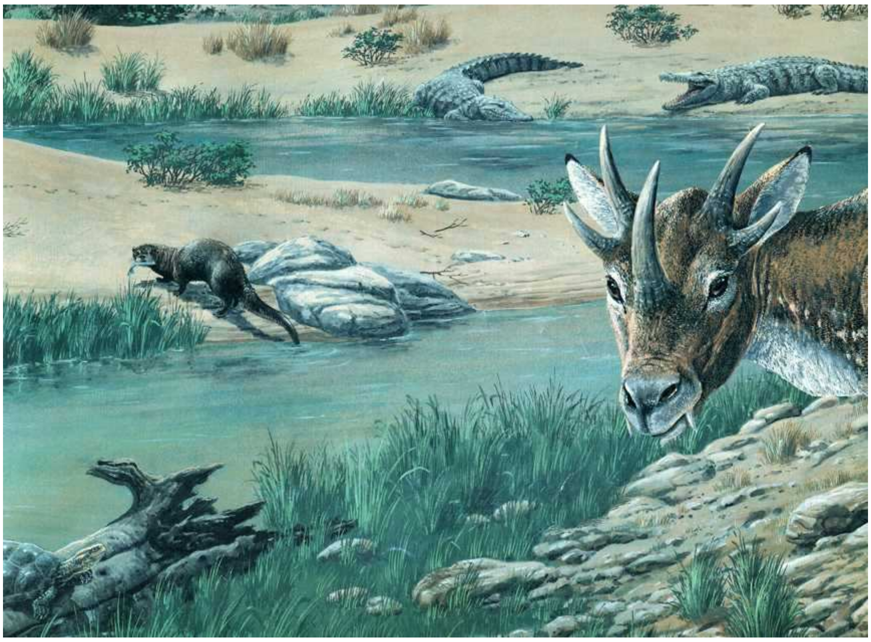
# Società Geologica Italiana

# 83ª Riunione Estiva

## (Chieti, 12-16 settembre 2006)

## The Miocene land-vertebrate fossil site of Scontrone (Central Apennine)



Imaginative reconstruction of the *Hoplitomeryx* habitat in a picture of S. Maugeri

THE MIOCENE LAND-VERTEBRATE FOSSIL SITE OF SCONTRONE (CENTRAL APENNINE)

Etta Patacca[1], Paolo Scandone[1] and Paul Mazza[2]

[1] Department of Earth Sciences, University of Pisa. Via S. Maria, 53. 56100 Pisa, Italy
[2] Department of Earth Sciences and Museum of Natural History, Section of Geology and Palaeontology, University of Florence. Via La Pira, 4. 50121 Florence, Italy

The Miocene land-vertebrate fossil site of Scontrone, which is located on the eastern slope of the Civita Mountain some 1180 m above the sea level, was discovered in the early nineties of the last century (RUSTIONI *et al.*, 1992). From that time, numerous remains of chelonians, crocodiles, lutrine carnivores and land mammals have been extracted, the latter including the problematic genus *Hoplitomeryx* and the giant insectivore *Deinogalerix freudenthali* BUTLER (MAZZA & RUSTIONI, 1996; MAZZA & RUSTIONI, in preparation). The fossils are embedded in Miocene peritidal carbonates, which locally form the lowermost portion of the *Lithothamnium* Limestone. These peritidal carbonates, which were deposited in coastal-flat and coastal-lagoon settings, are here called the Scontrone Member of the *Lithothamnium* Limestone (see fig. 4). The latter is a Tortonian-lower Messinian lithostratigraphic unit widespread in the Central Apennine, which in the Scontrone region disconformably overlies a lower Cretaceous-Paleocene platform-to-basin carbonate system referred to the Gran Sasso-Genzana tectonic unit (see figs. 1-3).

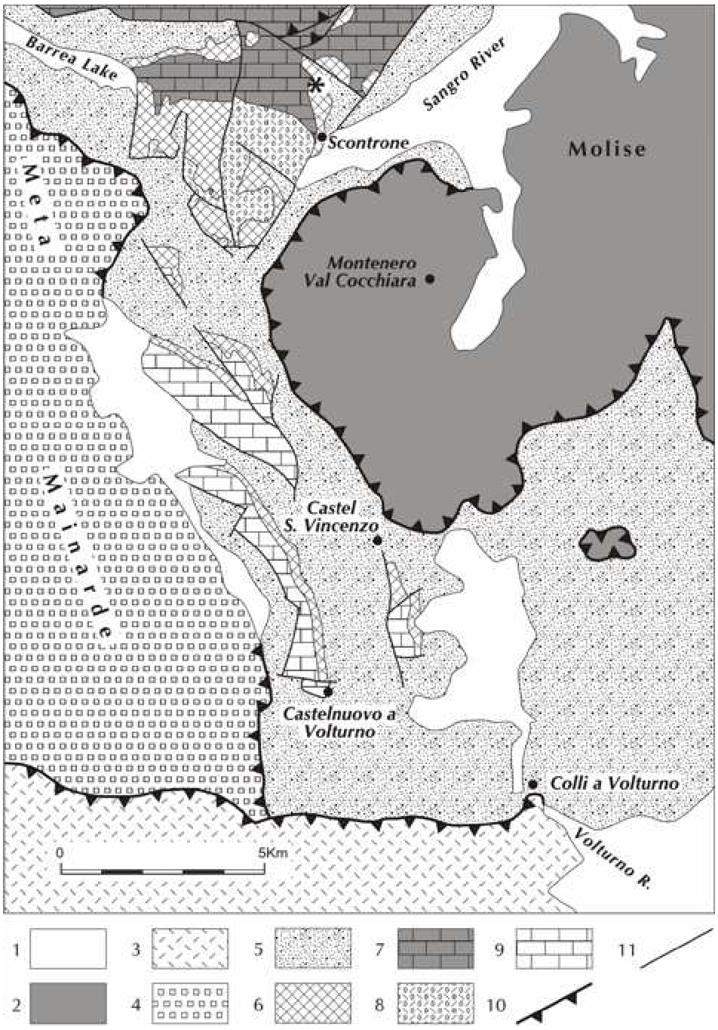



Figure 1.
Simplified geological map showing the deposits of the Gran Sasso-Genzana Unit between Scontrone and the High Volturno Valley. The map evidences an important disconformity between the upper Miocene ramp carbonates of the *Lithothamnium* Limestone and the underlying Cretaceous-Paleocene platform-to-basin carbonate system. The star shows the location of the Scontrone vertebrate fossil site.
1 Quaternary continental deposits. 2 Molise Nappe. 3 Simbruini-Matese Unit. 4 Western Marsica-Meta Unit. 5-9 Gran Sasso-Genzana Unit: 5 Messinian siliciclastic flysch deposits (Castelnuovo al Volturno Flysch);
6 Tortonian-lower Messinian carbonate-ramp deposits (*Lithotamnium* Limestone and *Turborotalia multiloba* Marl); 7 Cretaceous slope and basin deposits (Rudist-bearing Calcarenite, Scaglia Formation and Saccharoidal Limestone) discontinuously overlain by upper Paleocene reefal limestones (Coral-algal Boundstone);
8 Neocomian platform-edge limestones (upper portion of the Terratta Formation) and adjacent marginal slope breccias (Coral-bearing Calcirudite); 9 Neocomian platform-interior carbonates (Morrone di Pacentro Formation). 10 Thrusts. 11 Faults, including normal faults and strike-slip faults.

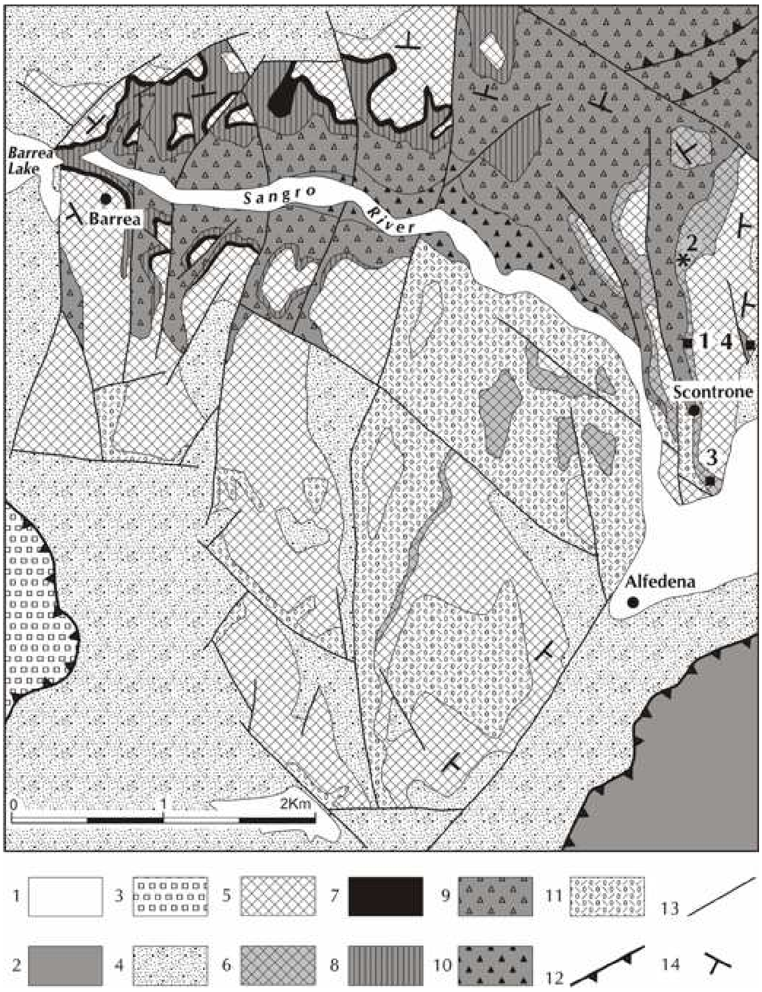



Figure 2.
Geological map of the Scontrone area. Arabic numerals around Scontrone indicate the location of the stratigraphic columnar sections of figure 4:
1 Scontrone North; 2 Scontrone Fossil Site; 3 Scontrone South;
4 Scontrone Cemetery.
1 Quaternary continental deposits.
2 Molise Nappe. 3 Western Marsica-Meta Unit. 4-11 Gran Sasso-Genzana Unit: 4 Castelnuovo al Volturno Flysch (Messinian); 5 *Lithothamnium* Limestone and *Turborotalia multiloba* Marl (inner-ramp to outer-ramp carbonate deposits, Tortonian *p.p.*-lower Messinian.); 6 Scontrone Member of the *Lithothamnium* Limestone (peritidal carbonate deposits, Tortonian *p.p.*);
7 Coral-algal Boundstone (carbonate buildup, late Paleocene); 8 Scaglia Formation and Saccharoidal Limestone (basin and ramp-slope carbonate deposits, Senonian); 9 Rudist-bearing Calcarenite (base-of-slope apron and slope-apron deposits, upper Albian-Cenomanian); 10 Coral-bearing Calcirudite (base-of-slope talus breccias, Neocomian); 11 Terratta Formation (platform-edge carbonates, Neocomian). 12 Thrusts. 13 Faults, including normal faults and strike-slip faults. 14 Attitude of strata.

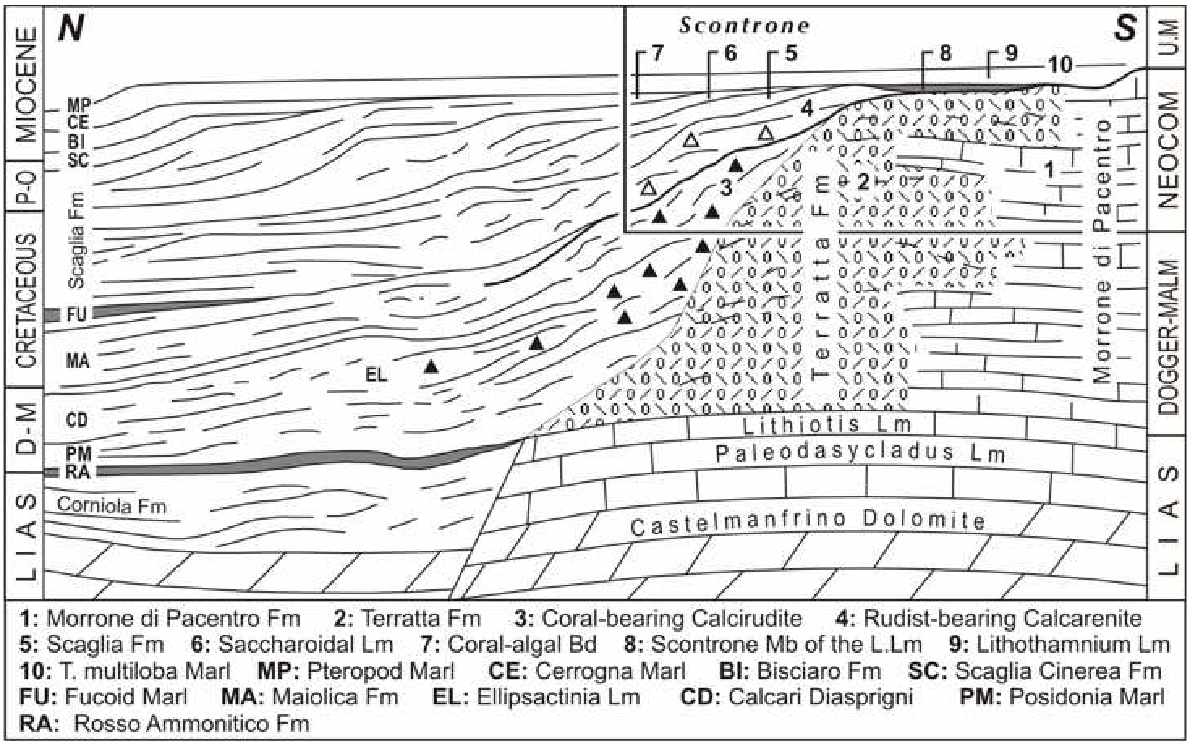



Figure 3. Stratigraphic architecture of the Gran Sasso-Genzana deposits in the Scontrone region (boxed area) and in northern basinal areas.

Frequent *Elphidium crispum* recovered at the base of the Miocene sequence imply that the Scontrone Member is not older than the Serravallian. In northern Majella, the *Lithothamnium* Limestone lies in disconformity on the hemipelagic deposits of the *Orbulina* Limestone with a hiatus temporally less extended than in the Scontrone area. Biostratigraphic analyses in this area (D. Merola, PHD Dissertation on the Majella Miocene deposits, in progress) indicate that the base of the *Lithothamnium* Limestone is of Tortonian age not older than the N16 Zone, above the First Regular Occurrence of *Neogloboquadrina acostaensis* which is astronomically dated 10.554 Ma (HILGEN et al., 2005). In northern Majella, the FRO of *N. acostaensis* has been recorded in the upper portion of the *Orbulina* Limestone. The Scontrone Member, therefore, dates around 10 Ma. In correspondence to the top of the *Lithothamnium* Limestone, planktic forams define the early Messinian (base of the *Turborotalia multiloba* Zone) both in the Majella and Scontrone areas.

The Scontrone Member of the *Lithothamnium* Limestone consists of peritidal carbonates forming as a whole a transgressive sequence represented by coastal flat and lagoon deposits (see fig. 4) overlain by high-energy lithobioclastic calcarenites (barrier bar deposits). The latter, which form the lower portion of the *Lithothamnium* Limestone in the Scontrone area, testify to a persisting transgressive trend. This phase of transgression caused a landward migration of the barrier shoals and the deposition of extensive sheet sands directly upon the Cretaceous substrate. A ravinement surface generated by shoreface erosion is present at the base of the transgressive *Lithothamnium* Limestone. This erosional episode caused a generalized, almost complete re-motion of the peritidal carbonates of the Scontrone Member.

Peritidal deposits at the base of the *Lithothamnium* Limestone are unusual in the Central Apennine. Until now, they have been recognized only in the Scontrone area and in a small outcrop sandwiched between the *Orbulina* Limestone and the overlying *Lithothamnium* Limestone along the eastern flank of the Majella anticline. The Scontrone fossil find represents an isolated case of Miocene land vertebrate record related to the local development, in Tortonian times, of coastal environments in which favourable conditions of life matched up with optimal conditions for fossilization.

A detailed stratigraphic and sedimentological analysis of the Miocene sequence in the Scontrone area shows that the basal transgressive deposits reveal a short-lived episode of shallowing before the flooding recorded by the coastal-lagoon deposits. This regressive episode led to the deposition of a “parasequence” which reaches a maximum thickness of 5 m in the Scontrone North section (SCa-SCc units in fig. 4). The fossil vertebrates have been recovered in the upper portion of this shoaling-up small-scale depositional sequence, embedded in tidal carbonates. The short episode of shoreline progradation demonstrates that the late Miocene transgression started with a slow sea level rise and with a comparatively higher rate of sedimentation.

Where the Scontrone Member sequence reaches its maximum thickness (8-10 meters), four facies units have been distinguished. The definition of these units (SCa-SCd intervals), based on the identification of major shift episodes in the depositional subenvironments and biotic associations, has resulted very useful for high-resolution correlations within the peritidal deposits exposed in the study area. In the next pages, we shall provide a brief description of the depositional units and related facies of the Scontrone Member in the Scontrone North, Scontrone Fossil Site and Scontrone South stratigraphic sections (see fig. 2 and 4). The Scontrone Cemetery section (fig. 4) exemplifies a case of ravinement surface at the base of the *Lithothamnium* Limestone with the complete re-motion of the Scontrone Member deposits.

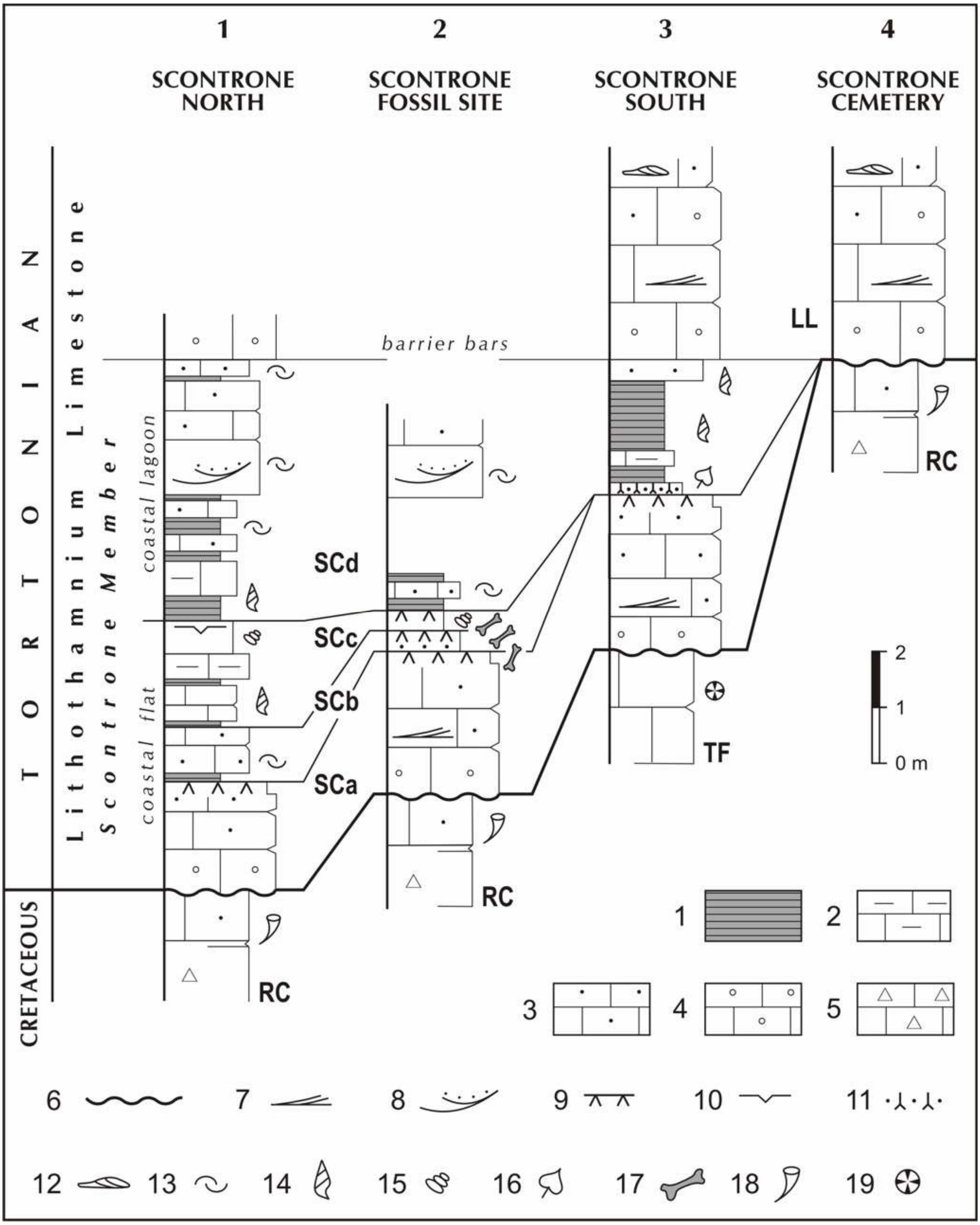



Figure 4. Columnar sections showing the stratigraphic position of the bonebeds in the Scontrone Fossil Site, as well as the lateral changes of facies within the Scontrone Member of the *Lithothamnium* Limestone (see location in fig. 2).

TF Terratta Formation; RC Rudist-bearing Calcarenite; SC Scontrone Member of the *Lithothamnium* Limestone; LL High-energy sandbars developed at the base of the *Lithothamnium* Limestone; SCa-SCd facies units of the Scontrone Member recording major shifts in the depositional setting and biotic associations.

1 Calcareous marls. 2 Marly limestones. 3 Bioclastic calcarenites. 4 Bioclastic calcarenites with oversized well-rounded lithoclast lags. 5 Lithoclastic calcirudites. 6 Major disconformity. 7 Low-angle cross-bedding. 8 Trough cross-bedding. 9 Root traces. 10 Desiccation cracks. 11 Microbial mat. 12 Heterosteginids. 13 Oyster shell-lags. 14 Cerithid shell-lags. 15 Hydrobiids. 16 Plant remains. 17 Bonebeds. 18 Rudists. 19 Corals.

*The coastal flat*

The lower portion of the coastal flat deposits is represented by low-relief bioclastic bars (SCa unit) showing at the top evidence of subaerial exposure. Landwards, SSW of Scontrone, the coastal bars disappear, laterally substituted by continental red soils directly overlying the lower Cretaceous limestones of the Terratta Formation. In the Scontrone North and Scontrone Fossil Site sections, the relatively high-energy grainy carbonates are gradually followed by intertidal- to supratidal-flat muddier deposits (SCb and SCc facies units). Moving towards the Scontrone South section, the SCb and SCc deposits merge into a deeply rooted fine-grained calcarenite. In the fossil site, the bulk of the vertebrates are embedded in the subtidal creek deposits of the SCb unit. Vertebrate remains have also been recovered, though less abundant, at the top of the underlying carbonate sandbars and in the immediately overlying supratidal marsh deposits of the unit SCc. The latter testify to a deposition in more humid climate conditions.

*SCa facies unit*

In the whole Scontrone area, the interval SCa consists of 2-3 m of off-white to buff litho-bioclastic calcarenites unconformably overlying upper Albian-Cenomanian base-of-slope-apron and slope-apron carbonate coarse resediments. These calcarenites have been interpreted as relatively high-energy sandbars bordering a tidal flat. In thin section, the calcarenites are represented by fine- to medium-grained litho-bioclastic grainstones grading upwards into packstones rich in *Ammonia sp.* and *Elphidium crispum* (fig. 5). Glauconite grains, fish scales, echinoderm and oyster debris, as well as fragments of barnacles, are quite frequent components. The common occurrence through the interval of very well-rounded and locally bored lithoclasts, together with deeply abraded and micritized skeletal fragments (the latter including Paleogene large foraminifers) indicates intense physical reworking and winnowing (figs. 6 and 7). Well-rounded quartz grains present in well-sorted bioclastic calcarenites (fig. 8) indicate sporadic episodes of wind transport. In the Scontrone South section, the biocalcarenites of the SCa interval unconformably overlie Neocomian platform-edge carbonates referable to the upper portion of the Terratta Formation. The overall lithologic characteristics of these Miocene basal deposits do not differ from those observed in the Scontrone North and Scontrone Fossil Site stratigraphic sections.

The top of the carbonate sandbars is everywhere capped by a 20-25 cm thick layer of rooted fine-grained calcarenite (fig. 9), typically gray to pinkish, locally rich in very large-sized specimens of fine-grained, well-sorted and well-rounded *Ammonia* and well-rounded comminute bone fragments. The framework grains consist of fine-grained, well-sorted, well-rounded, wind-blown (?) skeletal fragments frequently bored and lined with a FeO rim. This bed, interpreted as a backshore deposit, contains sparse large-sized vertebrate remains (first bonebed in fig. 4). Southwest of the village of Scontrone, the SCa sandbars are substituted by a continental terra-rossa layer containing large-sized FeO-rich pisoids which indicates long-lasting subaerial exposure of the Scontrone carbonate domain. The youngest reworked skeletal fragments in the sandbars, i.e. worn *Miogypsinoides* associated with a large amount of Paleogene bioclasts and lithoclasts, suggest that the area was exposed since the early Miocene. The terra rossa soil is stratigraphically overlain by dark muddy deposits indicative of a supratidal marsh.


Figure 5.
Litho-bioclastic packstone with *Ammonia sp.* and *Elphidium crispum*. A well-rounded lithoclast derived from the upper Cretaceous hemipelagic limestones of the Scaglia Fm can be seen on the lower left of the picture.
Coastal sandbars. Scontrone North stratigraphic section, upper part of the interval SCa in figure 4.


Figure 6.
Litho-bioclastic grainstone with very well-rounded oversized carbonate clasts set in a fine-grained skeletal debris (a large bryozoan fragment and a small specimen of *Elphidium* can be recognized in the lower-right and lower-left sides of the picture, respectively).
Coastal sandbars. Scontrone Fossil Site stratigraphic section, lower part of the interval SCa in figure 4.

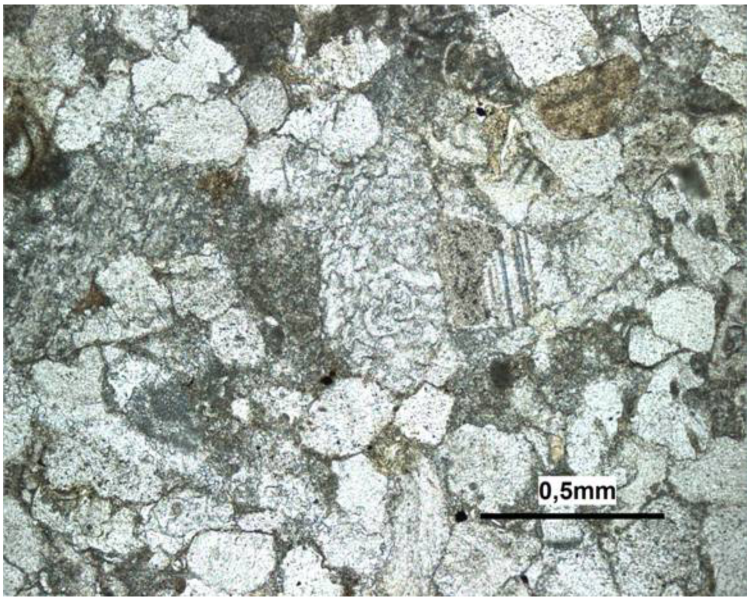



Figure 7.
Fine to medium-grained bioclastic packstone characterized by the occurrence of deeply abraded and micritized skeletal fragments. The intense physical reworking of the grains is evidenced by a worn specimen of *Miogypsinoides* (center) and by well-rounded phosphatic grains (upper right) characterized by brownish color at plane polarized light.
Coastal sandbars. Scontrone Fossil Site stratigraphic section, interval SCa in figure 4.

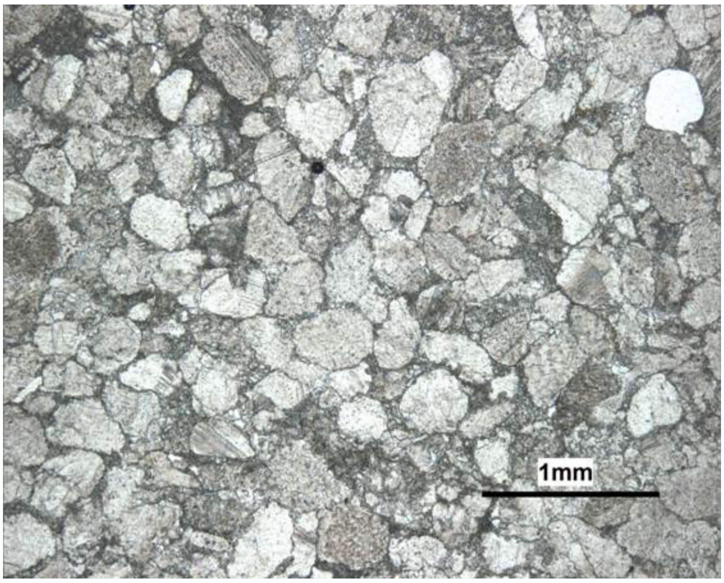



Figure 8.
Well-sorted calcarenite consisting of abraded and microbored skeletal debris. A well-rounded monocrystalline detrital quartz grain is recognizable on the upper right of the picture.
Coastal sandbars, blanket of wind-blown skeletal sand. Scontrone South stratigraphic section, upper part of the interval SCa in figure 4.

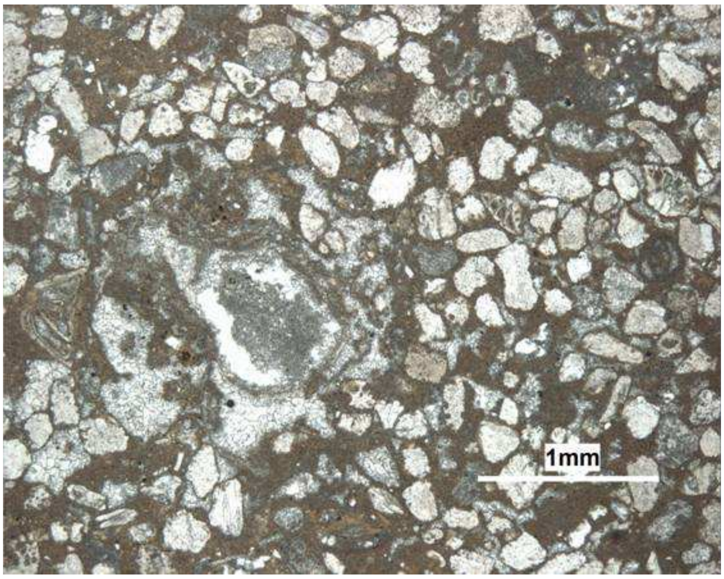



Fig. 9.
Pedogenically reworked carbonate sand at the top of the regressive coastal sandbars. Worn and microbored skeletal debris are dispersed in a dense red-brown micrite matrix showing large calcite-cemented irregular voids (see alveolar texture on the left of the picture. At the center, a large transverse section of a rhizocretion is lined with a micrite coat. The central void is partly filled with sparite and partly with micrite.
Pedogenic feature in the coastal sandbars. Scontrone Fossil Site stratigraphic section, top of the interval SCa in fig, 4.

*SCb facies unit*

The SCb facies unit is well represented in the Scontrone North and Scontrone Fossil Site sections. The interval has been interpreted as a blanket of migrating tidal-creek deposit developed in a low-gradient seaward-sloping coastal flat. At the fossil site, this unit is represented by 20-25 cm of a yellow-pinkish pebble calcarenite with characteristic nodular or mottled appearance (fig. 10). The pebbly layer contains soil crusts, large rooted intraclasts (fig. 11) and portions of the underlying beachrock dispersed in an ostracod-rich muddy matrix. This is the bed from which the bulk of the vertebrates derive. It yielded abundant and well preserved fragments of bones and of marsh turtle carapaces, as well as isolated teeth of artiodactyls and crocodiles. There are also numerous channel lag lithoclasts, likely related to tidal creeks.

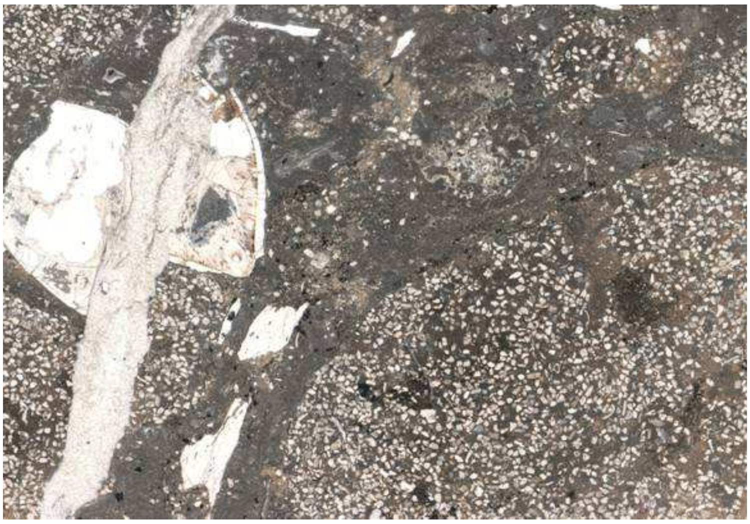


Figure 10.
Mottled fine-grained calcarenite with numerous vertebrate remains (teeth, upper left and bone fragments, lower left). The mottled appearance of this lithofacies is related to the presence of large-sized rooted pieces of the underlying bedrock dispersed in a dense dark-tan micrite matrix rich in comminuted fine-grained ostracod shells. The clasts have mainly derived from root-induced brecciation and subsequent reworking of the supratidal sandy substrate deposits. Tidal creek. Scontrone Fossil Site stratigraphic section, interval SCb in figure 4, second (major) bonebed.

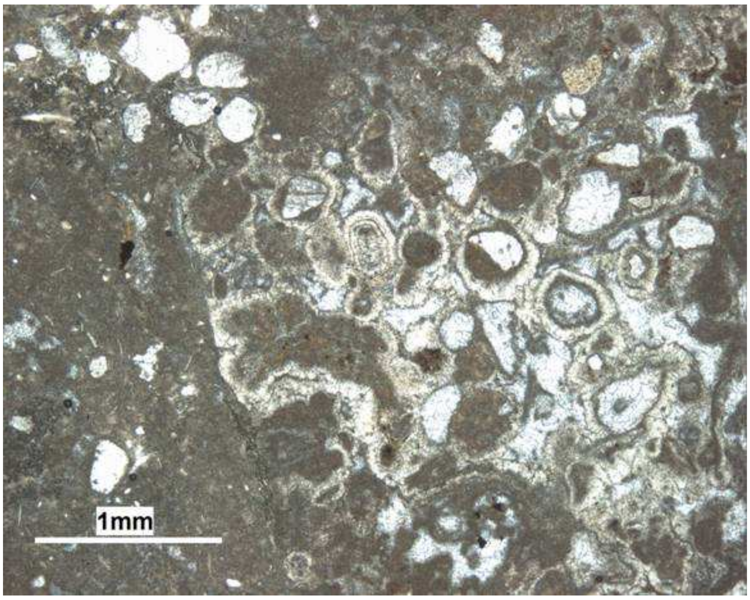



Figure 11.
Portion of gloebular soil crust constituted by a cluster of well preserved root tubules in transverse sections. The tubules consist of dark dense micrite walls coated by pendulant fibrous calcite locally arranged in multiple concentric layers, evidenced by dark inclusions (center of the picture). Calcite spar cement and/or dense micrite fill the tubular voids of the decayed roots. A complex network of spar-filled interlinked cavities lined with interconnective micrite walls shapes a distinctive alveolar septal texture between the rhizocretions. Fragment of a root-generated carbonate crust reworked in a tidal creek. Scontrone Fossil Site stratigraphic section, interval SCb in figure 4, second (major) bonebed.

In the Scontrone North section, the major bonebed is replaced by about 1 m of gray, oyster-rich calcarenites forming a sort of bank of disarticulated bored shells not in life position (fig. 12). This type of deposit, which is very frequent along tidal creeks, supports the interpretation of the fossil site's SCb facies. The winnowing of the currents generated by ebb and flood tides in the self-sustaining drainage channels of tidal creeks can explain the lag character of the Scontrone fossil bone accumulation, which is in fact a concentration of residual, badly transportable skeletal elements (skull, scapula, femur, astragalus and mandible remains) and teeth. South of the village of Scontrone, the SCb unit disappears, substituted by a soil profile characterized by a deep root penetration at the top of the SCa calcarenites.

Figure 12. Fine-grained bioclastic packstone with a large fragment of intensively bored oyster shell. Oyster bank in a tidal creek. Scontrone North Stratigraphic section, interval SCb in figure 4.

*CSc facies unit*

At the fossil site, this interval is represented by about 20 cm of dark thinly laminated mudstone (fig. 13) with discontinuous millimetric intercalations of pink to yellow fine-grained calcarenite. Towards the top of the bed, the pink/yellow layers are cracked forming a “flake breccia” characterized by flat, irregular intraclasts. Local thin laminations within the dark mudstone, often crinkled and disrupted, are related to the presence of well preserved calcified roots associated with microbial mats (figs. 14-17). The lighter calcarenite layers, consisting of very well-sorted, abraded and rounded skeletal grains, are related to episodic storm accumulation in a supratidal marsh. The SCc muddy deposit, indicative of a humid setting, contains quite numerous flushed bone fragments (fig. 18) comparatively worse preserved than those present in the underlying level.

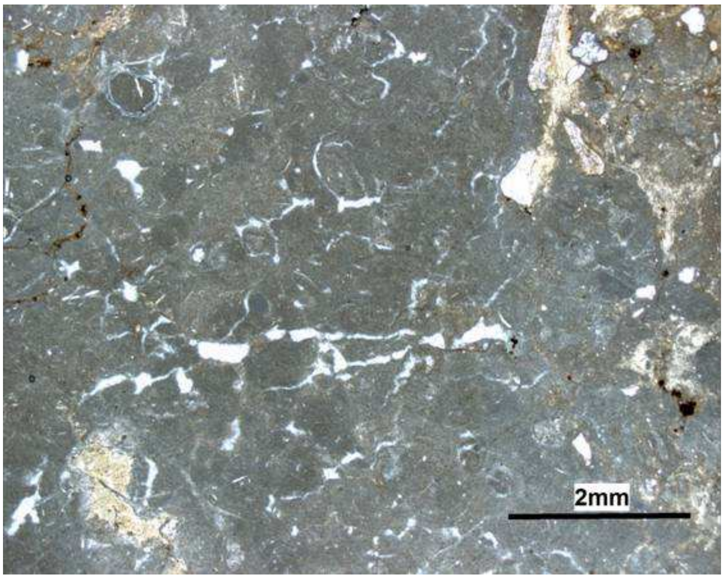



Figure 13.
Nodular dark mudstone showing a characteristic reticulate fabric produced by root activity and syneresis.
Supratidal marsh. Scontrone Fossil Site stratigraphic section, interval SCc in figure 4, third bonebed.

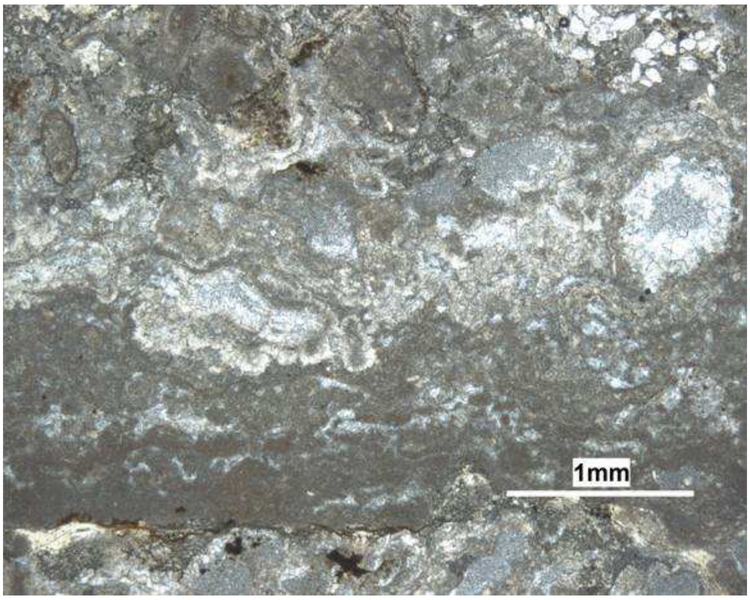



Figure 14.
Thinly laminated dark mudstone. The laminated structure, locally clearly crinkled, is related to alternating lighter laminae of calcified root mat and darker laminae of microbial mat. The former consist of irregular spar-filled voids lined with concentric micrite; the latter are constituted by discontinuous bumpy layers of dense pelleted micrite
Pedogenic carbonate crust related to a hydromorphic soil. Supratidal marsh. Scontrone Fossil Site stratigraphic section, interval SCc in figure 4, third bonebed.

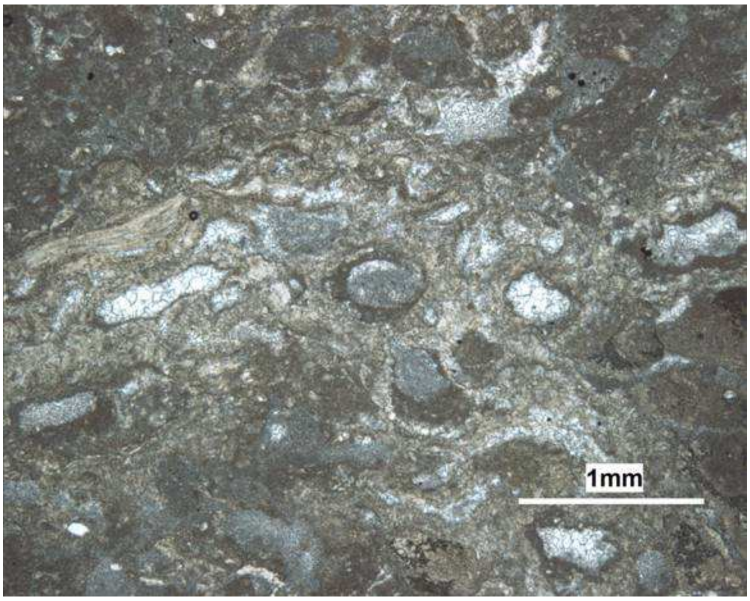



Fig. 15.
Detail of a calcified root mat still preserving calcified cortical cells (pale yellow calcite).
Supratidal marsh. Scontrone Fossil Site stratigraphic section, interval SCc in figure 4, third bonebed.

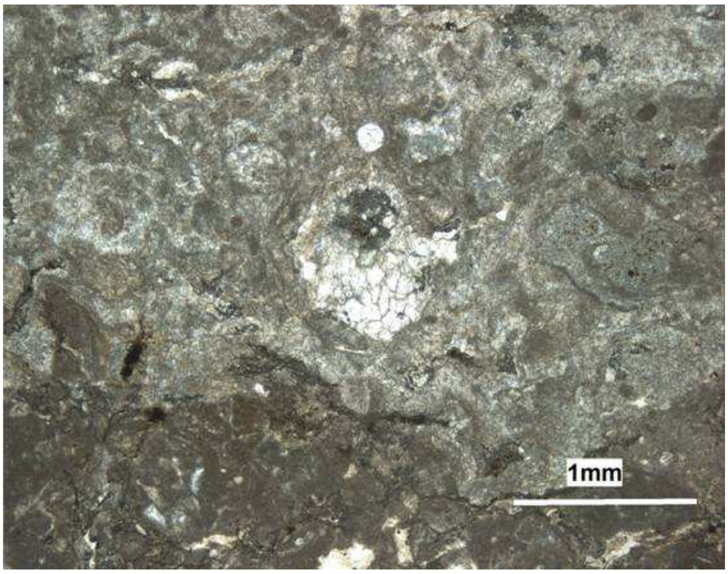



Figure 16.
Intracellularly calcified root still retaining quite well preserved and recognizable anatomical features. The dark central hollow, filled with dark micrite, corresponds to the vascular cylinder. Epiderms and cortical cells have been entirely replaced by single calcite crystals showing uniform or sweeping extinction at crossed nicols. Calcified root mat.
Supratidal marsh. Scontrone Fossil Site, interval SCc in figure 4, third bonebed.

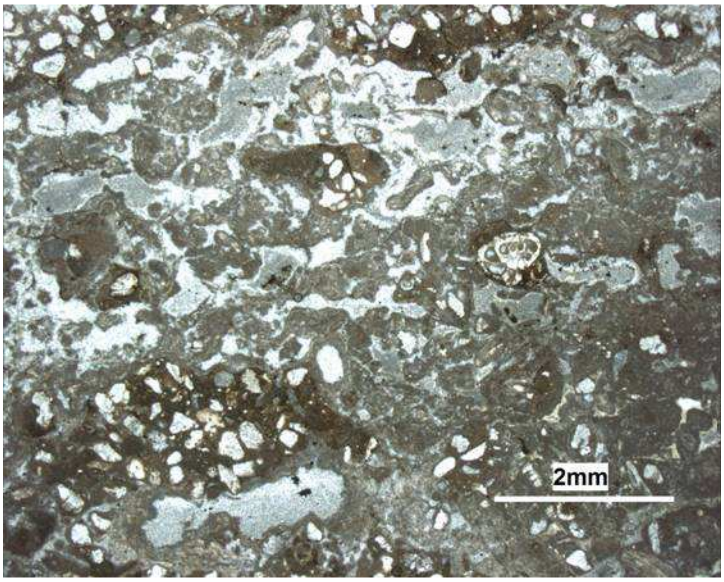



Fig. 17.
Soil crust characterized by a distinct alveolar structure generated by root penetration. The complex network of irregular voids, typically lined with micrite, is partly filled with blocky calcite cements and partly with microsparite. The sand-sized carbonate grains, mostly skeletal debris, indicate sporadic storm accumulation in a prevalently muddy soil. Supratidal marsh. Scontrone Fossil Site, interval SCc in figure 4, third bonebed.

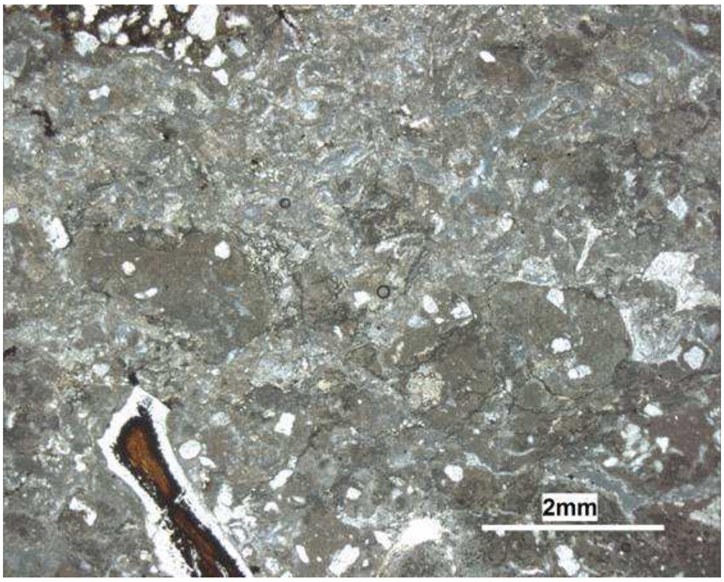



Figure 18.
Nodular dark sandy mudstone with a flushed bone fragment (left lower side of the picture). The mottled appearance of this deposit has been produced by root activity.
Supratidal marsh. Scontrone Fossil Site stratigraphic section, interval SCc in figure 4, third bonebed.

In the Scontrone North Section, the supratidal marsh deposits are laterally replaced by about 2 m of gray marly limestones and marls rich in ostracods and in smooth-shelled gastropods, mostly cerithids and hydrobiids (fig. 19). Small intertidal planar fenestrae are quite common features. At the top of the interval, an important episode of subaerial exposure attested by desiccation cracks, edgewise breccias and root casts (fig. 20) is correlated with the top of the third bonebed of the Scontrone fossil site.

In the Scontrone South section, the interval SCc is represented by a thin layer of very fine-grained, porous, black calcarenite made up of well-sorted and very well-rounded carbonate grains, mostly abraded skeletal debris, associated with dispersed wood fragments. The 4-5 cm of black calcarenite veneer covers the pervasively rooted top of the underlying carbonate sandbars and is in turn extensively intersected by small vertical root molds filled with bitumen. The occurrence of carbonate sand, unusual in a low-energy reducing environment, can be related to an eolian input. The very well-sorted texture, in fact, excludes depositional processes related to storm-surge influenced flood tides.

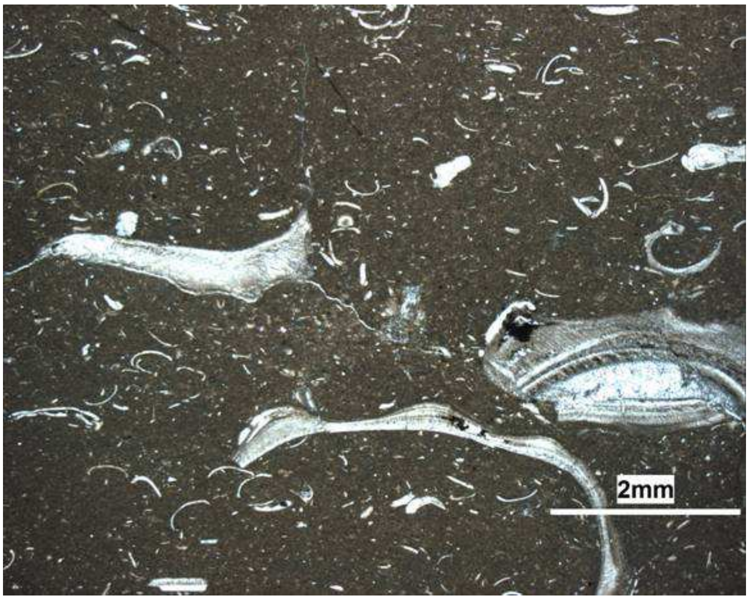



Figure 19.
Gray burrowed wackestone with disarticulated thin-shelled ostracods and sparse fragments of cerithids.
Lower intertidal mudflat.
Scontrone North stratigraphic section, interval SCc in figure 4.

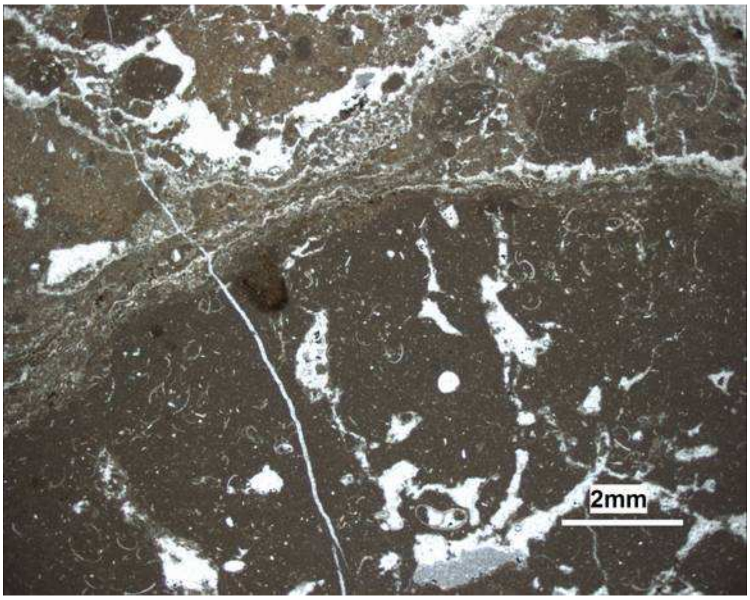



Figure 20.
Cracked mudstone. The downward oriented irregular vugs, locally geopetally filled with equant calcite and cryptocrystalline material, are interpreted as solution-enhanced root cavities. The vertical voids are overlain by a tan-stained pedogenic micrite with a complex cracking pattern.
Supratidal mudflat.
Scontrone North stratigraphic section, top of the interval SCc in figure 4.

*The coastal lagoon (SCd facies unit)*

Only the base of this interval, which is represented by 20 cm of dark-green clays and marly clays rich in ostracods (fig. 21), is well exposed in the Scontrone fossil site. It is followed by thin oyster banks.

In the Scontrone North Section, the interval SCd is constituted by about 4.50 meters of costal-lagoon deposits. The lower half portion of this facies unit consists of cerithid-bearing marly limestones and marls followed by marls with intercalated centimetric beds of tan fine-grained marly calcarenites rich in disarticulated, bored large oyster valves systematically associated with cerithids (fig. 22). The matrix of the cerithid lumachellas consists of a mudstone/wackestone with variable amounts of large-sized *Ammonia*, subordinate small *Elphidium* and thin-shelled ostracods. The cerithids, which usually preserve their original aragonite shell, appear frequently flattened and geopetally filled. The overlying oyster-rich beds, characterized by fragmented and bored mollusk shells set in a fine-grained biodetritus (mostly echinoid, serpulid and barnacle debris), have been interpreted as storm layers in a coastal lagoon.

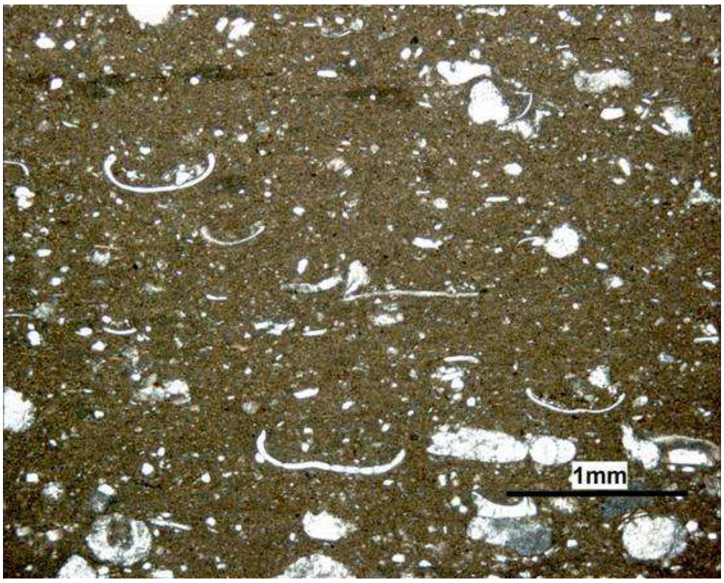



Figure 21.
Bioclastic wackestone with disarticulated ostracod valves and with corroded and abraded undefined rounded lithoclastic grains swept and accumulated in protected embayments by washovers.
Storm layer in a brackish-water lagoon.
Scontrone Fossil Site stratigraphic section, base of the interval SCd in figure 4.


Figure 22.
Bioturbated bioclastic packstone/wackestone with *Ammonia*, crushed cerithids and bored oyster shell fragments.
Storm layer accumulated in a brackish-water coastal lagoon.
Scontrone North stratigraphic section, SCd in figure 4.

In the Scontrone South section, the coastal-lagoon deposits of the SCd interval are represented at the base by a thin bed of porous dark calcisiltite containing dispersed crushed cerithid shells. In thin section, the porous limestone displays a characteristic clotted texture (fig. 23) related to the presence of a dense aggregate of microsphaerules of fibrous calcite radiating from a micritic clot or, rarely, from small filaments (figs. 24-26). The fabric of this unusual carbonate deposit, with its original porosity and tuffaceous appearance, suggests a microbially-induced precipitation of former aragonite or high-Mg calcite around coccoid cyanobacteria. The microbial mat layer is overlain by about 2 m of restricted-lagoon muddy deposits represented by thinly laminated dark peloidal marls containing cerithids, hydrobiids and abundant plant remains (figs, 27 and 28).

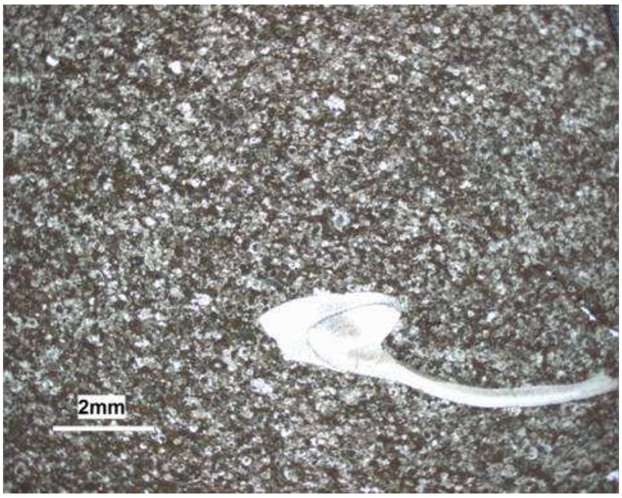
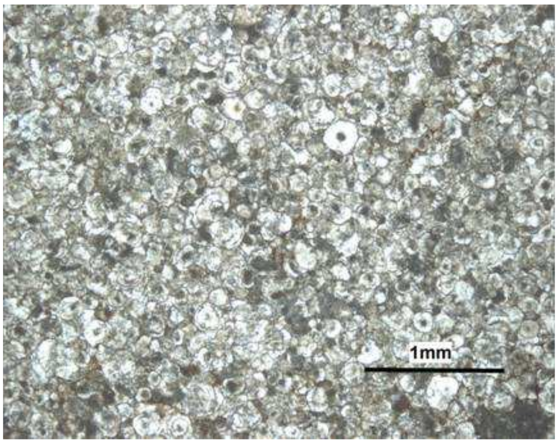



Figure 23.
Unusual dark porous calcisiltite with a fragment of cerithid shell set in a dense aggregate of microsphaerules. See details in figs. 24-26.
Microbial mat in a restricted marginal lagoon. The association of the coccoid filamentous framework precipitate with skeletal debris suggests periodic washover contamination during storms.
Scontrone South stratigraphic section, base of the interval SCd in figure 4.




Figures 24
From fig. 24 to fig. 26, details at varying higher magnification of the clotted texture characterizing the calcisiltite of fig. 23. The clotted texture is clearly related to the presence of microglaebules locally displaying concentric multiple lobate layers of botryoidal fibrous calcite with evident interference growth boundaries, as well as to the presence of small filaments (see fig. 25).

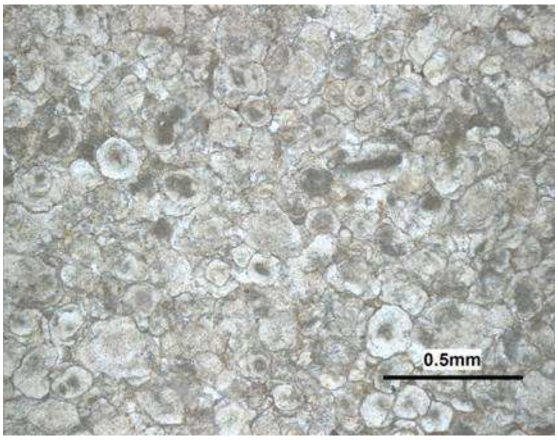



Figure 25.
See caption in fig. 24.

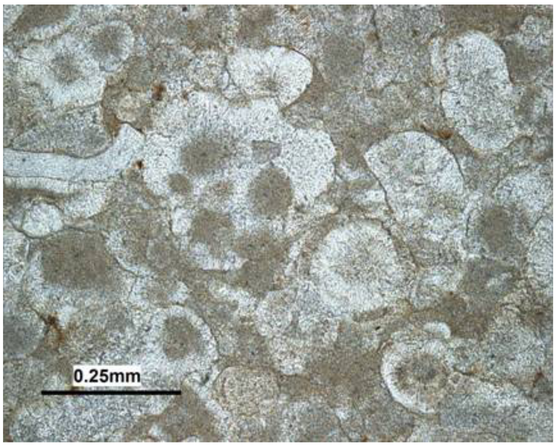



Figure 26.
See caption in fig. 24.

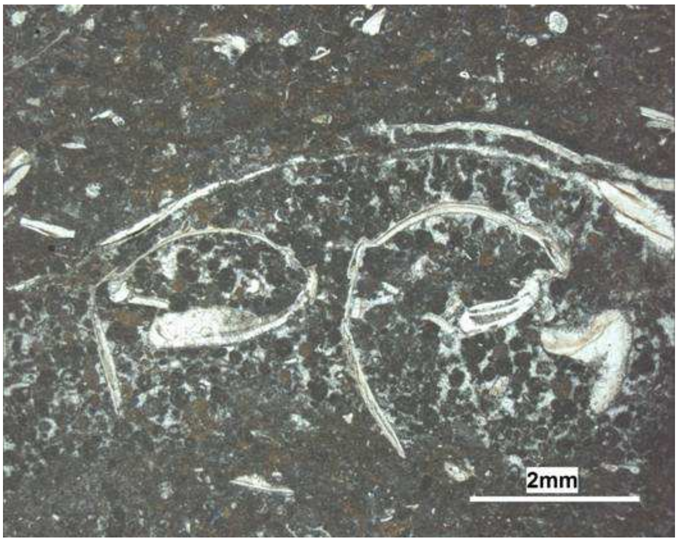



Figure 27.
Peloidal marly limestone with quite well preserved delicate thin-shelled gastropods.
Restricted-lagoon. Scontrone South stratigraphic section, interval SCd in figure 4.


Figure 28.
See caption in fig. 27.

In the whole Scontrone area, the described coastal-lagoon deposits are conformably overlain by cross-bedded medium to coarse-grained bioclastic calcarenites making up the transgressive high-energy sandbars at the base of the *Lithothamnium* Limestone.

The Scontrone fossil vertebrate population shows close similarities with the macromammal fauna of Gargano, which current literature dates to the Messinian or to the early Pliocene based on quite poor stratigraphic constraints (DE GIULI & TORRE, 1984; FREUDENTHAL, 1971, 1972). The marked endemic characters shared by the two faunas indicate that the terrestrial vertebrates lived in prolonged isolation in a single, vast and secluded paleobiogeographic province. The pertinence of the two faunas to the same province is also supported by palinspastic restorations, which relocate the two areas in the same paleogeographic domain before the incorporation of the Scontrone depositional realm in the Apennine thrust belt. The mammal colonization of the Scontrone-Gargano paleogeographic province took place during the early Oligocene, more precisely at about 29 Ma, when an important drop in the sea level caused the emergence of the Apulia Platform and of the central Adriatic region creating a landbridge from Dalmatia via Tremiti Islands (fig. 29). Through this filtering route and in this specific lapse of time representatives of the ancestor stock of the Hoplitomerycids, together with the forerunner of the giant insectivore *Deinogalerix*, spread into the Abruzzi-Apulia realm.

The landbridge connecting Dalmatia and Gargano was generated by three combined geological factors:

- Existence of prominent structural highs within the narrow basinal area created by the Jurassic extensional tectonics between the Adriatic and Apulia platforms. During part of the Jurassic and during the Cretaceous, these submarine highs were seat of condensed pelagic sedimentation;
- Occurrence of a global sea level drop around the end of the Cretaceous and progradation of shallow-marine deposits in the marginal areas of the platforms. During the subsequent transgression, deposition of Paleocene-Eocene ramp carbonates occurred along the margins of the platforms and on top of the aforementioned intrabasinal highs. As a consequence, a prominent shallow-water plateau developed in the Central Adriatic area;
- Occurrence of a major global sea-level drop around 29 Ma, which caused the subaerial exposure of the shallow-water plateau together with the bulk of the Apulia and Adriatic platforms.

The Dalmatia-Gargano isthmus, which in the Adriatic region separated a northern basinal area from a southern one, was completely submerged during the Langhian, when the Apulia Platform was cut away from any contact with the Dalmatian mainland. However, most of the Apulia Platform kept emerged for a long time period, allowing the development of a fairly varied landscape where relatively few taxa flourished, endemized and diversified. The isolation ended with the Messinian salinity crisis, when a new and wider landbridge re-emerged consenting several micromammalian taxa to colonize the Abruzzi-Apulia area.

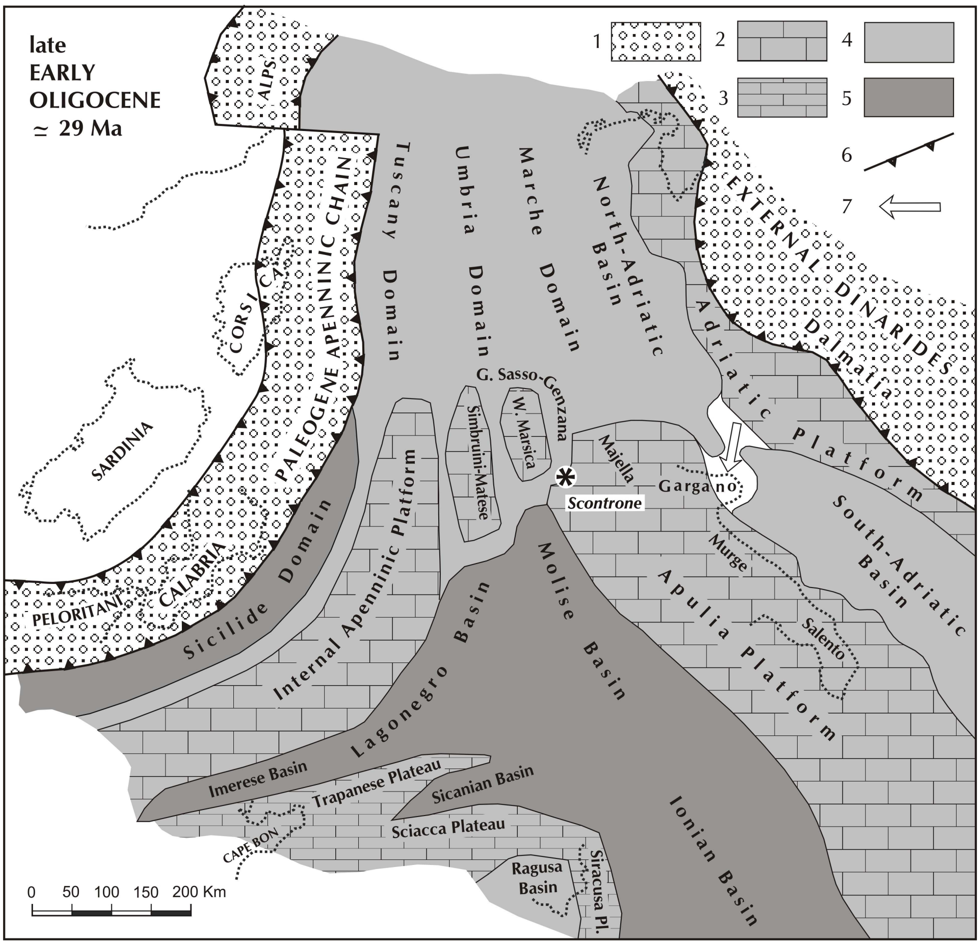



Figure 29. Palinspastic restoration of the Apenninic domains showing the pathway followed by the colonizing macromammals near the end of the early Oligocene.
1 Paleogene mountain chains. 2 Shallow-water carbonate platforms. 3 Wide pelagic plateaux. 4 Basins and isolated structural highs. 5 Deep-water basins floored by oceanic or thinned continental crust. 6 Front of the orogenic belts. 7 Dalmatia-Gargano landbridge.

## STOP DESCRIPTION

### *STOP 1. Alfedena, panoramic view on the Scontrone fossil site*

The structural configuration of the Scontrone area roughly corresponds to a faulted dome which emerges from the Messinian siliciclastic flysch deposits (Castelnuovo al Volturno Flysch) forming the uppermost portion of the Gran Sasso-Genzana sequence. Towards the north, the Scontrone structure is separated from the Monte Greco-Monte Tre Confini carbonate massifs by an important south-dipping normal fault.

The deepest portion of the sequence, represented by Neocomian platform-edge carbonates (Terratta Formation) and associated slope breccias (Coral-bearing Calcirudite) is well exposed in the Sangro Gorge. Between Scontrone and Barrea, Cretaceous slope and basin deposits crop out on the eastern side of the Sangro Valley (upper Albian-upper Cenomanian Rudist-bearing Calcarenite; Senonian Scaglia Formation and Saccharoidal Limestone), discontinuously overlain by upper Paleocene reefal limestones (Coral-algal Boundstone). Finally, the Cretaceous and Paleocene carbonates are disconformably covered by Tortonian-lower Messinian carbonate-ramp deposits (*Lithothamnium* Limestone) at the base of which there are remnants of peritidal carbonates (Scontrone Member of the *Lithothamnium* Limestone). The latter contain the vertebrate remains.

### *STOP 2. Scontrone fossil site and Scontrone North sections*

The richly fossiliferous bonebed was discovered in 1990, when a ranger of the National Park of Abruzzi showed some bone fragments to two researchers of the University of Florence, P. Mazza and M. Rustioni, who were then studying bears. The site is located on the eastern side of the Civita Mountain, some 1180 m above sea level. Three fossiliferous layers have been recognized, consisting of variously rooted carbonate materials formed in three different settings, a sandflat, a tidal creek and a marsh respectively. The three bonebeds are stratigraphically sandwiched between shallow-marine litho-bioclastic calcarenites (coastal sandbars) and coastal-lagoon limestones and marls rich in ostreids and cerithids. The lagoon deposits, poorly exposed at the fossil site, crop out along the road (Scontrone North section) downthrown by a system of N-S trending normal faults. A disconformable contact between the Miocene litho-bioclastic calcarenites and the upper Cretaceous Rudist-bearing Calcarenite is exposed near the fossil site.

Since discovery, excavations have been conducted on a yearly basis. The Scontrone mammalian remains are preserved at the Centro di Documentazione Paleontologico of Scontrone. The collection consists, at the moment, of 470 artiodactyl bones (22 cranial and maxillary bone fragments, 39 mandibles, 114 isolated cheek teeth, 153 postcranial bones, 142 indeterminate specimens) of six species the classification of which is under way. All these species can be attributed to the genus *Hoplitomeryx*, a puzzling ungulate represented until now only by the species *Hoplitomeryx matthei*, which was created by LEINDERS (1983) on Gargano fossil material. *Hoplitomeryx matthei* bears a curious five-horned skull with short muzzle and semi-stereoscopic orbits. Unfortunately, LEINDERS (1983) failed to describe the teeth and limb bones of these animals. He classified the *Hoplitomerycidae* among the *Cervoidea*, an opinion contested by MAZZA & RUSTIONI (1996) who highlighted an archaic mixture of cervid-, giraffid- and bovid-like features in these creatures. In 1999, a fragmental right maxillary of *Deinogalerix freudenthali*, with associated M3 and the postero-lingual portion of M2, was discovered in the site.

The exposed area is divided obliquely into three separate zones, which correspond to three stratigraphically superimposed bone-bearing layers. The lowest term is a gray to pinkish biocalcarenite that outcrops at the upper left: it contains only rare and heavily weathered bone fragments. The second layer is a stripe which crops out from the lower left to the upper right of the exposed area. This is a calcarenite with yellow/pinkish nodules, very rich in soil casts and rooted intraclasts derived from the underlying weathered calcarenite. This is where the vertebrate remains are most abundant and better preserved. Numerous bone fragments and a few isolated teeth of artiodactyls and crocodiles are visible, but the bone collection of this layer is largely dominated by marsh turtle carapax fragments. The third layer, a brecciated dark marly calcilutite, contains a lower amount of bones comparatively worse preserved than those of the underlying level.

The bones are well fossilized, but most are broken. They are all disarticulated, unsorted and randomly scattered in every layer. None shows evidence of reworking: all are fossilized in ferric oxides, and lack characteristic signs of transport, i.e. abrasion or polishing. In the collection of bones hitherto preserved at Scontrone, the percentage of KORTH's (1979) settling groups, which are practically a re-calibration of the VOORHIES (1969) groups for small mammals, is consistent with the value of BEHRENSMEYER's (1975) tooth/vertebra ratio. The best represented bones at Scontrone are those of KORTH's (1979) groups II (skull, scapula, molars, femur, astragalus), and II&III (mandible), which indicate a possible lag deposit, formed by elements gradually removed which are dragged, or just flip over, remaining basically associated with the substratum during transport. BEHRENSMEYER's (1975) tooth/vertebra ratio is high, 11.37, due to the comparatively large amount of isolated teeth, which are dense, lag elements. The co-occurrence of the land mammal elements, shattered marsh turtle carapax portions and teeth and sparse ossicles of crocodile implies that the bone amassment consists of elements of animals possibly mired in, or near, a marsh (WEIGELT, 1989), whose skeletons were dissected and scattered by tides and/or storms. Tidal currents can easily select the isolated bones, readily removing the lightest ones. Hence, all the paleontological constraints are perfectly consistent with the reconstructed settings.

*STOP 3. Scontrone South, lateral substitution of the three bonebeds by rooted marsh deposits*

In the Scontrone South section, the SCb interval, which corresponds to the major bonebed, is lacking, substituted by a rooted surface on top of the SCa bioclastic sandbars, The SCc interval is represented by 5 cm of dark calcarenite with vertical root molds filled with bitumen.

The rooted soil is overlain by a few centimeters of dark-colored marls followed by 12 cm of porous dark calcisiltite containing crushed cerithid shells. The analysis of a number of thin sections has shown that this limestone is a microbial mat deposited in a restricted marginal lagoon. The microbial mat is overlain by about 2 m of restricted-lagoon deposits represented by dark marls with cerithids and hydrobiids. The latter are sharply overlain by the high-energy sandbars of the lower portion of the *Lithothamnium* Limestone.

A few hundred meters west of the Scontrone South section, also the basal calcarenites are absent, laterally substituted by 1.5 m of red soil rich in FeO pisoids. This continental deposit, which entirely substitutes the SCa-SCb intervals of the Scontrone Fossil Site and Scontrone North sections, suggests a prolonged subaerial exposure. The red soil lies directly over the carbonates of the Terratta Formation and is overlain by dark nodular marsh deposits which are followed, in turn, by yellowish lagoonal marls with smooth-shelled gastropods. In the same stratigraphic section, the lagoon deposits are overlain by the cross-bedded calcarenites of the lower portion of the *Lithothamnium* Limestone.

*Acknowledgments*
The authors thank Barbara Taccini for careful map and columnar-section drawing.

References

BEHRENSMEYER, A., 1975. *The taphonomy and paleoecology of Plio-Pleistocene vertebrate assemblages east of Lake Rudolf, Kenya*. Bull. Museum of Comparative Zoology, **146**, 473-578.

DE GIULI, C., TORRE, D., 1984. *Species interrelationships and evolution in the Pliocene endemic faunas of Apricena (Gargano Peninsula, Italy).* Geobios, Mem. Spec. **8**, 379-383.

FREUDENTHAL, M., 1971. *Neogene vertebrates from Gargano peninsula, Italy.* Scripta Geologica, **3**, 1-10.

FREUDENTHAL, M., 1972. *Deinogalerix koeningswaldi nov. gen. nov. spec., a giant insectivore from the Neogene of Italy.* Scripta Geologica, **14**, 1-19.

HILGEN F., ABDUL AZIZ H., BICE, D., IACCARINO, S., KRIJGSMAN W., KUIPER, K., MONTANARI, A., RAFFI, I., TURCO, E., ZACHARIASSE, W.J., 2003. *The global boundary stratotype section and point (GSSP) of the Tortonian Stage (Upper Miocene) at Monte dei Corvi.* Episodes, **28**(1), 6-17.

HILGEN F.., KRIJGSMAN W., RAFFI I., TURCO E., ZACHARIASSE W.J., 2000. *Integrated stratigraphy and astronomical calibration of the Serravallian/Tortonian boundary section at Monte Gibliscemi (Sicily, Italy).* Marine Micropaleont., **38**, 181-211.

HOPE, G.S., 2002. *The Late Quaternary of Kiritimati (Christmas) Island, Kiribati*. In: Anderson, A., Martinsson Wallin, H., Wallin, P. (Eds.), The Prehistory of Kiritimati (Christmas) Island, Republic of Kiribati excavations and analyses. Oslo, Kon-Tiki Museum Occasional papers, 111-118.

KORTH, W.W., 1979. *Taphonomy of microvertebrate fossil assemblages*. Annals of the Carnegie Museum, **48**, 235-285.

LEINDERS, J., 1983. *Hoplitomerycidae fam. nov. (Ruminantia, Mammalia) from Neogene fissure fillings in Gargano (Italy). Part. 1: The cranial osteology of Hoplitomeryx gen. nov. and discussion on the classification of pecoran families*. Scripta Geologica **70**, 1-68.

MAZZA, P., RUSTIONI, M., 1996. *The Turolian fossil arctyodactils from Scontrone (Abruzzo, Central Italy) and their paleoecological and paleogeographical implications*. Boll. Soc. Paleont. Ital., **35**, 93-106.

MAZZA, P., RUSTIONI, M., in preparation. *Deinogalerix freudenthali* (Mammalia, Insectivora) from the lower Tortonian bonebed of Scontrone (Abruzzo, Central Italy).

PATACCA, E., SCANDONE, P.,  MAZZA, P., RUSTIONI' M., in preparation. The Miocene land vertebrates of Scontrone (Central Apennine): stratigraphic position and migration path.

RUSTIONI, M., MAZZA, P., AZZAROLI, A., BOSCAGLI, G., COZZINI, F., DI VITO, E., MASSETI, M., PISANÒ, A., 1992. *Miocene vertebrate remains from Scontrone, National Park of Abruzzi, Central Italy*. Atti Accad. Naz. Lincei, Rend. Cl. Sci. Fis. Mat. Nat., s. 9, **3**, 227-237.
SUPRIN, B., HOPE, G.S., 2001. *A Pleistocene record of Neocallitropsis pancheri (Cupressaceae) from the Plaine des Lacs, New Caledonia*. Quaternary Australasia **19**(2), 17-21.

VOORHIES, M., 1969. *Taphonomy and population dynamics of an early Pliocene vertebrate fauna, Knox County, Nebraska*. University of Wyoming Contributions to Geology, Special Paper **1**, Laramie, 69 pp.

WEIGELT, J., 1989. Recent vertebrate carcasses and their paleobiological implications. University of Chicago