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Integrated study of Quaternary marine and fluvial terraces and morphotectonic analysis: the example of the low Agri Valley (Southern Italy)

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Abstract

During the last decades, the ever-increasing knowledge of the Quaternary coastal morphogenic processes have made the marine terraces, and the associated palaeoshorelines, the most recognizable, widespread and scientifically reliable tools to determine, both qualitatively and quantitatively, the vertical movements that affected those coastal regions tectonically active during Pleistocene and Holocene times.

We propose a methodological approach based on the integration of the study of the marine terraces with the

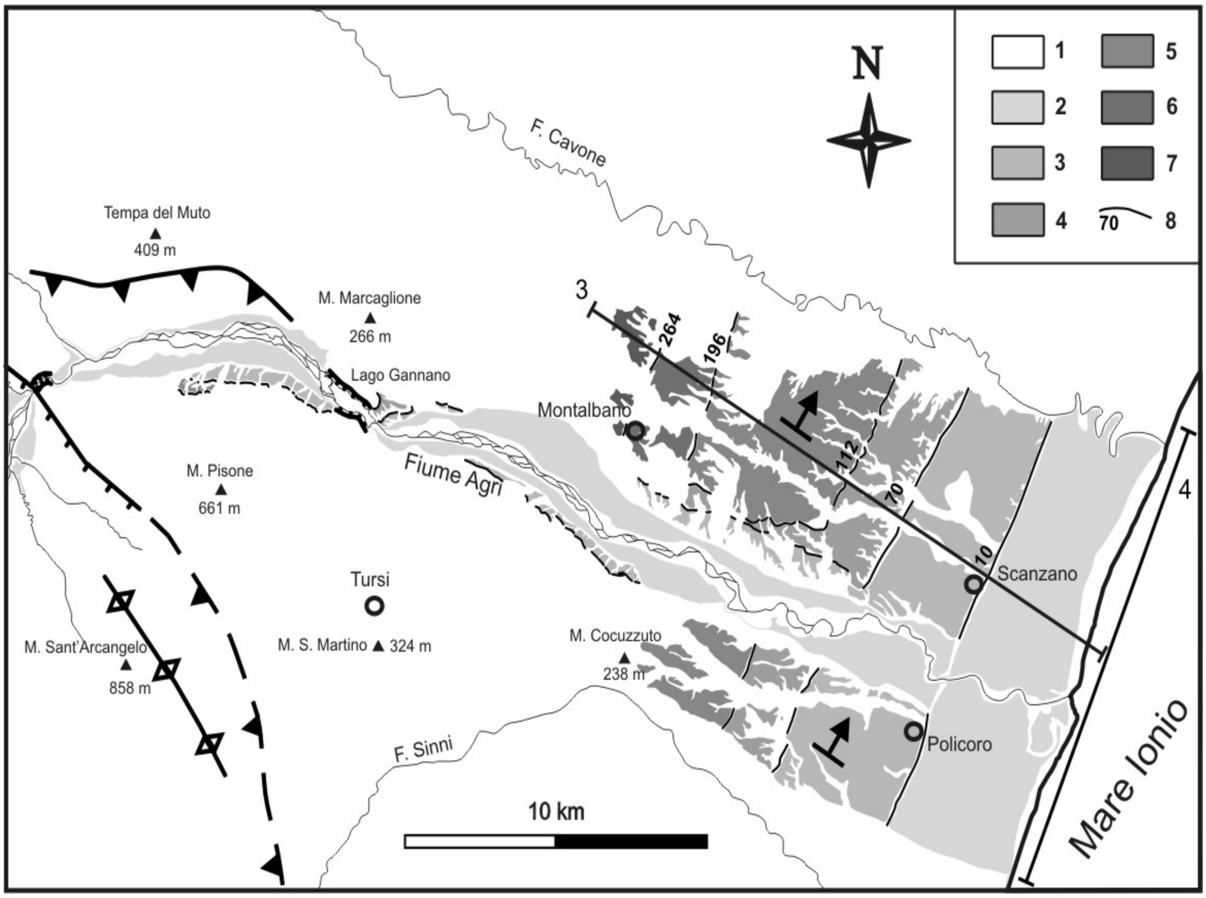

Figure 1. Morphotectonic map of the lower Agri Valley. Legend: 1 = substratum of the Quaternary fluvial and marine terraces; 2 = I-order fluvial and marine terraces; 3 = II-order fluvial terrace marine terraces; 4 = III-order fluvial terrace and marine terraces; 5 = IV-order marine terraces; 6 = V-order marine terraces; 7 = VI-order marine terraces; 8 = inner edge or fluvial and/or marine terrace and its elevation in m a.s.l.

analysis of the fluvial terraces occurring along the flanks of the coastal reach of the alluvial rivers.

In most cases, the orientation of the last reach of a river that flows into the sea is almost perpendicular to the present coastline. Therefore, the fluvial terraces of a low river valley are generally characterized by a trend quasi-perpendicular to the marine terraces, which instead are generally parallel to the present coastline. The Pleistocene and Holocene terraced marine and fluvial surfaces, and particularly their inner edges, are excellent markers of tectonic deformations, as their original shape is well known. For this reason, the integrated analysis of these morphological elements allows us to asses, firstly, whether the coastal area has undergone a homogeneous or differential tectonic raising and, secondly, whether the tectonic raising has occurred during or after the formation of the marine and fluvial terraces. In case of regional tectonic tilting and following this approach we can estimate the magnitude of the vertical tectonic deformation along two perpendicular directions (i.e. the river axis and the coastline) therefore corresponding to the two vector components of the real regional uplift.

Furthermore, if absolute chronological data of one or more terraced orders are available, it could be possible to estimate the uplift rates, starting from the oldest dated terrace. A succession of Quaternary marine terraces is to be considered as the result of the interaction between tectonic uplift and the glacio-eustatic sea level changes, described by the global eustatic curve of Chappel and Shackleton (1986). According to this morphogenic model, the inner edge of a marine terrace (i.e. a palaeoshoreline) represents the morphological record of one of the relative maximum highstand reached by the sea level during a main interglacial stage. In coastal regions which are believed to have been affected by a continuous tectonic raising, even if characterized by variable magnitude, a sequence of marine terraces can be considered as a set of morphological elements corresponding to as many mean interglacial stages.

We suggest a criterion based on a statistical approach searching for the best relationships between the observed and measured elevations of the palaeoshorelines and their hypothetical elevations carried out by deforming the eustatic curve with different values of uplift rates. As a first approximation, the uplift rates are considered constant. This statistical approach consists in the application of the χ^2 test by assuming different values of the uplift rate. The lowest result obtained from the χ^2 test indicates the best fit between observed and inferred palaeoshorelines, thus suggesting the most reliable value of the regional uplift rate that has generated the marine terraced succession and the most reliable absolute age of each marine terrace and palaeoshoreline. Moreover, following the theory, the number of combinations between measured and theoretical elevations gives the degree of freedom of the system and accordingly we can estimate the reliability of the χ^2 test.

We have applied the above-mentioned methods of morphotectonic analysis to the study of the lower sector of the Agri Valley (Basilicata, Southern Italy; Fig. 1).

The Agri Valley is a key area for understanding the Quaternary volution of a large sector of the external Southern Apennines, due to its E-W orientation across the NE verging fold-and-thrust orogenic belt. It also runs through one of the most tectonically active regions of Southern Italy and it therefore deserves a particular interest. The lower Agri Valley started forming during Middle Pleistocene due to the seaward river lengthening consequent of the progressive entrenching of the marine sediments that were continuously uplifted and inexorably brought into subaerial conditions.

In the study area, we have recognized six orders of marine terraces (five of which are bounded landward by their respective palaeoshorelines) and three orders of fluvial terraces, asymmetrically developed on both valley flanks (Fig. 1). The marine and fluvial terraces are generally characterized by the occurrence of sand-to-conglomerate deposits and are developed on the Lower Pleistocene marine clays of the Bradanic Foredeep. The orders of terraced surfaces and the respective inner edges have been numbered from the youngest (and lowest) to the oldest (and highest). The good correlation between the three orders of fluvial terraces with the three youngest marine terraces confirms, firstly, the crucial role played by eustatism in the overall morphogenic coastal process and, secondly, that we are dealing with different orders of marine terraces and not with a single marine surface vertically displaced by an array of normal faults parallel to the present coastline.

The longitudinal projection of the five orders of palaeoshorelines shows an evident northeastward tilting, due to a non-uniform tectonic uplifting of the coastal area acting during their formation (as indicated by the convergence of the lines).

It is worth noting that the magnitude of the tectonic raising decreases toward NE, i.e. the external sector of the Apennines orogenic belt. On the other hand, the longitudinal projection of the three orders of fluvial inner edges does not show a clear convergence or tilting, thus excluding any important component of differential uplift parallel to the Agri River. Consequently, we suggest that the lower Agri Valley has undergone a regional tectonic tilting toward NE (parallel to the present coastline) in the time interval between the oldest and youngest marine terraces.

Due to the lack of available absolute ages of the observed marine and fluvial terraces, we have applied the χ^2 test to the measured elevations of the six orders of palaeoshorelines (the elevation of the oldest marine terrace has been geometrically inferred). The best fit ($\chi^2 = 9.88$) has been achieved by the correlation between the actual elevations of the palaeoshorelines and the theoretical elevations obtained deforming the eustatic curve with an uplift rate of 1.5 mm/a (Fig. 2). Consequently, the six orders of marine terraces are likely to be correlated to the main interglacial peaks between OIT stage 3.1 (40 ka) and 7.5 (240 ka).

Using these ages and the actual elevations of the palaeoshorelines (corrected for the ancient sea level at the moment of their formation), a cumulative uplift curve, with the uplift rates estimated for the time intervals between two consecutive marine terraces, has been carried out.

This curve points out that the uplift rate is actually variable with time, ranging from about 1 mm/a to 2 mm/a.

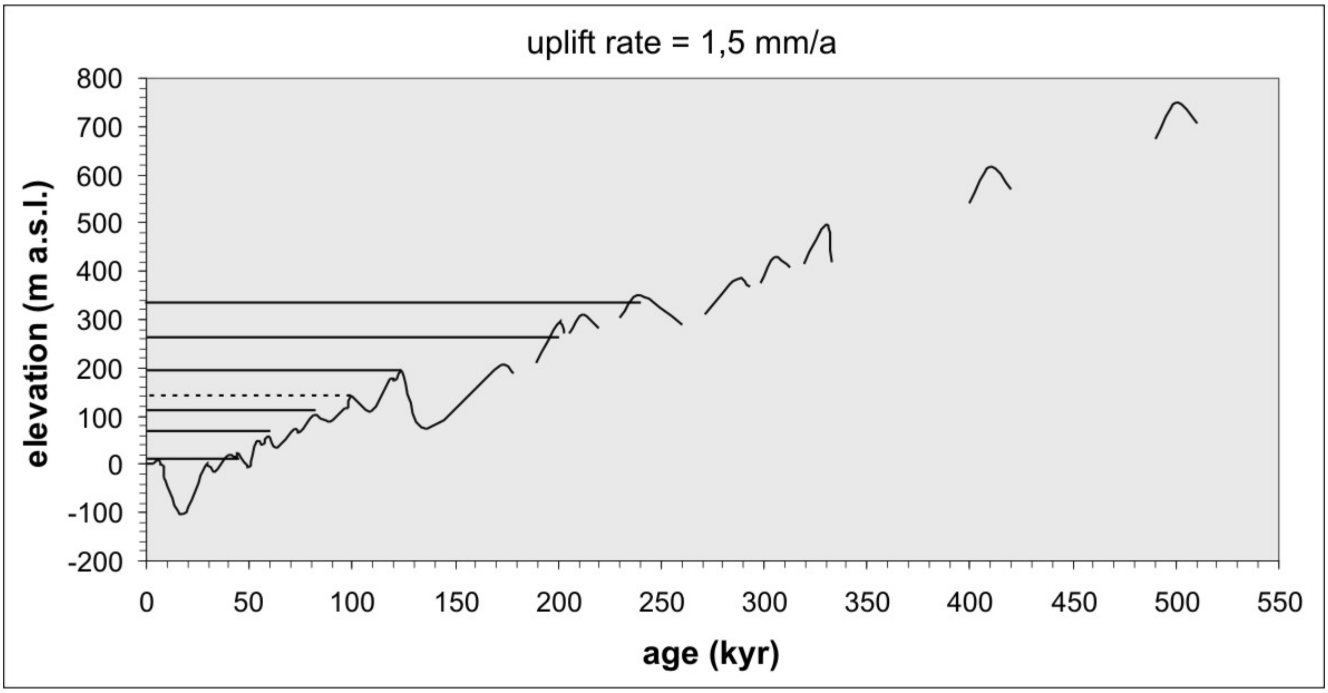

Figure 2. Global eustatic curve from Chappell & Shackleton (1986) modified by applying a constant uplift rate of 1.5 mm/a. According to the results of the χ^2 test, this rate gives the best fit between the measured elevations of the six orders of palaeoshorelines and the theoretical elevations of the sea-level highstands obtained deforming the eustatic curve.

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