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SG
Dipartimento di Scienze Geologiche

FACOLTÀ DI SCIENZE
MATEMATICHE FISICHE NATURALI

Dottorato in Geodinamica e Sismotettonica - Università di Catania

Neotettonica, morfologia e rischi ambientali nelle aree costiere

Scuola Estiva AIQUA-GIGS 2008

Dipartimento di Scienze Geologiche - Università di Catania
6 - 11 Ottobre 2008

FIELD TRIP GUIDE

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INTRODUCTION

Sicily sits astride the African-European plate boundary and much of the eastern coastline is defined by a major normal fault system responsible for destructive historical earthquakes. Normal fault segments are mainly located offshore and generated the largest tsunamis ever occurred in the southern Italy. This complex tectonic setting also involves Mount Etna, Europe’s most active volcano. Several coastal sites, particularly on the eastern (high uplift) and northern coastline (quasi still-stand), display well-preserved sequences of marine terraces, most notably including those assigned to the MIS 5.5 highstand (named also *Tyrrhenian* in Mediterranean sea) primarily on the basis of the distinctive *Strombus bubonious* warm-water fossil mollusc and now at elevations up to about 150 m. Newly published work by the leaders of the trip has extended the tectonic record into the Holocene by using uplifted and laterally extensive marine notch features formed at sea level; the carbonate bedrock and microtidal environment of the Mediterranean allowing unusually high precision.

Goal of this field trip in Sicily is to visit three coastal area in tectonically very different zone, the NE coast that show very active uplift up to Pleistocene with Holocene acceleration, the tsunami prone SW coastal area where Holocene sea level rise has been faster than tectonic uplift and, finally, the NW coast with few vertical movement (but showing horizontal movement due to strike slip faults).

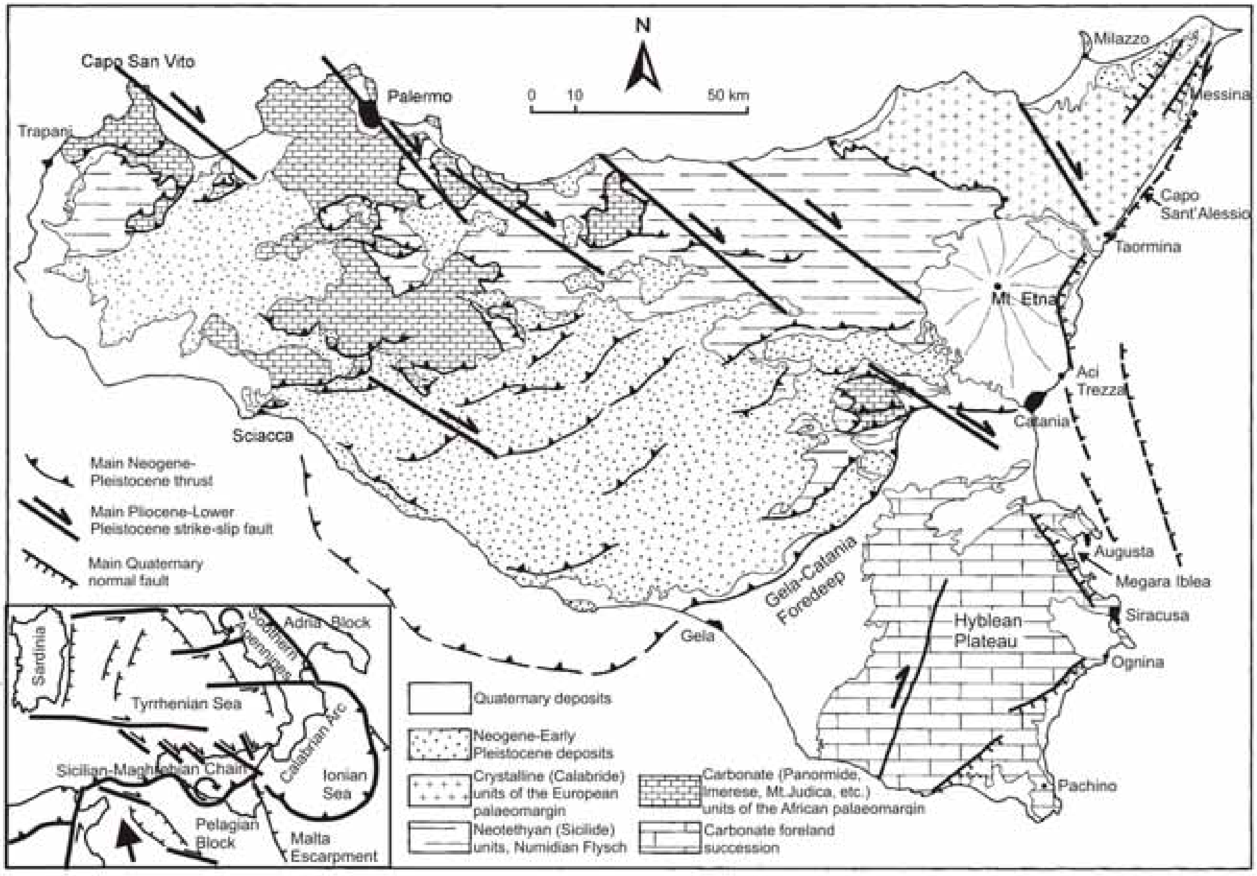

Fig. 1- Schematic geological map of Sicily. The inset shows a simplified model of lateral extrusion of the Calabrian Arc produced by the indentation of the Pelagian Block and by consequent opening of the Tyrrhenian Basin (from Catalano et al, 2004, modified). The large arrow shows the Late Tortonian to Present direction of convergence between Africa and Europe (from Mazzoli and Helman, 1994), circular arrows indicate the clockwise and counterclockwise orogen-scale rotations of the Sicilian-Maghrebides and Southern Apennines, respectively. Lines with triangles represent the front of the chain, lines with arrows the main Plio-Pleistocene strike-slip faults, lines with barbs the main Quaternary faults.

REGIONAL TECTONIC SETTING

In Sicily are exposed all the structural domains of the Sicilian-Maghrebian collisional belt which is a portion of the Alpine orogen (BEN AVRAHAM et al., 1990). From the south to north, these are represented by the Pelagian-Hyblean foreland, the Gela-Catania foredeep, and the Sicilian-Maghrebian chain (Fig. 1). To the east, along the Ionian offshore, a Mesozoic boundary (the Malta Escarpment; SARTORI et al., 1991) separates these continental domains from the oceanic crust of the Ionian basin (BUROLLET et al., 1978). The W-E trending Siculo-Maghrebian segment of the orogenic belt is linked to the NW-SE trending southern Apennines by the Calabrian Arc (see inset in Fig. 1). This latter is constituted by crystalline basement units which represent the inner portions of the orogenic system. The Sicilian-Maghrebian chain is composed by a thin-skinned south-verging fold and thrust system, developed during the Neogene to Quaternary Africa-Europe collision (DEWEY et al., 1989). Thrust sheets are formed by Meso-Caenozoic successions deriving from the oceanic realm of the Neotethys (i.e. Sicilide units) and from the Africa continental palaeo-margin (BIANCHI et al., 1987; BEN-AVRAHAM et al., 1990; ROURE et al.,1990; BELLO et al., 2000; CATALANO et al., 2000). Collisional processes involved the African palaeo-margin since the Middle Miocene, giving rise to thrust migration characterized by piggy-back propagation of SSE-verging flat and ramp thrusts.

During their Neogene-Quaternary propagation the distinct thrust sheets underwent strong clockwise rotations (SPERANZA et al., 1999, 2003 and references therein). Most of rotations are connected with the activity of NW-SE and WNW-ESE striking en-echelon right-lateral strike-slip faults, related to the Tyrrhenian Basin opening, which characterized the post-Miocene stages of the orogenesis (*Kumeta-Alcantara Line*, GHISETTI and VEZZANI, 1984; *Southern Tyrrhenian System*, FINETTI et al., 1996; LENTINI et al., 2006; *right-lateral W-E trending shear zone*, GIUNTA et al., 2000; RENDA et al., 2000). These fault segments deformed the previous compressive structures giving rise to large shifting of the chain front towards the southeast.

Since the Early Pliocene, the frontal thrusting of the chain was accompanied by out-of-sequence thrusting (LENTINI et al., 1990; BELLO et al., 2000) and by the development of syntectonic basins on top-thrust basins and in transtensional depressions at the rear of the Sicilian-Maghrebian chain (ABATE et al, 1982; 1991; GRASSO et al. 1991; GIUNTA et al., 2000). During the Late Pliocene-Early Quaternary times, the inner sectors of the Calabrian arc (Fig. 2) have been dissected by normal faults, both longitudinal and transversal with respect to the arc, which caused the fragmentation into structural highs and marine sedimentary basins (GHISETTI, 1979; MONACO et al., 1996a; CATALANO and DI STEFANO, 1997; LENTINI et al., 2004).

Currently, northern Sicily is characterized by moderate seismicity, mostly related to convergence along an E-W oriented regional shear zone, still active along the southern Tyrrhenian sea margin (GUEGUEN et al., 2002). Focal mechanisms are mostly characterized by strike–slip and reverse-oblique kinematics compatible with low-dip NNW–SSE to NNE–SSW trending P-axes, roughly consistent with the general convergence between the European and the African plates (Fig. 3) (FREPOLI and AMATO, 2000; NERI et al., 2005; LAVECCHIA et al., 2007). Shallow seismicity in northern Sicily has been related to the present-day activity of the right-lateral W-E trending shear zone (GIUNTA et al., 2004). This fault system deforms very recent deposits and controls drainage pattern along the coast of north-western Sicily (NIGRO et al., 2000; TONDI, 2007).

In eastern Sicily and Calabria, the contractional processes along the chain and the collapse at the rear have been followed by strong uplifting that has been recorded by the development of flights of Quaternary marine terraces along the Ionian and Tyrrhenian coasts. Uplift rates of about 0.5 mm/yr since about 400 ka along the south-eastern coast of Sicily and up to 1.7 mm/yr since 125 ka from the Mt. Etna coast to the Straits of Messina area have been estimated (GHISETTI, 1984; 1992; STEWART et al., 1997; BORDONI & VALENSISE, 1998; BIANCA et al., 1999; MONACO et al., 2002; CATALANO and DE GUIDI, 2003; ANTONIOLI et al., 2006; FERRANTI et al., 2006; WESTAWAY, 1993).

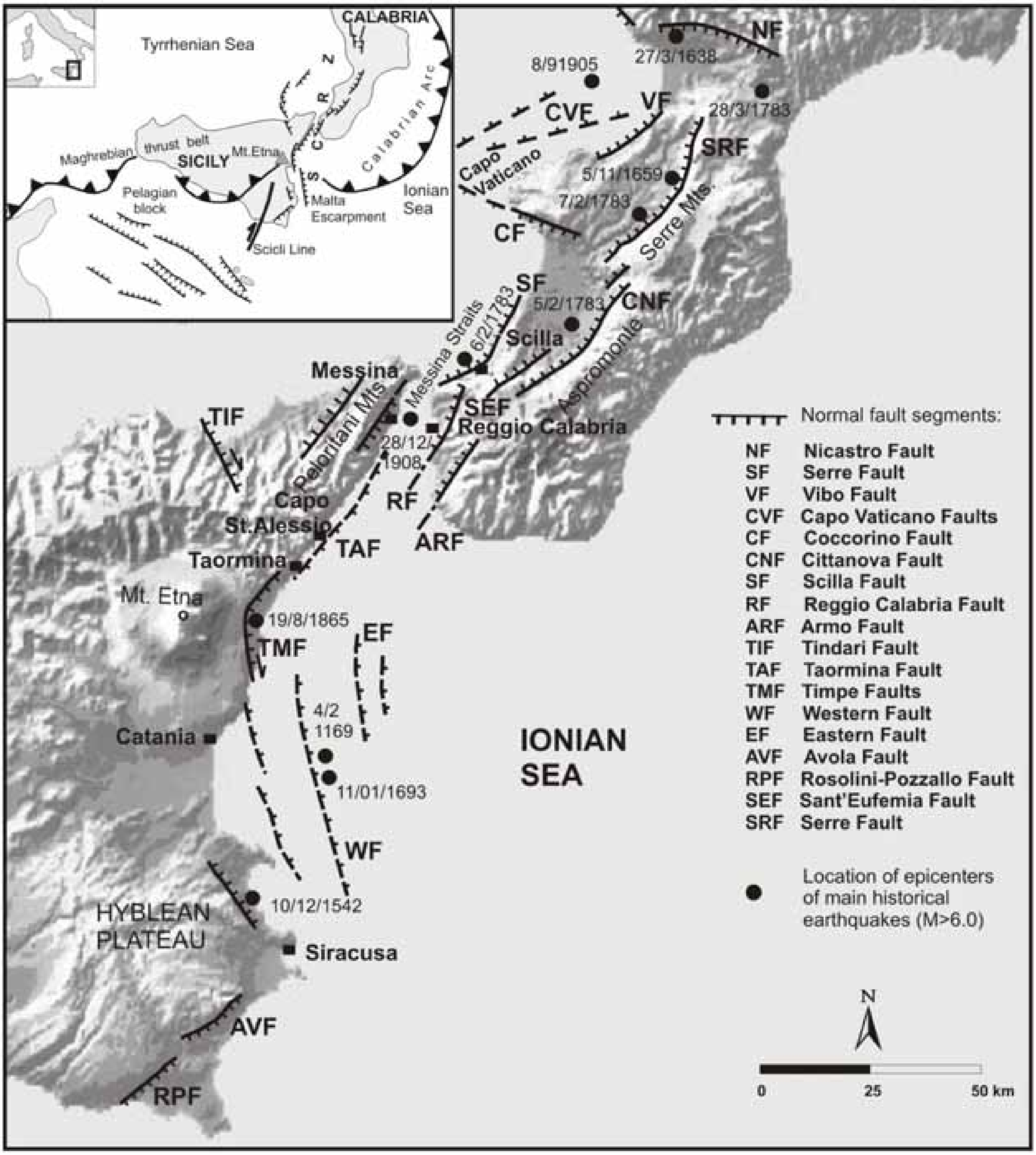

Fig. 2 – Morphotectonic map of southern Calabria and eastern Sicily showing the main Quaternary normal faults of the Siculo-Calabrian rift zone (from MONACO *and* TORTORICI*, 2000; 2007). Inset: tectonic sketch map of central Mediterranean; lines with triangles represent the front of the chain, lines with barbs the main Quaternary faults. SCRZ: Siculo-Calabrian rift zone.*

The strong regional uplifting of the whole Calabrian arc has been coupled with an important geodynamic change occurred in the region during the Middle Pleistocene, signalled by the end of frontal thrust displacement and stalling of subduction of the Ionian plate (Fig. 3a) beneath the Tyrrhenian domain (WESTAWAY, 1993; WORTEL and SPAKMAN, 2000; GOES et al., 2004). This process has probably also triggered the development of an incipient rifting that, cutting across the Straits of Messina, has reactivated the normal faults of the Tyrrhenian sector of Calabria and the Malta Escarpment in the eastern Sicily offshore (*Siculo-Calabrian rift zone*; MONACO and TORTORICI, 2000).

RECENT AND ACTIVE TECTONICS IN EASTERN SICILY

The Siculo-Calabrian rift zone is constituted by normal fault segments characterized by a very young morphology (Fig. 2) and is marked by active volcanism and strong crustal earthquakes mostly characterized by normal focal mechanisms (Fig. 3b). Several earthquake-generated tsunamis struck the Ionian coast of eastern Sicily in historical times (AD 1169, 1329, 1693, 1818, 1908, 1990; Tinti et al., 2004; see Tab. 1). According to published geological data and numerical modelling, the seismogenic source of these events should be located in the Messina Straits and in the Ionian offshore (the Malta Escarpment) between Catania and Siracusa (see Monaco and Tortorici, 2007 and references therein). In particular, the Catania area was struck by the destructive events (earthquake and tsunami) of 1169 and 1693 and by the 1990 event, while the Straits of Messina area was devastated by 1908 earthquake and consequent tsunami wave.

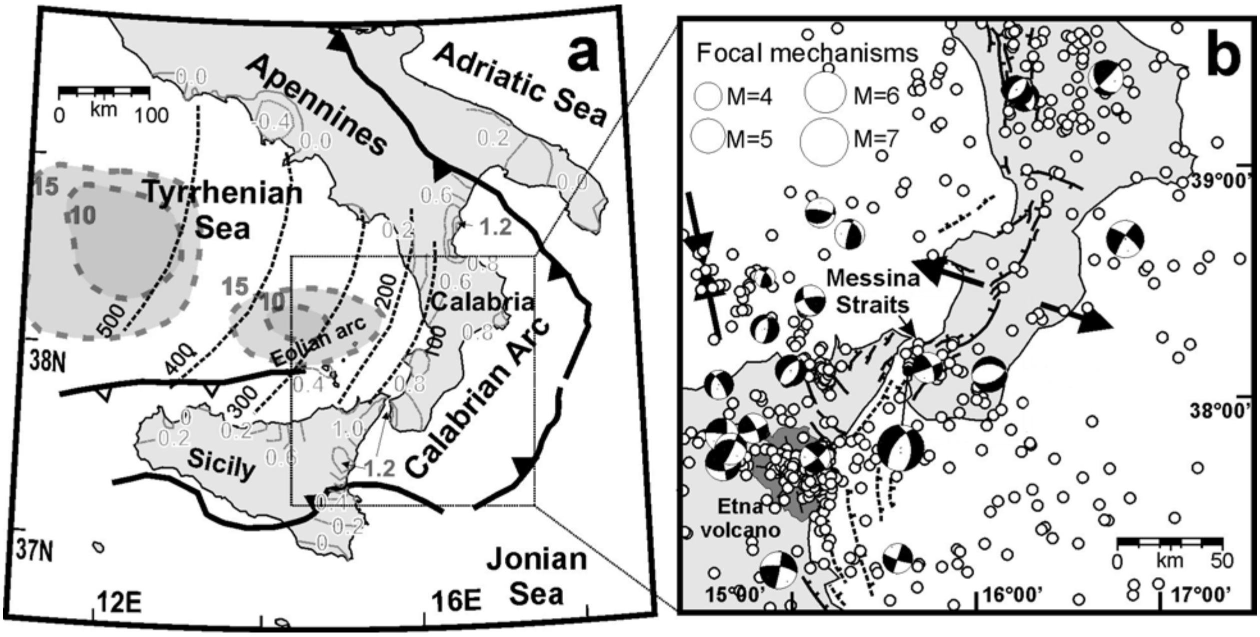

Fig. 3 - (a) Tectonic setting of southern Italy (after Ferranti et al., 2007). Solid black line: front of the contractional orogen in the Apennines and Sicily(empty teeth: belt of contractional earthquakes in northern Sicily); dotted black lines: depth (km) to the Benioff-Wadati zone of the Ionian slab (after Giardini & Velonà, 1988); grey patches bounded by thick dashed lines: parts of the Tyrrhenian Sea with Moho shallower than 15 and 10 km (after Cassinis et al., 2003); thin, solid grey lines: uplift and subsidence rates (mm/yr) in the Late Pleistocene [from Ferranti et al., 2006]. (b) Current deformation of the Calabrian Arc. Active faults of the Siculo-Calabrian rift zone after Monaco & Tortorici (2000); the double arrowed lines show extension direction in Western Calabria and Eastern Sicily and contraction direction offshore northern Sicily. Focal mechanisms of moderate to large earthquakes (M>4) after Harvard CMT (1976-2006) (http://www.seismology.harvard.edu/CMTsearch.html) and Mednet RCMT (1997-2006) (http://mednet.ingv.it/events/QRCMT/Welcome.html) catalogues (Pondrelli et al., 2002; 2004), Gasparini et al. (1985), and Anderson & Jackson (1987). Epicentres of 1981-2002 instrumental seismicity from CSI, Catalogo della sismicità italiana 1981-2002, versione 1.0. INGV-CNT, Roma (http://www.ingv.it/CSI/].

WNW-ESE trending regional extension along the *Siculo-Calabrian rift zone* was deduced from structural analysis (Tortorici et al., 1995; Monaco et al., 1997; Jacques et al., 2001; Ferranti et al., 2007), seismological data (Gasparini et al., 1985; Anderson and Jackson, 1997; Pondrelli et al., 2002; 2004; CMT e RCMT catalogs; Fig. 3b) and from VLBI (Ward, 1994) and GPS (D'Agostino and Selvaggi, 2004; Goes et al., 2004; Serpelloni et al., 2005) velocity fields. These latter indicate extension rates of 3-4 mm/yr across the Straits of Messina. In Sicily, rifting is superimposed on a general N-S trending convergence process (Lavecchia et al., 2007), currently active in the foreland (Bousquet and Lanzafame, 2004), in the chain (Belice earthquake; 15/01/68, M=5.4, Monaco et al., 1996b) and in the seismogenic belt occurring in the Tyrrhenian offshore (GIUNTA et al., 2004) (Fig. 3). It worthy to note that the rifting process has been coeval to strong uplifting of eastern Sicily and Calabria. The elevation of marine terraces and their offset across the main faults has been used to establish the relative contribution of regional and fault-related sources to uplift. According to WESTAWAY (1993), 1.67 mm/yr of post-Middle Pleistocene uplift of southern Calabria and north-eastern Sicily has been partitioned into ~1 mm/yr due to regional processes and the residual to displacement on major faults.

Shorter-term uplift-rate estimates are provided by raised Holocene beaches, wave-cut platforms and tidal notches (FIRTH et al., 1996; STEWART et al; 1997; RUST and KERSHAW, 2000; DE GUIDI et al., 2003; ANTONIOLI et al., 2003; 2004; 2006; FERRANTI et al., 2007). The field trips in eastern Sicily will be devoted to the observation of these markers that can be used to determine the vertical tectonic movements of coastal areas during the Holocene. Overall, the late Holocene uplift rate pattern is centred on the Messina Straits (Fig. 4a). On the Calabrian side, rates grow steadily toward 2.1 mm/yr at Scilla. On the Sicilian side, rates increase from north (Milazzo: 1.7 mm/yr; Messina-Ganzirri: 1.4 mm/yr) and south (Taormina: 1.9 mm/yr) toward a central location near St. Alessio (2.4 mm/yr). The uplift rates decrease at the edges of the region with a different asymmetry. The rates decrease smoothly in northern Calabria (Crotone-Capo Rizzuto: 1.2 mm/yr) and more sharply in south-eastern Sicily (Catania Plain and Siracusa: 0.5-0.8 mm/yr; Fig. 4b). The southernmost sector of south-eastern Sicily can be considered tectonically stable. These rates record the total vertical displacement at each site that may be the result of more than one process. In general, uplift of Calabria and northeastern Sicily results from a combination of sources located in the deep crust, as a response to removal of mantle lithosphere and asthenosphere upwelling (e.g. GVIRTZMANN and NUR, 2001; D'AGOSTINO and SELVAGGI, 2004), or breaking off of the slab (WESTAWAY, 1993; WORTEL and SPAKMAN, 2000), and of sources located in the brittle upper crust and expressed as an array of seismogenic normal faults (WESTAWAY, 1993; MONACO and TORTORICI, 2000; CATALANO et al., 2003). For sites located on the coast of the active Mt. Etna volcano (i.e. Aci Trezza), where uplift rates up to 3 mm/y were estimated by FIRTH et al. (1996), a local contribution derived from magma inflation probably account for these high values. Contribution from active faults has been well documented around Taormina (DE GUIDI et al., 2003) and on the eastern side of the Messina Straits (FERRANTI et al., 2007), where the uplift rates reach maximum values. The analysis indicates that vertical displacement resulted from the combination of steady and episodic motion, the latter attributed to co-seismic slip on normal faults, which are inferred to run immediately offshore this coast (MONACO and TORTORICI, 2000).

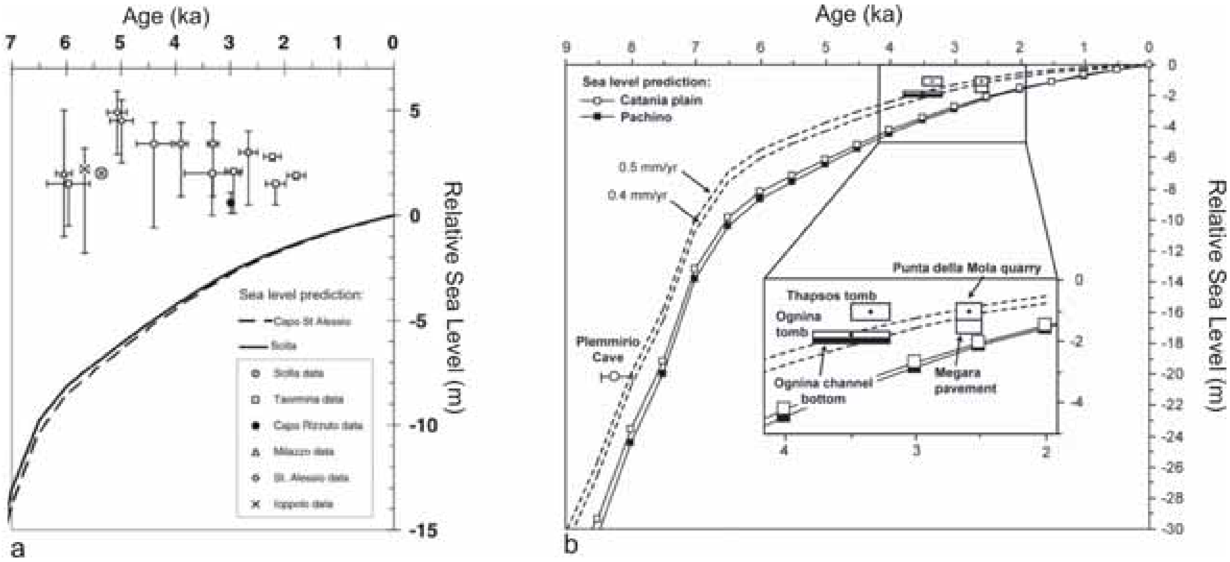

Fig. 4 – Comparison between predicted sea level curves calculated by LAMBECK et al. (2004) for southern Calabria and eastern Sicily coasts and elevation of observed, biological, geomorphologic and archaeological markers. a) Data from north-eastern Sicily and Calabria (from ANTONIOLI et al., 2006). b) Data from south-eastern Sicily; inset shows close up of archaelogical marker (from SCICCHITANO et al., 2008).

In south-eastern Sicily, Holocene sea level indicators are submerged because of slower rates of tectonic uplift (Fig. 4b). Here, data on relative sea-level change have been obtained by analysis of bore-holes carried out in the most depressed coastal sectors and by measures of submerged archaeological markers and of speleothems collected in submerged karstik caves. The southward decreasing Holocene uplift pattern broadly confirms the spatial trend previously evidenced in Late Pleistocene uplift (FERRANTI et al., 2006). These data are consistent with a general southward decrease of both the regional uplift and of the remote effect of the active normal fault system located in the Ionian offshore between Catania and Siracusa, at the bottom of the Malta Escarpment (BIANCA et al., 1999; ARGNANI and BONAZZI, 2005).

FIELD TRIP TO ACI TREZZA, TAORMINA AND SCILLA

Stop 1. Raised paleo-sea level markers in the Aci Trezza area

Near Catania, Holocene uplift is documented in the Aci Trezza area (Fig. 1), where shells of *Lithophaga*, sampled at 1.55 to 6 m elevation within an Holocene serpulid and algal reef encrusting 500 ka old basalts (Fig. 5a), yielded calibrated AMS ages between 1.8 and 6.0 ka BP (FIRTH et al., 1996). These data have large uncertainty since the *Lithophaga* holes are not related to a notch and the paleodepth cannot be accurately estimated (*Lithophaga* presently lives in the Mediterranean from 0 to -20 m). However, Holocene uplift at rates possibly as high as 3.0 mm/yr has been suggested.

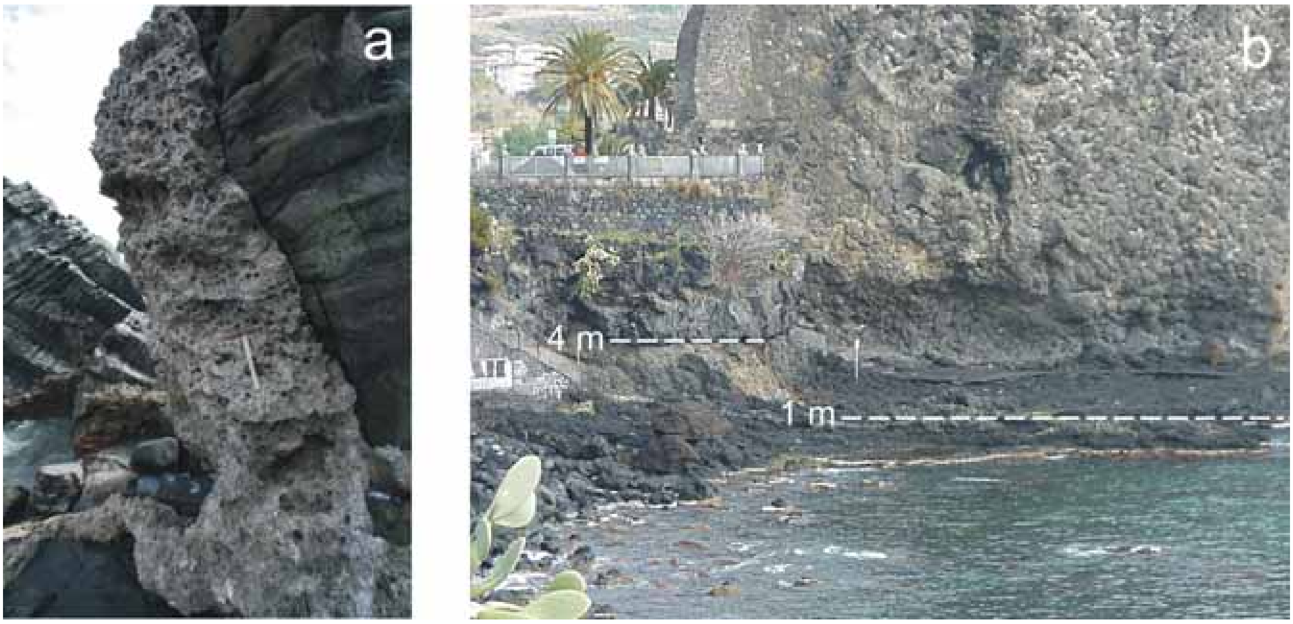

Fig. 5 – a) Aci Trezza, Holocene serpulid and algal reef encrusting 500 ka old basalts. b) Wave-cut platforms on the 500 ka old pillow lavas forming the Aci Castello rock.

Even though volcanics along Mt. Etna coastline usually do not preserve tidal notches, indication of recent uplift is represented by the two wave-cut platforms clearly exposed at 1 and 4 m a.s.l. on the 500 ka old pillow lavas forming the Aci Castello rock (Fig. 5b). Unfortunately, neither encrusting organisms nor fossiliferous beach deposits, useful to determine uplift rates, have been detected.

Stop 2. Raised Holocene notches along the Taormina coast (with the collaboration of G. De Guidi)

The rocky Jurassic limestone coast of Taormina (Fig. 1) is characterized by a prominent notch with well-defined roof, lying at 4.8 m above the biological mean sea level (b.m.s.l.) (5.5 m at Capo Sant'Alessio), above which no evidence of Holocene marine influence has been observed (ANTONIOLI et al., 2003). Therefore it marks the maximum height of relative sea level during Holocene sea-level rise.

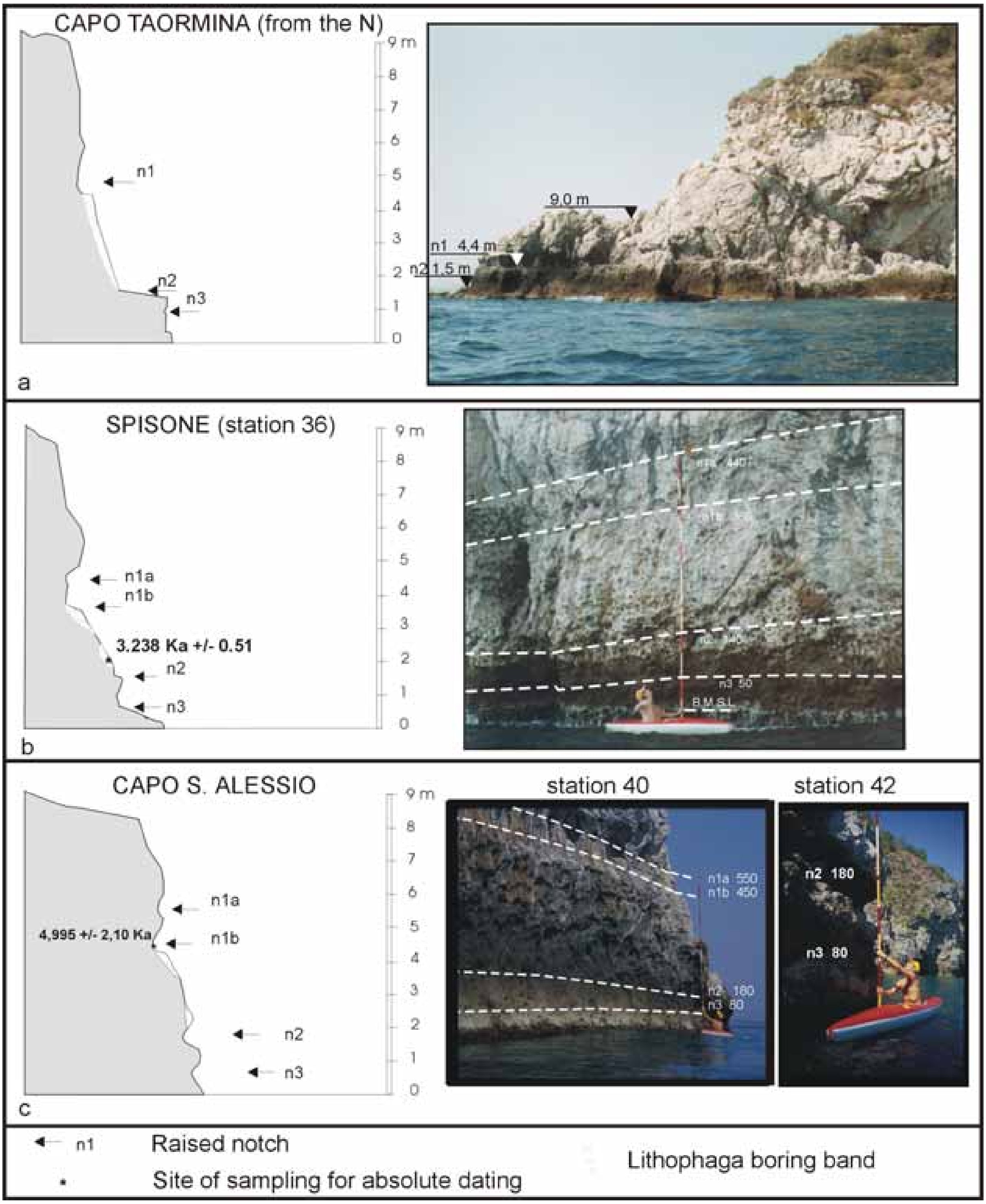

Fig. 6 – Marine notches and benches carving the calcareous promontories of Taormina, and Capo St. Alessio (see Fig.1 for location). In the topographic coastal profiles, the lithophaga boring bands and their absolute dating (STEWART et al., 1997) are also shown (from DE GUIDI et al., 2003).

The floor of +5 m notch is well-enough preserved to show it formed during a still-stand and lower notches are poorly displayed at 1.4-1.8 m and 0.5-0.8 m above b.m.s.l. (RUST and KERSHAW, 2000; DE GUIDI et al., 2003). It is worth to note the absence of a marine notch at present sea level, where it is possible to observe a well developed algal reef. Samples of *Lithophaga* related to the upper deeply cut notch at Capo St. Alessio (Fig. 7) were dated at about 5 ka cal BP (STEWART et al., 1997). At Taormina, samples of *Lithophaga*, *Cladocora* and Vermetids collected on coastal outcrops between 1.5 and 3.4 m a.s.l. yielded calibrated radiocarbon ages of between 1.8 and 6.0 ka BP (STEWART et al., 1997; ANTONIOLI et al., 2003). The finding of the Vermetid *Dendropoma* sp. at the Taormina site is particularly significant for rate determination, since this genus lives within an intertidal belt of ±0.10 m (ANTONIOLI et al., 1999). Overall, estimated Holocene coastal uplift rates (1.9-2.4 mm/yr, see Fig. 4a) exceeded sea-level rise (predicted curve from LAMBECK et al., 2004).

The vertical distribution of these paleao-sea level markers can be interpreted as the result of short-period variations in the rate of tectonic uplifting. The notches and their related bio-morphological bands developed at low rate of uplifting and have been displaced by three major seismic events in the past 5 ka, the strongest of which probably occurred at about 3.2 ka (Fig. 7; DE GUIDI et al., 2003). This co-seismic contribution to the total uplift is supported by a levelling survey carried out along the coast of Taormina and Capo St. Alessio, that showed the Holocene marine notches slightly tilted and converging towards the SW. All these features are compatible with the occurrence of an offshore active normal fault (the Taormina fault; Fig. 2) and indicate the temporary seismic gap for this structure, strongly suggesting that the seismogenic potential of this sector of Sicily needs to be re-evaluated.

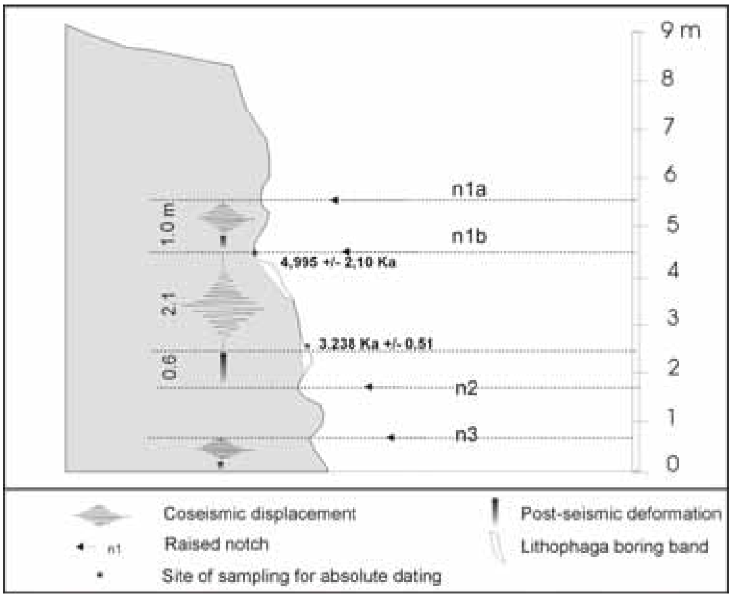

Fig. 7 – Schematic profile of the Taormina coastal region showing the morphological evidences, co-seismic and post-seismic displacements and the age constraints (STEWART et al., 1997) of three probable paleoseismic events in the past 5 ka (from DE GUIDI et al., 2003).

Stop 3. Recent tectonics of the Messina Straits (with the collaboration of D. Morelli)

Intense Quaternary extensional tectonics, coupled to a rapid surface uplift, are well documented in the Messina Straits (Fig. 8), a highly seismic area struck on December 28th, 1908 by a M ~ 7 earthquake and associated devastating tsunami (MONACO and TORTORICI, 2007 and references therein). This structural depression is bounded by normal faults, marked by well preserved scarps, which dissect several, strongly uplifted, Pleistocene marine terraces and Holocene shorelines (DUMAS et al., 1982; GHISETTI, 1984; 1992; VALENSISE and PANTOSTI, 1992; CATALANO et al., 2003; FERRANTI et al., 2007; 2008a).

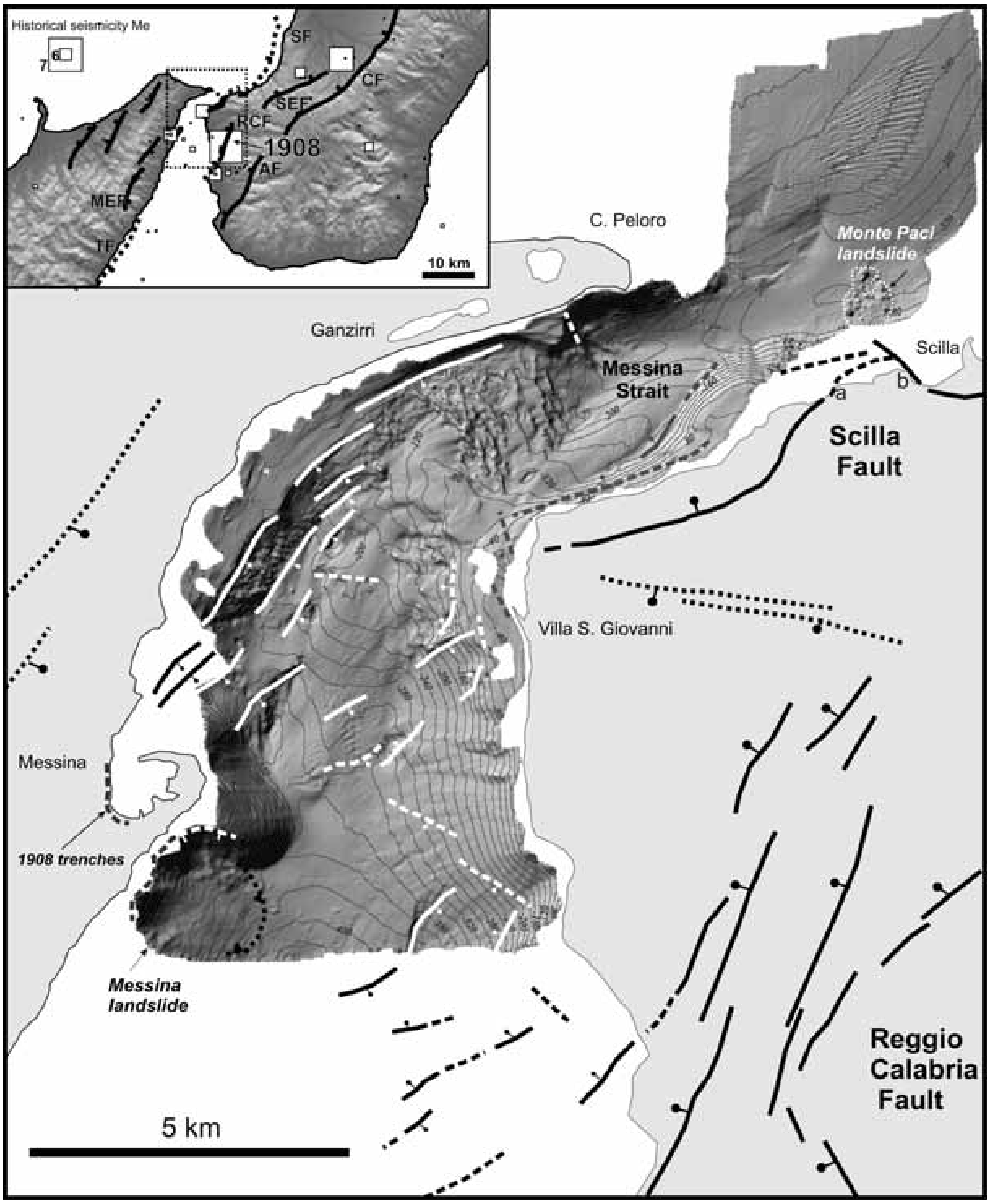

Fig. 8 - Morphostructural setting of the Messina Straits (after Ferranti et al., 2008b). Normal faults with balls on the downthrown side, dashed where inferred. On-land faults slightly modified from Ghisetti (1992), Tortorici et al. (1995), Del Ben et al. (1996), Ferranti et al. (2007); dotted are Early Pleistocene faults. The dotted black line with teeth indicates the trace of the deep toe of the Messina landslide. The white dotted line outlines the extent Punta Paci block landslide. On the Calabrian side raised paleo-shorelines occur at the footwall of the Scilla Fault (site a, Marina di San Gregorio; site b, Punta Paci).

The WSW-ENE to SSW-NNE striking extensional basin of the Messina Strait formed as a consequence of the Pliocene-Lower Pleistocene axial collapse of the inner sectors of the Calabrian arc. The Upper Pliocene-Lower Pleistocene deposition was followed by the uplift of the border fault footwalls and subsequent development, during the Lower-Middle Pleistocene, of huge submarine fan-delta systems (Messina gravels and sands). Since the Middle Pleistocene, the strong regional uplift has caused the emersion of these fan-delta systems. In the meantime, the interaction between the uplift process and the eustatic sea-level fluctuations caused the formation of flights of marine terraces on the basin flanks. Uplift rates have been higher in the Calabrian sector where the normal faults show evidence of recent activity. In particular, in the Ganzirri area the MIS 5.5 terrace is located at altitude of 90 m a.s.l., while in the Villa San Giovanni area it is uplifted up to 170 m a.s.l.

The recent faults in the area are arranged in two broad ~NW-SE trending arrays with opposing polarity separated by a NW-SE trending transfer zone located between Messina and Reggio Calabria (FERRANTI et al., 2008b). A ~8 km-long, SE-dipping fault array is tracked on the western side of the Straits north from the Messina harbor, and to the north swings following the curvature of the coastline (Fig. 8). The fault system is expressed in the multibeam image by fresh rectilinear scarps, locally coincident with reflector truncation up to the sea-bottom. The southward extension of the fault array projects right across the hook-shaped Messina harbor. Offshore east and south of this location, no evidence of young normal faults was found. The western array is parallel to major faults mapped on-land, which terminate at the latitude of Messina. A sub-parallel system of high-angle faults with NW dip forms the eastern array on the Calabrian side of the Straits. In contrast with the narrow western array, the Calabrian array is broader. The array is composed of two laterally offset systems, separated by a NW-SE striking transfer zone which follows bathymetry and isochronopaches gradients and controls the release of micro-seismicity (NERI, 2007). The northern system forms the offshore extension of the Scilla fault, and the southern accommodates displacement in the hanging-wall of the Reggio Calabria fault. This southern system is wider (~5 km) than the northern one, and large offsets of tens of meters are observed in the Middle Pleistocene-Holocene sequence.

Different sources have been modeled for the 1908 earthquake but all agree with dominant normal faulting on planes trending nearly parallel to the Messina Straits, with different locations and dipping (v. VALENSISE and PANTOSTI, 1992; AMORUSO et al., 2002 and references therein). However, high-resolution swath bathymetry and multichannel sparker profiles show that through-going ~N-S striking faults with surface trace in the Straits are not present. Conversely, the youthfulness and fresh bathymetric expression of many of the faults in the eastern array indicates that these faults may be activated during large or moderate-sized earthquakes. These observations and the macroseismic picture strongly suggests that the 1908 event could be related to rupture along the NE trending, west-facing Reggio Calabria fault including its offshore propagation on the Straits of Messina (see also SCHICK, 1977; BOTTARI et al., 1986; GHISETTI, 1984; WESTAWAY, 1992; TORTORICI et al., 1995). The area of major damages was in fact located along the Calabrian side of the Straits where permanent subsidence and ground fractures were recorded, whereas the damages of the Sicilian side were mostly related to the occurrence of the destructive tsunami. This interpretation is supported by the analysis of the focal mechanism that shows a slip occurring along a NNE trending, west-facing nodal plane (RIUSCETTI and SCHICK, 1975; SHICK, 1977) and is consistent with the regional structure of the Messina Straits area, characterized by master faults on the Calabrian side and associated antithetic faults on the Sicilian side (GHISETTI, 1984; MONTENAT et al., 1991; TORTORICI et al., 1995). However, as the strong rates of deformation on the high-angle west-dipping morphogenic fault along the Calabrian coastline has to be reconciled with the source model of a low-angle blind normal fault merging at the surface on the Sicilian side, an alternative model can be represented by displacement on two antithetic structures (see also MULARGIA and BOSCHI, 1983; BOTTARI et al., 1989). Finally, according to the numerical modelling simulations performed by TINTI and ARMIGLIATO (2000; 2001; 2003) on the basis of an east-dipping source, the tsunamigenic earthquake source is certainly placed under the Messina Strait, where caused subsidence of the sea floor, and extends to the south under the Ionian Sea.

Stop 4. Raised palaeo-shorelines along the Scilla coast

In the Messina Straits area new data on Holocene uplift derive from the Calabrian side (see Fig. 8). Along the Scilla coast two Holocene uplifted shorelines have been identified (ANTONIOLI et al., 2004; FERRANTI et al., 2007; 2008a). The upper shoreline is represented by a wave-cut platform locally covered by fossiliferous beach deposits including intact or fragmented bioclasts. At Marina di San Gregorio (Fig. 9a), the upper shoreline is conservatively estimated at 3.65 m a.s.l. midway between the upper limit of the beach sands and the upper limit of fossil shells observed in the deposit. Conversely, the availability of several elevation constraints allows a robust elevation estimate at ~2.9 m a.s.l. for the upper shoreline at Punta Paci (Fig. 9b), although the nominal uncertainty is quite large. The lower shoreline is characterized by a prominent barnacle band, and locally by a wave-cut platform. At Punta Paci the band lies at elevations ranging between ~0.8 and ~1.9 m a.s.l. (Fig. 9b). Here, an algal rim bored by *Lithophaga* holes is found at ~1.4 m a.s.l. below the denser patch of the barnacle band, and only isolated individuals are found beneath. Duration of the lower shoreline is tightly constrained by radiocarbon ages of barnacles between 3.5 and 1.9 ka (Fig. 9), and its inception is in good agreement with cessation of the older shoreline (FERRANTI et al., 2007; 2008a).

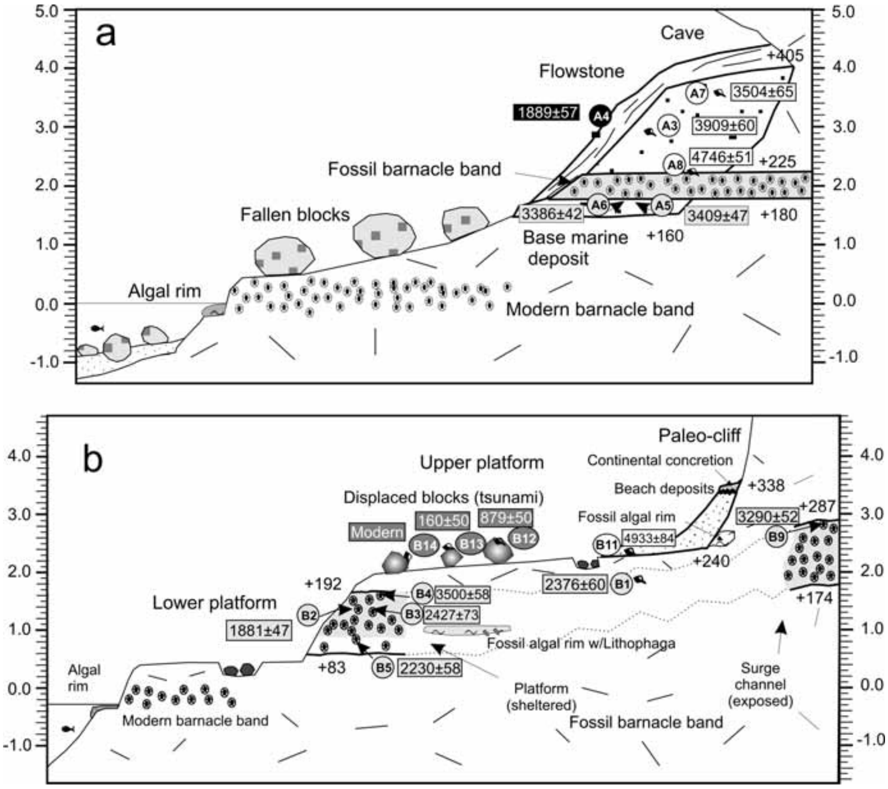

Fig. 9. Sketched profiles of Holocene outcrops along the Scilla coast (a, Marina di San Gregorio; b, Punta Paci, see Fig. 8 for location) showing the relations between morphological features of the upper and lower palaeo-shorelines, their elevation above the present sea-level, and the radiometric ages. Upper, lower shoreline, and displaced samples morphology and ages are indicated with white, light grey and heavy grey filling pattern, respectively. In (a), a flowstone sealing both palaeo-shorelines is shown with black filling pattern. No vertical exaggeration (from Ferranti et al., 2008a).

Integration of on-land and offshore geomorphological and structural investigations coupled to mapping and extensive radiometric dating of the raised Holocene beaches reveals that these are located at the footwall of the Scilla normal fault (Fig. 8) and that uplift has both steady and abrupt components (FERRANTI et al., 2007; 2008a). The ~30 km-long Scilla fault (Fig. 2) may be divided into three segments of ~10 km individual length. The central and northern segments are submerged, and in this area marine geophysical data indicate a youthful morphology and locally evidence of active faulting. The on-land strand of the western segment displaces marine terraces of the last interglacial (124 to 83 ka), but seismic reflection profiles suggest a full Quaternary activity. Structural data collected on bedrock faults exposed along the on-land segment provide evidence of normal slip and ~NW-SE extension, which is consistent with regional kinematic studies (MONACO and Tortorici, 2000), focal mechanisms of earthquakes (Neri et al., 2005) and GPS velocity fields (D'Agostino and Selvaggi, 2004). Radiometric dating of the shorelines indicates that rapid co-seismic displacements occurred at ~1.9 and ~3.5 ka, and possibly at ~5 ka (Fig. 10). Co-seismic displacement show a consistent site value and pattern of along-strike variation, suggestive of characteristic-type behaviour for the fault. The ~1.5-2.0 m average footwall uplift during co-seismic slips documents M_e~6.9-7.0 earthquakes with ~1.6-1.7 ka recurrence time. The palaeoseismological record based on the palaeo-shorelines suggests that the last rupture on the Scilla Fault during the February 6, 1783 M_W=5.9-6.3 earthquake was at the expected time but it may have not entirely released the loaded stress since the last great event at ~1.9 ka.

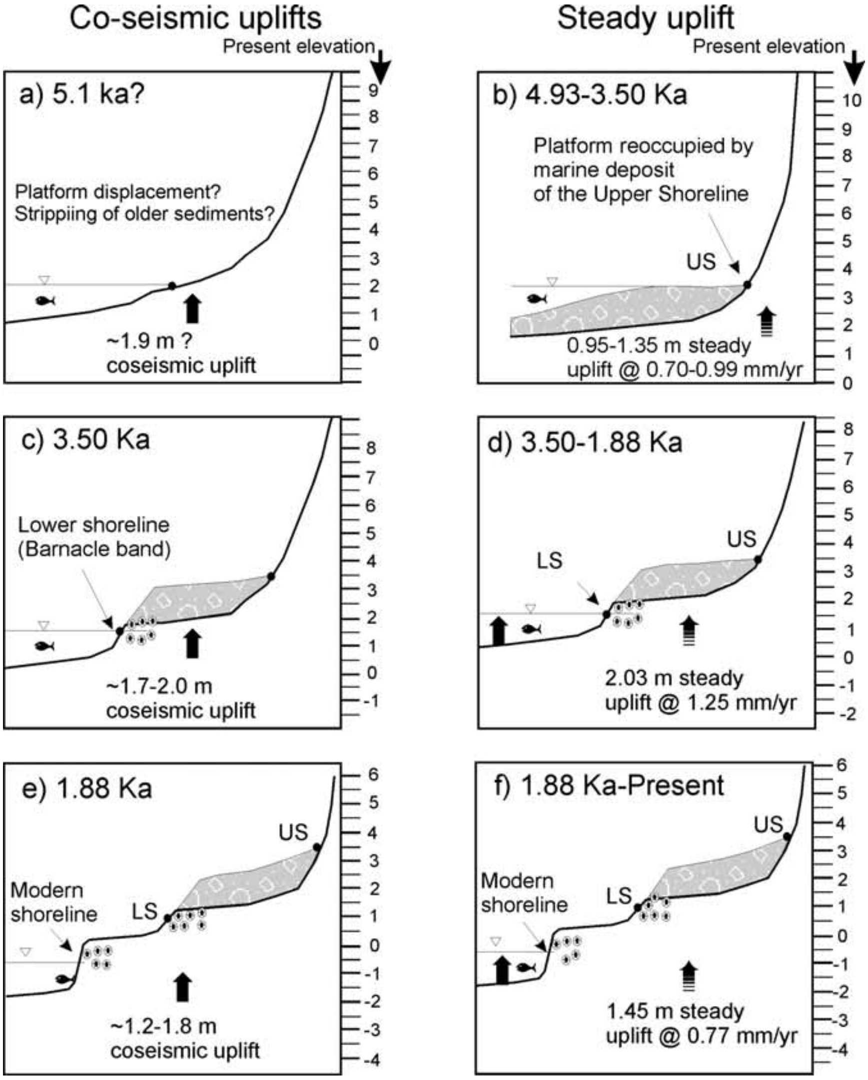

Fig. 10 – Uplift history of the Scilla coast during six distinct episodes of steady and abrupt displacement (from Ferranti et al., 2007). US, upper shoreline; LS, lower shoreline.

Precise compensation for sea level changes constrains Late Holocene steady uplift during the interseismic intervals at ~1 mm/yr, a value consistent with long-term (0.1-1 Ma) estimates of regional uplift (Westaway, 1993). Thus, Late Holocene total uplift at ~1.6-2.1 mm/yr (see Fig. 4a) is nearly equally balanced between regional and co-seismic components. Appraisal of the present elevation attained by a suite of 125 ka and younger marine terraces indicate that rapid net uplift occurred at ~100-80 Ka and since ~5 ka, which, given the ostensible constancy in regional uplift rate, are attributable to enhanced slip rate on the Scilla fault. Efficient seismic strain release was clustered in intervals of 10-20 ka, and intercalated with a ~80 Ka long period of fault quiescence.

FIELD TRIP TO MEGARA IBLEA AND OGNINA (SIRACUSA)

Stop 1. The submerged pier ("Banchinamento Orsi") in the archaeological site of Megara Iblea (with the collaboration of E.F. Castagnino Berlinghieri and G. Scicchitano)

Megara Hyblaea (Orsi, 1890; Cavallari, 1892) is an ancient Greek colony built alongside a large Quaternary calcarenite plateau (A.A.V.V., 1987) facing the Augusta Gulf, at an elevation of 10-15 m above sea level (Figs. 1 and 11a). It is located inside the modern Augusta harbour between two rivers, the Cantera to the north and the San Cusumano to the south. The most significant archeological marker is a submerged stone structure, at about 4 m off the present coastline near the north-eastern corner of the plateau (Fig. 11), previously observed by foreign visitors (Houel, 1785; Schubring, 1864) and first analyzed by Orsi (1890) who was able to recognize it during an exceptional low tide episode. This stone structure ("banchinamento"), later reconsidered by Villard and Vallet (1953) and Gras (1995), was interpreted as a harbour pier because of location, block typology, and building technique. It is 24.50 m long and 5.30 m wide (Fig. 11b) and it was built in the so called "Greek style" technique that is typical of landing or military structures of the Greek world. This technique is characterised by the use of large parallelepiped calcarenite blocks, as long as 1 m and without any joins or transversal blocks, arranged in four overlapping rows (Fig. 11c): the first one seems to be placed straight on the rocky seabed and no foundation level has been detected, the second one forms a large submerged platform. In the eastern sector, the sea-bottom relative to the second row is 1.20 m deep at the pier foot, and 0.80 m (corrected height - 0.88 m) at the pier head. Although only part of the four rows of blocks is still in place, one might hypothesize the existence of a complete four-row structure; if we consider the top of the mentioned structure and its original functional surface, the palaeo-sea level should be at 1.48 m depth.

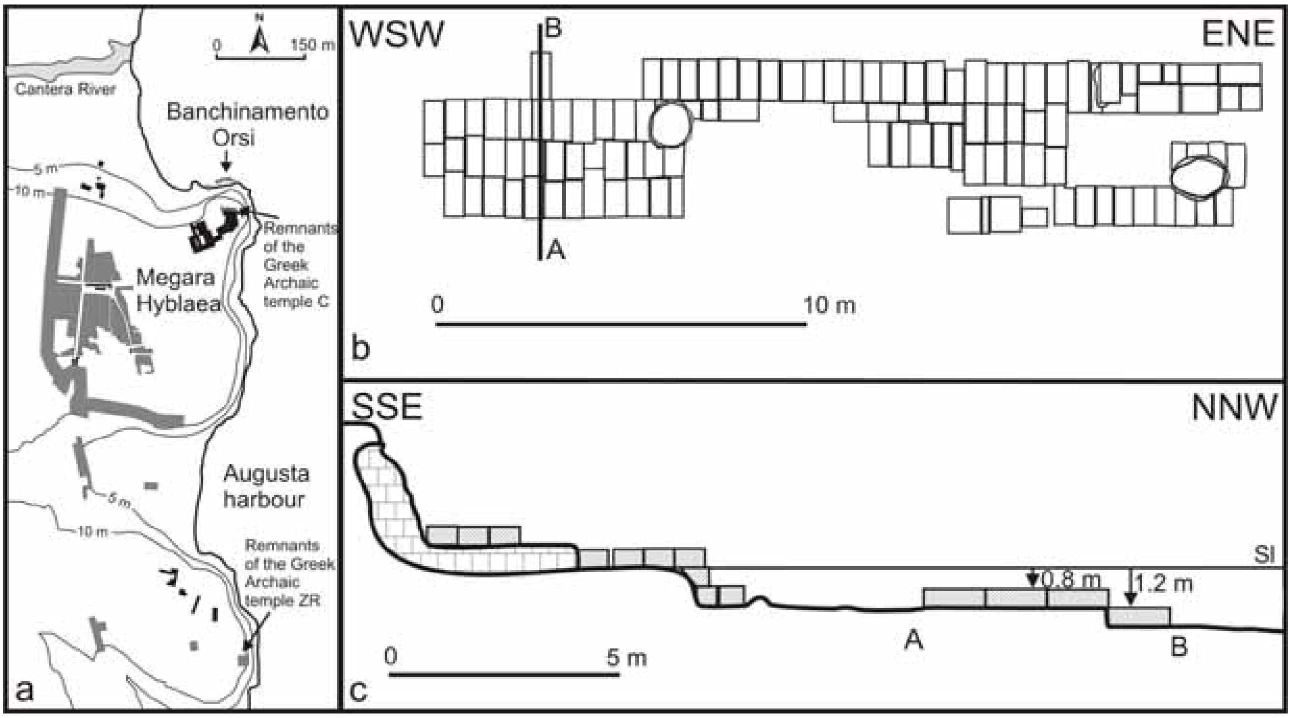

Fig. 11 – a) Sketch map of the archaeological site of Megara Hyblea (see Fig. 1 for location; from Scicchitano et al., 2008); the position of the submerged "Banchinamento Orsi" harbour pier is shown; b) plan and c) cross-section of the "Banchinamento Orsi" harbour pier (from Villard and Vallet, 1953).

According to Villard and Vallet (1953), the submerged stone structure, named "Banchinamento Orsi" should be a portion of a bigger complex ("portique à ailes ") connected with another structure transversally located onshore (Fig. 11a), which is built by stone blocks similar in size, but rather differently arranged in technique. Recent studies (GRAS, 1995; TRÉZINY, 2002; GRAS et al., 2004) interpreted the entire complex as a monumental fountain ("fontaine du Cantera") by comparison with similar old Greek structures. Regardless of the interpretation of the entire structure, the "Banchinamento Orsi" could well be a harbour pier area arranged since the Greek Archaic Age (2.5-2.7 ka) in order to support a channel-harbour on the ancient mouth of the Cantera river.

In the Siracusa area, submerged archaeological and geomorphological markers indicate that in the last 8 ka, sea level rise was faster than tectonic uplifting. The tectonic contribution can be evaluated as the difference between the observed local palaeo-sea level positions and the predicted sea level curve for the same locality (LAMBECK et al., 2004). The Megara pier head is located at – 0.88 m and considering a functional height of 0.6 m, the relative sea level should have been at -1.48 m depth 2.6±0.1 ka ago. Comparing this value with the predicted sea level, we obtain an uplift rate of 0.30 +0.03-0.04 mm/yr for the last 2.6 ka (see Fig. 4b).

Stop 2. The submerged markers in the archaelogical site of Ognina (with the collaboration of E.F. Castagnino Berlinghieri and G. Scicchitano)

The Ognina area is located 10 km south of Siracusa and is formed by two small promontories (Fig. 12a). The coast is mostly characterized by rocky platforms, carved on Miocene and Pleistocene calcarenites (A.A.V.V., 1987), placed between 3 and 0.5 m a.s.l. and gently sloping seaward. The archaeological site was mostly located on a former small peninsula (the main part is the Ognina island, inset in Fig. 12a), connected to the mainland by a narrow rocky isthmus, which is now submerged. It is a complex site with remnants of several archaeological phases, spanning the period from Neolithic to Byzantine. The submerged rocky isthmus provided in the antiquity the settlement with sheltered leeward anchorages and beaching places, and it is still in place, from -0.20 m down to -3.30 m relative to the present sea level.

On the tiny offshore island of Ognina a series of post-hole structures arranged in parallel alignments suggest the presence of a settlement established during the Neolithic Age while a stable Maltese trading center (BERNABÒ BREA, 1966; PARKER, 1980) flourished during the Bronze Age (3.8-3.2 ka). Close relationships with Malta are suggested by certain vessels which are matched with *Tarxien* (3.8-3.4 ka) and *Borg in Nadur* (3.4-3.2 ka) cultures (BERNABÒ BREA, 1958) and which reflect a series of long-distance contacts within an organised system of maritime trade. In the western sector of the islet (see inset in Fig. 12a), a partially submerged Bronze Age tomb of the rock-cut chamber type is carved in the calcarenites. This chamber is preceded by a long *dromos* with an elliptical opening, the floor of which is at – 1.20 m (corrected height – 1.21 m) below the present sea level. Taking into account the functional height, the palaeo-sea level should have been at ≤ -1.81 m depth.

Further meaningful indicators of sea level change come from the adjacent coastal mainland and are located along the channel as well as along the coast southward the Capo Ognina. Alongside the channel several partially submerged bollards are carved into the rock. Below the sea-surface a bollard has been detected which forms a small artificial mushroom shape, the foot of which is 0.9 m below the present sea level (Fig. 12b). The sea bottom inside the channel has been detected at maximum -3.00 m (-2.97 m corrected for tide and pressure). Taking into account at least 1.0 m of ship draught (CASTAGNINO BERLINGHIERI, 2003), the palaeo-sea level should have been ≥ -1.97 m depth. These two last data points are very significant if we relate them with the Bronze Age (3.8-3.2 ka) activity at the site by the Maltese and other seafaring people, as attested by archaeological evidence. It is worthwhile to note that the channel extends to the east where it is completely submerged, with bottom reaching a depth of -13 m b.s.l. (Figs. 12a and 12c).

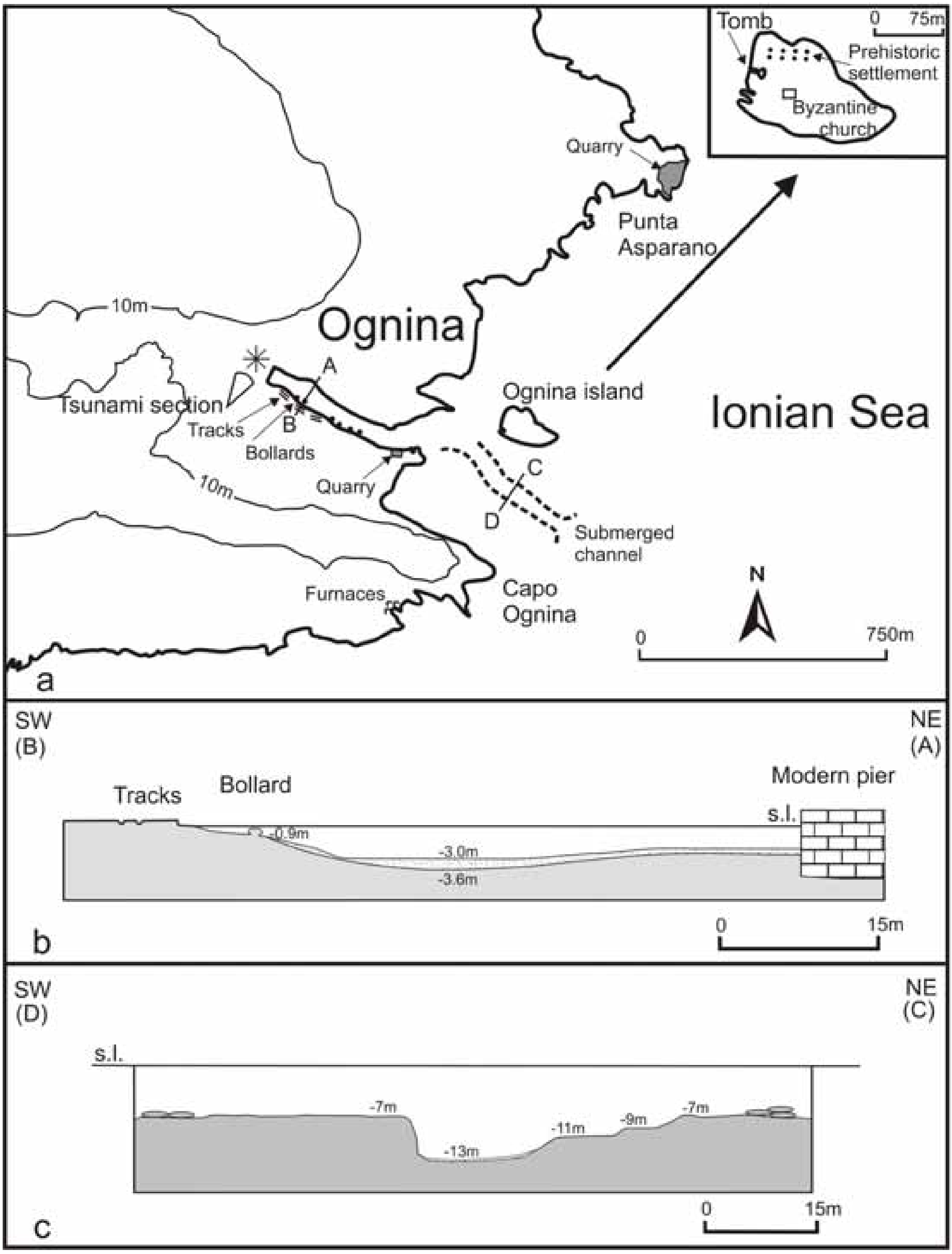

Fig. 12 - a) Sketch map of the archaeological site of Ognina (see Fig. 1 for location; from SCICCHITANO *et al., 2008); inset shows the islet with the position of the partially submerged tomb; b) cross sections of the emerged (A-B) and submerged (C-D) sectors of the Ognina channel.*

Along the edge of the channel (Fig. 12a) there are tracks (*carraie)*, previously discussed by CASTAGNINO BERLINGHIERI (1993-1995), which show clear sign of erosion and part of which are collapsed by the southern side of the channel border. Although shapeless shards of amphorae and common ware have been recovered from the submerged channel, it is rather difficult to assess the chronologic range of use, but it seems feasible to surmise that this road system was built to support the intense activity along the channel. Stone quarries are in fact located both on the north and on the south side of the present channel mouth; these are of uncertain age and currently partially submerged with floor located at maximum depths of 0.30 m below sea level. In addition, a partially submerged furnace of uncertain age has been found south of Capo Ognina (Fig. 12a).

A significant marker for identifying sea level comes from the Bronze Age tomb of Ognina islet, the floor of which is at – 1.21 m below the present sea level. Taking into account that the palaeo-sea level was at least 0.60 m lower than the original floor, that is 0.30 m above high tide (+0.30 m) to be always dry the relative sea level should have been at -1.81 m depth 3.5±0.3 ka ago. Comparing this value with the predicted sea level, we obtain a maximum uplift rate of 0.49 +0.09/-0.10 mm/yr for the last 3500 yrs (see Fig. 4b). These values can be compared to the Ognina channel topography which is characterized by sea-bottom maximum depths of -2.97 m (corrected for tide and pressure). If we consider that in the Bronze age (3.5 ka ago) the sea level was 3.5 m lower than the present (LAMBECK et al., 2004), it means that the channel bottom should have been emergent, unless tectonic uplift has occurred in the intervening time. Taking into account that the ships that used these coastal structures could have had a possible draught of about 1.0 m (KAPITAEN, 2002; CASTAGNINO BERLINGHIERI, 2002) and assuming negligible sedimentation accumulation since the Bronze age**,** the relative sea level should have been not more than 1.97 m lower than the present which might fit with the maritime topography analysed. Correcting this value for the predicted sea level, in this case we obtain a minimum tectonic uplift rate of 0.44 ±0.10 mm/yr (see Fig. 4b).

Stop 3. The historical tsunami section of Ognina (with the collaboration of A. Di Stefano, B. Costa, S. Longhitano and G. Scicchitano)

The effects of the 1169, 1693 and 1908 tsunamis are still recognizable in the Siracusa coastal area (Fig. 1) where boulders up to 182 ton in weight, encrusted by dated marine organisms, were removed and transported inland at a distance of up to 70 m (SCICCHITANO et al., 2007). Tsunami deposits can be recorded also in other different coastal settings along the same area, where sediment deposited after high-energy events can be sufficiently preserved by the erosive action of incident waves and by other depositional alluvial processes. An impressive example of this condition occurs at Ognina, about 20 km south of Siracusa (Fig. 1), where a beach-barrier system develops in a quasi-confined embayment (SCICCHITANO et al., submitted). Here, landward-shoaling waves can be subjected to hydraulic amplification and their effects into the beach can simulate destructive events. Accordingly, distinction between storm and tsunami deposits has to be afforded using multidisciplinary approaches (e.g. TAPPIN, 2007; KORTEKAAS and DAWSON, 2007; DAWSON and STEWART, 2007).

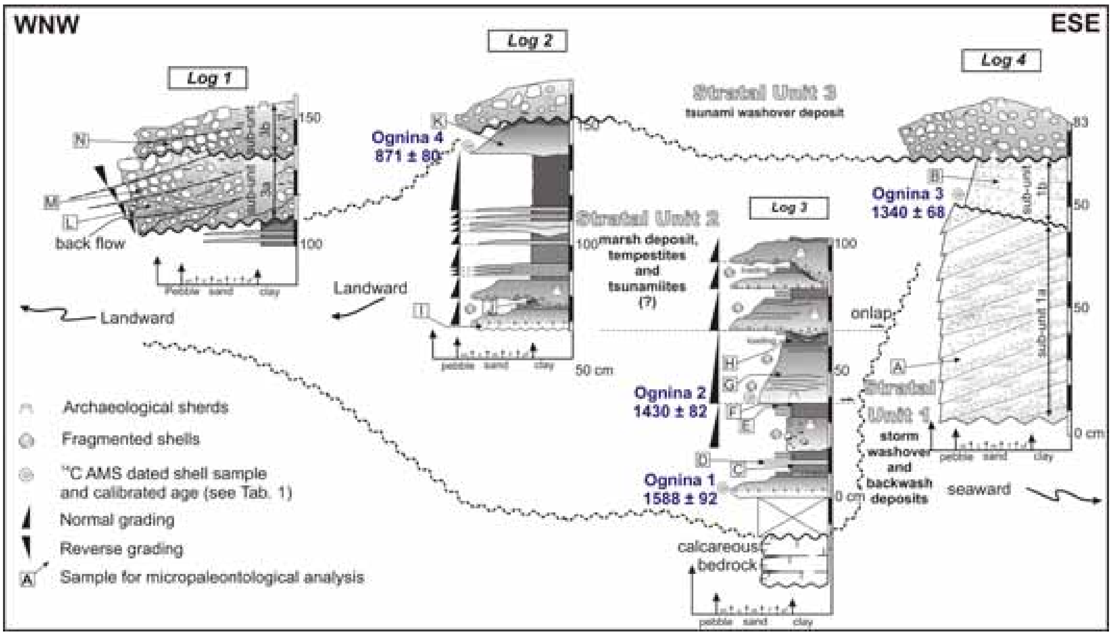

Fig. 13 - Sedimentological logs measured across the Ognina section (see Fig. 12a for location) showing samples location for radiocarbon and archaeological dating.

The analysed outcrop is represented by a natural section located on the back edge of the 500 m long Ognina coastal embayment, interpreted as a *ria* incised within Miocene limestones. Within a small valley, whose bottom lies at 0 m with respect to the mean sea level (msl), an ancient beach deposit has been preserved by marine erosion thanks to the internal and thus protected position and to the recent construction of a harbour quay just at the end of the natural channel. The ENE-WSW-oriented, 20 m long Ognina section is represented by a 0.3 to 1.8 m thick succession consisting of fine to coarse sediments lying unconformably on Miocene calcareous bedrock. The succession can be divided into three stratal units, separated by discontinuous and irregular bounding surfaces (Fig. 13).

Our cross-checked analyses have allowed us to interpret the three stratal units forming the Ognina section as follow (Fig. 13): the internal architecture of the well-sorted sediments forming the Stratal Unit 1 suggests that it might derive by the superimposition of a landward-directed washover fan (lower sub-unit 1a) and a seaward-directed small backwash fan (upper sub-unit 1b), whose emplacement we attribute to the depositional effect of a series of repeated storm surges of weekly/monthly duration and successive seaward beach recovery. Radiocarbon age of shells collected from Stratal Units 1 and 2 suggest that deposition of these units was partially coeval. The growth of Stratal Unit 1 produced, in fact, morphological confinement for the subsequent beach-barrier development. The isolation from the sea favored marsh sedimentation in the inner part of the system, seasonally reached by high-energy waves of short duration, and responsible of the deposition, within the marsh laminites, of the coarser lenticular layers containing a mixture of shallow-marine and brackish-water fauna associations (Stratal Unit 2). Radiocarbon dating of bivalve shells constrains the age of the bottom of the Stratal Unit 2 to the IV century, whereas its top can be younger than the XII century. Moreover, several pottery sherds and glass fragments of Late-Ancient age have been found at distinct levels in the bioclastic lenses. Taking into account the historical seismicity of south-eastern Sicily and the physiographic setting of the Ognina embayment, amplified marine storm waves or lower energy tsunami events could have been responsible for the deposition of some of the coarser intervals observed within the Stratal Unit 2. Radiocarbon dating suggest that the bottom and top coarse levels of the Stratal Unit 2 could have been triggered by the 365 A.D. earthquake, which struck the entire Mediterranean coasts, and by the seismic event of February 4, 1169, which destroyed south-eastern Sicily, respectively

The depositional system was dramatically deactivated after the emplacement of the chaotic deposit of the Stratal Unit 3, probably occurred between the XVII and the XVIII century. Textural and grain size characters of this unit, together with the overall internal architecture and palaeontological and archaeological contents (Fig. 13), indicate unequivocally the derivation from a destructive, high-energy and landward-directed surge of a non-gravitative mass flow. This chaotic material was instantaneously detached, transported and deposited by an anomalous wave that after having crossed the entire embayment and jumped over the barrier of Unit 1, erosively reached and filled the repaired lagoon. The whole features suggest that a tsunami wave would have been responsible for the deposition of this unit, as most characters are incompatible with the depositional regime of a beach-barrier environment. The catastrophic wave, probably related to the large tsunami of January 11, 1693, was subjected to hydraulic amplification due to the progressive inland narrowing of the gulf, which produced a series of high-energy sediment surges.

THE STABLE NORTH-WESTERN COAST OF SICILY

The NW sector of Sicily represent the emerged western edge of the Sicilian–Maghrebian Chain, which originated from the Neogene deformation of the Meso-Cenozoic northern African continental margin. The geological setting of the area (Fig. 1) is characterized by the Middle-Upper Miocene overthrusting of tectonic units referable to the Panormide carbonatic platform and its margins on units belonging to other palaeo-geographic domains (such as the Trapanese basin; CATALANO and

D'ARGENIO, 1982). Further (Pleistocene) disjunctive and strike-slip tectonics, occurred mainly along NW–SE, NE–SO, N–S and E–W oriented normal fault systems, caused the splintering up into blocks with differential raising and the formation of structural highs alternated to basins (D'ANGELO et al., 1997). In the Capo San Vito Promontory, near Trapani (Fig.1), this is reflected by the occurrence of lowered sectors, presently occupied by coastal plains (Castelluzzo and Cornino Plains; ABATE et al., 1991). Moreover, the recent tectonics created favorable conditions for the onset of both deep-seated and surficial gravitational slope deformations, which are particularly widespread along the eastern flank of the peninsula (AGNESI et al., 1995).

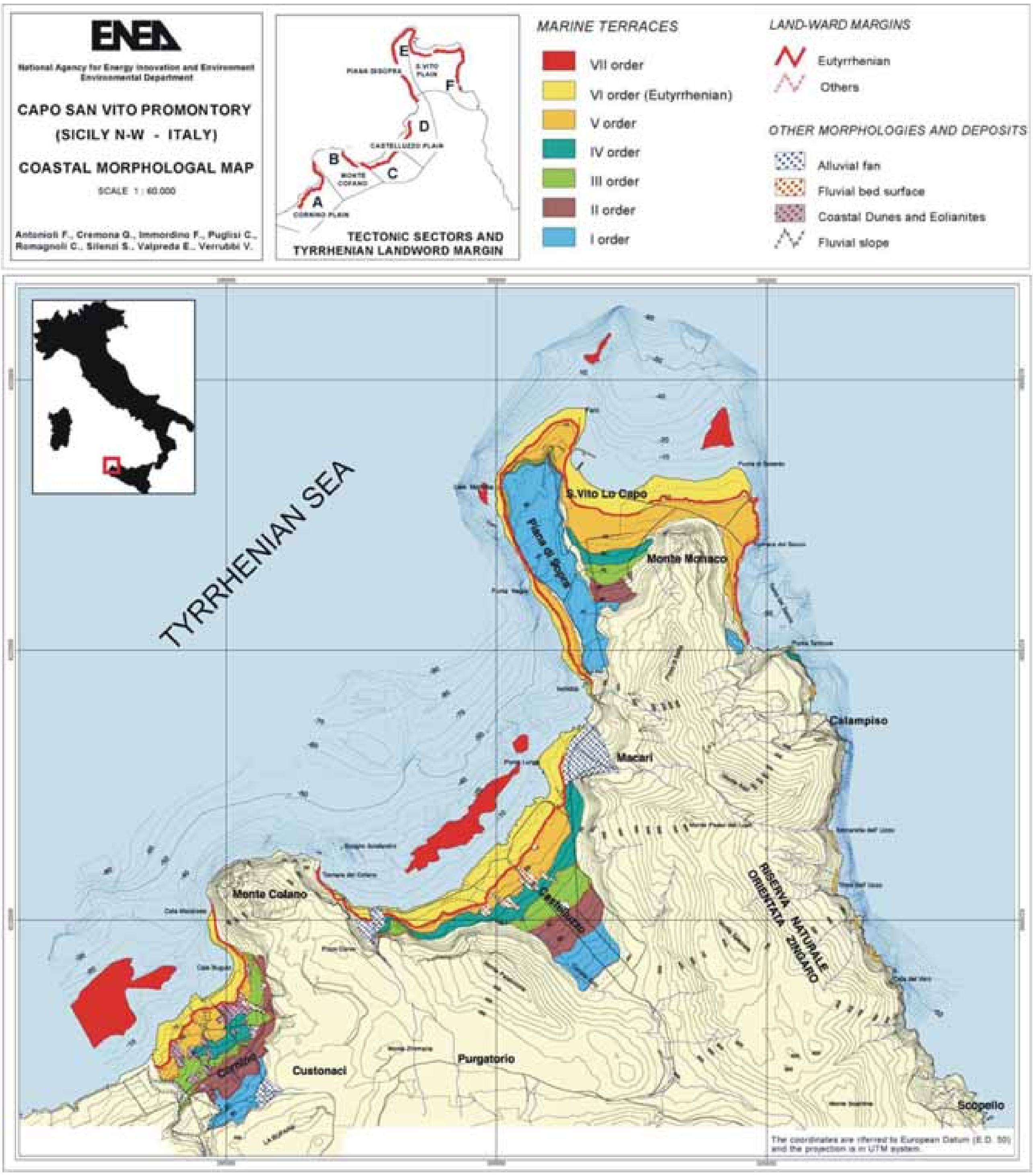

Fig. 14 - Coastal geomorphological map of the Capo S. Vito Promontory (from ANTONIOLI et al., 2002).

The St. Vito lo Capo coastal area (Fig. 14) is characterized by Mesozoic–Tertiary units composed of carbonatic, evaporitic and silicoclastic deposits, overlain in discordance by late orogenic clastic deposits (ABATE et al., 1991, 1996). Several orders of marine terraces are present at different altitudes (up to 160 m). Their formation has been considered to be of Middle-Upper Pleistocene age, since they cut not only carbonatic rocks and marl-stones of Mesozoic age but also terrigenous, evaporitic and calcarenitic formations of Late Miocene to Lower Pleistocenic age (D'ANGELO and VERNUCCIO, 1996). This area has been selected for the field trip for its uncommon conservative morphological setting, with well-preserved geomorphological and depositional features connected with Quaternary sea-level fluctuations, such as the succession of marine notches and terraces located both above and below the present m.s.l.; moreover, it is characterized by the presence of accurate and datable indicators of palaeo-sea levels (Vermetid bioconstructions and submerged speleothems), the use of which was subordinate to the knowledge of the vertical crustal movements affecting the coastal sector.

FIELD TRIP TO SAN VITO LO CAPO

Stop 1. Pleistocene terraces of San Vito lo Capo, in particular MIS 5.5 marine notch, inner margin and *Strombus b.*, *Elephants* and *Hippopotamus* in Early Pleistocene calcarenites

Extensive outcrops of Quaternary forms and deposits occur in the coastal plains of San Vito, Castelluzzo and Cornino (Fig. 14); they are represented by bioclastic calcarenites, conglomerates with sandy matrix, lacustrine sands and gravels and aeolian calcarenites. Particularly, littoral calcarenites and conglomerates, associated with the lowermost marine terrace, outcrop in lenses along the western coastal tract of the Capo San Vito Promontory. They have been ascribed (ABATE et al., 1993; 1996; MAUZ et al., 1997; ANTONIOLI et al., 2002) to MIS 5.5 higstand for the presence of a typical warm molluscan fauna (with *Strombus bubonius* and other Senegalese taxon). On the base of their present-day height along the western side of the Capo San Vito Promontory, these authors pointed out a relative stability and a limited differential uplift during the last 125 ka. The maximum elevation varies between 5 and 14 m, well marked by the inner margin of a very continuous terrace and few tidal notches. In some locations during the Holocene, Dendropoma platforms developed (ANTONIOLI et al., 1999) but these are not uplifted (see below). We interpret this to be a quasi-stable coast, even though strike-slip faulting was active after MIS 5.5 and reactivated during Late Holocene time. An example is at San Vito where some *Dendropoma* platform deposits are dated between 400 and 650 years, and are displaced by these active faults (TONDI, 2007).

Morphological evidences of seven marine terrace (from + 90 to about -18 m) occur (Fig. 14), consisting in sub-horizontal wave-cut platforms, with a remarkable lateral continuity and locally well-preserved marine deposits lenses (ANTONIOLI et al., 2002). Marine notches (at 8, 15, 45, 60 and 70 m above the present sea level) are also evident. The marine forms were ascribed to the Middle and Upper Pleistocene, by morphological and stratigraphic criteria. Dating trough U/Th method on speleothems, which locally coat marine notches, provide only the upper chronological limit for the Terrace II (linked to the notch at + 62 m) modelled in a period before 78 ka ago and for the lower terrace of the emerged sequence (Terrace VI, notch lying at 8 m a.s.l.; Fig. 15a) modelled before 20 ka BP, which means before the LGM and, as suggested by other observations, in correspondence of the Last Interglacial. Only the shallowest of presently submerged terraces (Terrace VII) shows a good lateral continuity and ranges from -15 to -18 m b.s.l. On the basis of its altitude this terrace could have developed during MIS 7 (BARD et al., 2002). The palaeontological analysis of the marine sediments showed the presence of a "Senegalese" fauna, with molluscs as *S. bubonius* in several bioclastic lenses overlying the VI-order Terrace.

Fig. 15 – a) Cala Mancina, MIS 5.5 marine tidal notch at 8 m a.s.l.; b) Tonnara del Cofano, broad Dendropoma platform; c) Cornino, Middle Pleistocene marine notch deformed by a normal fault.

Stop 2. Vermetid reef near the Tonnara del Cofano

Most carbonate rocky shores of NW Sicily are marked by a coalescence of living shells of the gastropod *Dendropoma* in a construction that is variably developed as a response to wave impact. The fossil reefs are reliable sea-level indicators (Fig. 16). The thickness of the reef samples never exceeds 30–40 cm below sea-level, whereas all ^{14}C dates fall within a range of few centuries. Some small fragments ejected by violent sea storms date back to 2500 years cal BP. No samples older than 6200 years cal BP have been detected so far. The present distribution of Mediterranean vermetid platforms should result from a northward migration related to the long term effect of the Holocene sea surface temperature warming. Some consideration on the morphology of the reefs and the comparison with the available data point out that *Dendropoma* reefs are excellent biological indicators of sea-level fluctuations especially when detected and sampled in tectonically stable areas as those in NW Sicily. On the contrary, if the palaeo-sea level curve is known, raised Vermetid rims can be used as tectonic uplift marker.

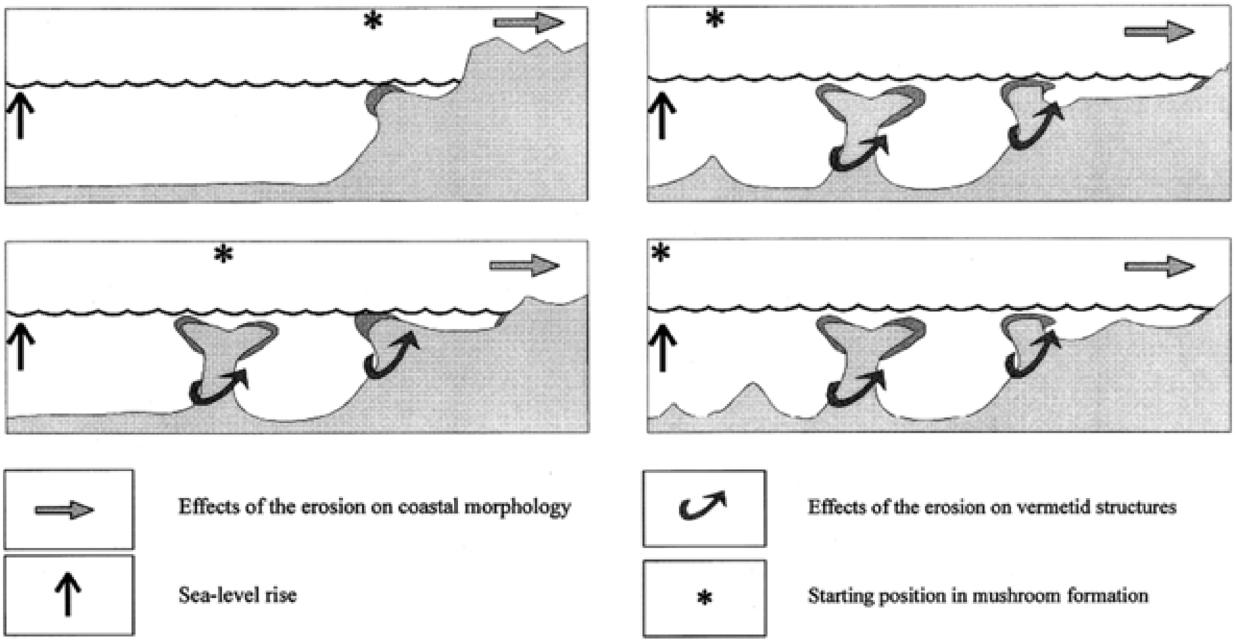

Fig. 16 – Outline of the mechanism of the mushroom-like Dendropoma concretioning (from ANTONIOLI *et al., 1999).*

Due to the lack of palaeoclimatic indicators comparable to coral reefs, geologists investigating recent climatic changes in temperate areas like the Mediterranean sea must rely on substitute reef-like indicators. *Dendropoma* platforms exhibit many characteristics pertaining to good indicators: first of all, their localization in warm-temperate areas such as Atlantic Ocean and the Mediterranean Sea, their easy access for sampling and dating purposes using ^{14}C techniques, then their limited range vertical growth, restricted to the intertidal level and, occasionally, to the uppermost part of the infralittoral zone. The samples dated were collected on flat areas where the *Dendropoma* reefs are mostly developed in broadness and thickness. On limestone promontories as San Vito, *Dendropoma* ledges are smaller, up to 1 m long and 10 cm thick. In flat coastal areas, *Dendropoma* platforms, from 5 to 10 m broad, coalesce to form a single, uninterrupted rim stretching for several kilometres (i.e. Tonnara del Cofano, Fig. 15b). Each platform is 20 to 40 cm thick, and the upper 8 to 10 cm consist of living organisms (Fig. 16). The upper, living part lies at MSL and, consequently, is exposed during low tide and submerged during high tide. Radiocarbon dating was carried out on the most ancient, fossil part of the reefs, which is located at 30–40 cm below the present sea-level. Because the whole studied area is tectonically stable, even though some vermetid reefs seem to be slightly deformed by strike-slipe faults, the 30–40 cm which separate the living individuals from the fossil *Dendropoma* are here deemed as indicative of the actual sea-level rise for the last 400–460 cal yrs (ANTONIOLI et al., 1999).

Stop 3. Cornino, faulted marine notch

A faulted marine notch occurs at the eastern border of the Cornino plain (Fig. 15c). This notch is related with the 2nd order terrace (Middle Pleistocene) largely outcropping in the area (Fig. 14). The height of the tidal noch (h in Fig. 17) is about 2 m, much larger than that of the present day tidal notch (between 60 and 35 cm), and allow us to hypothesize a different tide during Middle Pleistocene.

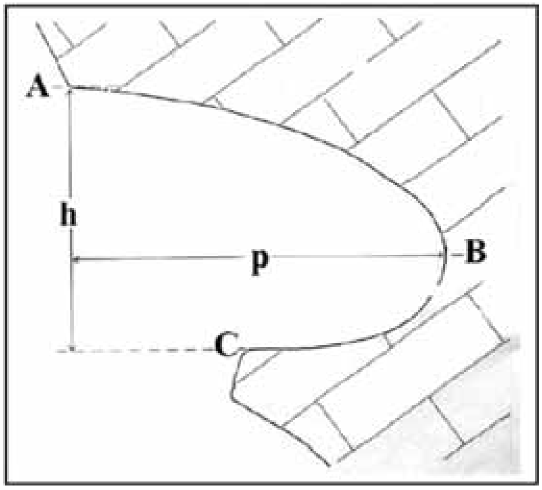

Fig. 17 – Morphological features of a tidal notch: A, roof corner, B, maximum concavity, C, base corner; h, height; p, depth.

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