicted sea-level in the western Mediterranean during the Last Glacial Maximum (LGM) is similar to that observed in the Caribbean (Pruzzo, 1991), allowing us to compare the two intermediate latitudes sites referred to the French Mediterranean coast, an area close to the Alassio et al. (1999) seafloor curve sites. In that particular, the glacio-sea-level curve for that area is typical of an intermediate location exhibiting a continuous rise throughout the Holocene.

Table 1

<table>
<thead>
<tr>
<th>Laboratory number</th>
<th>Fossil species</th>
<th>Elevation</th>
<th>Relative sea-level change</th>
<th>Maximum altitude sea bottom</th>
<th>Corrected elevation</th>
<th>Uncalibrated 14C age</th>
<th>Calibrated 14C uplift rate</th>
<th>Average of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) UCL-362</td>
<td>Cladocora</td>
<td>3.4</td>
<td>1.4</td>
<td>3.8</td>
<td>4.8-8.6</td>
<td>4295±120</td>
<td>4399±320</td>
<td>1.1-1.9</td>
</tr>
<tr>
<td>(2) B-81859</td>
<td>Lithophaga</td>
<td>2.0</td>
<td>1.1</td>
<td>7</td>
<td>3.1-10.1</td>
<td>3470±210</td>
<td>3331±510</td>
<td>0.9-3.0</td>
</tr>
<tr>
<td>(3) B-81859</td>
<td>Lithophaga</td>
<td>1.5</td>
<td>3</td>
<td>2</td>
<td>4.5-6.5</td>
<td>5570±150</td>
<td>5963±390</td>
<td>0.8-1.1</td>
</tr>
<tr>
<td>(4) GX 28038</td>
<td>Lithophaga</td>
<td>2.1</td>
<td>1</td>
<td>1</td>
<td>3.1-4.1</td>
<td>3160±50</td>
<td>2936±150</td>
<td>1.1-1.4</td>
</tr>
<tr>
<td>(5) GX 28039</td>
<td>Bolma rugosa</td>
<td>1.5</td>
<td>0.6</td>
<td>1</td>
<td>2.1-3.1</td>
<td>2500±50</td>
<td>2168±180</td>
<td>1.0-1.4</td>
</tr>
<tr>
<td>(6) GX 28040</td>
<td>Vermetid</td>
<td>2.8</td>
<td>0.6</td>
<td>0</td>
<td>3.4</td>
<td>2570±80</td>
<td>2229±150</td>
<td>1.5</td>
</tr>
<tr>
<td>(7) R-3540</td>
<td>Vermetid</td>
<td>1.9</td>
<td>0.5</td>
<td>0</td>
<td>2.4</td>
<td>203±62</td>
<td>179±160</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Samples 1–3 from Stewart et al. (1997) and samples 4–7 (this paper). The AMS 14C age determinations (samples 4-6) were provided by Geochron Laboratories, USA, and sample 7 by the Department of Physics, University of Rome. All samples were 14C corrected. A reservoir age of 400 years was added taking into consideration the paper by Siani et al. (2000) that reported values for Sicily (sample 24). Shells and transect sampling was carried out in September 1998.

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imum (LGM) has the same value at both Marseille (Morhange et al., 2001) and the Tyrrhenian Sea (Alessio et al., 1998), Argentario and Palinuro promontories (Fig. 1). These data give confidence in applying these curves to the Taormina area, rather than the Fairbanks (1989) curve used in previous studies. The result is that the calculated uplift rates are lower than those given by previous work of Firth et al. (1996), Stewart et al. (1997) and the later papers that applied those uplift rates (Kershaw, 2000; Rust and Kershaw, 2000).

3.5. Results

The four dated samples from Isolabella are shown in Table 1, together with previously determined dates from Stewart et al. (1997). The data show corrected altitude and calibrated ages (Stuiver et al., 1998, Calib. 4) of the old and new samples. The altitude was corrected, firstly, using the Italian and French sea-level curve, and, secondly, giving the data a maximum error for the non-intertidal fossils, in fact the scuba-aided transects allow us to give uplift errors for the $^{14}$C ages of the fossils. The discovery and dating of important intertidal biological markers such as vermetids (Dendropoma) constrain the error on sea-level change. All measurements of notches and fossils are referred to the top of the living coralline algal rim at tidal level. Note that the maximum range of the semidiurnal tide at Taormina is 0.3 m. The depth of all submerged features and samples collected is measured to present sea level, determined with a digital depth gauge (typical error ±0.1 m).

4. Discussion

4.1. Eustatic rise, isostatic rebound and uplift rate calculation

The altitude at which our fossil shells and
Fig. 9. (A–E). Underwater profiles of the areas sampled in this study, showing the seabed below the water surface. This local seabed constrains the maximum depth at which the encrusting fauna could develop in this area, which is important in defining the limits of sea level, discussed in the text. Note that at some sites submarine notches have been identified, representing abrasion notches and therefore not indicators of former sea-level positions. These profiles (see Fig. 4 for location) show the importance of obtaining morphological information from beneath, as well as from above, the water surface at these locations. Horizontal scale is the same as the vertical scale.
notches were observed and sampled is the summary of the eustatic component due to ice melting, glacio-hydro-isostatic rebound due to isostatic adjustment, and tectonic component. We know the present altitude of our sampled fossil beach and, with the aim to obtain the tectonic uplift, we compared this with an observed sea-level curve. Note that the tectonic component includes all non-glacio-hydro-isostatic and non-eustatic effects. The tectonic component therefore could be a combination of some or all of the following: uplift, subsidence by sediment loading,
crustal displacement by subduction, and any other effect. Thus, the difference between the sum of eustasy and isostasy, and the observed value, is then the tectonic signal. For the tectonic uplift rate values, it is of crucial importance to refer to a sea-level curve including isostasy values presumably similar to the site studied.

Previous studies calculated tectonic uplift rates by comparing the data with Fairbanks’ (1989) sea-level curve. In this paper, however, the Stewart et al. (1997) altitude data (Table 1) were corrected using the sea-level curves of Morhange et al. (2001) and Alessio et al. (1998). In addition, we take into consideration the error bars due to the imprecision related to the ecology of the non-infralittoral species (Lithophaga, for example, that actually lives in the Mediterranean from 0 to -20 m). Our new methodology (which includes an outline of the depth and morphology of the seabed), taking the maximum depth of the sea bottom immediately below the dated fossils, allowed us to assume that the fossils, when alive, had a maximum depth limit within Mazzaro Bay. This gives a maximum depth error for fossils that are not intertidal organisms (Bolma rugosa, Cladocora, Lithophaga; see Table 1). In this case we calculated an uplift maximum and minimum range.

Samples 5 and 6 of Table 1 consist of the Vermetid Dendropoma (an intertidal organism; Laborel et al., 1994; Antonioli et al., 1999) so do not need altitude correction. The uplift rates that we obtained (1.4/1.5 mm a\(^{-1}\); Table 1) were the same as those corrected by depth measurement of Stewart’s samples (1.46 mm a\(^{-1}\); Table 1). So, in this way, our new methodology was tested, reinforcing our view that the methodology applied is correct. Based on this approach, we estimate an uplift average of about 1.4 mm a\(^{-1}\) for the last 2500 cal yr BP (columns 6 and 7 in Table 1).

In the Mediterranean area the amount of work on relative sea-level change is limited. However, discussion and mathematical modelling of crustal behaviour by several authors (Lambeck and Johnston, 1995; Peltier, 1996; Pirazzoli et al., 1997; Lambeck and Bard, 2000), indicate that if sea-level change and isostatic rebound can be modelled, then an assessment of the influence of tectonic movements should be obtainable. Moreover, prediction of relative sea-level change in specific areas may be more accurate. Pirazzoli et al. (1997) report predicted sea-level data from work by Peltier and Lambeck for 2000 and 6000 yr BP (uncalibrated) for south Italy. Thus, the total predicted sea-level change (glacio-hydro-isostasy) gives a positive relative sea-level change, for Reggio Calabria town (Fig. 1; 50 km north of Taormina) of about 6.5 m for Lambeck and 4.5 m for Peltier for the last 6000 uncalibrated yr BP (6380 cal yr BP); see data in Pirazzoli et al. (1997). The predicted sea-level effect gives a relative sea-level rise and consequently relative crustal subsidence that is smallest near the Alps, and greater in south
Italy (about 3 m in the north Adriatic Sea and about 6 m in the south Tyrrenian, for the last 6000 years). We prefer to use the data of the curves of Morhange et al. (2001), and Alessio et al. (1998), rather than those predicted from Peltier and Lambeck (Pirazzoli et al., 1997); in fact, the first was effectively measured and recently published, whereas the second ones are foretold from models calculated 8 years ago. From predictions by Lambeck, the uplift rates would have been higher (approximately 1.7 mm a$^{-1}$). Our new data (using Dendropoma) provide an uplift rate that falls within the range of Stewart et al. (1997), thereby demonstrating that application of our new methodology to sea-level-sensitive species yields results that are consistent with other work. Thus, the data presented in this paper show that the uplift rates are robust results.

Fig. 10. Subsurface views of the coastline at Isolabella. View near Capo St. Andrea at a depth of $-3$ m, subaerial morphology is clearly shown.
4.2. Older uplift rates in the context of Quaternary glaciation cyclicity

With regard to the relative sea-level uplift rates during earlier times, it is possible to estimate these for the Tyrrhenian OIS 5.5 (approximately 125 ka BP), based on the altitude and age (using ESR methodology; Antonioli et al., submitted) of the terrace inner margin immediately below the town of Taormina. This terrace lies at about 115 m above modern sea level and, since the level of the Tyrrhenian Sea was close to that of the present day, it indicates an average of about 0.9 mm a\(^{-1}\) uplift since OIS 5.5.

Information for older periods is lacking in the Taormina area. However, Catalano and Di Stefano (1997) showed that the Naso terrace sequence in the north Sicilian coastal zone (Fig. 3) had a similar tectonic uplift rate because the OIS 5.5 terrace is also at an altitude of 130 m. On the oldest terrace of this sequence, at an altitude of 550 m, there are outcrops of clay and sand of Middle Pleistocene age and, on the basis of foraminifera, this terrace was related by those authors to an age of 650 ka, giving an uplift rate of about 0.9 mm a\(^{-1}\). Based on these data and calculations, we consider that the uplift rates in northeastern Sicily were relatively uniform (with the exception of the Catania area, where OIS 5.5 shows an uplift rate of 1.7 mm a\(^{-1}\)) through the Quaternary at approximately 0.9–1 mm a\(^{-1}\), but accelerated to about 1.4 mm a\(^{-1}\) over the last 6000 yr BP.
Because the Quaternary glaciations operated in cycles, it is interesting to speculate on how uplift rates might be related to glacial cycles. It is possible that the rate of 1.4 mm a$^{-1}$, slightly higher than the average 1 mm a$^{-1}$ rate for the last 125 ka, represents the highest uplift rate operating over recent times, and may be higher than the rate during the previous warm stage.

We know relatively well the timing and duration of the past interglacial periods thanks to the so-called SPECMAP curve (Imbrie et al., 1984) or other specific examples (Stirling et al., 1998; Zhao et al., 2001). However, the chronology of the warm oxygen-isotope record compiled from measurements on fossil foraminifera is tuned to maximise the expression of orbital frequencies and depends on several theoretical assumptions and simplifications. However, we wish to stress that, because Holocene sea level is still rising, we cannot be sure whether or not the current part of the glacial cycle (OIS 1, the Holocene) has really reached its maximum sea-level point. Thus, in our comparison of two different episodes within the warm period, the first (OIS 5) has concluded its cycle, but the second (OIS 1, modern) perhaps has not. It may also be that uplift rates are higher in the Holocene.

4.3. Submerged coastal features

Quaternary sea-level change involved approximately 120 m of sea-level fall in the LGM, so that some episodes of earlier relative sea-level stillstand may be submerged below modern sea level (see also Lambeck and Bard, 2000). Therefore, recognition of submerged marine notches and other sea-level stillstand markers is necessary, and the distinction between abrasion and dissolution processes in notch formation is a critical aspect of their application in sea-level investiga-
5. Conclusions

(1) Holocene sea-level change in the Taormina area of eastern Sicily is likely to have progressed at a slower rate than previously interpreted, on the basis of new sea-level curves produced by Alessio et al. (1998) and Morhange et al. (2001).

(2) New dates from Holocene material at Isolabella are consistent with previous results, and permit a clearer picture of the interpretations of sea-level change in the area. We conclude that the average uplift rate in the Taormina area over the past 6000 years is about 1.4 mm a\(^{-1}\). However, for the last 125 ka, the average uplift rate has been only about 0.9–1 mm a\(^{-1}\). The reason for the apparent recent acceleration of uplift is unclear.

(3) Scuba-aided transects allow us to give uplift errors calculated with the \(^{14}\)C ages of fossils that rarely can give us precise sea level estimates. The submarine results show that there are no dissolution notches (i.e. formed at sea level) beneath the present water surface.

(4) Study of notches both above and below sea level in the area confirms the mid-Holocene relative stillstand was significant and accounts for the formation of the prominent notch roof datum, at an elevation of about 5 m, marking the boundary between subaerial and marine processes. The uplift can be related to activity on the Messina fault system and the Malta Escarpment, and was the primary cause of the relative sea-level change in northeast Sicily. Components of seafloor subsidence and sea-level rise, due to glacio-hydro-isostasy, are clearly of minor importance, but are presumed to have operated due to glacial forebulge collapse.

Acknowledgements

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