

STRATIGRAPHIC AND CHRONOLOGIC FRAMEWORK OF THE UPPER MIOCENE CESSANITI SUCCESSION (VIBO VALENTIA, CALABRIA, ITALY)

ANTONELLA CINZIA MARRA^{1*}, GIUSEPPE CARONE², CLAUDIA AGNINI³,
MASSIMILIANO GHINASSI³, ORIOL OMS⁴ & LORENZO ROOK⁵

¹*Corresponding author. Dipartimento di Scienze Matematiche e Informatiche, di Scienze Fisiche e di Scienze della Terra, Università degli Studi di Messina, Viale Ferdinando Stagno d'Alcontres 31, I-98166 Messina, Italy. E-mail: amarra@unime.it

²Civico Museo di Ricadi (MURI), via Roma s.n.c, I-89861 Santa Domenica di Ricadi (VV), Italy. E-mail: p.carone@libero.it

³Dipartimento di Geoscienze, Università degli Studi di Padova, via Giovanni Gradenigo 6, I-35131 Padova, Italy. E-mail: claudia.agnini@unipd.it; massimiliano.ghinassi@unipd.it

⁴Departament de Geologia, Universitat Autònoma de Barcelona, Campus UAB, Edifici Cs, 08193 Cerdanyola del Vallès, Bellaterra, Spain. E-mail: joseporiol.oms@uab.cat

⁵Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Via G. La Pira 4, 50121 Firenze, Italy. E-mail: lorenzo.rook@unifi.it

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Abstract. This study revises the mammal-bearing stratigraphic succession of Cava Gentile, near Cessaniti (Calabria, southern Italy), with the aim of dating the Late Miocene fossiliferous succession by the integration of mammal biochronology with sedimentology, magnetostratigraphy and marine biostratigraphy. Since the first discovery of mammal remains at Cessaniti, the chronological framework of the sedimentary succession was based on the biochronological significance of the mammal assemblage and on the biostratigraphic characterisation of the capping unit. Chronological control of the sedimentary succession and the age range of the mammal faunal assemblage at Cessaniti is now possible by combining the mammal biochronological constraints with biostratigraphy and the characterisation of the magnetostratigraphy of the sedimentary succession. Our study allows the conclusion that: i) an overall transgressive trend is recorded at the late Tortonian succession of the Capo Vaticano area, with locally different depositional trends; ii) the late Tortonian transgression was punctuated by minor episodes of forced regression, as attested by soils and fluvial deposits intercalated within the Cava Gentile succession (documented here for the first time); iii) the relative sea level rises that characterised these sedimentation patterns allowed accumulation of marine and terrestrial fossils in specific transgressive horizons; iv) the combination of palaeomagnetic data and biostratigraphic analyses, together with the biochronological constraints offered by the Cessaniti mammal assemblage, allows the assignment of the basal unit of the Cessaniti (Cava Gentile) succession to the normal Chron C4n (8.1–7.5 Ma); and v) the maximum range of the Cessaniti land mammal assemblage from Cava Gentile is about 1 Ma, bracketed between 8.1 and 7.2 Ma.

INTRODUCTION

The Late Miocene site of Cessaniti (Vibo Valentia, Italy) is yielding a fossil mammal assemblage that is extremely informative regarding the complex history of the Tortonian/Messinian land mammals populating the central Mediterranean lands. The first account of the occurrence of a terrestrial mammal from the area was given by Ferretti et al. (2003), who reported the presence of the Afro-Arabian elephantid *Stegotherabelodon syrticus* at Cessaniti. This finding was considered of extreme interest as it provided the first proof of a land connection between the Cessaniti area (Calabria, southern Italy)

and North Africa. This evidence, in fact, increased our knowledge of the complex Late Miocene palaeobiogeography of Italy, where two distinct palaeobioprovinces, the Tusco-Sardinian and the Abruzzi-Apulian, both affected by remarkable insularity, have been well recognised (Rook et al. 2006).

The mammalian assemblage from the Cessaniti area actually documents a third bioprovience in the area of the central Mediterranean that differs completely from the previous ones and is characterised by North-African / Pikermian affinities. Other terrestrial mammals recovered in the area of Cessaniti are, in fact, attributable to continental taxa; these include two giraffid species (*Samotherium cf. boissieri* and *Bohlinia cf. attica*), a rhino and a bovid (Marra et al. 2011). The mammalian

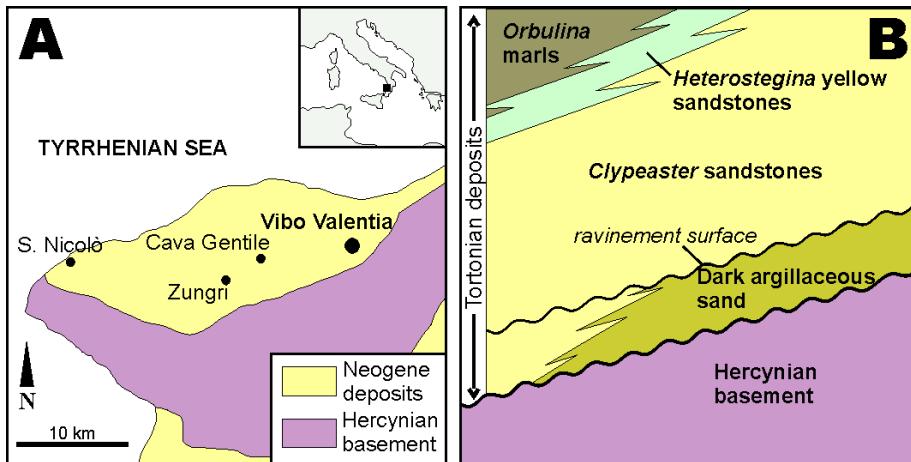


Fig. 1 - The study area. A) Geographic location and simplified geological map of the study area. B) Stratigraphy of the Tortonian succession (modified after Gramigna et al. 2012).

record of the Cessaniti succession is further enriched by the occurrence of marine mammals, among which is the extremely abundant sirenian *Metaxytherium serresii* (Carone & Domning 2007).

Previous papers have interpreted the age of the Cessaniti succession as late Tortonian, based on the occurrence of *Heterostegina papyracea* (a form occurring in the Mediterranean until the late Tortonian; Papazzoni & Sirotti 1999) in the “yellow sands” capping the succession. This interpretation fits with the occurrence of overlying middle-late Messinian “*Orbulina marls*” (Rao et al. 2007).

The aim of the present study is to detail the stratigraphic depositional context and provide a chronological constraint for the Cessaniti sedimentary successions (and mammal faunas). Our strategy was to perform a revision of the local stratigraphy, coupled with sampling for both magnetostratigraphic and micropalaeontological studies in the area between Capo Vaticano and Vibo Valentia, with a specific focus on two sections located at Cava Gentile (the most representative site of Cessaniti) and San Nicolò, respectively (Fig. 1).

The achievement of a firmer stratigraphic control and a better-constrained age of the fossiliferous deposits will allow a better understanding of the palaeogeographic significance of the Cessaniti mammal assemblage within the frame of the latest Miocene palaeobiogeographic history of the central Mediterranean.

GEOLOGICAL AND STRATIGRAPHIC SETTINGS

The Capo Vaticano promontory lies between the Calabrian Arc and the Tyrrhenian Basin, re-

presenting the Neogene back-arc basin associated with the Apennine subduction complex (Patacca et al. 1990). The Capo Vaticano-Monte Poro area (Fig. 1A) acted as a granitic topographic high since the late Tortonian, when it was onlapped by marine coastal deposits. The late Tortonian succession (Nicotera 1959; Papazzoni & Sirotti 1999; Carone & Domning 2007; Rao et al. 2007; Gramigna et al. 2008, 2012; Caracciolo et al. 2013) consists of two main intervals separated by a ravinement surface (Fig. 1B).

The lower interval, informally known as “dark argillaceous sands with *Ostrea* and *Cerithium*”, can reach a thickness of about 50 m. It consists of brackish, organic-rich muds with sandy interfingering deposits, which are interpreted as flood tidal deltas based on their geometry and the occurrence of sedimentary structures associated with bidirectional flows (Neri et al. 2005; Gramigna et al. 2008). In sites near the present coast (e.g. Santa Domenica; cfr. Gramigna et al. 2012; Caracciolo et al. 2013), this interval is characterized by a shallow marine waters facies (“Shallow water sandstones subunit”; Caracciolo et al. 2013), with a local thickness of a few tens of metres (about 30 m at Santa Domenica; Gramigna et al. 2012).

The upper interval is several tens of meters thick and consists of grey sands containing abundant echinoids and marine malacofaunas, as well as fish and mammal remains that are informally named “*Clypeaster* sandstones” (“Arenarie a *Clypeaster*”; Ogniben 1973). The “*Clypeaster* sandstones” grade upward and basinward into the “*Heterostegina* yellow sandstones” (Papazzoni & Sirotti 1999) and the overlying hemipelagic “*Orbulina* marls” (“Marne a *Orbulina*”; Rao et al. 2007). The Messinian and Pliocene-Pleistocene deposits, in turn, cover the Tortonian succession.

THE STUDY AREA SEDIMENTARY SUCCESSION

The Cava Gentile area

Sedimentology - In the Cava Gentile area, located about 10 km ESE of Vibo Valentia, the exposed upper Tortonian sedimentary succession is about 90 m thick (Fig. 2A). The vertically stacked sedimentary units have been labelled with composite names. In this study, the first two letters indicate the section name (CG: Cava Gentile), the next two letters designate the depositional environment: FL (fluvial), LG (lagoonal), SH (shoreface) and OT (offshore transition), and the number indicates the stratigraphic position within the formation (e.g. CG.FL2 points to the second fluvial unit of the section). Figure 3 offers a synopsis of the informal lithostratigraphic description of Cava Gentile available in literature and the sedimentary units recognised in the present study.

The lower part of the sedimentary succession (unit CG.LG) is at least 15 m thick and consists of horizontally-bedded organic-rich muds and sands with lenticular sandy intercalations (Fig. 2A). Muddy beds, up to 1 m thick, range from massive to tightly laminated, and contain plant debris, brackish malacofaunas (e.g. *Crassostrea* and *Cerithium*) and rare terrestrial vertebrates (Fig. 2C, E). Horizontal sandy beds, up to 20 cm thick, are made of coarse to fine sands, which can be massive, plane-parallel stratified or ripple-cross laminated. These beds form 30-80 cm thick packages characterised by a coarsening-upward trend in grain size. The lenticular sandy bodies (i.e. channel forms), which show concave erosive bases and flat tops, are 50-100 m thick and several tens of metres wide. These lensoid units show a fining-upward trend and are floored with a shell-rich pavement represented by very coarse sands with scattered pebbles. The lenses consist of large-scale inclined beds defining wedge-shaped sets in sections that run transverse to the palaeocurrent direction (Fig. 2B). Beds dip from 5° to 20° and consist of plane-parallel stratified sands.

A molluscan fauna recovered in the Cessaniti area, from an outcrop that correlates with CG.LG, shows variations that record typical estuarine conditions, from freshwater to brackish and marine environments (D'Amico et al. 2012; Ligios et al. 2012).

Organic-rich muddy deposits are abruptly overlain by very coarse pebbly sands (CG.FL1 in Fig. 2D). These deposits are up to 15 m thick and

consist of multilaterally arranged, erosive-based bodies showing a flat top and concave-upward base (i.e. channel forms). These bodies, which are up to 2 m thick and several tens of meters wide, contain superimposed sets of slightly inclined (3-5°) beds (Fig. 2F). The bedsets mainly dip parallel to the local transport direction and overlay a layer of fine- to medium-sized pebbles showing a well-developed a(t)b(i) imbrication (i.e. developed under tractional conditions). Beds consist mainly of relatively sorted, coarse to very coarse-grained sands with scattered pebbles. Sandy beds are up to 30 cm thick and show a well-developed, plane-parallel to planar-cross stratification. Fossils are absent.

The pebbly sands of unit CG.FL1 are sharply overlain by well-sorted sandy deposits that reach a maximum thickness of about 55 meters (Fig. 2A) and are floored by well-rounded, pebble- to cobble-sized gravels (Fig. 2G). These fossil-rich sandy deposits consist of four vertically stacked units (CG.SH1-4) bounded by uneven, laterally continuous erosive surfaces (Fig. 2A). CG.SH1-4 units consist of bioturbated, fine- to medium-grained sands with abundant echinoids and shell casts. Sands are commonly well sorted and matrix free, and locally shows a diffuse plane-parallel stratification. Fossils are concentrated in the lower part of these four unconformity-bounded units.

Unit CG.SH1 begins with sands up to 5 meter thick containing the echinoid *Amphiope bioculata*, typical of a shoreface environment (Stara et al. 2015). The overlying sands contain abundant and well-preserved echinoids belonging to the genus *Clypeaster*, typical of foreshore environment (Barbera & Tavernier 1990) and often associated with the sirenian *Metaxytherium serresii* (Fig. 2H, unit CG.SH1). These sands also contain gastropods moulds, *Ostrea* shells, selacian and Physitheroidea teeth and *Tryonix* carapax fragments, as well as land mammal remains (Rhinocerotidae, Anthracotheridae).

Unit CG.SH2 has medium- to fine-grained sands that contain abundant *Clypeaster* shells and fish teeth. Marine mammals are represented by *Metaxytherium serresii* and Delphinidae remains. The terrestrial mammals found in sediments of this unit included *Stegotetrabelodon* and Bovidae remains.

Unit CG.SH3 sands yield extremely abundant *Clypeaster* shells, with the species *Clypeaster insignis*, *C. redii* and *C. franchii*. *Metaxytherium serresii* is an extremely abundant form in this unit, while other marine

mammals (such as Delphinidae, Mysticetes indet., *Squalodon* sp. and Physiteroidae) are relatively rare. Terrestrial mammals from this unit are represented by Bovidae, *Boblinia* and *Stegotetrabelodon*.

Units CG.SH2 and CG.SH3 are capped by oxidised sands (up to 50 centimeter thick) that contain weathered (i.e. replaced by clay minerals) echinoid shells (Fig. 2J, K, L). These oxidised horizons are locally cut by erosive, concave-upward surfaces showing an erosional relief of about 1.5-3 m and hosting sandy deposit of units CG.FL2 and CG.FL3. These surfaces are commonly floored by fine pebbles and host superimposed sets of slightly inclined (3-5°) beds (Fig. 2A). Beds are composed of moderately sorted coarse to very coarse sands with scattered pebbles and show a well-developed plane-parallel to planar-cross stratification.

The sands of unit CG.SH4 show a high mud content and contains bivalves, brachiopods (*Terebratula sinuosa*), echinoderms (*Clypeaster portentosus*) and the large foraminifera *Heterostegina papyracea*. The occurrence of *Heterostegina papyracea* has been considered an *ante quam* term for the sequence of Cessaniti by Papazzoni & Sirotti (1999), starting from the evidence that the species was present in the Mediterranean until the late Tortonian.

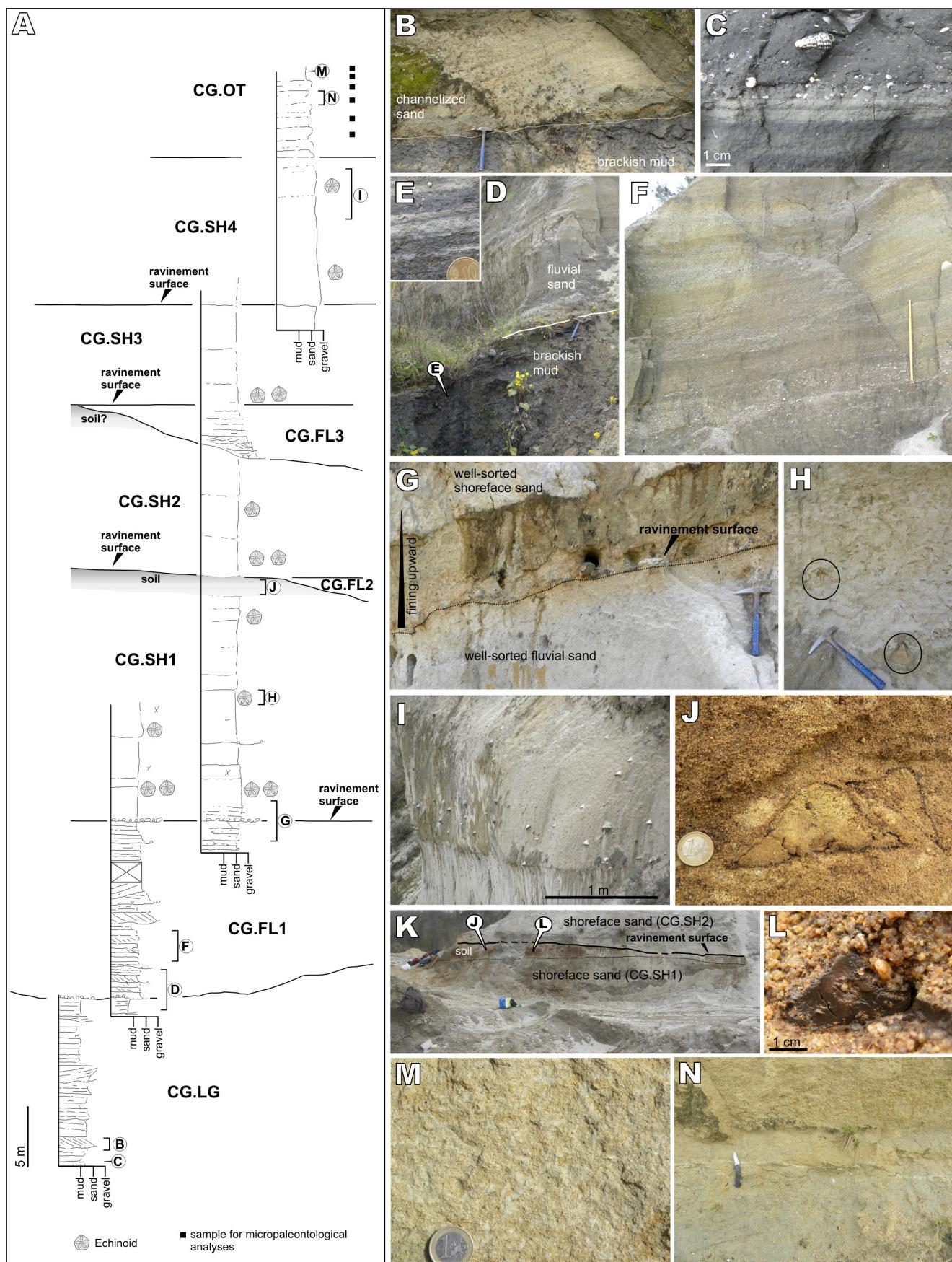
Sandy deposits of unit CG.SH4 are covered by a finer-grained interval about 7 m thick that consists of alternating highly bioturbated, medium- and fine-grained sands and muds (Fig. 2M, N) of unit CG.OT. This layer represents the beginning of the “*Orbulina* marls” (Rao et al. 2007), occurring with higher thickness in the nearby Cava Forcone and Cava Brunia (Carone & Domning 2007).

The section from the Cava Gentile area documents an overall transition from a coastal environment to open marine conditions (Carone & Domning 2007; Gramigna et al. 2008). The lower organic-rich deposits of unit CG.LG were emplaced in a restricted brackish environment (e.g. lagoon, Ligios et al. 2012), where muds settled from standing water and sands were deposited in small sinuous channels (i.e. lens-shaped bodies) or splays (i.e. tabular-bedded sands). These channels were probably fluvial in origin and delivered sediments eroded from the surrounding areas to the lagoon. The overlying CG.FL1 unit documents the establishment of a fluvial system that cut the muddy succession to develop a clear erosive surface. Downstream-dipping beds, clast-imbrication

and well-developed sedimentary structures indicate tractional sedimentation in low-sinuosity, multi-channel systems (cf. Bridge 1993). The pebbly lag that overlies these fluvial deposits is interpreted as a transgressive lag (cf. Hwang & Heller 2002), developed as a consequence of the establishment of shallow marine deposition (i.e. shoreface setting; Clifton 2006), as suggested by the occurrence of bioturbated, fossil-rich sands that represents the SG.SH1-4 units (Fig. 3).

Deposition in a shallow-water, wave-winnowed setting represents the background sedimentation that characterises units CG.SH1 to CG.SH4. Nevertheless, the occurrence of oxidised horizons and erosive-based pebbly sands suggests that nearshore sands was occasionally affected by subaerial exposure, which caused the formation of soils (i.e. oxidised horizons) and the establishment of fluvial deposition (unit CG.FL2). The weathered echinoids occurring in the oxidised horizons document the effect of pedogenic processes in operation during soil formation. The occurrence of fossil-rich layers at the base of shoreface deposits (such as units CG.SH1 to 4) documents the re-establishment of marine sedimentation through minor transgressive events, which caused development of flat and laterally-continuous ravinement surfaces. The uppermost, finer-grained deposits of unit CG.OT indicate a transition from shoreface sands into offshore transition deposits; these accumulated in a deeper setting, where waves winnowed the seafloor only during the main storm events (Clifton 2006). These

Fig. 2 - The Cava Gentile succession. A) Sedimentological logs in the Cava Gentile area. The location of the samples used for micropalaeontological analyses is indicated. B) Channelised sands interbedded within brackish muds. C) Laminated organic-rich muds with brackish malacofaunas. D) Erosional surface separating brackish muds from overlaying fluvial sands. E) Close view of D, showing the plane-parallel lamination of the organic-rich muds. F) Stratified gravelly fluvial sands overlying organic-rich muds. G) Gravelly transgressive lag separating fluvial sands from the overlying shoreface deposits. H) Well-preserved echinoids (*Clypeaster*) in bioturbated shoreface deposits. I) Echinoid-rich interval in the upper part of the Cava Gentile succession. J) Echinoid shells replaced by clay minerals in pedogenised shoreface sands. K) Reddish pedogenised horizon (soil) interbedded within shoreface deposits. L) Detail of an echinoid shell replaced by clay minerals in pedogenised shoreface sands. M) Bioturbated muddy deposits. N) Alternating offshore-transition muds and sands from the upper part of the Cava Gentile succession.



A	B	C	D
<i>Orbulina</i> marls	<i>not named</i>	Unit 4	CG.OT
<i>Heterostegina</i> yellow sands	circalittoral	Level 8	Unit 3 CG.SH4
<i>Clypeaster</i> sandstones ("Arenarie a Clypeaster")	mesolittoral	Level 7	CG.SH3
		Level 6	CG.FL3 CG.SH2
		Levels 4-5	CG.FL2 CG.SH1
	transitional	Level 3	CG.FL1
Dark clayey sands with ostracoids	lagoonal	Levels 1-2	CG.LG

Fig. 3 - Lithostratigraphic column of the Cava Gentile succession, with a synopsis of informal stratigraphic units recognised by previous authors: A) Nicotera 1959; Ogniben 1973; Rao et al. 2007; Gramigna et al. 2012. B) Carone & Domning 2007. C) Gramigna et al. 2008. D) The present study.

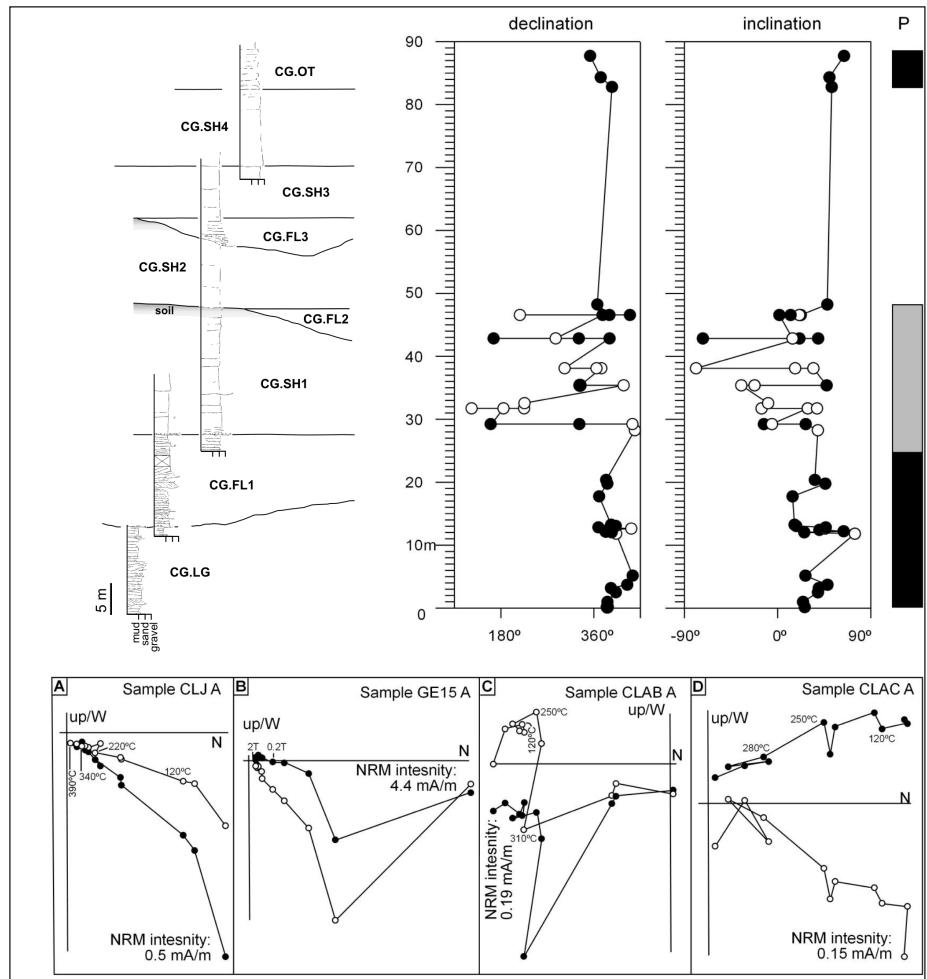
mud-rich sediments represent the lowermost portion of the so called “*Orbulina* marls” (Gramigna et al. 2008).

Age - The Cava Gentile section was dated by exploratory magnetostratigraphic and micropalaeontological studies. Magnetostratigraphic sampling of CG.LG was focused on mudstones and sandstones (hand sampled and drilled, respectively). CG.SH 1 to 3 and CG.FL 1 to 3 loose sands generally required the impregnation of the sediment with sodium silicate before block sampling. Completely

loose and very coarse grained sands from metres 50 to 80 hardly allowed any sampling. Sampling was easy again in the topmost metres of the section (CG.OT unit). Palaeomagnetic measurements were carried out at the Institute of Earth Sciences (SCT Universitat de Barcelona-CSIC). Specimens underwent a stepwise thermal demagnetisation with a TSD-1 demagnetiser (Schonstedt). A typical protocol included 12 steps from room temperature to a maximum of 390°C. Some samples were also demagnetised with an alternating field D-Tech 2000 demagnetiser (ASC Scientific). Remanence measurements were acquired with a superconducting rock magnetometer (2G-Enterprises). Bulk susceptibility was measured at room temperature and for each thermal demagnetisation step with the KLY-2 susceptibilimeter (Geofyzika Brno).

After discarding samples with very low intensity and unstable demagnetisation behaviour, two kinds of samples were used to derive palaeomagnetic components. The first type is represented by samples with a relatively stable demagnetisation that were fully demagnetised; these are labelled as ‘confident’ in Fig. 4 A and B (represented as closed circles in Fig. 4, top left). The second type is characterized by very low and relatively unstable intensity (C and D in Fig. 4). In some cases, viscous and secondary components (likely representing the present day field) are observed from room temperature to around 120 °C. At higher temperatures, a component directed to the origin is recorded (at least for the high confidence samples) and is considered to be a characteristic remnant magnetisation acquired at the time of rock formation. Isothermal remanent magnetization (IRM) experiment in one CG.LG sample suggested the occurrence of magnetite, as observed by saturation acquired at 300 mT. For the low temperature components, iron hydroxides are the likely carriers of magnetization. The obtained demagnetization results (see plot in Fig. 4, bottom) varied in quality according to the stratigraphic unit, being relatively well defined in the uppermost (CG.OT unit) and lowermost (CG.LG unit) units of the section (Fig. 4 top right). According to these data, normal polarities are obtained in the basal brackish muds and sands (CG.LG unit). The uppermost unit (CG.OT) also yielded normal polarities. On the contrary, data from the middle unit (CG.FL1, CG.SH1 units) are rather unclear and do not permit any assessment of polarity. Low confidence data predo-

Fig. 4 - Magnetostratigraphic analyses. Cava Gentile section and related magnetostratigraphic values, with closed and open dots indicating high and low confidence data, respectively. Polarity (P) is depicted in black for the normal intervals and in grey for the uncertain ones. Bottom: examples of orthogonal demagnetisation plots thermal demagnetised (except C, which was alternating field demagnetised). A and B belong to relatively confidence data, with relatively high intensities and origin directed, while C and D are of low reliability, with low intensities and less stability.



minate and the values are quite inconsistent, with even opposite polarities for a single stratigraphic level. The general pattern observed in Fig. 4 right is unclear, except that normal polarity seems to be dominant for the relatively confident data. Unfortunately, the primary origin of the characteristic magnetization could not be checked by means of a fold/tilt test, since the studied succession is almost horizontal. A remagnetization process cannot be proved neither discarded.

The mud to very fine-grained sand layers of the open marine deposits were sampled for the study of calcareous nannofossil assemblages. Samples from the shallow marine sands (CG.SH1 to 4 units) are barren of pristine calcareous nannofossils, but some reworked forms of Cretaceous and Paleogene taxa have been found. By contrast, the offshore transition deposits (CG.OT unit) are well diversified and moderately well preserved and the presence of *Amaurolithus primus* and *Amaurolithus delicatus*, and the absence of *Nickilithus amplificus* and *Reticulofenestra pseudoumbilicus* ($> 7 \mu\text{m}$) indicate that this suc-

cession can be ascribed to Zone CNM17 (Backman et al. 2012), which approximately coincides with the lower part of Subzone CN9b (Okada & Bukry 1980) (Fig. 7).

The S. Nicolò area

Sedimentology - At this site, located about 25 km East of Vibo Valentia (Fig. 1A), a ca. 10 meter thick succession unconformably overlies the Hercynian bedrock (Fig. 5A).

The basal deposits consist of a 50-150 centimeter thick, sheet-like gravel bed. The gravel is subangular to rounded and poorly sorted, with clasts ranging from pebbles to boulders. This gravel bed is clast supported and contains rare fragments of echinoids (species of *Clypeaster*). This basal horizon is overlain by a 4-5 meter thick interval consisting of poorly sorted, mud-devoid, fine pebbles grading upward to very coarse sands. These deposits are characterised by a poorly defined plane-parallel subhorizontal bedding, marked by subtle changes in grain size. Bioturbation is pervasive, and fossils

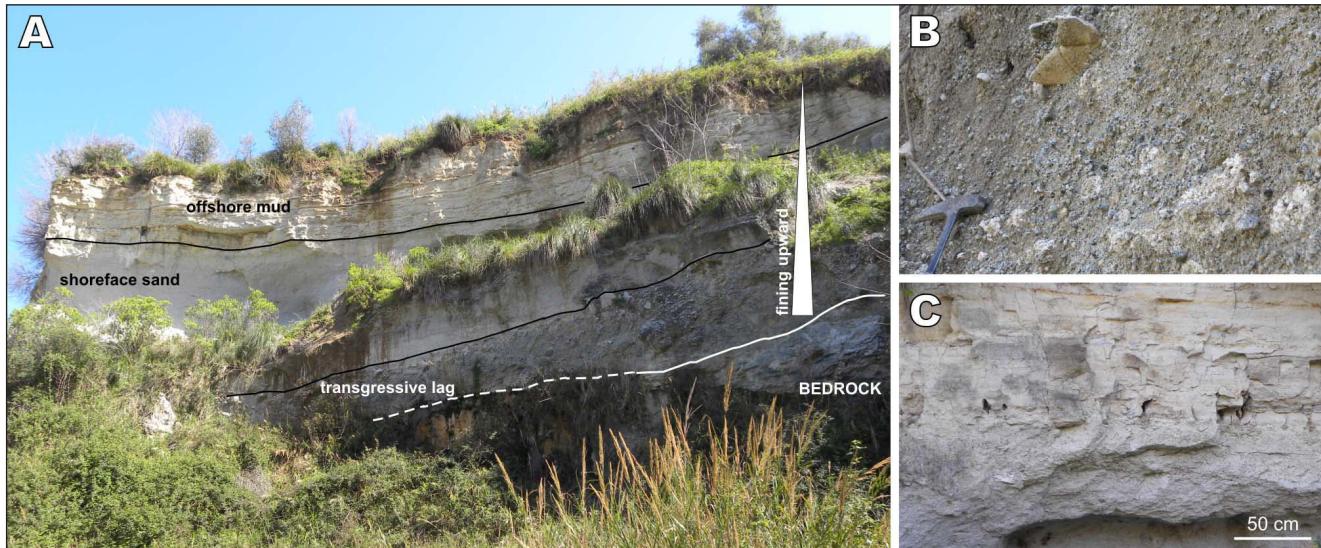


Fig. 5 - S. Nicolò area. A) Panorama of the S. Nicolò outcrop showing the rapid transition from the basal gravelly transgressive lag to open marine muds. B) Massive, bioturbated gravels from the basal transgressive lag. Note the presence of echinoids (*Clypeaster*) and rhodoliths. C) Horizontally bedded open marine muds.

are mainly represented by well-preserved echinoids (species of *Clypeaster*) and rhodoliths (Fig. 5B). The section is capped by horizontally bedded muds (Fig. 5) with scattered shells.

The basal gravelly interval SN.NSH represents a transgressive lag (cf. Hwang & Heller 2002) formed by winnowing of sea waves in the nearshore. The overlying sands and gravels are thought to be formed in a shoreface depositional environment dominated by waves; the sediment was subsequently homogenised by bioturbation (Johnson & Baldwin 1996; Rasmussen 2000). The fining-upward trend observed in the upper part of the section is ascribed to the transition from shoreface to offshore settings (i.e. offshore transition zone), and it documents a rapid deepening of the depositional environment.

Age - Limited accessibility of offshore muds prevented sampling for palaeomagnetic analyses; nevertheless, counts were performed on calcareous nannofossil assemblages from offshore deposits capping the section. Nannofossils vary from common to abundant and the preservation is poor to moderate. A peculiar trait of this set of samples is the high abundance of reworked Cretaceous and Paleogene (Eocene) forms that sometimes exceeds that of the Miocene ones. The absence of *Reticulofenestra pseudoumbilicus* ($> 7 \mu\text{m}$) and *Discoaster berggrenii* suggests that these sediments are older than those of Cava Gentile unit CG.OT and belong to Zone CNM15 (Backman et al. 2015), approximately coinciding with CN8b (Okada & Bukry 1980) (Fig. 7).

Other supporting data for this interpretation are the presence of *Discoaster bellus* and the absence of *Discoaster hamatus* and *Catinaster* spp.

CESSANITI MAMMAL FAUNA: DISTRIBUTION, BIOCHRONOLOGY, PALAEOECOLOGY

The Cessaniti deposits yielded mammalian faunas dated to the pre-Messinian-latest Miocene.

The most representative mammal at Cessaniti is the sirenian *Metaxytherium serresii* (Carone & Domning 2007). The terrestrial mammal assemblage includes the elephantid *Stegotetrabelodon syrticus*, the giraffids *Samotherium cf. boissieri* and *Bohlinia cf. attica*, a boselafine bovid, as well as remains attributable to the small sized bovids, Rhinocerotidae and Antracotheridae; the only taxa so far described in detail are *S. cf. syrticus*, a species with an exclusive Afro-Arabian distribution (Ferretti et al. 2003, 2017; Ferretti 2008) and *Samotherium cf. boissieri* and *Bohlinia cf. attica*, typical of the Pikermian biome (Marra et al. 2011).

Cetaceans

Odontocetes have been recovered from “Cava Gentile” at Cessaniti and in the surrounding area from sediments of the shoreface units (CG. SH1-4). Nine teeth (probably belonging to the same individual; Fig. 6C-F) from CG.SH1 unit and one isolated tooth from CG.SH3 unit represent Physe-

teroidea indet. (Marra et al. 2016). One isolated *Squalodon* sp. tooth comes from unit CG.SH3 while remains attributed to Odontocetes indet. are relatively abundant in units CG.SH1-3.

Mysticetes attributable to *Heterocetus cf. guisardi* are represented by remains (a mandibular fragment, a cranial fragment, a tympanic bulla and isolated vertebrae) from unit CG.SH3 while other fossils (a cranial fragment, a right mandibular ramus, an incomplete left mandibular ramus, vertebrae and ribs) have been recovered from unit CG.SH4 (Carone & Marra 2014).

Sirenians

The most common species, testified by a very rich record in units CG.SH1-3, but rare in CG.SH4, is the sirenian *Metaxytherium serresii* (6A-B), whose presence marks the first occurrence of this species (Carone & Domning 2007; Carone et al. 2013). Remains of *M. serresii* are also present in several sites in the inland of Monte Poro (Zungri, Papaglioni, Zaccanopoli, Caria, Rombiolo; Carone & Domning 2007; Carone et al. 2013).

Dugongidae are present in the fossil record of Calabria from late Burdigalian-Langhian (Carone et al. 2016). The genus *Metaxytherium* is recorded in Europe from the Early Miocene to the Middle Pliocene. In the Parathethys, *Metaxytherium* underwent an anagenetic evolution, with four recognised chronospecies (Domning & Thomas 1987). The third chronospecies *M. serresii* shows significant differences when compared to the previous and subsequent ones, such as a marked reduction in body size coupled with a relative increase in tusk size (the latter was probably related to a switch to feeding on seagrass rhizomes instead of leaves; Carone & Domning 2007). Before the findings from Cessaniti, the reduction in body size of the Lower Pliocene *M. serresii* was interpreted as a dwarfism induced by the impact of the Messinian salinity crisis on the availability of seagrasses, the primary food resources for sirenians (Domning & Thomas 1987). However, given the pre-Messinian age of the *M. serresii* sample from Cava Gentile, Carone & Domning (2007) suggested that an ecophenotypical dwarfism had occurred in response to the habitat impoverishment following the Tortonian salinity crisis (about 7.8-7.6 Ma; Kouwenhoven et al. 2003). The dating of As Sahabi (Libya), where *M. serresii* is present, at 6.7 Ma (Bernor & Rook 2008) is in accordance with the first occurrence of the spe-

cies before the Messinian Salinity Crisis.

Notably, the remains of its ancestor species, *Metaxytherium medium* (second chronospecies of the lineage), have been recorded in the Capo Vaticano-Monte Poro area. A complete skeleton has been collected in sands at Santa Domenica di Ricadi belonging to the “shallow water sandstone subunit” (Montcharmont Zei & Montcharmont 1987; Gramigna et al. 2012). This subunit correlates with the basal unit CG.LG described in this paper (cfr. models by Gramigna et al. 2012; Caracciolo et al. 2013). The specimen from Santa Domenica probably marks the last occurrence of the species (10.5-7.6 Ma; Bianucci et al. 2008).

Proboscideans

The primitive elephantoid *Stegotetrabelodon syrticus* occurs at Cessaniti both in deposits of lagoonal marls and sands (CG.LG unit) and in shoreface sands in the CG-SH1 to 3 units (Ferretti et al. 2003, 2017; Ferretti 2008).

A single worn DP4 comes from the basal part of the succession (CG.LG unit), whereas the entire Cessaniti *Stegotetrabelodon* collection (one mandible, one incisor, one fragmentary molar, two fragmentary humeri, one right II metacarpal and one incomplete femur) comes from the shoreface sands of CG-SH1 to 3.

The species is well documented at As Sahabi, in Libya (6.7 Ma; Bernor & Rook 2008). It has also been found in sites of the Baynunah Formation (Abu Dhabi, United Arab Emirates), whose estimated time ranges from 8.2 to 5.3 (Whybrow & Hills 1999; Bibi et al. 2012, 2013).

Arctiodactyla

Two giraffids, referable to two mid-sized species, are documented from shoreface sands at Cessaniti (Cava Gentile) and in the neighbouring area (Zungri, Fig. 1A) by a number of cranial and postcranial elements (Marra et al. 2011).

Remains attributable to *Boblinia cf. attica* are an upper toothrow and postcranial elements (a distal radius, two astragali, two cubo-naviculars and a distal tibia), all from Cava Gentile CG.SH3 unit (Fig. 6I).

By contrast, *Samotherium cf. boissieri* is represented by postcranial elements. At Cava Gentile (CG.SH1-3 units), recovered elements have included two metacarpals, two metatarsals and a distal tib-

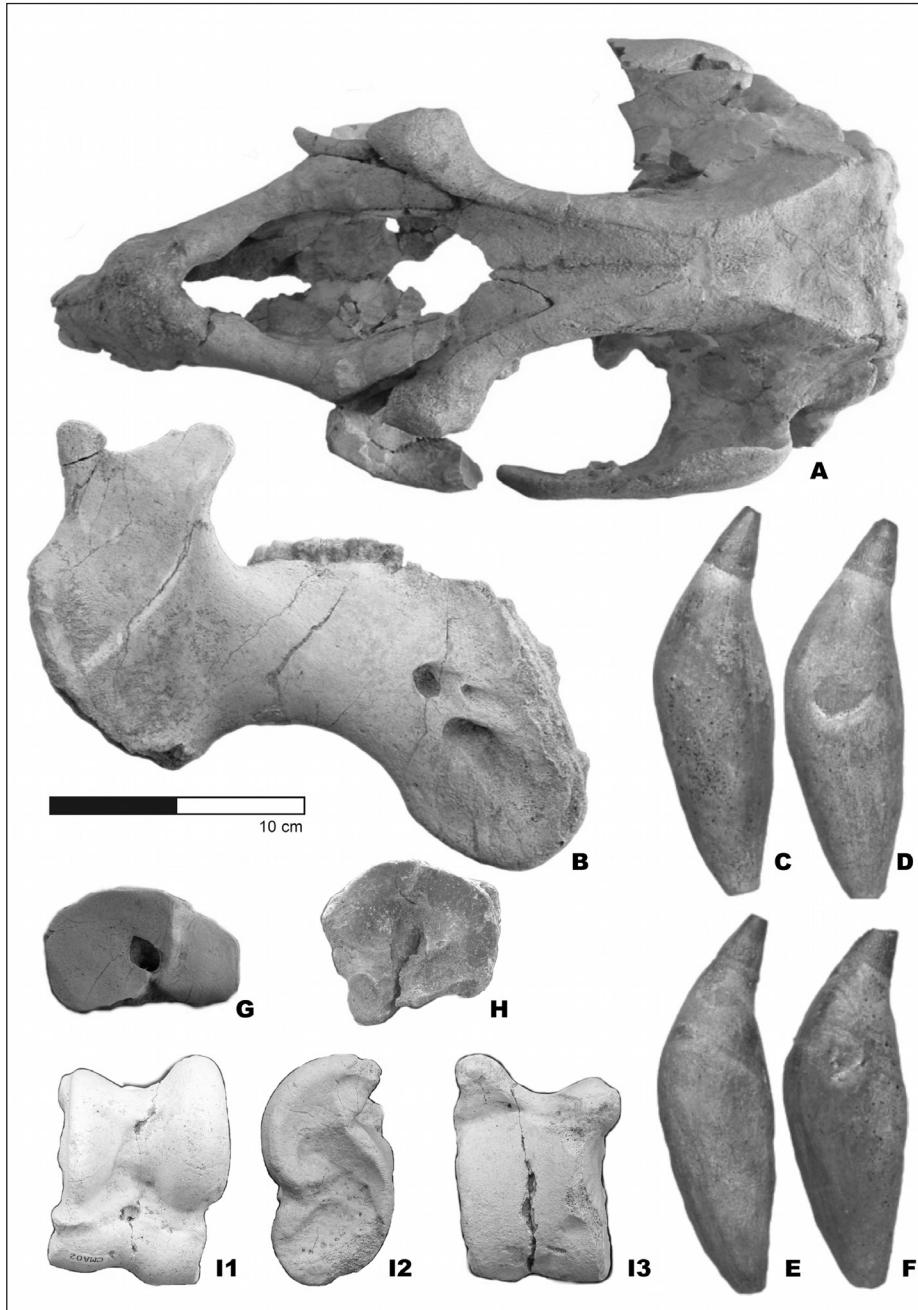


Fig. 6 - Mammals from Cessaniti and the surrounding area. A) Skull of *Metaxytherium serresii* in dorsal view (Cava Gentile, CG.SH1 Unit). B) Right hemimandible of *Metaxytherium serresii* in lateral view (Cava Gentile, CG.SH2 Unit). C-F) Four of nine teeth of Physeteroidea indet., probably belonging to the same individual (Cava Gentile, CG.SH1 Unit). G) Left metacarpal of *Samotherium* cf. *boissieri* in proximal view (Zungri, layers correlatable with CG.SH1). H) Left metatarsal of *Samotherium* cf. *boissieri* in proximal view (Cava Gentile, unit unknown). I) Left astragalus of *Boblinia* cf. *attica* in dorsal (a), external (b) and ventral (c) views (Cava Gentile, unit unknown). Specimens from A to G are stored in the Civico Museo di Ricadi (MURI), Santa Domenica di Ricadi (Vibo Valentia); specimens H and I are stored in the "Museo di Paleontologia" of the University of Calabria (Cosenza).

ia (Fig. 6H); at Zungri, sediments correlatable with the CG.SH1 unit yielded a complete left manus, a partially preserved left ulna and a distal epiphysis of a left radius (probably belonging to the same individual), a strongly damaged humerus and other fragmentary bones (Fig. 6G).

Boblinia attica is known from the Tortonian to the Messinian (Vallesian to late Turolian, according to European Land Mammal Ages) in the western regions of the Greco-Iranian bioprovince (Geraads et al. 2005; Kostopoulos 2009), while its presence in the Late Miocene of Chad, in Africa, is under debate (Harris et al. 2010).

Samotherium boissieri is another species com-

mon in the Greco-Iranian bioprovince, in some cases associated with *Boblinia*, between 8.0 and 7.4 Ma (early-middle Turolian). The first occurrence of *S. boissieri* was recorded at Gülpınar (Turkey) in the late Tortonian (Sen 2016). Although the species is not recorded in Africa, the genus *Samotherium* sp. is represented by scanty remains at As Sahabi in Libya, Bou Hanifia in Algeria and Nakali in Kenya (Harris et al. 2010).

Boblinia attica and *Samotherium boissieri* are typical species of the Pikermian biome, a peculiar mammalian community inhabiting a savannah-like environment which progressively formed in the Greco-Iranian bioprovince during the Late Mio-

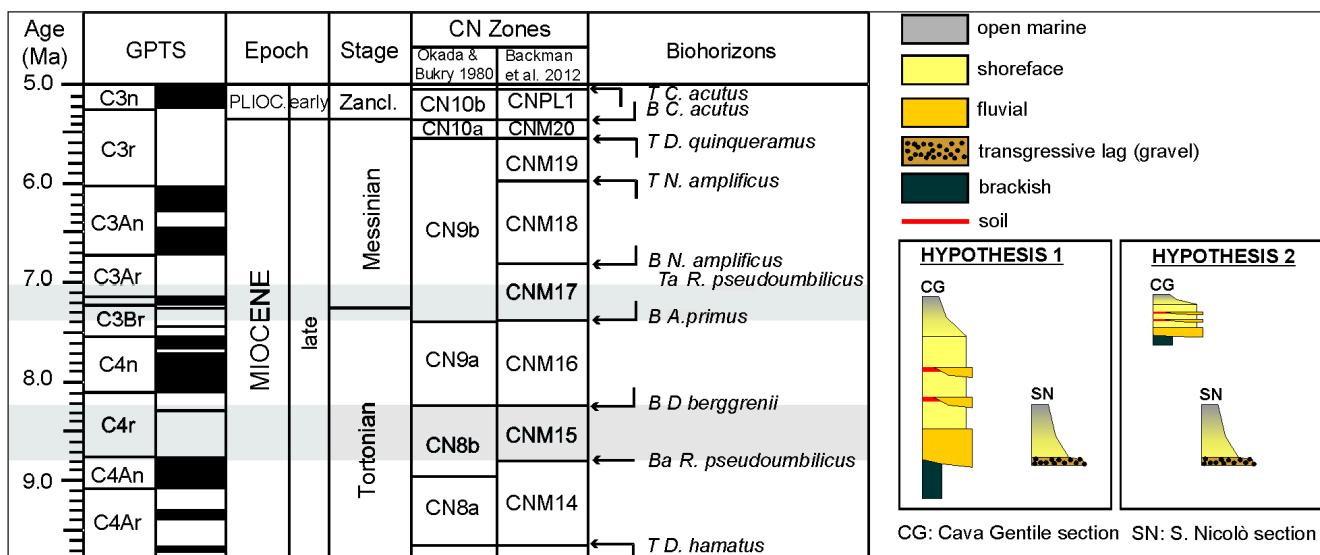


Fig. 7 - Age models for the study sedimentary succession. The biochronomagnetostratigraphic scheme is based on Backman et al. (2012). The Geomagnetic Polarity Time Scale (GPTS) follows Lourens et al. (2004). Calcareous nannofossil biozones are taken from Okada and Bukry (1980) and Backman et al. (2012).

cene (Solounias et al. 1999). The presence of the two giraffids at Cessaniti records the western expansion of the Pikermian biome through North Africa (Marra et al. 2011).

A boselaphine bovid tentatively attributed to *Tragopontax* has been recovered from the CG.SH2 and CG.SH3 units at Cava Gentile (Marra et al. in progress). The genus *Tragopontax* was widespread in Eurasia and Africa during Late Miocene (Kostopoulos 2009; Bibi 2011). The ecological niche of *Tragopontax* is comparable to that of the extant *Hippotragus*: a forest-savannah alternating with open spaces (Spassov & Geraads 2004). The remains of another still undetermined bovid (smaller in size) from the CG.SH2 and 3 units finally complete the bovid assemblage.

The occurrence of a hexaprotodontid hippopotamus from CG.SH1, previously indicated at Cessaniti (Ferretti et al. 2003; Marra et al. 2011), can be excluded following a deeper examination of the remains. Although the specimens (represented by an incisor and a femur) are still under study, they are better attributable to an Anthracotherid.

Perissodactyla

Rhinocerotid remains come from CG.SH1 at Cava Gentile. These are represented by a fragmentary skull, two fragmentary teeth and a few postcranial bones. The specimens – referred in faunal lists as referable to the genus *Diceros* (cfr.

Marra et al. 2011) – are in crucial need of a deeper revision and study, and a more cautious taxonomic attribution to as Rhinocerotidae indet. seems more convenient at present (Pandolfi & Rook 2017).

DISCUSSION

Age of the sedimentary successions

The sedimentary features of the studied successions fit well with the overall stratigraphic reconstruction depicted by previous Authors (Neri et al. 2005; Carone & Domning 2007; Gramigna et al. 2008): a transition from a continental to deep marine settings during the late Tortonian (Ferretti et al. 2003). Nevertheless, the Cava Gentile and S. Nicolò sections point to a progressive and an abrupt establishment of open marine conditions, respectively. This would be related either to different transgressive events or an alongstrike variability of the ratio between the creation of accommodation space and the sediment supply (cf. Ghinassi 2007). Two main hypotheses can be formulated based on the integration of the biostratigraphic and magnetostratigraphic data (Fig. 7).

Despite magnetostratigraphic limitations, the first hypothesis considers the brackish muds of Cava Gentile as the oldest deposits and ascribes them to the Chron C4An (Fig. 7). In this framework, the S. Nicolò succession is considered to

be coeval with the shallow marine deposits of Cava Gentile (Fig. 7). In the S. Nicolò area, the lack of soils and alluvial deposits can be ascribed to accumulation in a highly subsiding setting that caused a rapid establishment of open marine sedimentation; the latter developed in the Cava Gentile area only during the earliest Messinian, as suggested by biostratigraphic (i.e. biozone CNM17) and palaeomagnetic (i.e. normal polarised samples from top of C3Br Chron) data from CG.OT. In this model, units CG.FL1 to CG.SH4 accumulated between 8.8 and 7.2 Ma.

This hypothesis is weakened by the occurrence of proboscidean remains in the Cava Gentile succession, either in the basal “brackish” muds and sands (CG.LG unit) or in the overlying CG.SH1 to 3 units. This is in contrast with the known stratigraphic range of *Stegotetrabelodon*, which is not documented before 7.5 to 7.7 Ma (Sanders et al. 2010). Moreover, the species is considered very close to the East African *Stegotetrabolodon orbus*, and both forms seem to be well constrained in a time interval between 7.4 and 4.2 Ma (Sanders 2008). We exclude the presence of *S. syrticus* at Cessaniti as the first occurrence of the species.

The presence of the sirenian *Metaxytherium serresii* in the sands of Cava Gentile (CG.SH1-4) is also relevant for biochronology. Excluding the finds at Cessaniti, the oldest *M. serresii* fossils are recorded at As Sahabi (Bianucci et al. 2008). Moreover, the morphological peculiarities of the species (unique to the lineage of the genus) might be an ecophenotypical response to the habitat impoverishment due to the Tortonian salinity crisis, recorded about 7.8–7.6 Ma (Carone & Domning 2007). The occurrence of the ancestor species *M. medium* in the “Shallow water sandstones subunit” at Santa Domenica, correlatable to CG.LG (Gramigna et al. 2012; Caracciolo et al. 2013), is coherent with an age younger than the Tortonian salinity crisis (7.8–7.6 Ma, Kouwenhoven et al. 2003) for CG.SH1-4, where the derived species *M. serresii* occurs.

Given this biochronological constraint, we favour a second hypothesis that considers the S. Nicolò deposits as the oldest unit, and ascribes the brackish muds (CG.LG unit) of Cava Gentile to normal Chron C4n. This model also proposes the Cava Gentile area being affected by open marine deposition only during the earliest Messinian, whereas the S. Nicolò area was dominated by deep marine sedimentation since Tortonian time.

The Cava Gentile section: paleoenvironmental reconstruction

The so called “*Clypeaster* sandstones” were commonly ascribed to a shallow-marine, wave-dominated depositional environment (Gramigna et al. 2008; Carone & Domning 2007; Neri et al. 2005). Nevertheless, the accumulation of thick, monotonous shoreface deposits implies a long-lasting balance between the rate of sediment supply and accommodation space formation, an unusual condition for a tectonically active basin (Posamentier & Allen 1999). At the same time, the dominance of a stable marine depositional environment contrasts with the common occurrence of terrestrial mammal remains in the “*Clypeaster* sandstones” (Ferretti et al. 2003, 2017; Marra et al. 2011).

The occurrence of soil deposits in the Cava Gentile section represents a novelty of this work. The occurrence of erosion-based fluvial deposits within the shoreface sands (CG.FL1 to 3 units) also accounts for episodes of relative sea-level falls within the overall transgressive trend. These abrupt changes in accommodation space are consistent with a tectonically active basin, while the temporary establishment of an alluvial depositional environments fits with the common occurrence of terrestrial mammal remains. The thickest fluvial body of CG.FL1, cut on top of brackish muds, accounts for a major relative sea level fall forcing fluvial channels to cut the underlying brackish muds (cf. Catuneanu 2002).

This episode of accommodation space shrinkage was followed by alluvial aggradation and subsequent marine ingressions (i.e. transgressive lag) and caused accumulation of the overlying fossil-rich, shallow-marine deposits of the CG.SH1 unit. The soils and alluvial intercalations within the “*Clypeaster* sandstones” document at least two minor episodes of relative sea-level falls and subsequent rises (CG.FL 2 and 3 units). Relative sea-level falls promoted localised fluvial incisions (e.g. minor valleys?) and the development of soils in the interfluve areas.

During these relative sea-level falls and following lowstand stages, sediments transported by fluvial channels were derived from erosion of well-sorted shallow marine sands. This condition allowed the accumulation of well-sorted fluvial sands, which are poorly distinguishable from marine sands, except for the presence of gravel beds and the absence of well-preserved fossils. Subsequent trans-

gressions caused clastic sediment starvation and consequent concentration of marine and terrestrial fossils in defined horizons (cf. Kidwell 1993). This condition accounts for the occurrence of most of the vertebrate assemblages along specific horizons (Ferretti et al. 2003).

Land mammal assemblage

Although scanty, the identified mammalian taxa provide evidence of a peculiar Upper Miocene land mammal assemblage.

The proboscidean specimens from Cessaniti have some plesiomorphic characters with respect to the sample referred to *S. syrticus* from As Sahabi, Northern Libya, which released the type material (Ferretti et al. 2003, 2017). At present, the finding in Cessaniti is the only record of this species outside the Afro-Arabian province and is interpreted as an evidence of a land connection of a portion of extant Calabria to North Africa (Ferretti et al. 2003; Ferretti 2008).

The occurrence of *Bohlinia* cf. *attica* and *Samotherium* cf. *boissieri* at Cessaniti suggests a westward expansion of the Pikermian biome, a peculiar mammal community spread in the Greco-Iranian biogeographic province during the Late Miocene. The two giraffid species are found associated only at Samos and their occurrence in Africa is uncertain, due to the scanty fossil record.

The preliminary attribution of some bovid remains to *Tragopontax* seems to confirm the wide distribution of Tragopontacini throughout the Late Miocene of Europe and Asia. Tragopontacini (mainly referring to the genus *Tragopontax*) have been found in the Late Miocene of Africa (As Sahabi, Lothagam, Middle Awash, Samburu Hills and Langebaanweg), and Arabian peninsula (Abu Dhabi; Baynunah Formation) (Bibi 2011). Bibi (2011) considers the similarity of African and European/Asian tragopontacins as evidence for a great degree of biotic exchange between Africa and Eurasia during the Late Miocene or even later in time. Therefore, the preliminary data on *Tragopontax* at Cessaniti are in agreement with the remarks of Ferretti et al. (2003) regarding *Stegotetrabelodon syrticus*, and of Marra et al. (2011) regarding giraffids.

From an environmental point of view, the mammal assemblage indicates a mosaic environment with open spaces, probably similar to the modern savannah but less arid, in agreement with

the Pikermian biome. The assemblage is consistent with the evidence of expansion of Eurasian mammals to Africa (and then to Cessaniti) in the Late Miocene. Finally, the greater mammal bone accumulation during transgressions weakens the hypothesis of the casual sinking of carcasses after a long floating in open sea (Marra et al. 2011). It suggests that the remains come from a nearby emerged land whose position and areal extension, as well as possible connections to North Africa, need more investigations.

CONCLUSION

1) The overall transgressive trend documented by the upper Tortonian succession of the Capo Vaticano area shows locally different depositional trends, possibly associated with an alongstrike variability of the ratio between the rate of sediment supply and the accommodation space variations. The soils and fluvial deposits of the Cava Gentile succession, documented here for the first time, suggest that the late Tortonian transgression was also punctuated by minor episodes of forced regression, which caused abrupt shifts of alluvial depositional systems over lagoonal and shallow marine environments. Subsequent relative sea level rises allowed accumulation of marine and terrestrial fossils in specific transgressive horizons.

2) Although biostratigraphic analyses allows the proposal of two slightly different hypotheses for the chronological scenario observed for the Cava Gentile succession, the biochronological constraints offered by the Cessaniti mammal assemblage lead us to consider the basal CG.LG unit over the possible normal Chron C4n (8.1 - 7.5 Ma). In this model, the maximum range of the Cessaniti mammal assemblage from Cava Gentile is about 1 Ma, bracketed between 8.1 and 7.2 Ma.

3) The land mammal assemblage of Cessaniti is confirmed as a Late Miocene biogeographic crossroads between western Eurasia and sub-Saharan Africa Late Miocene faunas and its age, strengthened by the combination of palaeomagnetic and biostratigraphic data in this study, is consistent with the evidence of a certain degree of biotic continuity between Eurasia and Africa in the Late Miocene.

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