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# MULTI-PROXY RECONSTRUCTION OF LATE PLEISTOCENE TO HOLOCENE PALEOENVIRONMENTAL CHANGES IN SW CALABRIA (SOUTHERN ITALY) FROM MARINE AND CONTINENTAL RECORDS

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ABSTRACT: Bernasconi M.P. *et al*., Multi-proxy reconstruction of Late Pleistocene to Holocene paleoenvironmental changes in SW Calabria (southern Italy) from marine and continental records. (IT ISSN 0394-3356, 2010).
In this work we reconstructed the major climatic changes occurred since the last postglacial transition to the Holocene in SW Calabria (southern Italy). We applied a multidisciplinary approach based on both marine and continental paleoclimatic and paleoenvironmental proxies. In particular, we focused (i) on the effects of eustatic sea-level rise on the submerged continental shelf (interpreted through offshore seismic and core stratigraphy, along with paleoecological and palynological analyses), and (ii) on the geomorphic consequences on land of the main climatic changes and their interplay with late prehistoric to historic human activities (deforestation, cultivation, ploughing, etc.), recorded by soil features in archaeological contexts and pollens in marine cores. In particular, the transgressive and highstand systems tracts that overly the Last Glacial Maximum unconformity surface were reconstructed in detail. They indicate an upward deepening of sedimentary environments followed by overall depth stability, also confirmed by mollusc paleobiocoenoses. Geomorphic stability coupled with warm and humid climate characterized the middle Holocene, promoting major soil development during Neolithic times. Important changes in soil features towards the late Holocene point to a phase of climatic drying and land degradation (probably during the Bronze age, ~4 ka BP), followed by restored prolonged moisture availability alternated with minor warm or dry events. Different episodes of intense soil erosion and human impact occurred in this period, with increasing deforestation and cultivation during about the last 2 ka, as testified by soil features and pollen stratigraphy. The consequent marine response can be probably related to seaward progradation of the late Holocene sedimentary units, also reflecting river systems adjustment to eustatic base-level rise and highstand.

*RIASSUNTO: Bernasconi M.P.* et al., *Ricostruzione multi-proxy delle variazioni paleoambientali dal tardo Pleistocene all'Olocene in Calabria sud-occidentale (Italia meridionale) attraverso record marini e continentali. (IT ISSN 0394-3356, 2010).*
*In questo lavoro sono state ricostruite le principali variazioni climatiche avvenute dall'ultima transizione postglaciale all'Olocene in Calabria sud-occidentale (Italia meridionale). È stato applicato un approccio metodologico multidisciplinare basato su indicatori paleoclimatici e paleoambientali sia marini sia continentali. Particolare attenzione è stata rivolta (i) agli effetti della risalita eustatica del livello del mare sulla piattaforma continentale sommersa (interpretati attraverso stratigrafia sismica e di carote di sondaggio a mare, unitamente ad analisi paleoecologiche e palinologiche), ed (ii) alla risposta a terra dei processi geomorfici ai principali cambiamenti climatici ed alla loro interazione con le attività antropiche tardo-preistoriche e storiche (deforestazione, coltivazione, aratura, ecc.), registrate nei caratteri pedogenetici dei suoli in contesti archeologici e nei pollini in carote marine. In particolare, sono stati ricostruiti in dettaglio i sistemi trasgressivi e di stazionamento alto sovrastanti la discordanza angolare dell'Ultimo Massimo Glaciale. Essi indicano un approfondimento verso l'alto degli ambienti sedimentari, seguito da una generale stabilità della profondità, anche confermati dalle paleobiocenosi a molluschi. Condizioni di stabilità geomorfologica e clima caldo-umido hanno caratterizzato l'Olocene medio, promuovendo un importante sviluppo del suolo durante il Neolitico. Rilevanti modificazioni nei caratteri pedogenetici verso l'Olocene superiore indicano una fase di inaridimento climatico e di degradazione del suolo (probabilmente avvenuta durante l'età del Bronzo, ~4000 anni fa), seguita da un ripristino di condizioni di prolungata umidità, alternata ad episodi minori caldi o aridi. In questo periodo avvengono diverse fasi di intensa erosione del suolo ed impatto antropico, con un incremento della deforestazione e delle coltivazioni grossomodo negli ultimi 2000 anni, come testimoniato dai caratteri dei suoli e dalla stratigrafia pollinica. La conseguente risposta in ambiente di piattaforma può probabilmente essere messa in relazione con la progradazione verso mare delle unità deposizionali tardo-oloceniche, che riflettono anche il riequilibrio dei sistemi fluviali in funzione della risalita eustatica e dello stazionamento alto del livello di base.*

Keywords: seismic and core stratigraphy; paleoecological reconstruction; mollusc; pollen analysis; soil development; Late Pleistocene to Holocene climatic changes; deforestation

*Parole chiave: stratigrafia sismica e di sondaggio; ricostruzione paleoecologica; molluschi; pollini; sviluppo pedogenetico; variazioni climatiche del tardo Pleistocene – Olocene; deforestazione*

## INTRODUCTION

This paper reports the results of a multidisciplinary study that integrates a wide variety of continental and marine geological and morphostratigraphic data along the Tyrrhenian Sea margin of Calabria, in southern Italy. Most of the existing literature concerns methods and data that deal with onshore and offshore environments, separately. Very little is known about correlations between continental and marine stratigraphic records in the light of morpho-evolutionary reconstructions, i.e. in terms of submerged sedimentary environment responses to geomorphic processes in adjacent onshore catchments. Only few papers make such an attempt in the Calabria region, focusing on modern sediment composition and provenance, role of eustatic versus tectonic base-level changes on sedimentary/erosive phases during the Quaternary, relationships among sea-floor morphologies, seismicity and mass wasting phenomena (Le Pera & Critelli, 1997; Le Pera *et al*., 2000; Robustelli *et al*., 2005; Rebesco *et al*., 2009; Martorelli *et al*., 2010). In particular, Le Pera & Critelli (1997) evidence a strict relationship among modern petrofacies of the main river/stream drainage catchments, coastal beaches and marine environments along the northern-central sector of western Calabria. They show that marine sediment composition mainly reflects feeding sources from metamorphic and pluto-no-metamorphic rocks of the Coastal Range, Sila Massif and Monte Poro inland relieves, which can be expected to have controlled also past depositional environments. Also the role of river systems interacting with postglacial sea-level rise and marine seismic stratigraphy is explored by Martorelli et al. (2010). Moreover, Robustelli *et al*. (2005) evidence the interplay between tectonically-induced trenching of alluvial fans debouching from the mountain front of the Coastal Range and paleovalleys dissected onto the emerged continental shelf during the last glacial sea-level lowering, as pathways for seaward sediment delivery. Conversely, they indicate major phases of alluvial fan aggradation during interglacial sea-level rise, possibly coupled with tectonic subsidence, that created suited accommodation space. The role of Quaternary climatic changes on sediment production and delivery was also highlighted.

In this framework we applied an integrated multidisciplinary approach to characterize the main environmental changes occurred both on the continental shelf and inland during the late Pleistocene postglacial transition and the Holocene, using different proxies and methods (stratigraphy, palaeontology, palynology, geomorphology, geoarchaeology and pedology). We aimed at a multiproxy interpretation of climatically-driven changes in the main geomorphic processes, trying to correlate data from different morphostratigraphic contexts. Moreover, we focused on an attempt to discriminate natural from anthropogenic-induced signals.

## DATA AND DISCUSSION

The main climatic and environmental changes since the Last Glacial Maximum through the Holocene were reconstructed on the basis of offshore boreholes and seismostratigraphic data in the continental shelf located offshore the Paola-Briatico sector (along the eastern edge of the Coastal Range and the S. Eufemia plain), a borehole along the present coastline near Briatico and onshore pedostratigraphic successions from an archaeological site in the surroundings of Palmi (at the southern end of the Gioia Tauro plain) and from the Monte Poro plateau, which borders the same plain to the north (Fig. 1a). This sector of Calabria consists of alternating morphotectonic highs and tectonic depressions, bordered by NE-SW and WNW-ESE-trending fault systems (e.g. Catalano et al., 2008). The coastal zone preserves a typical sequence of stair-like marine terraces, which testify high uplift rates (Miyauchi *et al*., 1994; Balescu *et al*., 1997; Tortorici *et al*., 2003).

The main paleoenvironmental changes occurred in the continental shelf during the considered time span, were reconstructed using seismostratigraphic interpretation and core stratigraphy. The stratigraphic analysis was integrated with paleoecological data obtained from mollusc fossil assemblages and pollen analyses (the latter only performed on clayey deposits). Marine deposits show variable characteristics, pattern of depocenter depths and thickness, which indicate significant changes in sedimentation rates, related to differential sedimentary input, accommodation space and tectonic behavior (as also evidenced along northern sectors of the Tyrrhenian Sea; Chiocci *et al*., 1989; Argnani & Trincardi, 1993; Carboni *et al*., 2005; Martorelli *et al*., 2010). On the continental shelf, the seismostratigraphic architecture of the shallow subsurface is described by Martorelli (2000) and Martorelli *et al*. (2010). It is characterized by a well developed postglacial depositional sequence (PDS), lying on a regional erosional unconformity, i.e. the Last Glacial Maximum unconformity (LGM-U), with a maximum age of about 20,000 years BP. The LGM-U is outlined by a high-amplitude reflector which truncates the underlying Plio-Pleistocene prograding units (Fig. 1b). The PDS is an incomplete and still evolving depositional sequence made up of both the transgressive systems tract (TST) and the highstand systems tract (HST). The deposits of the PDS occur on almost all the continental shelf reaching a notable thickness (up to 65 m) on the inner sector. The TST consists of up to 3 parasequences with a retrogradational stacking pattern, that are laterally confined by the irregularities of the LGM-U. TST deposits are characterized by a number of isolated depocentres. The HST is made up of two parasequences, arranged in a progradational and aggradational stacking pattern. These parasequences are probably of Holocene age and are bounded by a non-depositional surface. The lower parasequence lies directly on the maximum flooding surface (MFS) and shows a constant low-amplitude acoustic facies throughout the area. It is generally prograding and the reflectors become concordant with respect to the MFS only on the outer shelf. The upper parasequence shows a variable acoustic facies, especially in its upper part, which varies from a completely transparent facies to a high continuity-high amplitude seismic facies. The distribution of the HST deposits is rather regular with an almost continuous wedge over the entire area. The thickness of HST deposits is maximum (50 ms t.w.t., around 40 m) offshore of the Savuto River, the larger fluvial catchment in the study area dissecting the Coastal Range, north of the S. Eufemia plain, and diminishes rapidly seaward. There, the relatively thick (~15 m) upper parasequence is characterized by discontinuous high-amplitude internal reflectors, which may indicate coarser lithologies linked to its river delta. Slope breaks, in places revealing terraced surfaces and/or bioherms, that probably represent sea-level stillstands, can be identified at about 3-4 km from the present coastline across the LGM erosional surface. Moreover, the latter is incised by deep paleovalleys, some of which developed during exposure of the shelf as a response to glacial sea-level lowering, and subsequently filled and sealed by the Holocene sedimentary wedge. Well developed transgressive deposits (up to tens of meters thick) made of nearshore sands and gravels, provided a detailed record of the last transgression and highstand (MARTORELLI, 2000; MARTORELLI *et al.*, 2010). In order to correlate these data with those on the land sites, the closer cores collected offshore of Briatico were analyzed (4A, 4Arip, 6A, 6B, 6Brip), ranging in length between 170 and 450 cm (Fig. 1c), and compared with the top section of a nearby coastal one (BRIA 2). These cores clearly show part of the transgressive and highstand deposits. The age of the base of offshore cores ranges from 11326 to 9296 cal. years BP (radiocarbon dates on mollusc shells) in sand and silty sand transgressive deposits, respectively. Sometimes, quite dissimilar core stratigraphy depths and/or sedimentary facies even at very short distance, suggest the occurrence of some depositional hiatuses. This feature is highlighted by some much younger radiocarbon dates (as the 2573 cal. years age in core 6A) recorded in the lower-intermediate portion of few cores, very close (~ 60 cm) to the depth of layers dated to about 10 ka. The closeness of these cores to river mouths, feeding important sedimentary input to the shelf environment, might explain the discontinuous sedimentary records. For instance, in core 6A this is also consistent with an opposite trend of sedimentological and paleobiotope data in depth (especially in the upper core section) with respect to those from the other offshore cores. This hypothesis is also supported by a prominent role of steep and high-sloping river catchments located close to the coast, which could have enhanced sediment transport and distribution onto the shelf.

In the offshore cores paleobiological and sedimentological evidence detect two depositional systems: from core bottom to top, it is noteworthy an upward deepening of the paleobiotope, followed by a phase characterized by a depth stability of the paleoenvironments (MAROZZO, 2004). Molluscan assemblages are interpreted according to the Meditrerranean benthic bionomy of PÉRÈS & PICARD (1964) and PÈRÈS (1982). Acronyms used to identify Mediterranean biocoenoses are derived from their original French names and their English translation as reported in BERNASCONI & ROBBA (1993). The increasing depth is marked by the replacement of infralittoral epifaunal species strictly related to the Biocoenoses of *Posidonia* seagrass (HP) and of Photophilous Algae (AP), such as *Bittium reticulatum, Obtusella macilenta* with those related to the circalittoral Biocoenoses of Coastal Detritic Bottoms (DC) and of Terrigenous Mud (VTC) (*Timoclea ovata, Parvicardium minimum and Turritella communis*). The depth stability is reached when molluscan assemblages are characterized by high dominance values of Kelliella abyssicola, a species strictly related to the Biocoenosis of Bathyal Mud (VP). The transition represents the maximum flooding surface of the transgression, recorded slightly later (upward) than observed in seismostratigraphic data (Fig. 1c).

The onland core collected near Briatico (BRIA 2) is 8 m in length and is still in study. In its mid- to upper section (0-5 m) shows, from bottom to top, marine grey clay deposits (~2.5 m thick) overlaid (up to the top) by two moderately-developed, organic-rich, dark brown soils (the lower also exhibiting some illuvial clay coatings within pores), intercalated by centimetre- to deci-

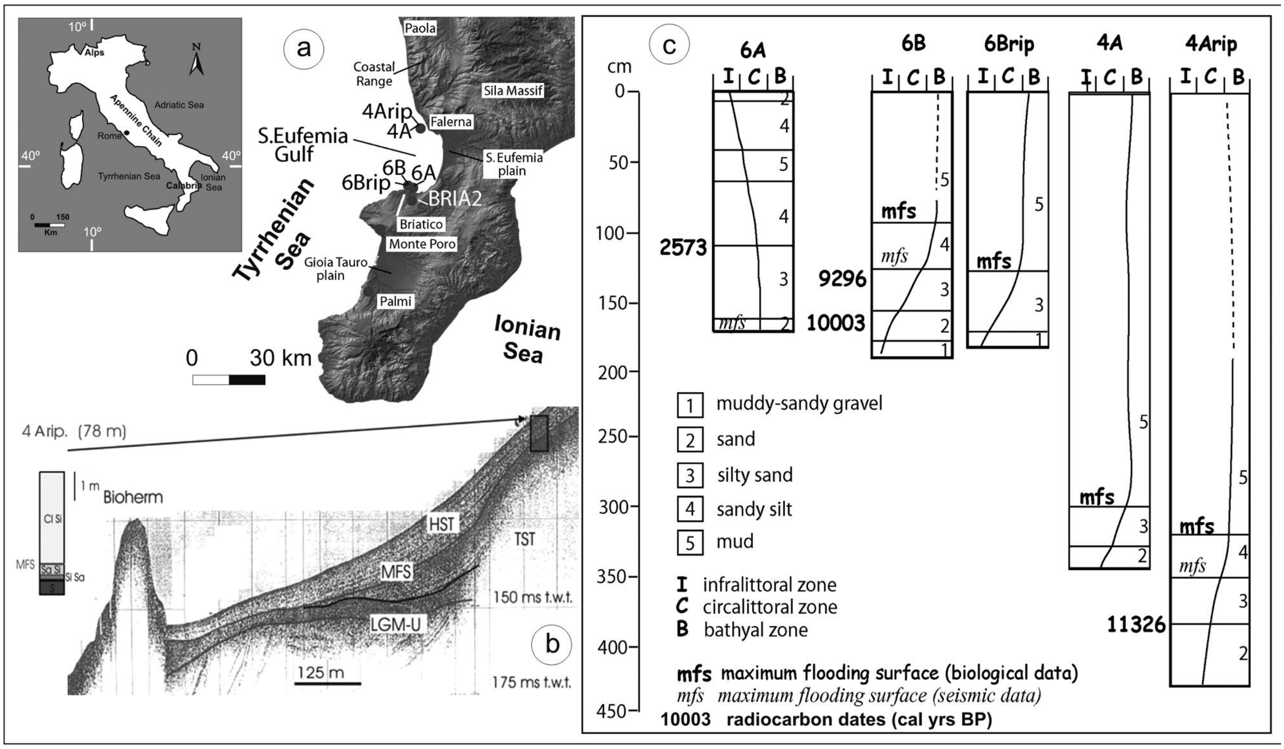


Fig. 1 - Location map of the study sites and stratigraphic cores (a); seismic profile passing across core 4Arip (b); schematic stratigraphy of selected cores (6A, 6B, 6Brip, 4A, 4Arip) and radiometric ages (c). See text for details.

*Ubicazione dei siti di studio e dei sondaggi (a); profilo sismico passante dal sondaggio 4Arip (b); stratigrafia schematica dei sondaggi selezionati (6A, 6B, 6Brip, 4A, 4Arip) ed età radiometriche (c). Si veda il testo per i dettagli.*

metre-thick, whitish $CaCO_3$-concretioned layers, tentatively correlated with the soils described in the archaeological excavations, reported below.

The pedostratigraphic succession excavated in the onshore site close to Palmi, on a wide terrace at 500 m a.s.l., mainly consists of silt loam soils with some volcanic input and variable morphological features, which can be partly dated on the basis of *in situ* archaeological settlements and finds. They include well developed, dark yellowish-brown buried argillic (Btb) horizons, overlaid by truncated and buried, often artificially reworked, dark brown organic-mineral (Ab) horizons (Fig. 2a). These layers can be ascribed to about 6500-5800 cal. years BP thanks to the occurrence of late Neolithic ceramic artefacts (*Diana* style facies) and typical incineration burials found in biconical vases. They are in turn overlaid and strongly superimposed by a widespread paleosurface related to late early Bronze age colonization (about 4000-3700 cal. years BP), which shows similar features to the *Palma Campania* and *Capo Graziano* archaeological facies defined in other sites of southern Italy (e.g. ALBORE LIVADIE, 1999). This surface is affected by many pole holes left by not preserved large wooden huts, ploughed furrows, excavated cisterns, ditches and trenches, often filled with organic-rich dark brown soil material, also filling some large pockets in argillic horizons. Also hearths with charcoal remains, burials, vases and other diagnostic ceramic fragments occur. Above the Bronze age surface, the upper stratigraphic succession consists of brown anthropogenically disturbed organic-mineral (Ap) horizons that appear cyclically ploughed during historical times (archaeologically not well dated because of their reworking for agricultural practices), in places disturbing with abrupt irregular boundaries the underlying horizons. The chronological constraints supplied by the archaeological stratigraphy are in agreement with the volcanic glass content identified at the microscopic scale in all soil horizons, using SEM-EDS analysis (Fig. 2b). The dominant rhyolitic composition of volcanic pumices is quite similar to that analyzed in the analogous, widespread *Andisols* (IUSS Working Group WRB, 2006; Soil Survey Staff, 2010) of Monte Poro upland and Gioia Tauro plain, which can be related to late Pleistocene to Holocene volcanic eruption/s from the Aeolian Islands (ARAMINI *et al*., 2005; SCARCIGLIA *et al*., 2006). This chronological constraint is also supported by the late Palaeolithic to late Neolithic and late Bronze Age archaeological settlements and artefacts found in the volcanic soils of Monte Poro (PACCIARELLI, 2008). Therefore major soil development probably occurred during most of the Holocene (and maybe the late Pleistocene).

The above soil features, coupled with chemical, physical and mineralogical analyses, as well as micromorphological observations performed on thin sections from undisturbed soil samples (FITZPATRICK, 1984), allowed us to propose the following reconstruction. A period of geomorphic stability under warm and humid climatic conditions (with high moisture availability and some seasonal contrast) characterized the latest phases of the Neolithic and likely the following initial stages of the Bronze age, with important soil development under a stable vegetation cover, that can be related to the upper part of the Holocene climatic *optimum* (cf. SCARCIGLIA *et al*., 2009). This hypothesis is supported by the presence of clay coatings in Bt horizons (quite enhanced in warm and humid climates) and by their relict significance (i.e. the present inactivity of illuvial processes) highlighted by micromorphological observations, showing that they often appear fragmented and with smooth-banded to grainy extinction patterns between crossed polars (Fig. 2c) (FITZPATRICK, 1984; CATT, 1989). Coherently, the latest phases of important clay illuviation in temperate mid-latitude and Mediterranean environments are well documented just during the Holocene climatic *optimum* (e.g. CATT, 1989; SCARCIGLIA *et al*., 2009). The above conditions are further supported by: (i) more abundant phyllosilicate clays detected by X-ray diffractometry in argillic horizons; (ii) overall lower amounts of short-range order minerals (SROM) and less developed andic properties (*sensu* IUSS Working Group WRB, 2006; Soil Survey Staff, 2010), estimated on the basis of field morphological features, FT-IR spectroscopy and the oxalate-extracted Al and Fe index (ICOMAND, 1988). These climatic conditions are quite consistent with the climate amelioration characterized by progressive temperature and moisture increase, documented for the Lateglacial and the early-middle Holocene (RUSSO ERMOLLI & DI PASQUALE, 2002; CARBONI *et al*., 2005; GIRAUDI, 2005; DI DONATO *et al*., 2008), and the concurrent sea-level rise (approaching the present-day level at about 6-7 ka BP; BUCCHERI *et al*., 2002; LAMBECK *et al*, 2002), also recorded in the offshore cores.

This period was followed by a severe land degradation during the Bronze age at about 4000 cal. years BP, also identified in many places along the Italian peninsula, where a drought phase (tentatively recorded by the carbonate-concretioned layers within the brown soils in the BRIA 2 coastal core) presumably contributed to the effects of deforestation (e.g. DI RITA & MAGRI, 2009). This phase is testified by erosion and human impact extensively affecting surface A horizons. On the other hand, it cannot be excluded a relevant role of other dry episodes during the middle-late Holocene, such as those at 5.4 and 3-2.3 ka BP, likely related to the global scale RCC events of MAYEWSKI (2004) and recently identified by DI DONATO *et al*. (2008) in the Salerno Gulf (more than 200 km far to the north). These climatic phases might have prepared and enhanced, respectively, the above land degradation.

Although no detailed chronological data are available for the whole postglacial depositional sequence, the occurrence of two HST parasequences, their progradational and aggradational stacking pattern, coupled with their maximum thickness offshore of the Savuto River, suggest that some relevant changes occurred inland during their emplacement in terms of erosion and sediment delivery within and from the main river catchments seaward. These modifications can be related to adjustment of river systems after mere glacio-eustatic sea-level rise and highstand, possible Holocene tectonic uplift (cf. PIRAZZOLI, 2005) though not evidenced by our data, as well as to the effects of human impact in their feeding areas. In particular, the above land degradation during and after the Bronze age could be tentatively correlated to progradation of the upper parasequence forming the upper part of the highstand system tract, which very likely represents the

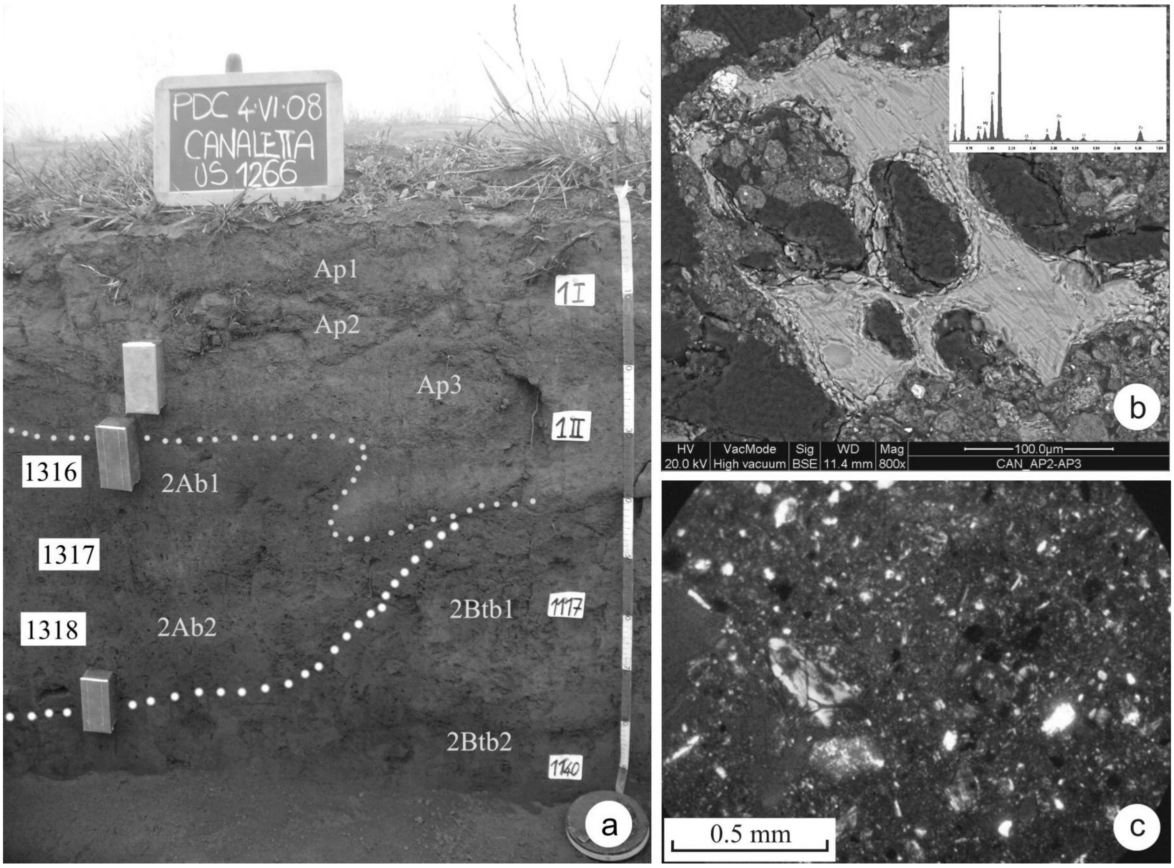


Fig. 2 - Soil profile in the archaeological excavation close to Palmi (a): the upper dashed line represents the late early Bronze age paleosurface (~4000-3700 cal. years BP) affected by clear ploughing traces, also involving younger overlying disturbed Ap horizons; all the underlying soil layers, i.e. buried organic-mineral (Ab) horizons and argillic (Bt) horizons, date to late Neolithic (~6500-5800 cal. years BP); SEM image of a volcanic micropumice and associated EDS spectrum from the lower Ap horizon of the profile (b); microphotograph showing fragmented and smooth-banded clay coatings from horizon 2Btb2 in crossed polarized light (c).

*Profilo pedologico nello scavo archeologico vicino a Palmi (a): la linea tratteggiata superiore rappresenta la paleosuperficie del tardo Bronzo Antico (~4000-3700 anni fa) interessata da tracce di aratura ben evidenti, che coinvolgono anche i sovrastanti orizzonti Ap; tutti i livelli pedologici inferiori, cioè gli orizzonti organico-minerali sepolti (Ab) ed argillici (Bt), sono databili al Neolitico finale (~6500-5800 anni fa); immagine al SEM e relativo spettro EDS di una micropomice vulcanica dall'orizzonte Ap inferiore del profilo (b); microfoto mostrante pellicole d'argilla frammentate ed a bande sfumate dall'orizzonte 2Btb2 in luce polarizzata incrociata (c).*

late Holocene stratigraphic record. We cannot rule out a simultaneous coastline progradation, because no clear morphostratigraphical records are available. Nevertheless, the possible coarse-grained delta facies identified in the thick HST upper parasequence offshore of the Savuto River may be associated to a late Holocene coastline progradation. In addition to anthropogenic impact on land, such fluvial and shelf deposition could be likely related to a transition towards higher moisture availability in soils (subsequent to the above drought phase), which also underwent repeated, undetermined phases of ploughing throughout the late Holocene. In fact, *andic* properties appear more developed in A horizons, where abundant short-range order aluminosilicates are associated with minor phyllosilicates (as also supported by their dominant isotropic matrix in crossed polarized light), which suggests the occurrence of a regime with prolonged (and overall seasonally poorly-contrasted) moisture availability. This phase might be at least partly related to temperate cooling events during the last 3000 years, characterized by minor warm or dry episodes, as testified by higher lake levels or burial of soils by glacial/periglacial deposits in central Italy and glacier expansions in the Alps (Giraudi, 2005, 2007).

On the other hand, the effects of soil degradation, deforestation and agricultural practices are highlighted by truncation of late prehistoric fertile A horizons, once developed at surface under particularly suited climatic conditions (the above Neolithic *optimum*) and vegetation cover, but nowadays not completely preserved in situ. The organic-rich filling of soil pockets in the argillic horizons and more extensively of ploughing furrows and artificial excavations, likely represents the eroded material. Moreover, A horizons include some reddish-yellow, subrounded pedorelicts exhibiting fragments of clay coatings, probably stripped away from the underlying Bt horizons by erosion or ploughing activities.

Also the pollen analysis evidenced a drastic change in the vegetation cover, presumably caused by this anthropogenic land degradation, which probably went on even during more recent times. An extremely severe reduction of arboreal *taxa* typical of the Mediterranean

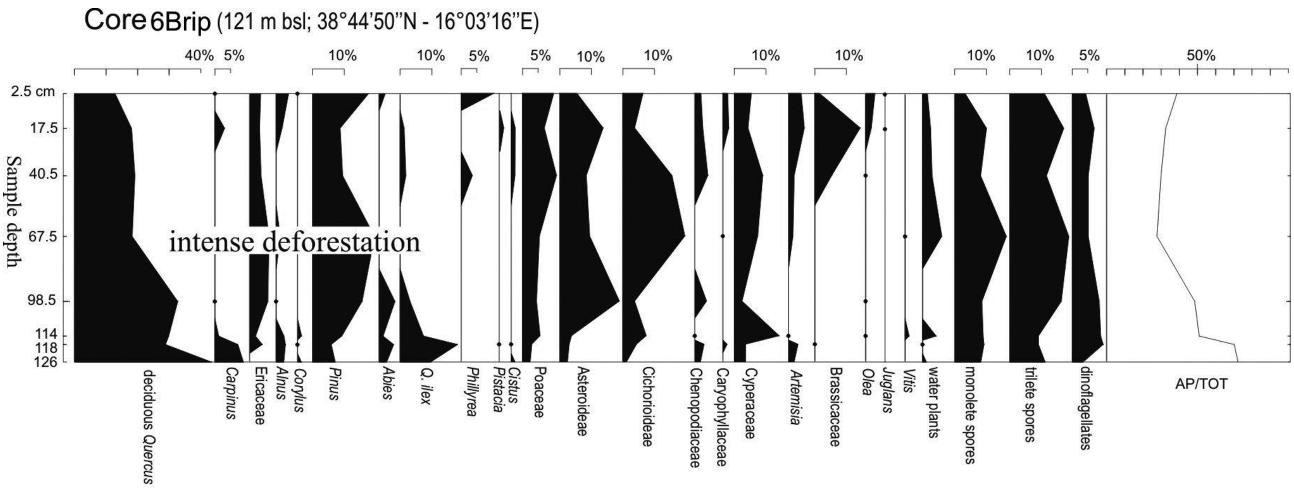


Fig. 3 - Pollen spectra from core 6Brip.
*Spettri pollinici della carota 6Brip.*

mesophilous forest is observed in two cores located offshore of Briatico, at the base and in the middle of the clayey portion from cores 6Brip (~118 cm) and 4A (~147 cm), respectively. This deforestation is followed and partly accompanied by the onset of cultivations, which are clearly recorded in the upper part of these two cores, mainly in 6Brip (Fig. 3). The start of deforestation and of intensive olive cultivation was already pointed out in the Salerno Gulf and dated to the early Middle Ages (Russo Ermolli & Di Pasquale, 2002). Here, the increase of Brassicaceae at the core top should represent the cabbage cultivation, which was one of the most common orchard product during the Roman age, as testified in the sediments of the ancient Roman harbour of Naples (1st century BC - 5th century AD; Allevato *et al*., 2009; Amato *et al*., 2009). On this basis, despite the lack of definite chronological constraints for these cores, a late Holocene time span can be supposed for the analyzed pollen record. It might be tentatively related to about 2000 yr BP in core 6Brip (also consistent with the above discussed hypothesis of local sedimentary hiatuses) and possibly to some thousands before in core 4A, where a longer stratigraphic record is included and evidence of deforestation starts only in the mid clayey section. This interpretation is also supported by clear evidence of deforestation and cultivation during about the last 2 ka from another site in Calabria, i.e. in the nearby Sila Massif upland (Pelle *et al*., 2010 and references therein), and a further one in the Basilicata region, still in southern Italy (Allen *et al*., 2002).

In addition to these environmental changes, previous climatic fluctuations could have occurred during the early Holocene (and/or the late Pleistocene), as revealed by the main features of deeper soils underlying and predating the above archaeological layers (occasional grey glosses and blackish mottles of Btg horizons caused by partially impeded drainage and transient reducing conditions, in turn overlying another *andic*-like A horizon).

## CONCLUSIONS

The integrated study of seismic profiles, stratigraphic cores and soil profiles located offshore and onshore of the Tyrrhenian Sea coast of Calabria (southern Italy) allowed the reconstruction of the main late Pleistocene to Holocene environmental changes. Based on a number of proxies, we identified the major responses of geomorphic processes to changing climatic conditions and human activities. Seismostratigraphic interpretation and core stratigraphy, coupled with paleoecological analyses, provided a detailed record of the Holocene maximum flooding surface and highstand depositional units of the last marine transgression, which overly the Last Glacial Maximum unconformity. The Lateglacial to early Holocene climatic amelioration that caused such a sea-level rise, culminated into the mid-Holocene (Neolithic) climatic *optimum*, characterized by warm and humid conditions and geomorphic stability, promoting important soil formation under a stable vegetation cover. The variability in depth of *andic* properties, phyllosilicate formation and illuvial pedofeatures in Holocene soils suggests climate changes probably occurred at the transition from the climatic *optimum* to the cooler but still humid upper Holocene, after one or more periods characterized by drought, land degradation, severe soil erosion and human impact during and after the Bronze age. This phase was presumably coupled with deforestation and agricultural practices likely more intense during the last 2 Ka, clearly highlighted by soil features and pollen analysis in marine cores.

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