Rivista Italiana di Paleontologia e Stratigrafia	volume 116	no. 1	pp. 103-118	March 2010

THE CONTRIBUTION OF MAMMAL-BEARING DEPOSITS TO TIMING LATE PLEISTOCENE TECTONICS OF CAPE TINDARI (NORTH-EASTERN SICILY)

LAURA BONFIGLIO, GABRIELLA MANGANO & PAOLO PINO

Received: June 15, 2009; accepted: December 21, 2009

Key words: Marine terraces, terraced vertebrate-bearing deposits, North-Eastern Sicily, Upper Pleistocene.

Abstract. At Cape Tindari, in North-Eastern Sicily, both right-lateral and extensional displacements are documented, but very little is known about the timing of the Upper Pleistocene faults. On the steep cliffs delimiting Cape Tindari, a triangular shaped fissure opens, named Donnavilla Cave, which contains the remains of a continental mammal-bearing deposit plastering the walls of the fissure bored by *Lithodomus* holes from 73 m up to 85 m a.s.l. New geological, palaeontological and radiometric data on the Cape Tindari mammal-bearing deposits are here exposed and they are compared with the known terraced mammal bearing deposits in North-eastern Sicily. The mammal-bearing deposits and the walls bored by *Lithodomus* holes point to the previous existence at Cape Tindari of the inner margin of the MIS 5.5 marine terrace and of the overlying coastal plain deposits. A stalagmite crust previously overlying the mammal-bearing deposits and now hanging and sloping inward into the cave, points to an erosion phase of the inner margin of the coastal plain younger than the stalagmite crust which is 40 ± 4 ka old. At 104 m a.s.l. an older abrasion platform and littoral deposits up to 111 m a.s.l. have been recognised. The two coastal lines and the deeply eroded continental deposits furnish for the first time chronological evidence from stratigraphy and biochronology to time the Late Pleistocene faulting previously recognised at Cape Tindari. They are probably responsible for a lowering of Cape Tindari of about 20 m after the MIS 5.5 substage and for cutting of part of the coastal plain deposits after the deposit of the stalagmite crust.

Riassunto. L'area di Capo Tindari è caratterizzata da una intensa attività tettonica genericamente datata al Plio-Pleistocene, documentata da sistemi di faglie trascorrenti destre e di faglie distensive. Sulle ripide pendici che delimitano Capo Tindari si apre un'ampia fessura di forma triangolare, denominata Grotta di Donnavilla, le cui pareti, forate da Litodomi, sono tappezzate dai residui di una breccia ossifera di ambiente continentale. In questa nota vengono esposte nuove evidenze geologiche, paleontologiche e radiometriche sui già noti depositi a mammiferi fossili di Capo Tindari, che vengono confrontati con i depositi terrazzati a mammiferi della Sicilia nord orientale. I fori di Litodomi di Capo Tindari sono l'evidenza del margine interno di un terrazzo marino che viene correlato al sottostadio MIS 5.5 mentre i soprastanti depositi a vertebrati continentali documentano l'esistenza del margine interno di una pianura costiera soprastante al terrazzo marino e popolata da una fauna di mammiferi pleistocenici. Una spessa crosta stalagmitica, che originariamente ricopriva i depositi a vertebrati e che ne cementa i residui, è sospesa e inclinata dall'esterno verso l'interno della fessura e documenta una fase erosiva che ha interessato il margine interno della pianura costiera posteriormente alla deposizione della crosta stalagmitica, datata a 40 ± 4 ka. A sud est della fessura è stata rinvenuta una linea di costa più antica rappresentata da una piattaforma di abrasione alla quota di 104 m s.l.m. e da ghiaie litorali estese fino alla quota di 111 m s.l.m. Le due linee di costa e il deposito continentale profondamente eroso forniscono per la prima volta dati cronologici ricavati da evidenze stratigrafiche e biocronologiche utili per la datazione di faglie tardo-pleistoceniche, già riconosciute a Capo Tindari. Queste sono probabilmente responsabili di un abbassamento del Capo di circa 20 metri successivo al sottostadio MIS 5.5 e della scomparsa, successiva a 40 ± 4 ka, di parte del margine interno del terrazzo e dei soprastanti depositi di pianura costiera.

Introduction

North-Eastern Sicily is part of the Apennine thrust-fold belt which in this area is constituted by the Kabilian-Peloritani-Calabrian nappe thrusting on top of the Sicilian-Maghrebian thrust sheet. The Kabilian-Peloritani-Calabrian nappe is made up of several tectonically superimposed thrust sheets, representing tectonic assemblages derived from different palaeogeographic units and they are the result of the convergence of African and Eurasian plates (Amodio Morelli et al. 1976; Atzori et al. 1978; Ghisetti 1979; Lentini & Vezzani 1975; Lentini et al. 2000). Late Miocene and Plio-

Department of Earth Sciences, University of Messina, Via Sperone, 31- I-98166, S. Agata di Messina, Italy. E-mail: lbonfiglio@unime.it; gmangano@unime.it; pinop@unime.it

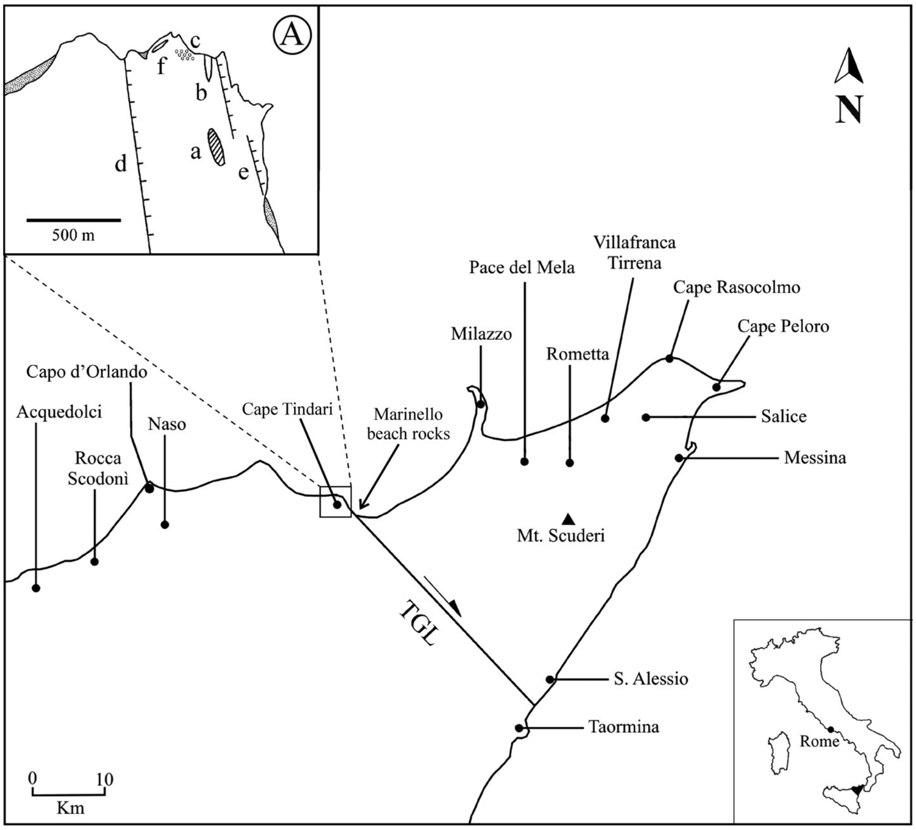

Fig. 1 - Location of Cape Tindari in North Eastern Sicily and of the sites quoted in the text. The Tindari-Giardini line (TGL) is redrawn from Lentini et al. (2000). A) sketch of the significative elements at Cape Tindari: a) littoral conglomerate at 104-111 m a.s.l.; b) Donnavilla cave; c) *Lithodomus* holes on the north western side of the cave; d), e) fault scarps, according to Lentini et al. (2000) and Billi et al. (2006); f) uplifted notch located at 4-6 m a.s.l.

Pleistocene post-orogenic deposits overlie the units of the orogenic belt.

One of the most impressive characters of North-Eastern Sicily is represented by raised Pleistocene marine terraces occurring at different heights with respect to the present sea level and by Holocene raised marine notches and littoral deposits. Marine terraces cut the different substrates and are documented by sloping marine platforms overlain by littoral deposits, while fossil shorelines are represented by remnants of the inner margins of the terraces, i.e. abrasion platforms, marine notches, *Lithodomus* holes and/or other biological sea level markers. The continental sedimentary cover of some terraces is made up of vertebrate-bearing coastal plain deposits.

In this paper the field evidence of the mammal-bearing deposits of Donnavilla Cave, located in the steep northern cliffs of Cape Tindari, are reconsidered, taking into account new stratigraphical and chronological constraints. The detailed stratigraphic reconstruction, also including the relationships with respect to the substratum bored by *Lithodomus* holes, the comparison with Pleistocene vertebrate-bearing terraced deposits of North-Eastern Sicily and the ^{230}Th/^{234}U dating of a stalagmite crust overlying the fossiliferous deposits, provide new data and furnish a paleontological contribution to timing tectonics which affected Cape Tindari during the latest Pleistocene.

Geological setting

Cape Tindari is located in the northern side of the Peloritani Mountain Belt on the northern coast of Sicily (Fig. 1) and consists of crystalline rocks, middle to high metamorphic grade, with prevailing felsic-Ca-silicatic marbles. They are part of the Aspromonte Unit of Lentini & Vezzani (1975), the uppermost unit of the Kabilo-Calabride Chain. The deepest Kabilo-Calabride unit consists of epimetamorphic Variscan basement and remnants of mostly carbonate sedimentary covers of Meso-zoic-Cenozoic age (Longi-Taormina Unit: Amodio Morelli et al. 1976) and rests directly on the Appenninic-Maghrebian substratum, mostly terrigenous (Lentini et al. 2000, and references therein).

The present morphology of North-Eastern Sicily and the outline of the coastal lines have been controlled by the Plio-Pleistocene evolution of the area which gave origin to Pliocene and Lower - Middle Pleistocene diachronic tectono-sedimentary basins (Kezirian 1992; Lentini et al. 2000) and to Middle and Upper Pleistocene terraced deposits.

Evidence of two stages is provided by the Plio-Pleistocene sedimentary sequences which was controlled by tectonic activity (Kezirian 1992; Barrier 1995). In the first stage, beginning in the Early Pliocene, a transgressive sequence has been deposited in the diachronic tectono-sedimentary basins which includes: Lower Pliocene calcareous marls (trubi); Lower Pliocene to Lower Pleistocene calcarenites of littoral environment or redeposited by gravity flow in circalittoral or epibathyal zones; Lower to Middle Pleistocene epibathyal marls (bathymetry of deposition > 600 m) associated with micritic limestones, including bathyal corals (Kezirian 1992; Lentini et al. 2000; Violanti 1989, 1991). In a second stage, probably since the late Early Pleistocene, the Peloritani Range was strongly uplifted. Deltaic marine gravels and sandy deposits ("Messina Formation") overlie the epibathyal marls of the early Middle Pleistocene which outcrop as high as 550 m at Rometta (Violanti et al. 1987) and 550 m at Naso (Di Stefano & Caliri 1996). At Mount Scuderi, presently uplifted at the height of 1250 m a.s.l., Lower Pleistocene micritic limestone of circalittoral environment overlies the metamorphic substrate (Bonfiglio 1970; Barrier 1987).

The rate of uplift is difficult to assess, as the exact bathymetry of the deposits is still poorly known.

In the Middle and Late Pleistocene, numerous marine terraces have been originated as the result of the interaction between Pleistocene glacio-eustatic changes of the sea level and the general, intense long-term uplift affecting North-Eastern Sicily and the Messina Straits area.

In North Eastern Sicily, a well-developed flight of marine terraces with numerous orders may be found (Robillard 1975; Hugonie 1979). The elevation of the inner margin of the raised Pleistocene marine terraces in North Eastern Sicily has been used to evaluate the uplift rate of the region and to infer neotectonic events (Catalano & Di Stefano 1997; Monaco & Tortorici 2000; Catalano & De Guidi 2003; Catalano et al. 2003; Antonioli et al. 2006; Ferranti et al. 2006).
Uplift Holocene notchs at Taormina and Cape S. Alessio, north of Taormina, at the height of about 5 m a.s.l. have been described and dated by numerous authors (see Lambeck et al. 2004 and references therein). Along the coasts of the Milazzo peninsula also uplifted Holocene notchs have been described by Rust & Kershaw (2000). Holocene upper infralittoral gravels outcropping up to 3.50 m of altitude have been described and dated by Gringeri et al. (2004).

In North-Eastern Sicily marine terraces cut the different types of substrate, i.e. the metamorphic rocks of the Peloritani Range, the carbonatic Mesozoic rocks of the Longi-Taormina Unit, the Plio-Middle Pleistocene sedimentary units and the terrigenous substratum of the Apenninic-Maghrebian Units.

Cape Tindari and the vertebrate-bearing deposits of the Donnavilla Cave

Cape Tindari is the most seismically active area in North-Eastern Sicily and it is a key-site for understanding present seismicity and tectonics in the Southern Tyrrhenian Sea (Billi et al. 2006).

Both right-lateral and extensional displacements are documented along the Tindari Fault System (TFS) (Ghisetti 1979; Fabbri et al. 1980; Lentini et al. 1996, 2000; Billi et al. 2006). Eastern cliffs of Cape Tindari represent the morphological expression of a segment of the Tindari Fault System which has been named also as Tindari – Giardini line (Atzori et al. 1978; Ghisetti 1979). At present, very little is known about the timing of the latest Pleistocene faults and the temporal relationships between the normal and strike slip faults. Published age constraints allow only to date the faults generically to the Plio-Pleistocene up to the Middle Pleistocene (Ghisetti 1979; Fabbri et al. 1980; Billi et al. 2006). According to Ghisetti (1979) and Fabbri et al. (1980), in the Tindari area extensional faults activity is as young as Middle-Late Pleistocene. The Neogene-Pleistocene sediments to the East of the TFS are lowered and the Upper Pleistocene terraces located on the two sides of the fault plane underwent displacements that reach 50-60 m. According to Lentini et al. (2000) Cape Tindari is a fault-bounded block, and the present morphological processes of the Cape affect steep cliffs structurally controlled by very young tectonics, which however have not been dated. N-S and NNW-SSE faults are recognized at Cape Tindari by Lentini et al. (2000) and Billi et al. (2006). Billi et al. (2006) documented extensional fractures affecting the beach rocks on the Marinello beach formations, which are as old as 120-130 years BP and lie eastward of Cape Tindari on the hanging wall of a segment of the TFS. At the foot of the Cape Tindari cliff raised marine cemented gravels up to 2-4 m above the present sea level have been mentioned by Atzori et al. (1978) and Fabbri et al. (1980). Northward the cliffs are incised by a well defined laterally continuous marine notch at ~ + 4.00 – 6.00 m a.s.l., not yet dated (Bonfiglio et al. 2003).

A cave opens on the eastern side of Cape Tindari, at the height of 73 m a.s.l. (Fig. 1, A). The cave, locally known as "Grotta della Fata Donnavilla", is hollowed in the felsic-Ca-silicatic marbles of the Aspromonte unit. According to Malatesta (1958) e to Gliozzi & Malatesta (1984) a thick detrital deposit, which formerly almost filled the cave up to the ceiling, contains irregularly scattered fossil remains of mammals. The walls of the cave underneath the breccia are bored by *Lithodomus* holes. The mammal assemblage includes *Dama carburangelensis, Cervus elaphus siciliae*, *Hippopotamus pentlandi*, *Ursus* cf. *arctos* (Caloi 1973; Caloi & Palombo 1984; Gliozzi & Malatesta 1984; Abbazzi et al. 2001). In the inner part of the cave a stalagmite layer cementing scarce remains of the bone breccia is hanging and sloping inward into the cave for about 12 m. Nearby the cave, Malatesta (1958) recognised a littoral conglomer-

Fig. 2 - The Donnavilla cave. The arrow shows the hanging speleothem in the upper part of the entrance.

ate at the height of 70 m a.s.l. The conglomerate and the *Lithodomus* holes were correlated by him with the MIS 5.5 raised beach of Cape Milazzo, which extends between the altitudes of 85 and 50 m a.s.l. The environmental significance of the mammal-bearing deposits with reference to the present morphology of the site was not taken into consideration in the detailed description of Malatesta (1958) and Gliozzi & Malatesta (1984).

New data

From new field investigations the following features have been recognised:

The Donnavilla Cave is a triangular shaped fissure having an height of about 20 m and a maximum width of about 20 m (Fig. 2); it is oriented according the N-S striking set of faults recognised in this area.

The walls delimiting the fissure are interrupted northward by the vertical cliff of Cape Tindari. On these walls the *Lithodomus* holes are densely distributed, not abraded and confined between the heights of 73 m and 85 m a.s.l. Remnants of the bone breccia are scattered and plaster the bored walls in the outer portion of the cave, while larger blocks of the breccia are preseved at the base of the eastern wall as well as in the inner portion of the cave (Fig. 3). The detrital elements (up to 50 cm large), generally poorly matrix supported, are made up of crystalline limestone and the bones appear more abundant in the inner, more protected, portion of the cave (Fig. 3, a-b). A rhythmic stratification (thickness: 10-20 cm) is highlighted by repeated granulometric variations and by the preferential orientation of the long axis of rock fragments parallel to the maximum slope angle of the beds, which are dipping towards the inner part of the cave with angles variable between 15° and 35°. No internal sedimentary structures and grading within the beds were observed, while lenticular structures are sometimes found. A wedge-shaped geometry of the detrital body may be reconstructed, which formerly almost filled the cave up to the ceiling, with a maximum thickness of about 10 m in the outer portion of the cave decreasing inward the cave (Fig. 4). In this inner and lower portion the detrital body shows the typical toe geometry and the uppermost horizon is made up of prevailing sandy-silty brown matrix. Volcanic ash has been recognised in the finest sediments.

The superior surface of the detrital body is eroded and shows in the inner and lower portions a symmetric channel with gentle walls (width: 2-3 m; height: up to 1.40 m), cut into the bone breccia (Figs. 3, 5). The eroded surface, including the channel, is covered by the stalagmite crust, thick up to 20-25 cm, made up of clean prismatic calcite layers (about 2 cm thick) alternating with thin laminae of microcrystalline calcite mixed with terrigenous silt. The structure of the stalagmite crust is typically mammillary and the superior surface shows small drops directed to the inner portion of the cave. The provenance of the running waters is not from the cave as the walls of the cave crossing the speleothem are not covered by concretionary calcium carbonate.

The channel is filled with brown, very fine and dense sands and silts containing volcanic ash also. In this uppermost unit the chromatic variations and the preferential orientation of the long axis of the rare rock fragments and bones highlight the soft and dense stra-

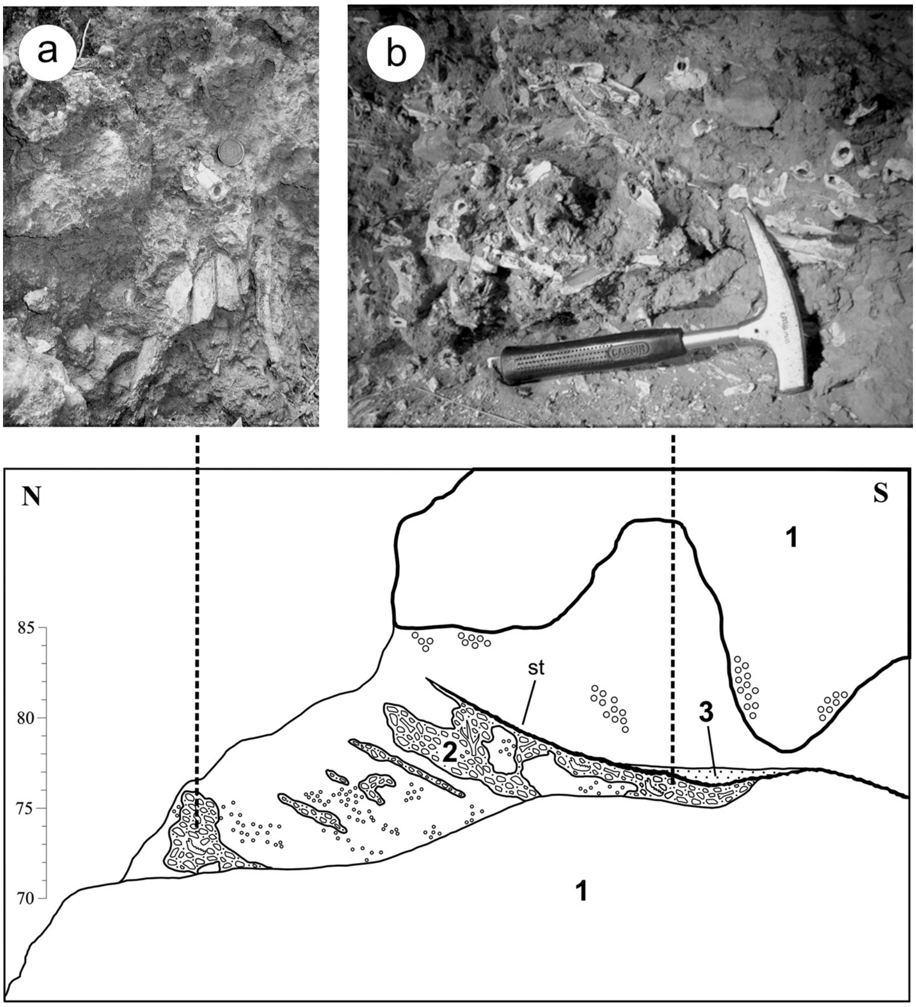

Fig. 3 - Stratigraphic sequence of the eastern wall of the Donnavilla Cave. 1) substrate of felsic-Ca-silicatic marbles; 2) bone breccia; 3) very fine sands filling the channel and overlying the speleothem; st) stalagmite crust; circles *Lithodomus* holes; a) cranial remains of *Hippopotamus pentlandi* in the bone breccia; b) fossil bones in the uppermost sandy-silty brown portion of the bone breccia.

tification, which is substantially parallel to the maximum slope angle of the underlying stalagmite crust and is directed to the inner part of the cave.

South of the cave, between the height of 104 m and 111 m a.s.l. (see a in Fig. 1, A), a seaward gently dipping conglomerate extends, consisting of wedge-

Fig. 4 - The hanging speleothem overlying the eroded bone breccia in the inner portion of the Donnavilla Cave.

Fig. 5 - The channel overlying the speleothem, filled with very fine brown sands and silts. *Lithodomus* holes on the walls of cave are seen in the back; sa) fine sands and silts; st) stalagmite crust.

shaped multilayer of well cemented crystalline boulders and well rounded cobbles. The clasts are set in a massive, not graded and clast-supported deposit with scarce massive arenite matrix (Fig. 6). Rare, fragmented and not identifiable mollusc shells are present. In the neighbouring of the conglomerate we found a small abrasion platform at the height of 104 m a.s.l. The abrasion platform is a triangular shaped prominent ramp cutting across sub-vertical crystalline beds and abruptly interrupting the morphological profile of the eastern slope of the Cape.

Finally we observed that the flat surfaces of very large prismatic boulders (about 8x5 m large) fallen from the eastern slopes of the Cape and accumulated at the present sea level show well preserved kinematic indicators (lineations). This appears an evidence that recent coastal erosion of the retreating eastern sea-cliff is shaping fault cliffs structurally controlled by very young tectonics.

Fig. 6 - The Cape Tindari littoral conglomerate located at 104-111 m a.s.l.

U/Th dating of the stalagmite crust

The portion of the flowstone directly in contact with the fossil remains was dated using the $^{230}Th/^{234}U$ method. This method is based on the different chemical behaviour that uranium and thorium display in the hydrosphere. When authigenic calcite is formed, it tends to contain appreciable uranium concentrations, because highly soluble, but negligible thorium. This leads to a situation where ^{230}Th is strongly deficient relative to its parent ^{234}U. The subsequent regeneration of ^{230}Th, directly produced by decay of its parent ^{234}U, can then be used as a dating tool. The age of the deposit can be determined by measuring the growth of the daughter up to the point when its abundance is within error of secular equilibrium (about 350 ka; Dickin 1995). Three main requirements are needed: 1) calcite speleothem must contain sufficient uranium; 2) the system must be closed after coprecipitation of uranium in calcite; 3) no ^{230}Th must be deposited in calcite. Where the activity ratio between ^{230}Th and ^{232}Th (the isotope of thorium enriched in the detrital fraction) is higher than 20, it is presumed that radiogenic ^{230}Th completely predominates and contamination is not significant (Ford & Williams 2007). Since the flowstone from Tindari cave speleothem shows a $^{230}Th/^{232}Th$ activity ratio > 90, a single sample provided the actual age of the speleothem, which results of 40 ± 4 ka. Uranium concentration, activity ratios and the age of the flowstone are reported in Tab. 1.

Tab. 1 - Uranium and thorium activity ratio of a sample of the flowstone from the Tindari Cave stalagmite crust.

Sample	U ppm	($^{234}U/^{238}U$)	($^{230}Th/^{234}U$)	($^{230}Th/^{232}Th$)	Age (ka)
2007SP32	1.804 ± 0.110	1.005 ± 0.029	0.311 ± 0.029	95.147 ± 5.132	40 ± 4

Discussion on new data

At Cape Tindari the exposed features indicate a complex history of marine and continental sedimentary processes. The ubiquitous presence of *Lithodomus* holes suggests that the Donnavilla Cave was shaped under marine conditions, which gave also origin to the littoral conglomerate recognised by Malatesta (1958) nearby the cave at the height of 70 m a.s.l. Detrital deposits with angular fragments mixed to abundant fossil remains of terrestrial mammals point to depositional processes in continental environment. This detritic phase was followed by a time interval characterized by quiet circulation of carbonate-charged water, which led to the deposition of the stalagmite layer. The uppermost layers rich in fine matrix were probably deposited from palaeosoils containing volcanic ash and located outward of the cave.

This uppermost deposit, overlying the stalagmite crust, previously attributed to eolic transport by Malatesta (1958), probably might be attributed to the reworking by running water of external palaeosoils, also containing the volcanic ash. The exclusive eolic supply is to be excluded as at that time the cave entrance was almost completely closed by the bone breccia and the overlying stalagmite crust.

Widespread peculiar pyroclastic deposits, known as “Brown Tuffs” and emplaced in the time span between about 70 and 13 ka, occur all over the Aeolian Islands (Calanchi et al. 2002; Lucchi et al. 2004). Volcanic ash known as “Tuffloess” probably coming from the Aeolian Islands overlies MIS 5.5 littoral deposits at Cape Milazzo (Colonna & La Volpe 1968; Crisci et al. 1983). The volcanic ash contained in the bone breccia at Cape Tindari, probably coming from the Aeolian Islands, may have been emplaced in the time span between about 70 and 13 ka.

The structural features of the bone breccia indicate multiple sedimentation events under gravity control along a palaeorelief extended eastward of the cave, i.e. eastward of Cape Tindari. The present geometry of the Cape is in fact not compatible with the structural features of the detrital body. Rock fragments and fine brown matrix have been carried by gravity and/or by superficial water stream inward into the cave.

Vertebrate-bearing deposits in North-Eastern Sicily

To assess the palaeoenvironmental significance of vertebrate-bearing deposits of Cape Tindari they have to be discussed in the context of the vertebrate-bearing deposits of North Eastern Sicily, often embedded in the continental sedimentary cover of Pleistocene marine terraces.

Faunal assemblages

In Sicily the rich fossil record of endemic vertebrates allows the construction of a fairly detailed biochronological frame based on stratigraphic data, as well as geochemical and radiometric dating.

Taphonomic data show that Pleistocene vertebrates remains are distributed in deposits of both cave environment and broad, open coastal environments. Close relationships have been found between vertebrate-bearing deposits and terraced marine deposits which can be correlated with the $\delta^{18}O$ isotopic record and the main palaeogeographic events in Sicily (Di Maggio et al. 1999).

At present five Faunal Complexes (FC), characterised by the occurrence of differently marked endemic features, have been recognised (Masini et al. 2008).

The two older FC (Monte Pellegrino FC, *Elephas falconeri* FC) are not found in North-Eastern Sicily. Of the three younger Faunal Complexes which are found in North-Eastern Sicily (*Elephas mnaidriensis* FC, Grotta di S. Teodoro-Pianetti FC, and Castello FC) only the assemblages of the *Elephas mnaidriensis* FC are contained in deposits of open environments, such as the fully marine deposits of the “Messina Formation” and the coastal plain deposits overlying some marine terraces.

The *Elephas mnaidriensis* FC contains a balanced faunal assemblage (*Elephas mnaidriensis, Hippopotamus pentlandi, Cervus elaphus siciliae, Canis lupus, Dama carburangelensis, Ursus* cf. *arctos, Crocuta crocuta spelaea, Bos primigenius siciliae, Sus scrofa, Vulpes vulpes*). The hippo *Hippopotamus pentlandi* is exclusive of this Faunal Complex. Most of the taxa of the *Elephas mnaidriensis* FC found in North Eastern Sicily at present live in open spaces and none of them inhabits caves.

The extant hippo (*Hippopotamus amphibius*), which is closely related to the European Pleistocene hippopotamuses, is a gregarious animal and lives in rivers and lakes bordered by grassland. The extant cervids (fallow deer, *Dama dama*, red deer *Cervus elaphus*) favour open deciduous woodland. The extant elephants, which are however not closely related to extinct European Pleistocene elephants, are characteristic of forested savanna, usually not far from water (Stuart 1982).

Recent researches in Sicily clarified that most of the vertebrate bearing deposits known in the literature as cave deposits are in fact coastal plain deposits located at the base of carbonatic cliffs where the caves open.

Vertebrate-bearing deposits and Pleistocene marine terraces

Terraces are morphological features consisting of a plane surface gently inclined seaward and bounded by a scarp uphill and downhill (inner and outer paleo-sea cliff; Carobene 1980). Each terrace is correlated with a glacio-eustatic high sea level. The geological structure of a terrace consists of different elements which have been originated by the geological processes occurring in the uplifted regions. In Fig. 7 an oversimplified outline of the geological structure of a terrace is shown, according to Bosi et al. (1996), Carobene (1980) and Ferranti et al. (2006). Skeletal elements of vertebrate within the coastal plain sedimentary cover are also shown.

Tidal notches, *Lithodomus* holes, abrasion platforms and other sea level biological markers preserved on the inner margin of a terrace represent the evidence of the highest shoreline at high stand stage, generated during a short time coastal uplift and more or less stable sea level, though the exact position of shoreline is difficult to assess (Ferranti et al. 2006).

According to Ferranti et al. (2006) the distribution of the markers reflects primary paleoclimatic and paleogeographic conditions and subsequent tectonic processes, combining regional and local displacements.

Coastal plain deposits hosting continental, often fossiliferous, deposits of different environment (fluvial, lacustrine, colluvial) are often found overlying the sea level markers.

The terrace chronology depends on dates obtained from palaeontological evidence. Only the highest littoral deposits of the inner margin and/or the notches and biological sea level markers, when definitely dated, are to be used to evaluate the uplift rate of the region, while the faunal assemblages of the continental cover give mainly palaeoenvironmental and/or palaeogeographic evidence. Geochemical dating from vertebrates remains are often not strengthened by stratigraphic data.

A comprehensive frame for the marine terraces of North Eastern Sicily is not available at present, though numerous recent papers deal with Pleistocene marine terraces (Catalano & Cinque 1995; Catalano & Di Stefano 1997; Catalano & De Guidi 2003; Catalano et al. 2003; Antonioli et al. 2006; Ferranti et al. 2006).

The most exhaustive paper concerning Pleistocene marine terraces of North-Eastern Sicily is by Hugonie (1979), who takes into account morphological characters but points out also that the extension of a terrace and the thickness of the sedimentary cover are strongly conditioned by the nature of the substrate, by the sediment supply and by the hydrographic features. Unfortunately, at Hugonie's time, definite chronological data were lacking. According to field investigations by Hugonie, pedogenesis, cementation and weathering of terraced deposits have to be regarded as indices of terrace age as they tend to be more advanced in higher and older terraces.

In the area of Acquedolci – Capo d'Orlando, Hugonie (1979) and Robillard (1975) recognized Pleistocene marine terraces at the height of: 700, 500 or 400, 300, 200, 80-100, 60, 35 m a.s.l.

The widest terrace of North-Eastern Sicily, named "Grand replat" by Hugonie (1979) and "Po" by Catalano and De Guidi (2003), is located between the altitudes of 150-135 and 60 m a.s.l. and includes two abrasion platforms, whose inner edges are located respectively at the height of 150-135 m a.s.l. and the height of 110 a.s.l. According to Catalano & De Guidi

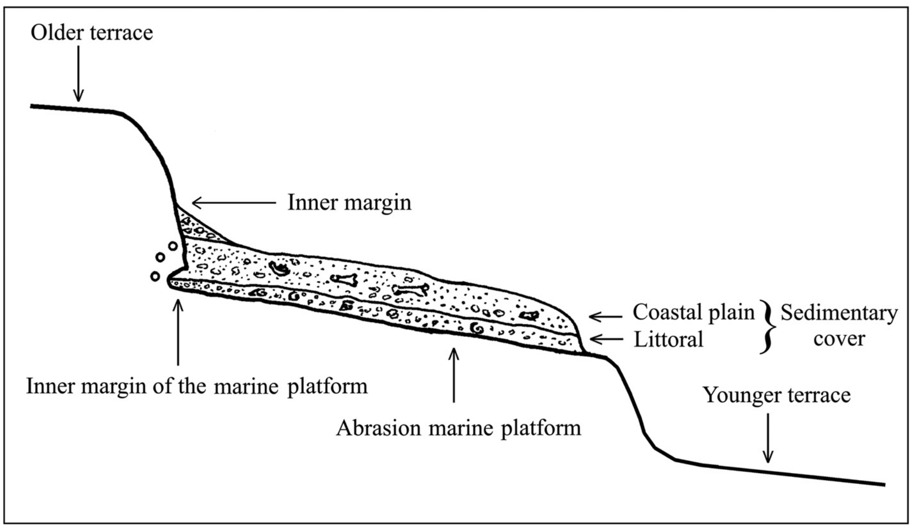

Fig. 7 - Oversimplified outline of the geological structure of a terrace (according to Carobene 1980; Bosi et al., 1996; Ferranti et al. 2006). Circles: *Lithodomus* holes.

(2003) the "Po", in the Cape Rasocolmo area, is represented by a 1.5 km-wide platform that carves crystalline rocks and consists of a polycyclic marine feature made up of two distinct abrasion surfaces, named **I** (inner edge at about 140 m a.s.l.) and **II** (inner edge at about 100 m a.s.l.). This widest terrace extends from Cape Peloro westwards up to Acquedolci and to the South on the Ionian cost up to Taormina. It has been used as key terrace for regional terrace correlation in North Eastern Sicily (Bonfiglio 1991; Antonioli et al. 2006). The widest terrace is lacking in the area between Cape Tindari and Capo d'Orlando.

Palaeontological, radiometric and geochemical dating

At present in North Eastern Sicily, palaeontological dating from terraced littoral deposits containing *Strombus bubonius* at Cape Peloro (Bonfiglio & Violanti 1983), geochemical dating from Cape Peloro and Milazzo (Hearty et al. 1986a) and ESR methodology from Taormina (Antonioli et al. 2006) are only available.

At Cape Peloro terraced deposits overlie an abrasion surface cutting the Middle Pleistocene gravels of the "Messina Formation". The sedimentary cover is made up by a sequence of marine sands culminating with brackish deposits at the height of 110 m a.s.l. Continental reddish gravels, about 20 m thick, constitute the top of the sedimentary cover. *Strombus bubonius* and *Glycimeris* sp. have been found at the height of about 105 m a.s.l. *Strombus bubonius* is the worldwide known palaeontological evidence for the last interglacial highstand in the Mediterranean, referred to the marine isotope substage MIS 5.5, whose geochronology is based on orbital tuning of high-resolution deep-sea oxygen isotope stratigraphy. Absolute dating, primarly U-series dates on corals directly associated with *Strombus bubonius*, provided an indipendent date of 127 ± 4 ka (Hearty et al. 1986 b) or 121 ± 7 ka (Myiauchi et al. 1994).

The aminoacid ratios (alle/ile ratio) in specimen of *Glycymeris* sp. collected at Milazzo and Cape Peloro (0.41 ± 0.03 and 0.41 respectively) have been assigned to the aminogroup E which has been correlated with the MIS 5.5 substage and a marine transgression ~ 125 k.a. B. P. (Hearty et al. 1986a; 1986b).

A fossiliferous marine conglomerate deposit on a terrace with an inner margin at 115 m, has been discovered and studied at Taormina by Antonioli et al. (2006). Palaeontological analysis on molluscs collected at +105 m indicates that the sea was few metres deep. Based on ESR methodology applied to a *Patella* and *Venerupid* shells, Antonioli et al. (2006) obtained an age of 124.5 ± 15.0 ka and attribute this terrace to MIS 5, probably MIS 5.5 substage. On geomorphological grounds, Antonioli et al. (2006) made correlation of the MIS 5.5 terrace at Taormina with the terrace at Capo Peloro that contains *Strombus bubonius*. Bonfiglio (1991) also on geomorphological grounds made correlation of the MIS 5.5 terrace at Capo Peloro with the widest terrace extending on the northern side of the Peloritani up to Acquedolci.

The D-alloisoleucine/L-isoleucine (alle/ile) ratio measured in the tooth enamel of some taxa of the *Elephas mnaidriensis* FC from several sites of Sicily, including *Dama carburangelensis* from Cape Tindari, yielded an average value of 0.094 ± 0.004 to which an age of 200 ± 40 ka has been attributed by Bada et al. (1991).

ESR dating for teeth enamel of *Elephas mnaidriensis* and *Hippopotamus pentlandi* from Contrada Fusco (South Eastern Sicily), underlying Tyrrhenian marine deposits, provided an age ranging between 146.8 ± 28.7 and 88.2 ± 19.5 ka (Rhodes 1996).

Taphonomical and stratigraphical evidence

In North Eastern Sicily the vertebrate bearing deposits of the *Elephas mnaidriensis* FC are contained in the following deposits:

Messina Formation. Disarticulated, fragmented, worn and mechanically selected fossil remains of elephant, hippopotamus, red deer, bear and tortoise are contained in the "Messina Formation" deltaic marine deposits (Bonfiglio & Berdar 1979) which extend from Cape Peloro to South of Cape S. Alessio (Lentini et al. 2000). At Cape Peloro, the MIS 5.5 marine terrace deposits containing *Strombus bubonius* truncate the underlying foreset beds of the Gilbert-delta setting.

Acquedolci. At Acquedolci the north-western front of the carbonate Mesozoic Longi-Taormina Unit crops out, resting directly on the Apenninic-Maghrebian terrigenous substratum (Monte Soro Flysch). Carbonatic outcrops are limited northward by vertical cliffs of tectonic origin (Robillard 1975) and the widest terrace located between the height of 135 and 60 m a.s.l. extends northward. Fig. 8 summarizes the geological structure of the largest terrace ("Po" by Catalano & De Guidi, 2003) according to the evidence recognised at Acquedolci but also at Taormina, Scodonì, Pace del Mela, Villafranca Tirrena (see after). The older terrace, extending 180-220 a.s.l. and the younger terrace (extending ~ 30 m a.s.l.) are also shown.

At Acquedolci vertical cliffs are articulated in a complex alternation of small rocky promontories and fissures which are oriented according the NNW-SSE – striking set of faults recognised in the Mesozoic Unit by Robillard (1975) and Lentini et al. (2000).

On the inner margin of the 135 – 60 m terrace, at the base of the carbonate cliffs, seven trenches have been excavated (Fig. 9, a-b). Detailed mapping of the vertebrate-bearing deposits has demonstrated that the site is a Pleistocene lacustrine basin, where thousands of re-

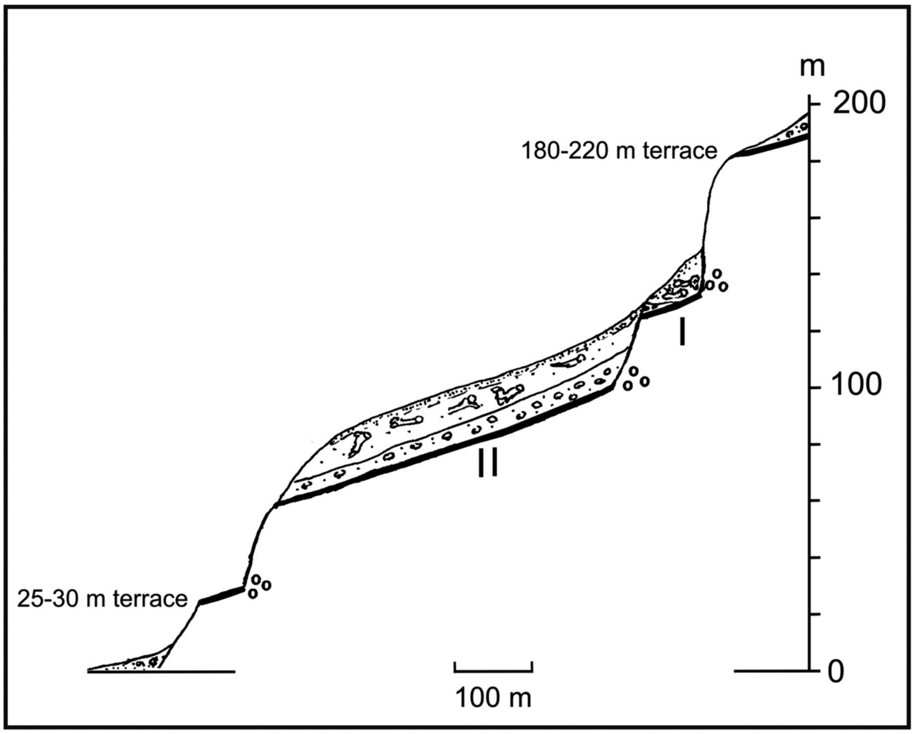

Fig. 8 - Schematic representation of the geological structure of the largest terrace ("Po" by Catalano & De Guidi 2003), according also to Bonfiglio (1987, fig. 2). The older terrace, extending 180-220 a.s.l. and the younger terrace (extending ~ 30 m a.s.l.) are also shown. **I**: abrasion platform at the height of 131 m a. s. l.; **II**: MIS 5.5 abrasion platform at the height of 60-90 m a. s. l.; circles: *Lithodomus* holes.

mains of hippo (*Hippopotamus pentlandi*) and scarce remains of deer (*Cervus elaphus siciliae*), wolf (*Canis lupus*), bear (*Ursus* cf. *arctos*), tortoise (*Testudo* cf. *hermanni*) and birds have been accumulated (Bonfiglio 1992, 1995; Mangano 2005).

Large clasts, made up of debris from the limestone cliffs, are scattered in a fine grained matrix made up of fine silts with variable contents of clay fraction (trench F; Fig. 9, b). A silty, laminated portion of the lacustrine deposits, mostly destroyed by erosion, extends northward.

Palaeontological, sedimentological and taphonomical evidence suggests an unusual depositional environment in which a slope talus was accumulating on the

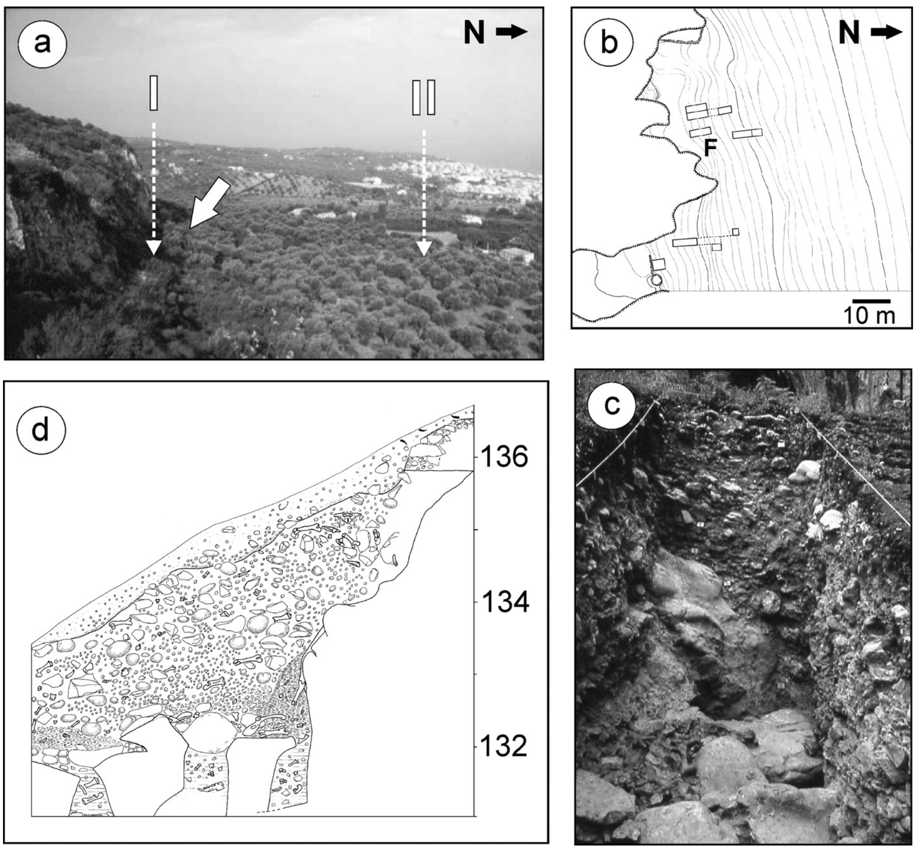

Fig. 9 - Acquedolci: a) the northern steep cliffs of the Longi-Taormina carbonate massif and the northward extending terrace; the arrow shows the location of the excavated trenches; **I** and **II** represent respectively the 131 and the MIS 5.5 abrasion platforms; b) topography of the inner margin of the largest terrace at Acquedolci and location of the trenches. F: trench F; c), d) structure of the fossiliferous deposits in the trench F, overlying the steep carbonate cliffs and the abrasion platform (from Bonfiglio 1995).

edge of a lacustrine basin. The bone assemblage consists of mixed skeletal material which has not been brought into the site as sedimentary clasts but accumulated in situ as a consequence of carcass floating in a lacustrine environment and subsequent entrapment within the silty and/or detritic bottom. A maximum thickness of 14 m has been reconstructed (Bonfiglio 1995). The vertebrate-bearing deposits overlie a coastal line made up by sterile beach gravels and an abrasion platform which cuts the base of the carbonatic substrate for about 8 m at the height of 131 m a.s.l. (**I,** Fig. 9, a-c). Rare *Lithodomus* holes, polished by the erosion, are preserved on the carbonatic cliffs up to about 142 m a.s.l.

The lacustrine deposits point to the previous existence of a coastal plain environment North of the carbonatic cliffs which partially protected them by washing of meteoric water up to the present.

The sedimentary cover of the terrace northward (**II,** Fig. 9, a) has been investigated by means of several drillings for building purpose. It has a maximum thickness of about 20 m and is made up by sterile gravels, silts, travertines and blackish clays (unpublished data by L. Bonfiglio) overlying an abrasion platform extending from 90 to 60 m a.s.l. correlated to the MIS 5.5 substage.

Rocca Scodonì. At Rocca Scodonì the MIS 5.5 abrasion platform, which extends between 90 and 60 m a.s.l., cuts the carbonatic substratum of the Longi-Taormina unit and is overlain by sterile gravels and continental vertebrate-bearing gravels with *Elephas mnaidriensis*, *Hyppopotamus pentlandi* and *Ursus* cf. *arctos* remains. The fossiliferous deposits have not been excavated. The inner margin of the abrasion platform is not well defined as it cuts the Apenninic-Maghrebian terrigenous substratum. The vertical cliffs of the carbonatic Rocca Scodonì, which crops out from terraced deposits, are partially covered by slope debris. The top of Rocca Scodonì, located at about 132 m a.s.l. and bored by *Lithodomus* holes, probably represents the evidence of the same 131 m coastal line highlighted at Acquedolci. The inner paleo-sea cliff of a younger terrace extending 25-30 m is densely bored by *Lithodomus* holes (Bonfiglio 1987, Fig. 2).

Pace del Mela, Villafranca Tirrena. In this area the largest terrace has a great extension but its inner margin is not clearly identifiable, owing to the lithology of the substratum which is prevalently made up of Lower and Middle Pleistocene sands, clays and epibathyal marls. A continental sedimentary cover made up of reddish gravels, grey silts and clays, up to 20 m thick, overlies the MIS 5.5 substage abrasion platform extending 80-90 m a.s.l. (Fig. 10). Assemblages of the *E. mnaidriensis* FC have been found in the continental deposits (Mangano 2000).

Taormina. Several recent papers deal with marine terraces of the Taormina area which are carved in the different lithotypes of the carbonate Longi-Taormina Unit. Catalano & De Guidi (2003) recognized in the Taormina area six orders of marine terraces. Seven orders of marine terraces have been recognized by De Guidi et al. (2003) who have carried structural and morphological analyses based on 1:10.000 and 1:33.000 scale aerial photographs and field surveys on 1:10.000 scale topographic maps. Antonioli et al. (2006) based their interpretation on field surveys of the inner margins and study of 1:10.000 aerial photographs. They analysed only three terraces whose inneredges are respectively: 225, 205, 115 m a.s.l. The 115 m terrace is correctly attributed to MIS 5.5 substage by Antonioli et al. (2006) who disagree with the Catalano & De Guidi (2003) and De Guidi et al. (2003) estimates for the elevations of the MIS 5.5. terrace whose inner margin elevation arrives at 180 m a.s.l. in the Taormina area.

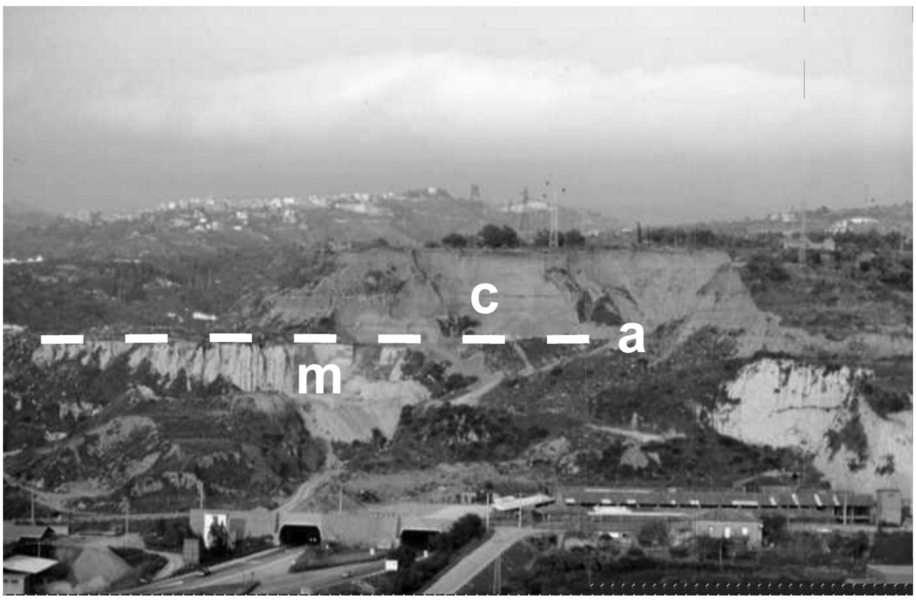

Fig. 10 - Continental reddish gravels and sands (about 20 m thick) overlying late Lower Pleistocene epybathial clayey marls at Villafranca Tirrena; m: clayey marls; a: MIS 5.5 abrasion platform; c: continental reddish gravels and sands.

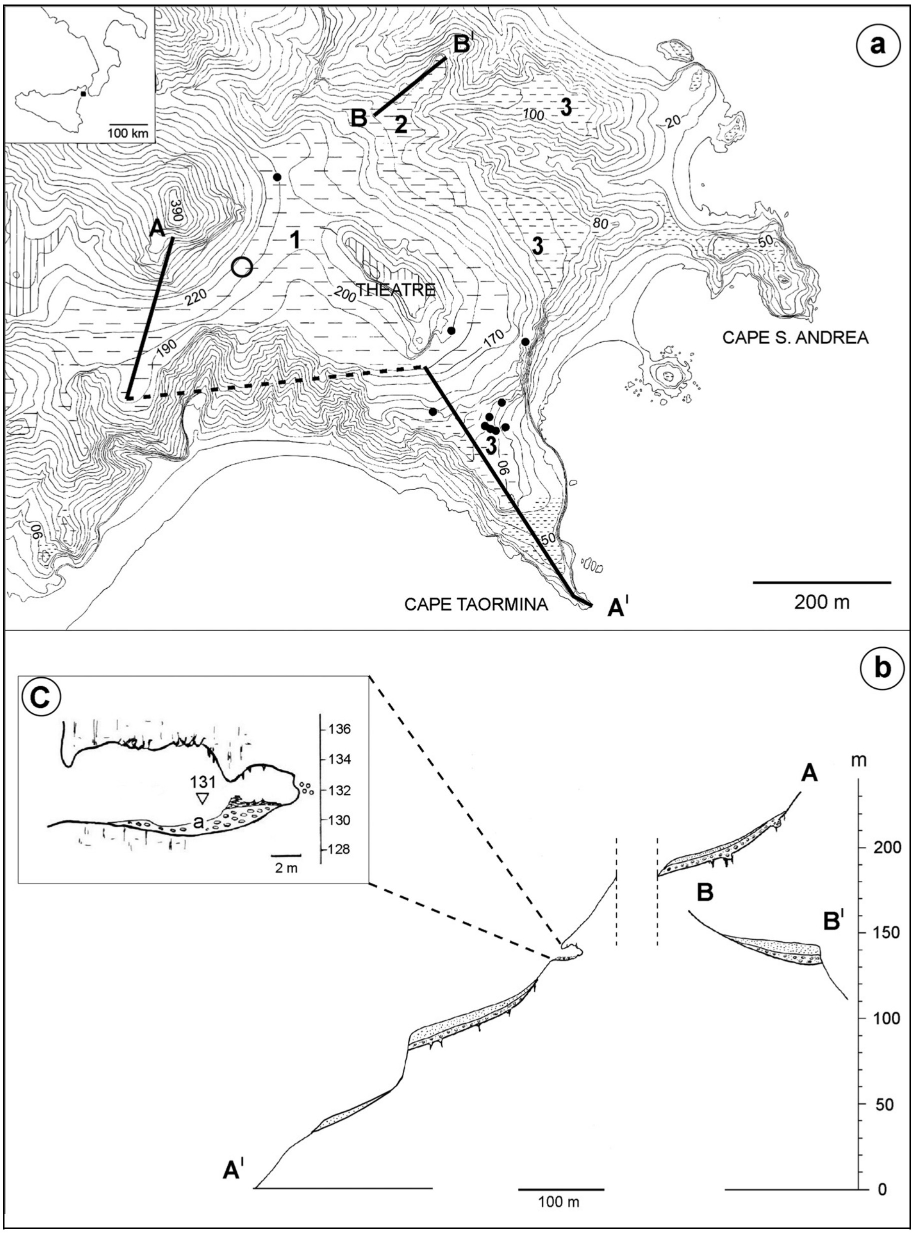

Fig. 11 - a) Map of the Taormina area: 1, 2, 3, terraces respectively 220-180, 160-140, 120-90 m a.s.l.; circle: Taormina town; black circles: caves; A-A'; B-B': traces of the profiles; b) littoral and overlying continental deposits upon the 220-180, 160-140, 120-90 m terraces; the 60-30 terrace is also shown; c) details of the 131 m cave. a: littoral gravels; Circles: *Lithodomus* holes (modified from Bonfiglio 1981, 1991).

Bonfiglio (1981) based the study of Taomina area on 1: 2.000 scale topographic maps and detailed field survey of the sedimentary covers of terraces. Fig. 11, a shows the distribution and the extension of some Pleistocene marine terraces which have been controlled by the different lithotypes of the substrate. The profile A-A' (Fig. 11, b) shows the 180-220 terrace (the terrace upon which Taormina town is built and the terrace around the Greek theatre), the 90-120 terrace (correlated with the substage MIS 5.5) and a younger terrace 30-60 m a.s.l. Inside a cave at about 131 m a marine notch, *Lithodomus* holes, Vermetid (*Dendropoma*) and a sterile conglomerate are the evidence of a coastal line which however, apparently is not associated with any terraces. In the North Eastern sector of the map a 140 - 160 m terrace (the terrace upon which the cemetery is located, profile B-B', Fig. 11, b) carves the scarcely resistant calcareous semischists. This terrace is probably to be correlated with the coastal line inside the cave at 131 m. The 90-120 terrace lacks east of the A–A' profile where several caves open on the steep cliff of hard-resistant carbonate rocks at the same heights of the MIS 5.5 abrasion platform. On these cliffs *Lithodomus* holes are also found.

The marine sedimentary covers of the 180-220, 140-160 and 90-120 terraces are made by littoral fossiliferous deposits (Bonfiglio 1981, and references therein).

According to Seguenza (1900) the remains of *Hippopotamus pentlandi* and *Cervus siciliae*, come from cemented littoral gravels contained inside a cave at the height of 200 m a.s.l. Only the continental covers of the 140-160 and 90-120 terraces, which are made prevalently by gravels and piroclastites, and the correlated

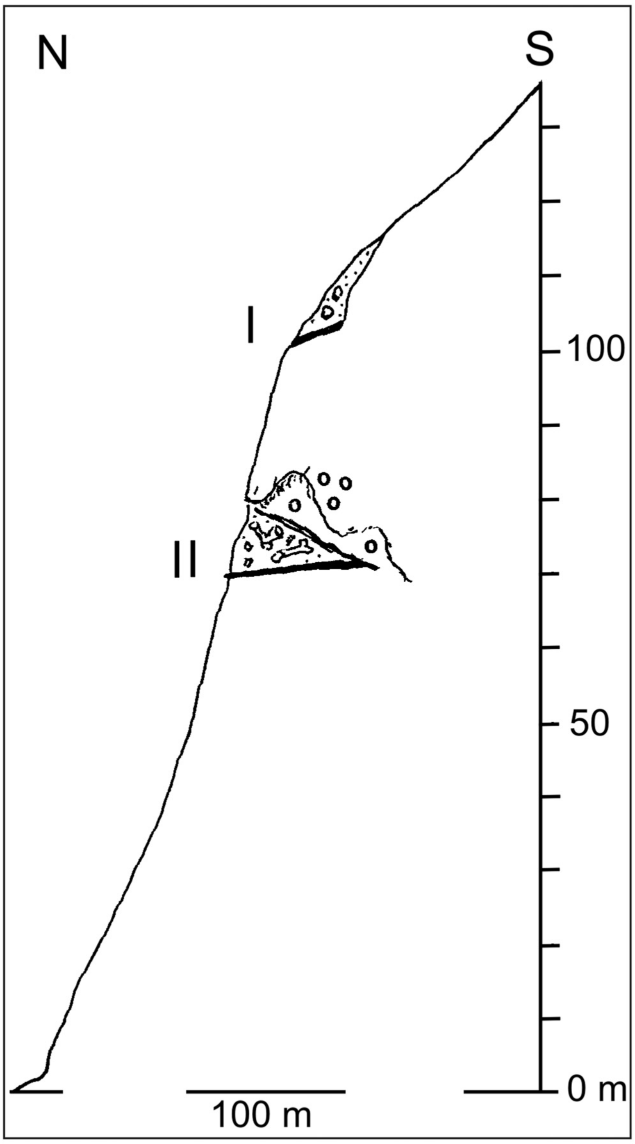

Fig. 12 - N-S profile of the steep cliffs of Cape Tindari. **I:** 104-111 coastal line; **II:** MIS 5.5 abrasion platform and coastal line. The profile of the Donnavilla cave is also shown; circles: *Lithodomus* holes.

caves, contain remains of Pleistocene mammals (*Cervus elaphus siciliae*, *Elephas mnaidriensis*, *Hippopotamus pentlandi*).

Discussion and tectonic implications

At Cape Tindari two coastal lines have been recognised respectively at the altitude of 70 and 104-111 m a.s.l. Fig. 12 shows a N-S profile of the steep cliffs of Cape Tindari. **I** and **II** represent the higher and the lower coastal line. The mammal bearing deposits overlie the 70 m coastal line evidence and the bone breccia has similar features to the detrital portion of the Acquedolci mammal-bearing deposits. Palaeontological and sedimentological evidence now recognised at Donnavilla cave, which is very similar to that observed by detailed excavations on the innermost margin of the 135-60 m terrace at Acquedolci, point to the previous existence at Cape Tindari of the inner margin of a marine terrace and overlying coastal plain deposits. The width of this terrace is unknown, but it may have been very narrow, as it was cut into resistant carbonate rocks.

The evidence collected during field researches and systematic excavations at numerous sites of North-Eastern Sicily shows that, except for the mammal remains found in the Middle Pleistocene marine deposits of the Messina Formation and of the 220-180 m terrace at Taormina, the assemblages of the *Elephas mnaidriensis* FC are contained in coastal plain deposits overlying two marine terraces, respectively the terrace attributed to the MIS 5.5 substage, whose abrasion platform extends at the height of 90-60, and an older marine platform, whose inner edge is about 130 m a.s.l.

Consequently the Pleistocene terrace underlying the mammal-bearing deposits at Cape Tindari may be correlated with the 90-60 m marine platform, attributed to the MIS 5.5 substage, or alternately with the older terrace about 40 m higher.

The difference in elevation of the two coastal lines recognised at Cape Tindari seems to be not casual as it is the same difference existing between the two abrasion platforms of the largest terrace at a regional scale (see Fig. 8). The downthrown of about 20 m of the two coastal lines at Cape Tindari represent a local displacement due to tectonics (Ferranti et al. 2006). The 70 m coastal line underlying continental mammal-bearing deposits is to be correlated with the MIS 5.5 substage

The 40 ± 4 ka old speleothem, previously deposited upon the bone breccia and now hanging and sloping inward into the cave, shows that erosion of the bone breccia started after 40 ± 4 ka, and that up to that time the palaeorelief lying eastward of the cave protected the mammal-bearing deposits from meteoric water. At Cape Tindari, unabraded *Lithodomus* holes point to a very recent age for the erosional process of the bone breccia.

These observations imply two consequences for the chronology of the Upper Pleistocene tectonics at Cape Tindari: 1) the inner margin of the abrasion platform referred to the MIS 5.5 substage, which is as high as 90 m a.s.l. in North Eastern Sicily, has been downthrown by about 20 m after the MIS 5.5 substage; 2) a palaeorelief lying eastward of the cave has been downthrown after 40 ± 4 ka. Faults previously recognized at Cape Tindari may be involved in the downward displacement of the MIS 5.5 substage marine platform (see Fig. 1, A – d) and of the palaeorelief previously lying eastward of the cave (see Fig. 1, A – e).

In fact according to Billi et al. (2006) Marinello beach formations, eastward of Cape Tindari, lie on the hanging wall of a segment of the Tindari fault system.

Conclusions

The palaeoenvironmental significance of Upper Pleistocene mammal-bearing deposits preserved at Cape Tindari has been applied to reconstructing the previous existence of a coastal plain populated by mammal communities.

For the first time chronological data from stratigraphy and biochronology are available to constrain the timing of the Upper Pleistocene tectonics of Cape Tindari.

At Cape Tindari, the mammal bearing deposits of coastal plain environment overlie the inner margin of the MIS 5.5 substage marine platform, located at 70 m a.s.l., while the inner margin of the same MIS 5.5 substage terrace is as high as 90 m a.s.l. all around North Eastern Sicily.

The portion of the inner margin of the MIS 5.5 substage marine platform lying eastward of the cave has been cut after the deposition of a 40 ± 4 ka old speleotheme.

The extensional faulting previously recognized at Cape Tindari is probably responsible for the cutting of most of the coastal plain deposits and for the downward displacement of the inner margin of the MIS 5.5 substage terrace. These tectonic events are posterior to the MIS 5.5 substage and/or to 40 ± 4 ka.

The previously recognized undated marine notch at about + 4.00 – 6.00 m a.s.l. probably postdates these faults, as it is probably correlated with the Holocene uplift notches at Taormina and Cape S. Alessio and with the Holocene littoral gravels at Milazzo.

The downward displacement of the latest Pleistocene coastal plain deposits represents local displacements which are the surface expression of the crustal processes which affected Cape Tindari in the latest Pleistocene interval.

Acknowledgments. Field survey at Cape Tindari has been performed by P. Pino. The analysis of the speleothem was performed at the "Isotope and Environmental Geochemistry Laboratory" of "Roma Tre" University using the alpha counting technique. The number in the Laboratory list was 2007SP32. Thanks are due to Prof. S. Quartieri, R. Rasà and M. Triscari, to Dr. S. Casella and G. Sabatino, and to Mr. L. Lopes, who all supported our work.

We thank Dr. Alberto Malinverno, Lamont Observatory of Columbia University, for insightful comments, which helped to greatly clarify the contents of this paper. We thank also Prof. Maurizio Gaetani, for his patience and valuable comments, and Prof. Luigi Carobene for critical review.

REFERENCES

Abbazzi L., Bonfiglio L., Marra A.C. & Masini F. (2001) - A revision of medium and small sized deer from the Middle and Late Pleistocene of Calabria and Sicily. *Boll. Soc. Paleont. It.*, 40(2): 115-126.

Amodio Morelli L., Bonardi G., Colonna V., Dietrich D., Giunta G., Ippolito F., Liguori V., Lorenzoni S., Paglionico A., Perrone V., Piccarreta G., Russo M., Scandone P., Zanettin-Lorenzoni E. & Zuppetta A. (1976) - L'arco Calabro-peloritano nell'orogene appenninico-maghrebide. *Mem. Soc. Geol. It.*, 17: 1-60.

Antonioli F., Kershaw S., Renda P., Rust D., Belluomini G., Cerasoli M., Radtke U. & Silenzi S. (2006) - Elevation of the last interglacial highstand in Sicily (Italy): a benchmark of coastal tectonics. *Quat. Intern.*, 145-146: 3-18.

Atzori P., Ghisetti F., Pezzino A. & Vezzani L. (1978) - Struttura ed evoluzione geodinamica recente dell'area Peloritana (Sicilia Nord-Orientale). *Boll. Soc. Geol. It.*, 97: 31-56.

Bada J.L., Belluomini G., Bonfiglio L., Branca M., Burgio E. & Delitala L. (1991) - Isoleucine epimerization ages of Quaternary Mammals of Sicily. *Il Quaternario*, 4(1): 5-11.

Barrier P. (1987) - Stratigraphie des dépôts pliocènes et quaternaires du Dètroit de Messine. *Documents et Travaux IGAL*, 11: 59-81.

Barrier P. (1995) - The Straits of Messina during Pliocene and Pleistocene times (Italy). In: Guglielmo L., Manganaro A. & De Domenico E. (Eds) - The Straits of Messina Ecosystem. Proceedings of the Symposium held in Messina 4-6 April 1991: 71-82.

Billi A., Barberi G., Faccenna C., Neri G., Pepe F. & Sulli A. (2006) - Tectonics and seismicity of the Tindari Fault System, Southern Italy: crustal deformations at the transition between ongoing contractional and extensional domains located above the edge of a subducting slab. *Tectonics*, 25: 1-20.

Bonfiglio L. (1970) - Facies biodetritica tardopliocenica nei Peloritani a 1250 m di altitudine. *Boll. Soc. Geol. It.*, 89: 499-506.

Bonfiglio L. (1981) - Terrazzi marini e depositi continentali quaternari di Taormina. *Quaternaria*, 23: 81-102.

Bonfiglio L. (1987) - Nuovi elementi faunistici e stratigrafici del Pleistocene superiore dei Nebrodi (Sicilia nord-orientale). *Riv. It. Paleont. Strat.*, 93(1): 145-164.

Bonfiglio L. (1991) - Correlazioni tra depositi a mammiferi, depositi marini, linee di costa e terrazzi medio e tardo-pleistocenici nella Sicilia orientale. *Il Quaternario*, 4(1b): 205-214.

Bonfiglio L. (1992) - Campagna di scavo 1987 nel deposito pleistocenico a *Hippopotamus pentlandi* di Acquedolci (Sicilia nord-orientale). *Boll. Soc. Paleont. It.*, 30(3): 157-173.

Bonfiglio L. (1995) - Taphonomy and depositional setting of Pleistocene mammal-bearing deposits from Acquedolci (North-Eastern Sicily). *Geobios*, 18: 57-68.

Bonfiglio L. & Berdar A. (1979) - Gli elefanti delle ghiaie pleistoceniche di Messina. *Quaternaria*, 21: 139-177.

Bonfiglio L., Formica S., Geremia F., Lanza S., Mangano G. & Randazzo G. (2003) - Evoluzione morfotettonica tardoquaternaria di Capo Tindari (Sicilia nord-orientale). *Convegno "Il contributo dello studio delle antiche linee di riva alla comprensione della dinamica recente. Escursioni nello Stretto di Messina", Messina 5-8 maggio 2003. Abstracts book*: 29.

Bonfiglio L. & Violanti D. (1983) - Prima segnalazione di Tirreniano ed evoluzione pleistocenica del Capo Peloro (Sicilia nord-orientale). *Geogr. Fis. Din. Quatern.*, 6(2): 3-15.

Bosi C., Carobene L. & Sposato A. (1996) - Il ruolo dell'eustatismo nella evoluzione geologica dell'area mediterranea. *Mem. Soc. Geol. It.*, 51: 363-382.

Calanchi M., Lucchi F., Pirazzoli P.A., Romagnoli C., Tranne C.A., Radtke U., Reyss J.L. & Rossi P.L. (2002) - Late Quaternary relative sea-level changes and vertical movements at Lipari (Aeolian Islands). *J. Quat. Sci.*, 17 (5-6): 459-467.

Caloi L. (1973) - Resti di cervo e di ippopotamo quaternari nella grotta di Capo Tindari. *Boll. Serv. Geol. It.*, 93: 227-249.

Caloi L. & Palombo M.R. (1984) - *Hippopotamus pentlandi* von Meyer di Capo Tindari (Messina). *Geologica Romana*, 21: 390-395.

Carobene L. (1980) - Terrazzi marini, eustatismo e neotettonica. *Geografia Fisica e Dinamica Quaternaria*, 3: 35-41.

Catalano S. & Cinque A. (1995) - Dati preliminari sull'evoluzione neotettonica dei Peloritani. *Studi Geologici Camerti*, 2: 113-123.

Catalano S. & De Guidi G. (2003) - Late Quaternary uplift of north-eastern Sicily: relation with the active normal faulting deformation. *J. Geodynamics*, 36: 445-467.

Catalano S., De Guidi G., Monaco C., Tortorici G. & Tortorici L. (2003) - Long-term behaviour of the late Quaternary normal faults in the Straits of Messina area (Calabrian arc): structural and morphological constraints. *Quater. Intern.*, 101-102: 81-91.

Catalano S. & Di Stefano A. (1997) - Sollevamenti e tettogenesi pleistocenica lungo il margine tirrenico dei Monti Peloritani: integrazione dei dati geomorfologici, strutturali e biostratigrafici. *Il Quaternario*, 10(2): 337-342.

Colonna V. & La Volpe L. (1968) - Notizie sugli affioramenti di piroclastiti della penisola di Milazzo (Sicilia). *Rivista Mineraria Siciliana*, 109-111: 6-22.

Crisci G.M., Delibrias G., De Rosa R., Mazzuoli R. & Sheridan M.F. (1983) - Age and petrology of the Late Pleistocene Brown Tuffs on Lipari, Italy. *Bull. Volcan.*, 46(4): 381-391.

De Guidi G., Catalano S., Monaco C. & Tortorici L. (2003) - Morphological evidence of Holocene coseismic deformation in the Taormina region (NE Sicily). *J. Geodynamics*, 36: 193-211.

Dickin A.P. (1995) - Radiogenic Isotope Geology. V. of 490 pp. Cambridge University Press, Cambridge.

Di Maggio C., Incandela A., Masini F., Petruso D., Renda P., Simonelli C. & Boschian G. (1999) - Oscillazioni eustatiche, biocronologia dei depositi continentali quaternari e neotettonica nella Sicilia Nord - Occidentale (Penisola di San Vito Lo Capo - Trapani). *Il Quaternario*, 12(1): 25-50.

Di Stefano A. & Caliri A. (1996) - Dati biostratigrafici sui depositi pleistocenici di Naso (Messina), Sicilia nord-orientale. *Boll. Soc. Paleont. It.*, 35(3): 229-238.

Fabbri A., Ghisetti F. & Vezzani L. (1980) - The Peloritani Calabria range and the Gioia basin in the Calabrian arc (Southern Italy): relationships between land and marine data. *Geologica Romana*, 19: 131-150.

Ferranti L., Antonioli F., Mauz B., Amorosi A., Dai Pra G., Mastronuzzi G., Monaco C., Orrù P., Pappalardo M., Radtke U., Renda P., Romano P., Sansò P. & Verrubbi V. (2006) - Markers of the last interglacial sea level high stand along the coast of Italy: tectonic implications. *Quater. Intern.*, 145-146: 30-54.

Ford D. & Williams P. (2007) - Karst Hydrogeology and Geomorphology - John Wiley & Sons ed., 562 pp.

Ghisetti F. (1979) - Relazioni tra strutture e fasi trascorrenti e distensive lungo i sistemi Messina-Fiumefreddo, Tindari-Letojanni e Alia-Malvagna (Sicilia nord-orientale): uno studio microtettonico. *Geologica Romana*, 18: 23-58.

Gliozzi E. & Malatesta A. (1984) - A megacerine in the Pleistocene of Sicily. *Geologica Romana*, 21: 311-389.

Gringeri G., Bonfiglio L., Di Geronimo I., Mangano G. & Antonioli F. (2004) - Uplifted holocene littoral deposits in the Milazzo peninsula (North-Eastern Sicily, Italy). *Quaternaria Nova*, 8: 141-153.

Hearty P.J., Bonfiglio L., Violanti D. & Szazo B.J. (1986a) - Age of late Quaternary marine deposits of Southern Italy determined by aminostratigraphy, faunal correlation and uranium-series dating. *Riv. It. Paleont. Strat.*, 92: 149-164.

Hearty P.J., Miller G.H., Stearns C.E. & Szabo B.J. (1986b) - Aminostratigraphy of Quaternary shorelines in the Mediterranean basin. *Bull. Geol. Soc. America*, 97: 850-858.

Hugonie G. (1979) - L'évolution géomorphologique de la Sicile septentrionale. PhD Thesis, Paris-Sorbonne University, Paris.

Kezirian F. (1992) - Evolution tectono-sedimentaire post-nappes des Monts Peloritains (Sicile, NE). *Mémoire de géologie de l'IGAL*, 49: 1-260.

Lambeck K., Antonioli F., Purcell A. & Silenzi S. (2004) - Sea-level change along the Italian coast for the past 10,000 yr. *Quat. Sci. Rev.*, 23: 1567-1598.

Lentini F., Carbone S., Catalano S. & Grasso M. (1996) - Elementi per la ricostruzione del quadro strutturale della Sicilia Orientale. *Mem. Soc. Geol. It.*, 51: 179-195.

Lentini F., Catalano S. & Carbone S. (2000) - Carta Geologica della provincia di Messina (scala 1: 50.000). Note illustrative, pp. 1-70. Assessorato Territorio - Servizio Geologico, Messina. S. E L. C A., Firenze.

Lentini F. & Vezzani L. (1975) - Le unità meso-cenozoiche della copertura sedimentaria del basamento cristallino peloritano (Sicilia nord-orientale). *Boll. Soc. Geol. It.*, 94: 537-554.

Lucchi F., Tranne C.A., Calanchi N. & Rossi P.L. (2004) - Late quaternary fossil shorelines in the Aeolian Islands (Southern Tyrrhenian sea): evaluation of long-term vertical displacements. *Quaternaria Nova*, 8: 115-139.

Malatesta A. (1958) - Osservazioni sul Pliocene e il Pleistocene della costa settentrionale della Sicilia tra Gualtieri Sicaminò e Gioiosa Marea. *Boll. Serv. Geol. It.*, 79(1-2): 291-326.

Mangano G. (2000) - Nuovi resti di elefante e revisione di alcuni resti di mammiferi del Pleistocene superiore della Sicilia nord-orientale. *Giornale di Geologia*, Supplemento, 62: 103-109.

Mangano G. (2005) - *Cervus elaphus siciliae* from Pleistocene lacustrine deposits of Acquedolci (North-Eastern Sicily, Italy) and its taphonomic significance. *Geo. Alp*, 2: 61-70.

Masini F., Petruso D., Bonfiglio L. & Mangano G. (2008) - Origination and extinction patterns of mammals in three central Western Mediterranean islands from the Late Miocene to Quaternary. *Quater. Intern.*, 182: 63-79.

Monaco C. & Tortorici L. (2000) - Active faulting in the Calabrian arc and eastern Sicily. *J. Geod.*, 29: 407-424.

Myiauchi T., Dai Pra G. & Sylos Labini S. (1994) - Geochronology of Pleistocene marine terraces and regional tectonics in the Tyrrhenian coast of South Calabria, Italy. *Il Quaternario*, 7(1): 17-34.

Rhodes E.J. (1996) - ESR dating of tooth enamel. In: Basile B. & Chilardi S. (Eds) - Le ossa dei Giganti. Lo scavo paleontologico di Contrada Fusco: 39-44. Arnaldo Lombardi, Siracusa.

Robillard D. (1975) - Les depots quaternaires du versant tyrrhénien de la Sicile (secteur d'Aquedolci-Capo d'Orlando): stratigraphie et tectonique. *D.E.A.*, Université des Sciences et Technologie de Lille, pp. 1-143, Lille.

Rust D. & Kershaw S. (2000) - Holocene tectonic uplift patterns in northeastern Sicily: evidence from marine notches in coastal outcrops. *Mar. Geol.*, 167: 105-126.

Seguenza L. (1900) - L'*Hippopotamus pentlandi* Falconer di Taormina. *Atti e Rendiconti dell'Accademia di Scienze Lettere ed Arti degli Zelanti di Acireale*, 10: 1-8.

Stuart A.J. (1982) - Pleistocene vertebrates in the British Isles. Longman ed., pp. 1-212.

Violanti D. (1989) - I foraminiferi plio-pleistocenici del versante settentrionale dei Monti Peloritani: analisi biostratigrafica e paleoambientale. *Riv. It. Paleont. Strat.*, 95(2): 173-216.

Violanti D. (1991) - Pliocene-Pleistocene foraminiferal assemblages of North-Eastern Sicily: analysis of recent data. *Atti dell'Accademia Peloritana dei Pericolanti*, 67(1): 365-393.

Violanti D., Bonfiglio L. & Saccà D. (1987) - Foraminiferi pleistocenici ed interpretazioni paleoambientali in un affioramento della Sicilia nord-orientale (Rometta, Messina). *Riv. It. Paleont. Strat.*, 93(2): 251-286.