Boll.Soc.Geol.It. (*Ital.J.Geosci.*), Vol. 127, No. 1 (2008), pp. 51-73, 8 figs., 7 plates

The Miocene land-vertebrate fossil site of Scontrone (Central Apennines, Italy)

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ABSTRACT

In the early nineties of the last century, a Miocene fossil site yielding numerous teeth and bones of land mammals, together with abundant remains of chelonians and crocodiles, was discovered at the southern border of the Abruzzi National Park (Central Apennines) near the village of Scontrone. The mammalian fauna of Scontrone shows close similarities to a fauna discovered in the Gargano region about twenty years before. The endemic characters of the Scontrone and Gargano associations suggest the existence of a paleobiogeographic province isolated from the nearest mainland areas. The present paper synthesizes the results of a detailed geological study aimed at defining the stratigraphic position and the depositional setting of the vertebrate bonebeds. The paper, in addition, provides some information on the time in which the mammal colonization took place and on the migration route followed by the new incomers to reach the Scontrone-Gargano region.

The Scontrone land vertebrates are embedded in coastal-tidal-flat carbonates locally preserved at the base of the *Lithothamnium* Limestone, a Miocene carbonate-ramp depositional unit characterized by a rich rhodalgal facies widespread in the Central-Southern Apennines and, more in general, in the whole Mediterranean region. The age of the base of the *Lithothamnium* Limestone, and consequently the age of the Scontrone vertebrate fossil association, is Tortonian, not older than the N16 Zone after the First Regular Occurrence of *Neogloboquadrina acostaensis* (a bioevent astronomically dated at 10.554 Ma). The colonization of the terrestrial mammals, on the contrary, is much older as it dates back to the latemost early Oligocene, at 29-30 Ma, when an important global sea level drop exposed the Apulia Platform and a part of the Central Adriatic region creating a landbridge that allowed the terrestrial fauna migration from Dalmatia to Gargano via the Tremiti Islands. The following marine transgression (maximum flooding was reached during the Langhian, i.e. between 16.4 and 14.8 Ma) lead to the isolation of the Apulia Platform and brought about, as a consequence, a secluded paleobiogeographic province where land vertebrates endemized, flourished and diversified. The Miocene Scontrone fossil fauna represents an exceptional case, in the Central Apennines, of land vertebrate finding related to the occurrence, during Tortonian times, of a wide coastal plain where tidal flats, ephemeral marshes and coastal lagoons created favourable conditions for life matched with optimal conditions for fossilization. Owing to the presence of ravinement surfaces associated with subsequent transgressive events, sedimentary records of paralic environments at the base of the Miocene ramp carbonates are rarely preserved in the Apennines.

KEY WORDS: *Stratigraphy, calcareous microfacies, Tortonian land vertebrates, Oligocene paleogeography.*

RIASSUNTO

Il giacimento miocenico a vertebrati di Scontrone (Appennino Centrale, Italia).

All'inizio degli anni '90 fu scoperto a Scontrone, in Abruzzo, un importante giacimento fossilifero a vertebrati con resti di mammiferi terrestri, cheloni e coccodrilli. La fauna a mammiferi di Scontrone, di età miocenica, mostra forti somiglianze con faune scoperte nel Gargano una ventina d'anni prima, attribuite al Messiniano da alcuni autori e al Pliocene inferiore da altri. Il carattere endemico delle associazioni di Scontrone e del Gargano suggerisce la loro appartenenza ad una provincia paleobiogeografica isolata rispetto alle aree continentali circostanti. In questo lavoro vengono sintetizzati i dati di uno studio di dettaglio volto a precisare la posizione stratigrafica dei livelli fossiliferi e a definirne l'ambiente deposizionale. Vengono inoltre forniti nuovi elementi sull'età di colonizzazione della Piattaforma Apula che risulta circoscritta intorno alla fine dell'Oligocene inferiore. I livelli fossiliferi di Scontrone appartengono a depositi carbonatici costieri mesotidali sporadicamente preservati alla base dei Calcari a *Lithothamnium*. Questi ultimi sono rappresentati da depositi rodalgali di rampa carbonatica, molto diffusi nel Miocene dell'Appennino Centro-meridionale e, più in generale, dell'intera regione mediterranea. L'età della base dei Calcari a *Lithothamnium*, e quindi l'età dei vertebrati fossili di Scontrone, è tortoniana non più antica della FRO di *Neogloboquadrina acostaensis*, un bioevento datato astronomicamente a 10.554 Ma. La colonizzazione dei mammiferi terrestri, invece, è molto più antica e risale alla parte terminale dell'Oligocene inferiore, a circa 29 milioni di anni fa, quando un importante abbassamento del livello marino a scala globale determinò l'instaurarsi di condizioni subaeree nell'intera Piattaforma Apula e nell'Adriatico Centrale con la creazione di un ponte che permise l'immigrazione di faune terrestri provenienti dalla Dalmazia. La trasgressione marina che seguì l'evento di regressione oligocenico e che raggiunse la sua acme nel corso del Langhiano causò l'isolamento totale della Piattaforma Apula. Quest'ultima, di conseguenza, si trovò a costituire una provincia biogeografica a sé stante, all'interno della quale i vertebrati terrestri poterono svilupparsi e diversificarsi raggiungendo quei caratteri di endemismo molto spinti testimoniati dalle faune di Scontrone e del Gargano. La fauna a vertebrati fossili di Scontrone rappresenta nell'Appennino Centrale un raro caso di ritrovamento legato alla fortuita, locale preservazione di depositi costieri (piane tidali, paludi e lagune) dove favorevoli condizioni di vita coincidevano con ottime condizioni per la fossilizzazione. Queste facies sono preservate solo raramente in Appennino a causa degli estesi fenomeni di erosione sviluppati alla base dei soprastanti depositi trasgressivi.

TERMINI CHIAVE: *Stratigrafia, microfacies calcaree, vertebrati terrestri tortoniani, paleogeografia oligocenica.*

1. INTRODUCTION AND GENERAL GEOLOGICAL FRAMEWORK

The Miocene land-vertebrate fossil site of Scontrone, located at the southern border of the Abruzzi National Park (Central Apennines), was discovered in the early nineties of the last century (RUSTIONI *et alii*, 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 vertebrates of Scontrone display close similarities to a fossil assemblage discovered in the Gargano region in the early seventies (FREUDENTHAL, 1971, 1972), including remarkable endemic charac-

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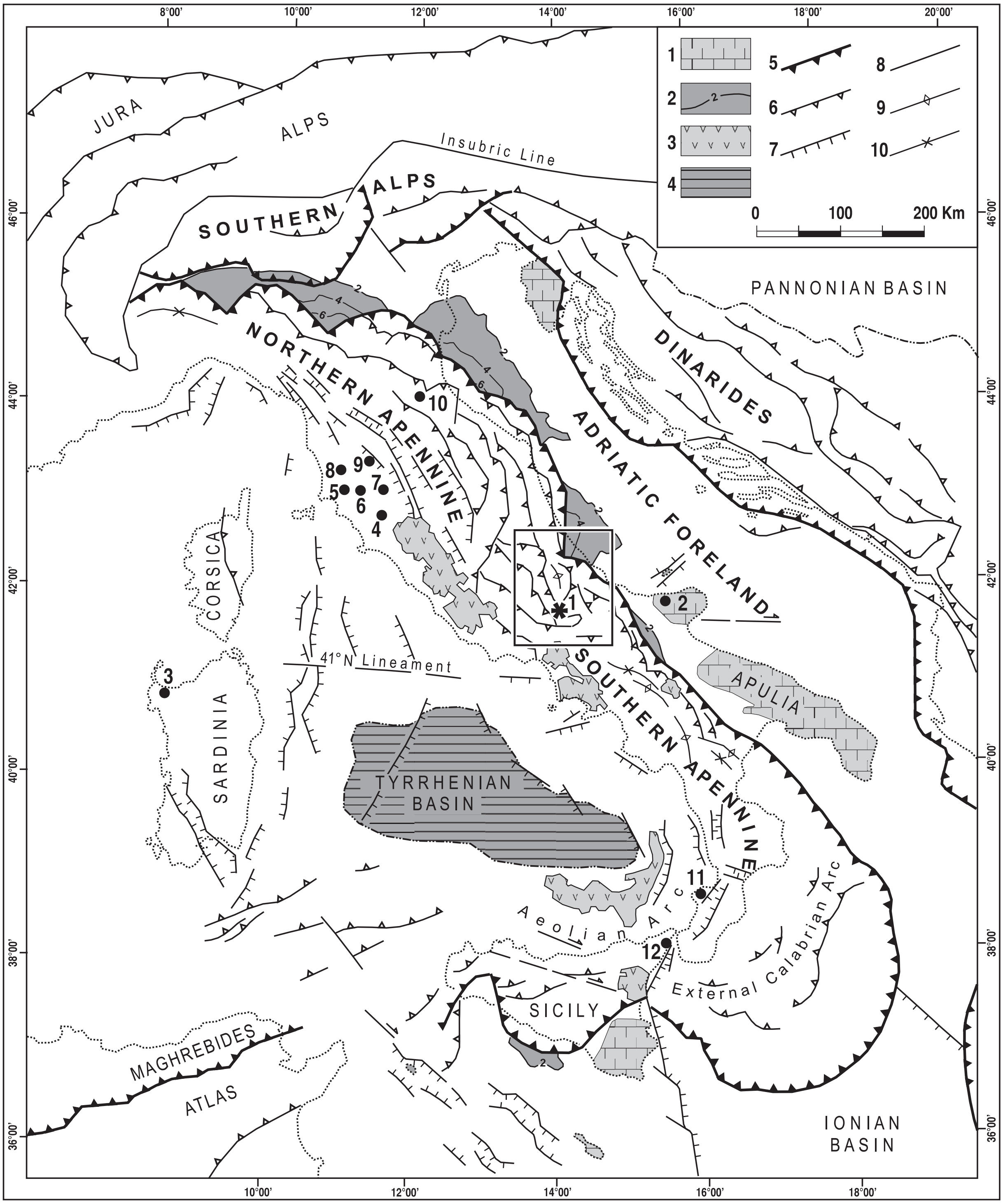


Fig. 1 - Structural sketch of Italy and surrounding regions (after PATACCA & SCANDONE, 2004 with slight modifications) showing the location of the Scontrone fossil site together with the location of the most important Miocene land-vertebrate fossil sites in the Italian Peninsula: 1 Scontrone; 2 Apricena (Gargano); 3 Fiume Santo; 4 Baccinello; 5 Montebamboli; 6 Montemassi-Ribolla-Casteano; 7 Velona; 8 Serrazzano; 9 Il Casino; 10 Brisighella; 11 Cessaniti; 12 Gravitelli. The box delimitates the area represented in fig. 3. 1) Mesozoic-Tertiary carbonates of the foreland areas. 2) Depth (in kilometers) of the base of the Plio-Pleistocene deposits in the Apennine and Sicily foredeep basins. 3) Major Quaternary subaerial volcanoes. 4) Areas with Bouguer gravity anomalies exceeding 200 mgals, floored by oceanic crust or thinned continental crust. 5) Front of the Maghrebides, Apennines, Southern Alps and Dinarides. 6) Major thrusts. 7) Normal faults. 8) High-angle faults, mostly strike-slip faults. 9) Anticline axis. 10) Syncline axis.

– Schema strutturale della penisola italiana ed aree circostanti (da PATACCA & SCANDONE, 2004 con lievi modifiche) con l'ubicazione del giacimento di Scontrone e degli altri principali giacimenti di vertebrati terrestri miocenici: 1 Scontrone; 2 Apricena (Gargano); 3 Fiume Santo; 4 Baccinello; 5 Montebamboli; 6 Montemassi-Ribolla-Casteano; 7 Velona; 8 Serrazzano; 9 Il Casino; 10 Brisighella; 11 Cessaniti; 12 Gravitelli. Il riquadro delimita l'area rappresentata in fig. 3. 1) Depositi carbonatici mesozoico-terziari delle aree di avampaese. 2) Profondità (in chilometri) della base dei depositi plio-pleistocenici nei bacini di avanfossa dell'Appennino e della Sicilia. 3) Principali edifici vulcanici subaerei quaternari. 4) Aree con anomalie di Bouguer superiori a 200 mgals, con crosta oceanica o crosta continentale assottigliata. 5) Fronte della catena nelle Maghrebidi, nell'Appennino, nelle Alpi Meridionali e nelle Dinaridi. 6) Principali faglie inverse e sovrascorrimenti. 7) Faglie normali. 8) Faglie ad alto angolo, in prevalenza faglie trascorrenti. 9) Asse di anticlinale. 10) Asse di sinclinale.

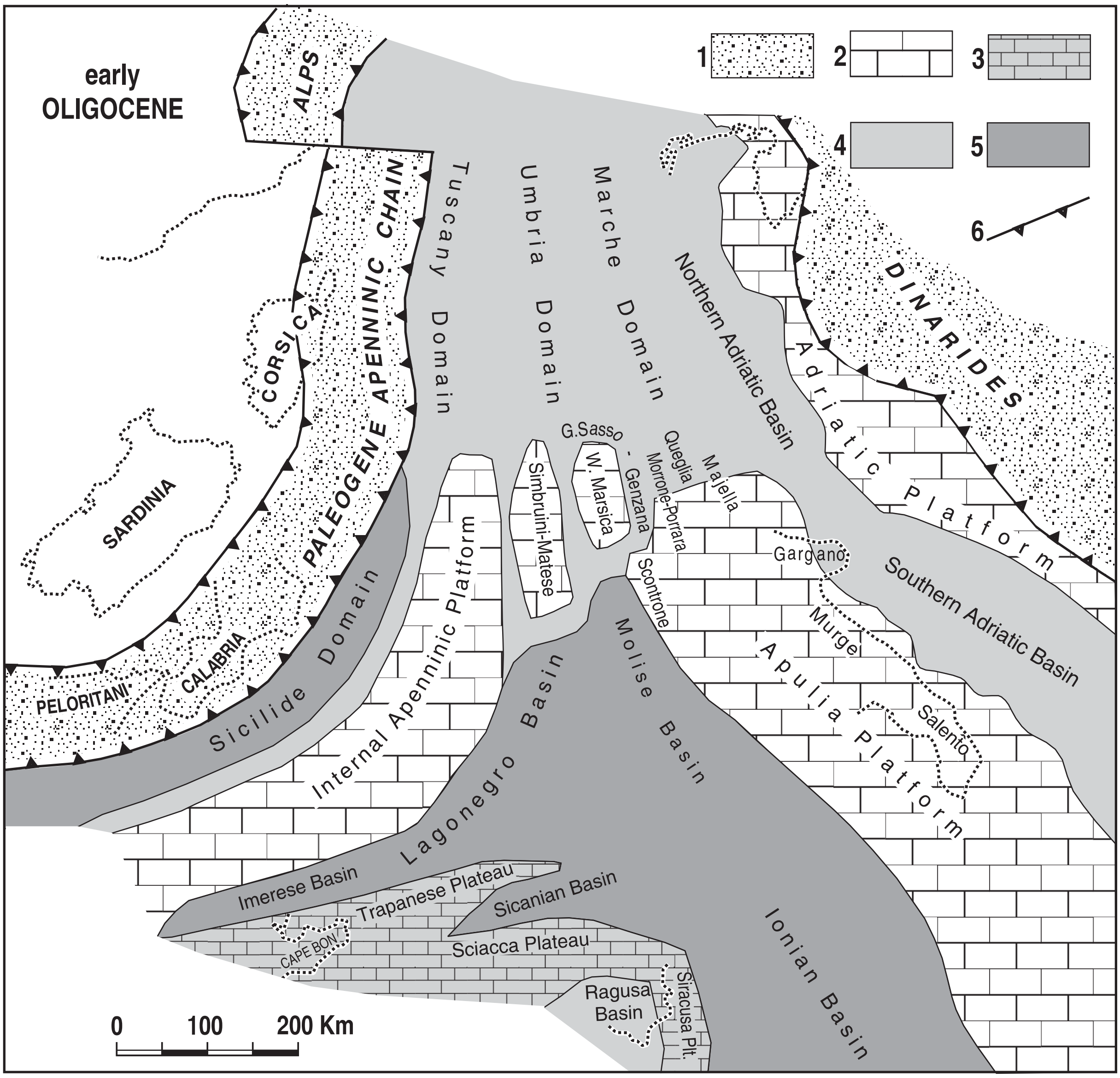


Fig. 2 - Palinspastic restoration of the Apenninic domains during the Oligocene, just before the major global sea level drop that occurred around the Rupelian-Chattian boundary. In that time the peri-Adriatic region was not yet reached by the Neogene compression (after PATACCA & SCANDONE, 2007). 1) Paleogene mountain chains. 2) Long-lasting (Mesozoic-Tertiary) shallow-water carbonate domains. 3) Wide pelagic plateaux. 4) Basins and isolated submarine structural highs. 5) Deep-water basins floored by oceanic or thinned continental crust. 6) Front of orogenic belts.

– Ricostruzione palinspastica dei domini appenninici nell'Oligocene, poco prima dell'importante abbassamento del livello del mare che si verificò a scala globale intorno al limite Rupeliano-Chattiano. In quel momento l'area periadriatica non era stata ancora raggiunta dalla compressione neogenica (da PATACCA & SCANDONE, 2007). 1) Catena paleogenica. 2) Piattaforme carbonatiche di mare basso persistenti dal Mesozoico al Terziario. 3) Vasti plateaux pelagici. 4) Bacini ed isolati alti strutturali sottomarini. 5) Bacini profondi a crosta oceanica o continentale assottigliata. 6) Fronti di catena.

ters that suggest the existence of a paleobiogeographic province isolated from the nearest mainland areas. Conversely, they differ very much from other vertebrate faunas recovered in upper Miocene deposits of the Northern Apennines, Calabria, Sicily and Sardinia (ROOK *et alii*, 2006 and references therein). The Sardinia and Northern Apennine land mammals show phylogenetic affinities with European species, and such affinities are well-recognizable also in the oldest, endemic forms of the Tusco-Sardinian paleobioprovince. The Calabrian and Sicily vertebrates, on the contrary, reveal an overall North-African affinity. The structural scheme of fig. 1, showing the location of the Scontrone-Gargano fossil findings and of the other late Miocene land vertebrate recoveries in Italy, highlights the different tectonic settings of these vertebrate fossil sites. The Fiume Santo fossil site is located in the Sardinia hinterland while all other vertebrate findings are located within the thrust belt, except the Gargano site which is located in the slightly deformed Adriatic-Apulia foreland. The close similarities between the Gargano and Scontrone faunas can be easily explained considering that both sites were part of the same paleogeographic domain (Apulia Platform domain, see fig. 2) before the Scontrone depositional realm was incorporated in the Apennine

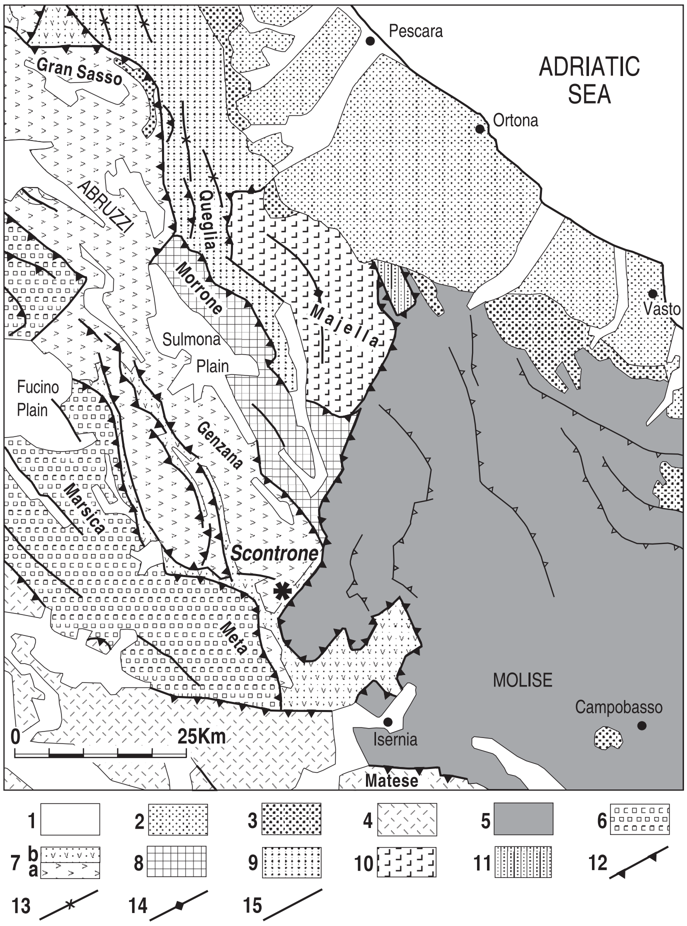


Fig. 3 - Simplified structural map of the eastern sector of the Central Apennines (boxed area in fig. 1, after Patacca & Scandone, 2007 with slight modifications). The asterisk indicates the location of the Scontrone fossil site. 1) Holocene deposits. 2) Pleistocene deposits. 3) Pliocene deposits. 4) Simbruini-Matese Unit: Mesozoic-Tertiary shallow to deeper water carbonates overlain by Tortonian siliciclastic flysch deposits. 5) Sannio and Molise Nappes: Mesozoic-Tertiary basinal carbonates overlain by Langhian-Serravallian (Sannio) or by uppermost Tortonian-lower Messinian (Molise) siliciclastic flysch deposits; in angular unconformity, uppermost Tortonian-Messinian terrigenous deposits lying on top of the Sannio Nappe and Messinian evaporites lying on top of the Molise Nappes. 6) Western Marsica-Meta Unit: Mesozoic-Tertiary shallow to deeper water carbonates overlain by a lower Messinian siliciclastic flysch deposited before the salinity crisis. 7) Gran Sasso-Genzana Unit. 7a: Mesozoic-Tertiary shallow to deeper water carbonates; 7b: Messinian siliciclastic flysch deposited before, during and after the salinity crisis. 8) Morrone-Porrara Unit: Mesozoic-Tertiary shallow to deeper water carbonates overlain by a Messinian siliciclastic flysch deposited during and after the salinity crisis. 9) Queglia Unit: upper Cretaceous-Miocene basin and ramp carbonates followed by Messinian evaporites and by uppermost Messinian-lower Pliocene siliciclastic flysch deposits. 10) Majella Unit: Mesozoic-Tertiary shallow to deeper water carbonates followed by Messinian evaporites plus brackish-water marls (Lago-Mare facies) and by lower Pliocene siliciclastic flysch deposits. 11) Pliocene marly clays overlying the Mesozoic-Tertiary carbonates plus Messinian evaporites of the Casoli-Bomba structural high. 12) Thrusts. 13) Syncline axis. 14) Anticline axis. 15) Normal faults and strike-slip faults.

– Carta strutturale semplificata del settore orientale dell'Appennino Centrale (area in riquadro nella fig. 1, da Patacca & Scandone, 2007 con lievi modifiche). L'asterisco fornisce l'ubicazione della località fossilifera di Scontrone. 1) Depositi olocenici. 2) Depositi pleistocenici. 3) Depositi pliocenici. 4) Unità Simbruini-Matese: carbonati mesozoico-terziari di mare basso e mare profondo seguiti da depositi silicoclastici di tipo flysch di età tortoniana. 5) Falde Sannitiche e Molisane: carbonati bacinali mesozoico-terziari seguiti da depositi silicoclastici di tipo flysch di età langhiano-serravalliana nelle Falde Sannitiche e di età tortoniano superiore-messiniana inferiore nelle Falde Molisane; depositi terrigeni di età tortoniano superiore-messiniana inferiore in discordanza angolare sulle Falde Sannitiche ed evaporiti messiniane in discordanza angolare sulle Falde Molisane. 6) Unità Marsica Occidentale-Meta: carbonati mesozoico-terziari di mare basso e mare profondo seguiti da un flysch silicoclastico di età messiniana pre-crisi di salinità. 7) Unità Gran Sasso-Genzana. 7a: carbonati mesozoico-terziari di mare basso e mare profondo; 7b: flysch silicoclastico di età messiniana deposto prima, durante e dopo la crisi di salinità. 8) Unità Morrone-Porrara: depositi carbonatici mesozoico-terziari di mare basso e mare profondo seguiti da un flysch silicoclastico di età messiniana deposto durante e dopo la crisi di salinità. 9) Unità Queglia: depositi carbonatici mesozoico-terziari di rampa e bacino seguiti da evaporiti messiniane e da depositi silicoclastici di tipo flysch di età messiniana superiore-pliocenica inferiore. 10) Unità Majella: carbonati mesozoico-terziari di mare basso e mare profondo seguiti da evaporiti messiniane e da marne di ambiente salmastro (facies Lago-Mare); depositi silicoclastici di tipo flysch di età pliocenica inferiore. 11) Argille marnose plioceniche sovrastanti i carbonati mesozoico-terziari e le evaporiti messiniane dell'alto strutturale di Casoli-Bomba. 12) Sovrascorrimenti. 13) Asse di sinclinale. 14) Asse di anticlinale. 15) Faglie normali e faglie trascorrenti.

chain near the end of the Messinian. On the contrary, the differences between the Northern Apennine faunas and the Scontrone-Gargano ones, as well as the differences between the latter and the Calabria-Sicily faunas, demonstrate the existence, during the late Miocene, of natural barriers that prevented faunal homogenization.

The Scontrone fossil vertebrates have been recovered in a stratigraphic sequence that pertains to the Gran Sasso-Genzana Unit, a cover nappe widespread in the Central Apennines from Northern Abruzzi to Alto Molise (see structural map in fig. 3) which is composed of Mesozoic-Tertiary shallow-water and deeper-marine carbonates followed by Messinian siliciclastic flysch deposits. The stratigraphic scheme in fig. 4 describes the primary relationships between the lithostratigraphic units making up the Gran Sasso-Genzana pre-flysch sequence in the area that extends from the Genzana Mountain (north) to the High Volturno Valley (south). The scheme, based on original data as concerns the Scontrone-High Volturno region, takes into account the available geological literature on the whole area (see among many others Colacicchi & Praturlon, 1965; Colacicchi, 1967; Praturlon, 1968; Parotto & Praturlon, 1975, 2004; Accordi & Carbone, 1988; Accordi *et alii*, 1988; D'Andrea, 1988; Damiani *et alii*, 1992; D'Andrea *et alii*, 1992; Miccadei, 1993; Società Geologica Italiana 2003). Geometries and sedimentary features of the major depositional units in the area allowed the reconstruction of a fault-controlled, backstepping Jurassic-lower Cretaceous platform edge that turned during the late Cretaceous into a distally-steepened carbonate ramp with retreating margin and finally, from the latemost Cretaceous to the early Messinian, into a carbonate ramp characterized by an overall prograding geometry. As a rule in the platform-to-basin depositional systems of the Central Apennines (see fig. 2), the northern sequences (Monte Genzana region) are made up of middle Liassic-Paleogene basinal deposits followed by uppermost Oligocene-Miocene outer ramp carbonates. The southern sequences (High Volturno region), on the contrary, are characterized by persisting shallow-water conditions through Mesozoic times, with Neocomian platform-margin limestones and coeval platform-interior carbonates unconformably overlain by upper Miocene inner to outer ramp carbonate deposits. The geological map of fig. 5 provides the areal

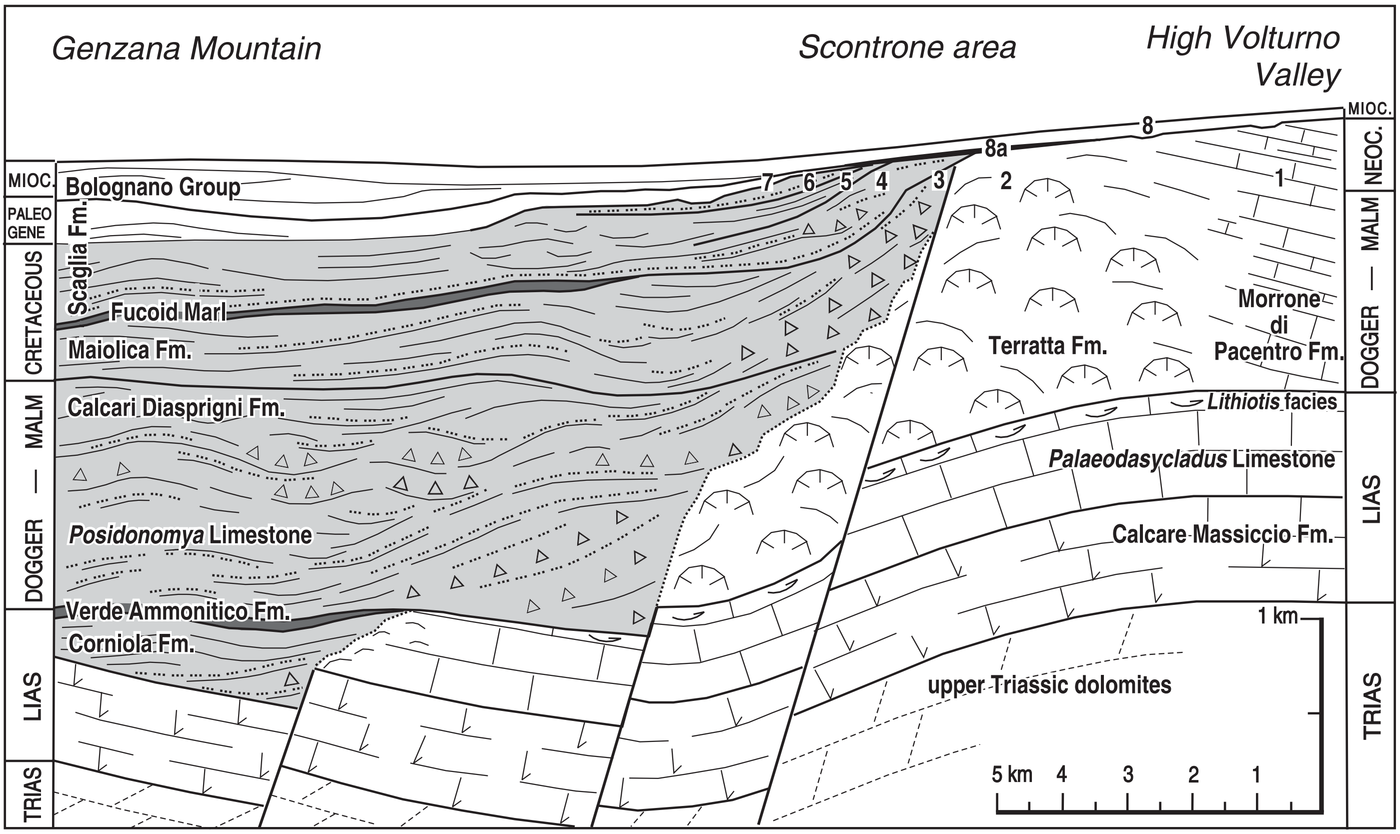


Fig. 4 - Stratigraphic architecture of the Mesozoic-Tertiary carbonates of the Gran Sasso-Genzana Unit between the Genzana Mountain and the High Volturno Valley. The extent of these carbonates in the study area is shown in figs. 5 and 6. The Arabic numerals 1-8a refer to the lithostratigraphic units cropping out in the Scontrone-High Volturno region: 1) Neocomian platform-interior limestones (Morrone di Pacentro Fm); 2) Neocomian platform-edge limestones (Terratta Fm); 3) Neocomian marginal slope-breccias (Coral-bearing Calcirudite); 4) Upper Albian-lowermost Turonian slope-apron calcarenites (Rudist-bearing Calcarenite); 5) Coniacian-Campanian basinal limestones (Scaglia Fm); 6) Maastrichtian outer ramp biocalcarenites (Saccharoidal Limestone); 7) Upper Paleocene reefal limestones (Coral-algal Limestone); 8) Tortonian-lowermost Messinian rhodalgal ramp carbonates (Lithothamnium Limestone); 8a) Tortonian peritidal carbonates (Scontrone Member of the Lithothamnium Limestone). – *Architettura stratigrafica dell'Unità Gran Sasso-Genzana nel settore Monte Genzana-Alta Valle del Volturno. La distribuzione nell'area di studio dei depositi attribuiti a questa unità è indicata nelle figg. 5 e 6. I numeri 1-8a si riferiscono alle unità litostratigrafiche affioranti tra Scontrone e l'Alta Valle del Volturno: 1) calcari di piattaforma protetta del Neocomiano (Formazione Morrone di Pacentro); 2) calcari di margine di piattaforma del Neocomiano (Formazione Terratta); 3) brecce marginali di scarpata del Neocomiano (Calciruditi a frammenti di Coralli); 4) calcareniti di slope apron dell'Albiano superiore-Turoniano inferiore (Calcareniti a frammenti di Rudiste); 5) calcari bacinali del Coniaciano-Campaniano (Formazione della Scaglia); 6) biocalcareniti di rampa esterna del Maastrichtiano (Calcari Pseudosaccaroidi); 7) calcari di scogliera del Paleocene superiore (Calcari a Coralli ed Alghe); 8) calcari ad alghe rosse del Tortoniano-Messiniano inferiore (Calcari a Lithothamni); 8a) carbonati peritidali (Membro di Scontrone dei Calcari a Lithothamni).*

distribution of the major depositional units featuring the platform-to-basin system between Scontrone and the High Volturno Valley. The map evidences an important disconformity at the base of the Miocene carbonate deposits that have yielded the fossil vertebrates. In the High Volturno Valley, where the southernmost Mesozoic-Tertiary carbonates belonging to the Gran Sasso-Genzana Unit crop out, upper Miocene rhodalgal ramp carbonates (*Lithothamnium* Limestone in this paper) directly overlie, by means of a considerable temporal gap, Neocomian platform-interior carbonates referable to the upper portion of the Morrone di Pacentro Formation. In the outskirts of the Scontrone village, the *Lithothamnium* Limestone disconformably overlies Neocomian platform-margin limestones and adjacent slope to basin deposits with a hiatus amplitude gradually decreasing towards the north. North of Scontrone the *Lithothamnium* Limestone, conformably overlain by hemipelagic deposits (*Turborotalia multiloba* Marl), constitutes as a whole a deepening-upward sequence occupying the upper portion of the Bolognano Group (see fig. 4). The latter is an upper Oligocene-upper Miocene high-rank lithostratigraphic unit informally quoted in the geological literature as the Bolognano Formation (see Crescenti *et alii*, 1969; Centamore *et alii*, 2003) or the Calcari a Briozoi e Litotamni Formation (Brandano & Corda, 2002; Pomar *et alii*, 2004), which is characterized by several internal disconformity surfaces (sequence boundaries). A detailed cartography of the Miocene *Lithothamnium* Limestone and of the underlying Cretaceous-Paleocene deposits exposed in the Scontrone area is provided in the geological map of fig. 6 showing a faulted dome of Mesozoic-Tertiary carbonates emerging from more weathered and eroded siliciclastic flysch deposits. The deepest portion of the carbonate sequence, represented by Neocomian platform-edge limestones (upper portion of the Terratta Formation) and coeval slope breccias (Coral-bearing Calcirudite), is spectacularly exposed in the Sangro River gorge not far from the Scontrone village. The younger portion of the sequence, quite well exposed along the northern flank of the Sangro Valley, consist of slope-apron and basinal carbonate deposits (upper Albian-lowermost Turonian Rudist-bearing Calcarenite and Coniacian-Campanian Scaglia

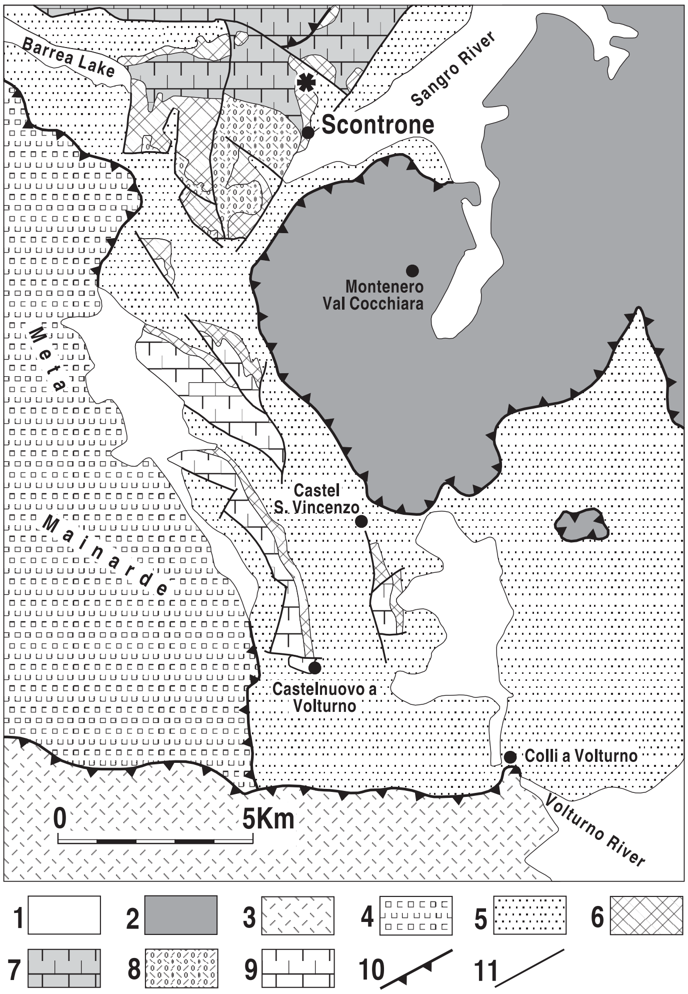


Fig. 5 - Simplified geological map of the region between Scontrone and the High Volturno Valley. The asterisk north of the Scontrone village indicates the location of the vertebrate fossil site. 1) Continental Quaternary deposits. 2) Molise Nappes. 3) Simbruini-Matese Unit. 4) Western Marsica-Meta Unit. 5-9) Gran Sasso-Genzana Unit: 5) Messinian *p.p.* siliciclastic flysch deposits (Castelnuovo al Volturno Wildflysch); 6) Tortonian-lowermost Messinian ramp carbonates (*Lithothamnium* Limestone, 8 and 8a in fig. 4) and overlying lower Messinian hemipelagic deposits (*Turborotalia multiloba* Marl); 7) Cretaceous basinal limestones (Coral-bearing Calcirudite, Rudist-bearing Calcarenite and Scaglia Formation, 3, 4 and 5 respectively in fig. 4) locally followed by Maastrichtian outer ramp limestones (Saccharoidal Limestone, 6 in fig. 4) and by upper Paleocene reefal limestones (Coral-algal Limestone, 7 in fig. 4); 8) Neocomian platform-edge limestones (upper portion of the Terratta Formation, 2 in fig. 4); 9) Neocomian protected-platform limestones (upper portion of the Morrone di Pacentro Formation, 1 in fig. 4); 10) Thrusts; 11) Normal faults and strike-slip faults.

– Carta geologica semplificata dell'area compresa tra Scontrone e l'Alta Valle del Volturno. L'asterisco a nord del paese di Scontrone indica l'ubicazione del giacimento fossilifero a vertebrati. 1) Depositi continentali quaternari. 2) Falde Molisane. 3) Unità Simbruini-Matese. 4) Unità Marsica Occidentale-Meta. 5-9) Unità Gran Sasso-Genzana: 5) depositi silicoclastici messiniani di tipo flysch (Wildflysch di Castelnuovo al Volturno); 6) depositi tortoniano-messiniani di rampa carbonatica (Formazione dei Calcari a Lithothamnium, *8 e 8a in fig. 4) e sovrastanti depositi emipelagici del Messiniano inferiore (Marne a* Turborotalia multiloba); *7) calcari cretacei bacinali (Calciruditi a frammenti di Coralli, Calcareniti a frammenti di Rudiste e Formazione della Scaglia, 3, 4 e 5 rispettivamente in fig. 4) a luoghi stratigraficamente ricoperti da calcari maastrichtiani di rampa esterna (Calcari Pseudosaccaroidi, 6 in fig. 4) e da calcari di scogliera del Paleocene (Calcare a Coralli e Alghe, 7 in fig. 4); 8) calcari neocomiani di margine di piattaforma (parte alta della Formazione della Terratta, 2 in fig. 4); 9) calcari neocomiani di piattaforma protetta (parte alta della Formazione Morrone di Pacentro, 1 in fig. 4); 10) Faglie inverse e sovrascorrimenti; 11) Faglie dirette e faglie trascorrenti.*

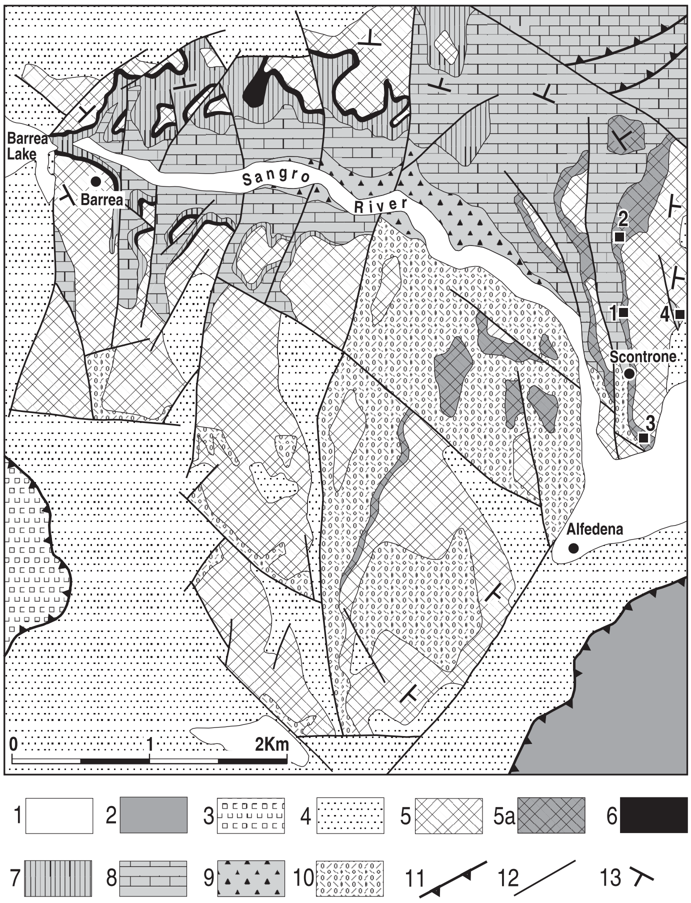


Fig. 6 - Detailed geological map (modified after Ceragioli *et alii*, 1996) with the distribution of the lithostratigraphic units cropping out in the Scontrone area (see fig. 4). Arabic numerals indicate the location of the stratigraphic columnar sections shown in fig. 7: 1 Scontrone North; 2 Scontrone Fossil Site; 3 Scontrone South; 4 Scontrone Cemetery). 1) Quaternary continental deposits. 2) Molise Nappes. 3) Western Marsica-Meta Unit. 4-10) Gran Sasso-Genzana Unit: 4) Castelnuovo al Volturno Wildflysch (Messinian *p.p.*); 5) *Lithothamnium* Limestone and overlying *Turborotalia multiloba* Marl (Tortonian *p.p.*-lower Messinian); 5a Scontrone Member of the *Lithothamnium* Limestone (Tortonian *p.p.*); 6) Coral-algal Limestone (upper Paleocene); 7) Scaglia Formation and minor outcrops of the overlying Saccharoidal Limestone (Senonian); 8) Rudist-bearing Calcarenite (upper Albian-lowermost Turonian); 9) Coral-bearing Calcirudite (Neocomian); 10) upper portion of the Terratta Formation (Neocomian); 11) Thrusts; 12) Normal faults and strike-slip faults; 13) Attitude of strata.

– Carta geologica di dettaglio (da Ceragioli et alii, *1996, con modifiche) mostrante la distribuzione delle unità che affiorano nell'area di Scontrone (v. fig. 4). I numeri indicano l'ubicazione delle sezioni stratigrafiche illustrate in fig. 7: 1 Scontrone Nord; 2 Giacimento Fossilifero; 3 Scontrone Sud; 4 Cimitero di Scontrone). 1) Depositi continentali quaternari. 2) Falde Molisane. 3) Unità Marsica Occidentale-Meta. 4-10) Unità Gran Sasso-Genzana: 4) Wildflysch di Castelnuovo al Volturno* (*Messiniano* p.p.); *5) Calcari a* Lithothamnium *e Marne a* Turborotalia multiloba *(Tortoniano* p.p.*-Messiniano inferiore); 5a Membro di Scontrone dei Calcari a* Lithothamnium *(Tortoniano* p.p.); *6) Calcari ad Alghe e Coralli (Paleocene superiore); 7) Scaglia, con discontinui piccoli affioramenti dei sovrastanti Calcari Pseudosaccaroidi (Senoniano); 8) Calcareniti a frammenti di Rudiste (Albiano superiore-base Turoniano); 9) Calciruditi a frammenti di Coralli (Neocomiano); 10) parte alta della Formazione della Terratta (Neocomiano); 11) Faglie inverse e sovrascorrimenti; 12) Faglie normali e faglie trascorrenti; 13) Pendenze di strato.*

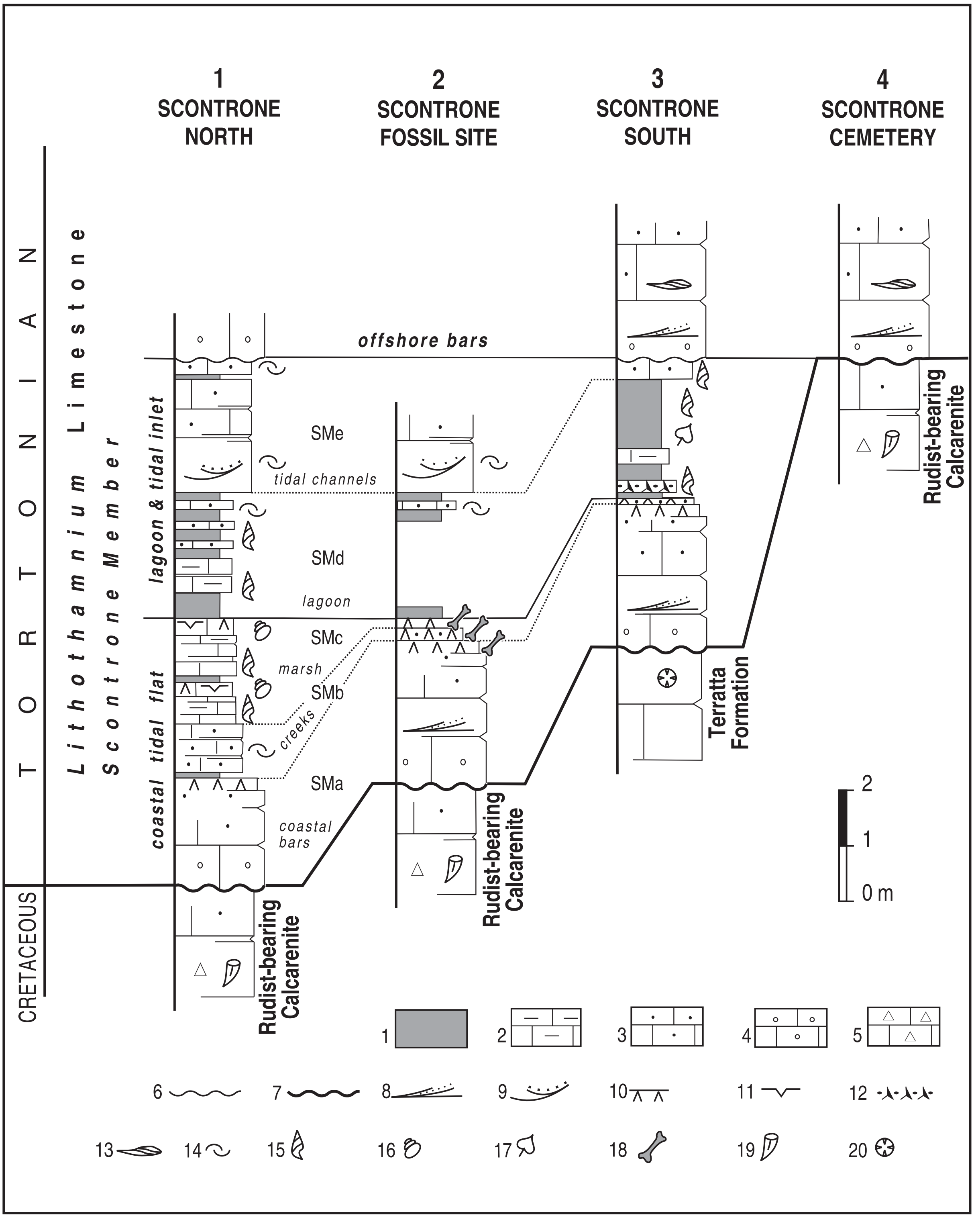


Fig. 7 - Columnar sections showing the position of the bonebeds in the Scontrone fossil site and the major lateral variations of facies in the Scontrone Member of the *Lithothamnium* Limestone (see location in fig. 6). The stratigraphic correlations between the columnar sections follow time-correlation horizons identified by major shifts in the depositional setting and major changes in the biotic associations. 1) Marls and limey marls. 2) Marly limestones. 3) Bioclastic calcarenites. 4) Bioclastic calcarenites with oversized well-rounded lithoclast lags. 5) Calcirudites. 6) Ravinement surface. 7) Major disconformity. 8) Low-angle cross-bedding. 9) Trough cross-bedding. 10) Root traces. 11) Desiccation cracks. 12) Calcispherulid-bearing limestones. 13) Heterosteginids. 14) Oyster shell lags. 15) Cerithid shell lags. 16) Hydrobiids. 17) Plant remains. 18) Bonebeds. 19) Rudist fragments. 20) Coral fragments.

– Sezioni colonnari mostranti la posizione dei resti di vertebrati nel giacimento di Scontrone e le principali variazioni laterali di facies all'interno del Membro di Scontrone dei Calcari a Lithothamnium *(v. ubicazione delle sezioni in fig. 6). Le correlazioni stratigrafiche tra le sezioni colonnari sono correlazioni temporali basate su significativi ed improvvisi cambi dell'ambiente deposizionale e delle associazioni biotiche. 1) Marne e marne calcaree. 2) Calcari marnosi. 3) Calcareniti bioclastiche. 4) Calcareniti bioclastiche con litoclasti sovradimensionati ben arrotondati. 5) Calciruditi. 6) Superficie di erosione. 7) Disconformità principale. 8) Stratificazione incrociata a basso angolo. 9) Stratificazione incrociata concava. 10) Tracce di radici. 11) Fessure da disseccamento. 12) Calcari a calcisferulidi. 13) Heterosteginidi. 14) Accumuli di gusci di ostreidi. 15) Accumuli di gusci di cerithidi. 16) Hydrobiidi. 17) Resti di piante. 18) Resti di vertebrati. 19) Frammenti di rudiste. 20) Frammenti di coralli.*

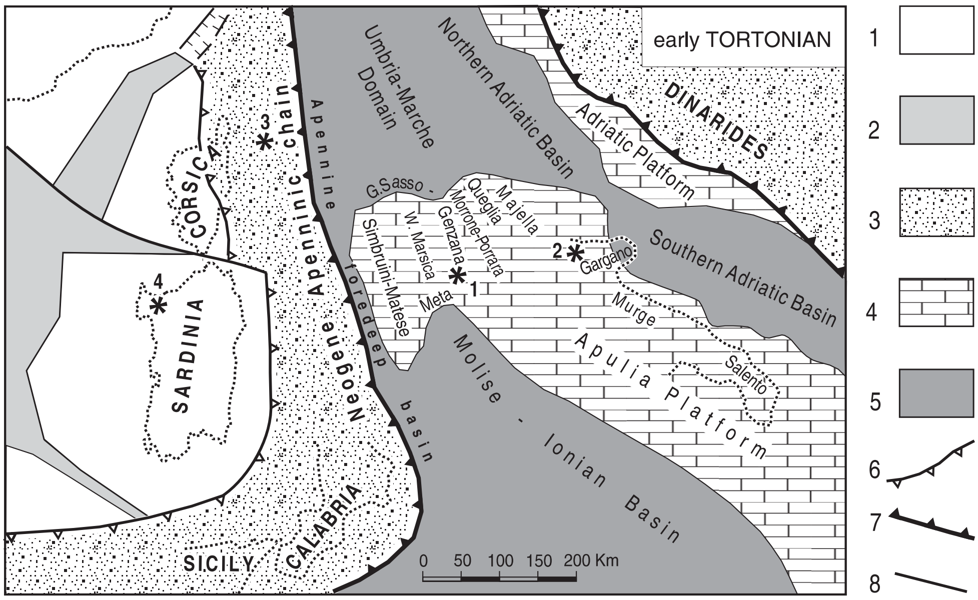


Fig. 8 - Paleogeographic reconstruction of the peri-Adriatic region in early Tortonian times. The asterisks indicate the location of the Scontrone (1), Gargano (2), Baccinello (3) and Fiume Santo (4) land-mammal fossil sites. 1) Areas of the European hinterland floored by continental crust. 2) Areas of the European hinterland floored by oceanic or thinned continental crust. 3) Thrust belts. 4) Subaerial and shallow-water areas of the Adriatic-Ionian foreland. 5) Deep-water areas of the Adriatic-Ionian foreland and foredeep basin at the front of the Apennine chain. 6) Inactive front of the Europe-verging Paleogene thrust system. 7) Active front of the Africa-verging thrust system in the Apennines and Dinarides. 8) Major strike-slip faults.
– Ricostruzione palinspastica dell'area periadriatica nel Tortoniano inferiore. Gli asterischi indicano la posizione dei giacimenti fossiliferi di Scontrone (1), del Gargano (2), di Baccinello (3) e del Fiume Santo (4). 1) Aree del retropaese europeo con crosta continentale. 2) Aree del retropaese europeo con crosta oceanica o crosta continentale assottigliata. 3) Catene montuose. 4) Aree emerse ed aree di mare basso nell'avampaese adriatico-ionico. 5) Aree di mare profondo nell'avampaese adriatico-ionico e bacino di avanfossa al fronte dell'Appennino. 6) Fronte inattivo del sistema di catena Europa-vergente. 7) Fronte attivo del sistema di catena Africa-vergente nell'Appennino e nelle Dinaridi. 8) Principali faglie trascorrenti.

Formation, respectively) that grade into Maastrichtian outer-ramp bioclastic calcarenites (Saccharoidal Limestone). The latter, in turn, are disconformably overlain by scattered remains of upper Paleocene reefal limestones (Coral-algal Limestone). Both Cretaceous and Paleocene carbonates are disconformably covered by the Miocene *Lithothamnium* Limestone. The map provides the areal extent of the lithofacies yielding the fossil vertebrates. This lithofacies is developed at the base of the *Lithothamnium* Limestone and consists of more or less rooted carbonates deposited in a tidal flat coastal environment. The bonebeds are stratigraphically sandwiched between coastal-bar litho-bioclastic calcarenites and coastal-lagoon muddy deposits rich in ostreids and cerithids. The latter

Plate 1 - Characteristic microfacies of the coastal bar deposits of the Scontrone Member (SMa facies interval in fig. 7). Fig. a. Quite well sorted, fine-grained lithobioclastic 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 on the lower right and lower left of the picture, respectively). Coastal bar. Scontrone Fossil Site stratigraphic section, facies interval SMa in fig. 7. Fig. b. Lithobioclastic packstone with abundant large-sized *Ammonia* sp. and scattered *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 bar. Scontrone North stratigraphic section, facies interval SMa in fig. 7. Fig. c. 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 bar. Scontrone Fossil Site stratigraphic section, facies interval SMa in fig. 7. Fig. d. Very well-sorted calcarenite consisting of abraded and microbored skeletal debris. A well-rounded monocrystalline detrital quartz-grain recognizable on the upper right of the picture indicates wind blown sand. Coastal bar. Scontrone South stratigraphic section, facies interval SMa in fig. 7. Fig. e. Pedogenically reworked carbonate sand at the top of coastal sandbars. Worn and microbored skeletal debris are dispersed in a dense red-brown micrite matrix showing large calcite-cemented irregular voids (alveolar texture, mostly developed on the left of the picture). Near the center, a large transverse section of a rhizocretion is lined by a micrite coat. The central void is partly filled with sparite and partly with micrite. Top of a coastal bar. Scontrone Fossil Site stratigraphic section, uppermost part of the facies interval SMa in fig. 7. Fig. f. Very fine-grained bioclastic packstone with well preserved vertebrate teeth. The teeth show the characteristic high-refringent brownish dentine surrounded by a thick ring of worn colorless enamel. Top of coastal bar. Scontrone Fossil Site stratigraphic section, top of the facies interval SMa in fig. 7.
– Microfacies caratteristiche dei depositi di barra costiera del Membro di Scontrone (intervallo SMa in fig. 7). Fig. a. Grainstone litobioclastico a grana fine, abbastanza ben classato, con clasti carbonatici sovradimensionati, ben arrotondati, immersi in un biodetrito a grana fine (in basso a destra e in basso a sinistra è possibile riconoscere rispettivamente un grosso frammento di briozoo e un piccolo esemplare di Elphidium). *Barra costiera. Sezione stratigrafica Scontrone Giacimento, intervallo SMa in fig. 7. Fig. b. Packstone litobioclastico con* Ammonia *sp. ed* Elphidium crispum. *In basso a sinistra è riconoscibile un litoclasto ben arrotondato di calcare emipelagico del Cretacico superiore riferibile alla Formazione della Scaglia. Barra sabbiosa costiera. Sezione stratigrafica Scontrone Nord, parte superiore dell'intervallo SMa in fig. 7. Fig. c. Packstone bioclastico a grana da fine a media caratterizzato dalla presenza di frammenti di gusci abrasi e microperforati. L'intenso rimaneggiamento è evidenziato dall'esemplare corroso di* Miogypsinoides *visibile al centro e da granuli fosfatici ben arrotondati visibili in alto a destra. Barra costiera. Sezione stratigrafica Scontrone Giacimento, intervallo SMa in fig. 7. Fig. d. Calcarenite ben classata costituita da resti di gusci abrasi e micritizzati. In alto a destra, un granulo fine di quarzo detritico ben arrotondato è indicativo di un trasporto ad opera del vento. Barra costiera. Sezione stratigrafica Scontrone Sud, intervallo SMa in fig. 7. Fig. e. Sabbia carbonatica rimaneggiata da processi pedogenetici alla sommità di barre costiere. Si tratta di un detrito fine di gusci corrosi e microperforati dispersi in una matrice bruno-rossastra caratterizzata da cavità irregolari riempite da calcite dovute ad attività di radici (tessitura alveolare). Al centro è ben visibile la sezione trasversale di una rizoconcrezione costituita da un involucro micritico. La cavità centrale è riempita in parte da sparite e in parte da micrite. Porzione superficiale di una barra costiera. Sezione stratigrafica Scontrone Giacimento, sommità dell'intervallo SMa in fig. 7. Fig. f. Packstone bioclastico a grana molto fine con denti di vertebrati ben preservati. I denti mostrano la caratteristica dentina bruna altamente rifrangente circondata da un anello di smalto consunto privo di colore. Sommità di una barra costiera. Sezione stratigrafica Scontrone Giacimento, parte altissima dell'intervallo SMa in fig. 7.*

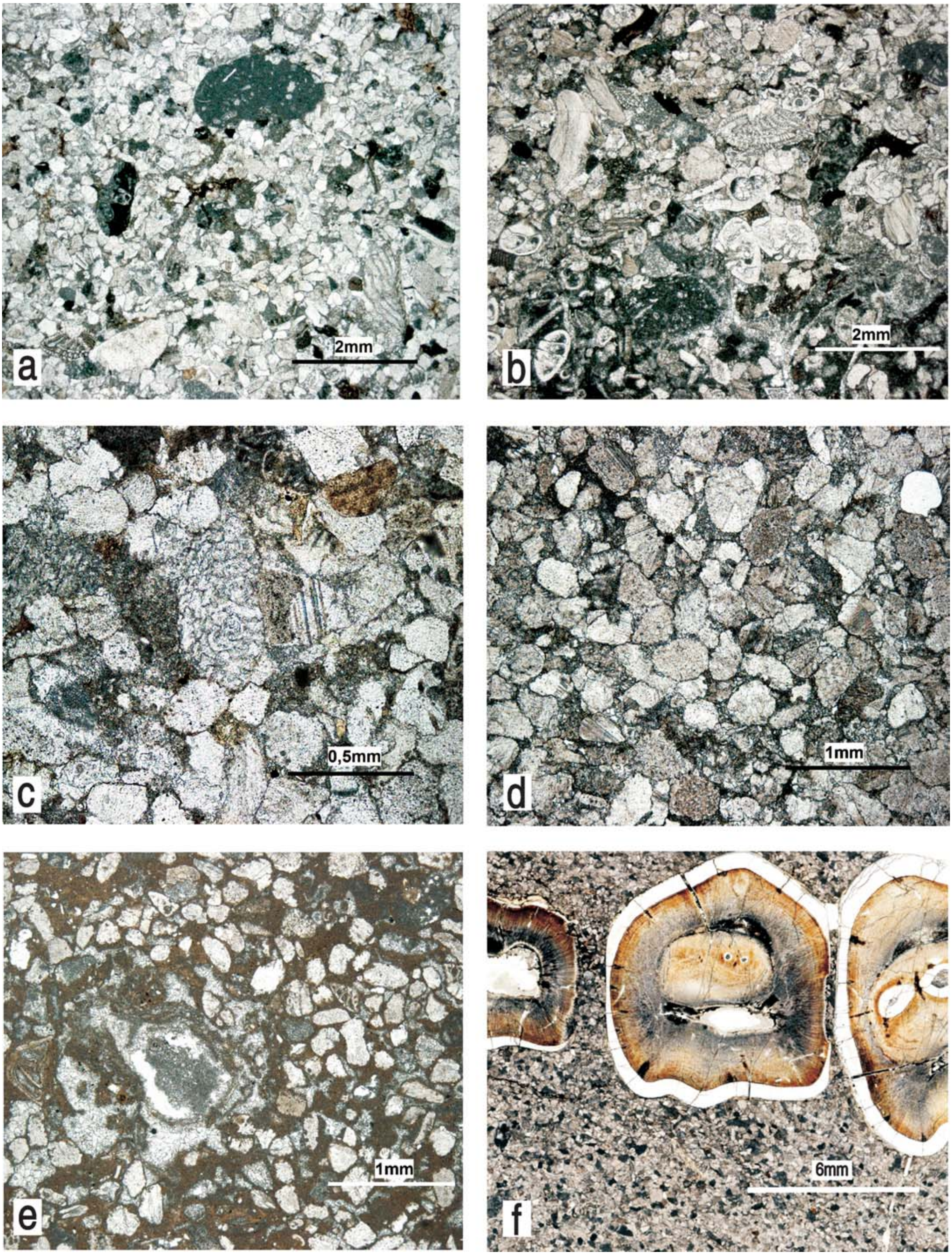


Plate 1.

are followed by barrier-bar cross-bedded calcarenites rich in large benthic foraminifers that commonly represent, in the area, a transgressive high-energy deposit at the base of rhodolith-rich facies of the *Lithothamnium* Limestone. The peritidal carbonates deposited before this high-energy transgressive episode, from the coastal-bar to the coastal-lagoon deposits, are formally named in this paper the Scontrone Member of the *Lithothamnium* Limestone Formation. The Arabic numerals in fig. 6 indicate the location of the stratigraphic sections that have been selected for illustrating the stratigraphic position of the fossil vertebrates and the depositional setting of the Scontrone Member (see fig. 7).

The exact age of the Scontrone vertebrate-bearing deposits cannot be directly established in the type locality because the fossil contents are not age-diagnostic. The common occurrence of large specimens of the long-lasting benthic foraminifer *Elphidium crispum* from the base of the Scontrone Member accounts for a generic age not older than the Miocene. However, the common regular occurrence of *Elphidium crispum* in the Miocene Mediterranean benthic associations usually starts with the middle Miocene. An early Messinian age is documented in condensed deposits rich in phosphatic coprolites and glauconite grains at the top of the *Lithothamnium* Limestone, about 15 m above the Scontrone Member. These deposits contain a benthic-foraminifer association rich in buliminids (*Bulimina, Brizalina, Rectuvigerina*) indicative of the *Bulimina echinata* Zone of COLALONGO *et alii* (1979). Moreover, hemipelagic marls directly overlying the *Lithothamnium* Limestone yielded an age-diagnostic planktonic-foraminifer association, with well preserved specimens of *Turborotalia multiloba*, indicative of a late early Messinian age (PATACCA *et alii*, 1992; CERAGIOLI *et alii*, 1996). In conclusion, the paleontological data available in the Scontrone area allowed us to constrain the age of the vertebrate bonebeds between a probable middle Miocene and the early Messinian. Additional constraints on the age of the Scontrone fossil site have been acquired taking into account and analyzing more complete sections exposed farther in the north, where the *Lithothamnium* Limestone lies with smaller temporal gaps above older, well-dated lithostratigraphic units of the Bolognano Group. The best conditions are offered by a number of sections exposed in the northern part of the Majella Mountain, in a stratigraphic sequence belonging to a tectonic unit more external than the Gran Sasso-Genzana Unit (see Majella Unit in fig. 3). In Northern Majella,

Plate 2 - Characteristic microfacies of the tidal creek and marsh deposits (SMb and SMc facies intervals in fig. 7). Fig. a. Fine-grained bioclastic packstone with large fragments of oyster shells. The pervasive boring shown by the shell fragments suggests proximity with open-marine environments where oyster parasites and predators proliferated. Oyster banks are common features along creeks dissecting tidal flats. Scontrone North Stratigraphic section, facies interval SMb in fig. 7. Fig. b. Color-mottled fine-grained calcarenite with numerous vertebrate remains. A fractured and displaced tooth and smaller bone fragments can be seen on the left of the picture. The mottled appearance of this lithofacies is related to the presence of large-sized soft clasts of pinkish to yellow, deeply rooted calcarenites and to gloebular pieces of calcareous soils dispersed in a dense dark-tan micrite matrix. The calcarenite clasts have clearly derived from root-induced brecciation and reworking of oxidized sandy intertidal deposits. Upper reach of a tidal creek. Scontrone Fossil Site stratigraphic section, facies interval SMb in fig. 7. Fig. c. Piece of gloebular soil crust showing a cluster of well-preserved root tubules in transverse sections. The tubules consist of dark dense micrite walls coated by pendulant fibrous calcite. Locally (center of the picture) the tubules are rimmed by fibers of calcite arranged in multiple concentric layers evidenced by dark inclusions. Calcite spar cement and/or dense micrite fill the tubular voids of the decayed roots. A complex network of spar-filled interlinked cavities lined by interconnective micrite walls shapes a distinctive alveolar septal texture between the rhizocretions. Fragment of a root-generated carbonate soil crust in the upper reach of a tidal creek. Scontrone Fossil Site stratigraphic section, facies interval SMb in fig. 7. Fig. d. Densely packed bioclastic muddy limestone showing intense bedding-parallel compaction and crushing of small, smooth shells of hydrobiids and of thin-walled ostracods. Low-intertidal to subtidal marsh. Scontrone North stratigraphic section, facies interval SMc in fig. 7. Fig. e. Cracked and brecciated mudstone containing sparse disarticulated ostracods (lower part of the picture). The downward oriented irregular vugs, locally geopetally filled with meteoric equant calcite and cryptocrystalline carbonate material, are interpreted as solution-enhanced root cavities. The rooted ostracod-bearing limestone is overlain by a barren tan-stained pedogenic micrite showing a complex cracking pattern. The pedogenic micrite contains scattered small clasts reworked from the underlying ostracod-bearing limestone. High-intertidal to supratidal marsh. Scontrone North stratigraphic section, top of the facies interval SMc in fig. 7. Fig. f. Soil crust characterized by a distinct alveolar structure generated by root penetration and cementation. The complex network of irregular voids, typically lined by a rim of dark micrite, is partly filled with meteoric blocky calcite cements and partly with microsparite. The sand-sized material, mostly represented by worn marine skeletal debris, indicates sporadic storm accumulation in a protected muddy coastal wetland characterized by a dense vegetation. High-intertidal to supratidal marsh. Scontrone Fossil Site, facies interval SMc in fig. 7.

– Microfacies caratteristiche dei depositi di canale tidale e di palude del Membro di Scontrone (intervalli SMb e SMc in fig. 7). Fig. a. Lumachella costituita da un packstone bioclastico a grana fine con frammenti di gusci di ostree intensamente perforati. L'alto grado di perforazione dei gusci suggerisce prossimità ad ambienti di mare aperto generalmente caratterizzati da alti tassi di parassitismo e predazione. Banco ad ostree accumulato ai bordi di un canale tidale. Sezione stratigrafica Scontrone Nord, intervallo SMb in fig. 7. Fig. b. Calcarenite a grana fine con numerosi resti di vertebrati (dente in alto a sinistra, frammenti di ossa più in basso). La tessitura disomogenea di questa litofacies è dovuta alla presenza di frammenti non del tutto litificati di calcareniti intertidali e di suoli calcarei dispersi in una matrice micritica più scura. Limite superiore di un canale tidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMb in fig. 7. Fig. c. Frammento di suolo calcareo costituito da un aggregato di tubuli radicali ben preservati. I tubuli (in sezione trasversale) sono costituiti da un bordo di micrite scura ricoperta da calcite fibrosa, localmente disposta in strati multipli concentrici evidenziati da inclusioni scure (centro della foto). Un complesso reticolo di cavità intercomunicanti orlate da micrite e riempite da cemento spatico disegna la struttura alveolare caratteristica delle rizoconcrezioni. Frammento di suolo calcareo legato all'attività di radici di piante nella parte superiore di un canale tidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMb in fig. 7. Fig. d. Lumachella con gusci di gasteropodi compressi e fratturati. La foto mostra piccoli gasteropodi a guscio liscio riferibili al gruppo degli idrobiidi e ostracodi a guscio liscio. Palude da subtidale a basso intertidale. Sezione stratigrafica Scontrone Nord, intervallo SMc in fig. 7. Fig. e. Mudstone ad ostracodi con cavità verticali irregolari prodotte da radici e successivamente allargate da processi di dissoluzione. Le cavità sono riempite geopetalmente da materiale carbonatico criptocristallino e da calcite romboedrica di origine meteorica. Il mudstone ad ostracodi è sormontato da una crosta calcarea di color marrone, ad andamento irregolare, che mostra un complesso reticolo di fessure. Questa crosta calcarea contiene piccoli clasti sparsi derivanti dal rimaneggiamento del sottostante mudstone ad ostracodi. Ambiente palustre da alto intertidale a sopratidale. Sezione stratigrafica Scontrone Nord, sommità dell'intervallo SMc in fig. 7. Fig. f. Suolo calcareo mostrante la caratteristica struttura alveolare legata all'attività biologica delle piante (penetrazione da parte delle radici e cementazione). Questa struttura è resa riconoscibile dal complesso reticolo di cavità irregolari marcati da bordo micritico, successivamente riempiti in parte da calcite meteorica a tessitura pavimentosa e in parte da microsparite. I granuli carbonatici di dimensioni arenitiche, sopratutto frammenti bioclastici usurati, indicano sporadici accumuli da tempesta in un ambiente fangoso protetto caratterizzato da alta densità di vegetazione. Ambiente palustre da intertidale a sopratidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7.

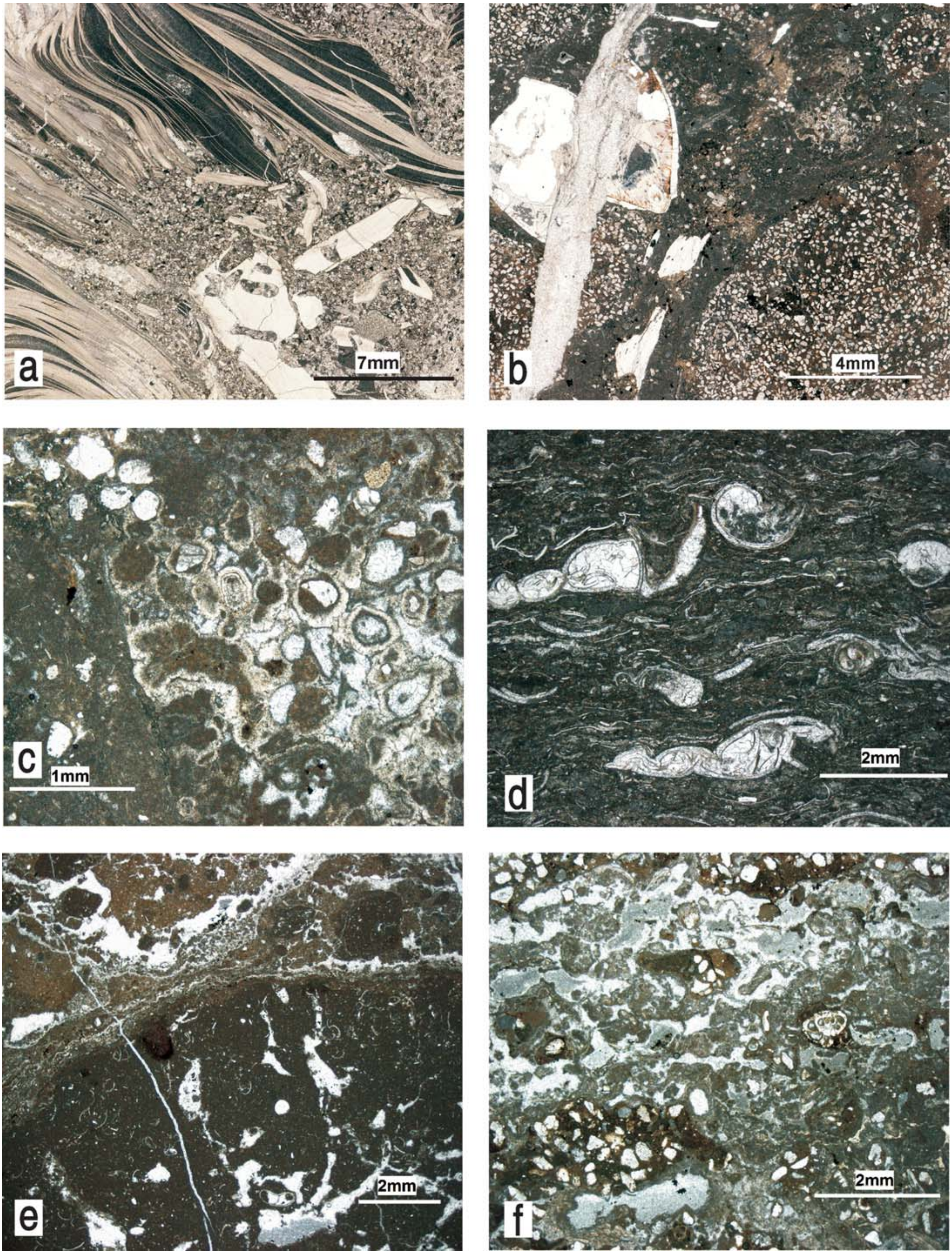


Plate 2.

where the type locality of the Bolognano Group is, a quite complete stratigraphic section of Miocene deposits has long been described (e.g. LOTTI, 1925; PRINCIPI, 1938). In this area the *Lithothamnium* Limestone lies in relative conformity over middle/upper Miocene hemipelagic marly limestones (*Orbulina* Limestone Formation) rich in planktonic foraminifers. On the basis of micropaleontological investigations, the lower portion of the *Lithothamnium* Limestone was attributed to the Tortonian in the early sixties by DI NAPOLI ALLIATA (1964). More recent detailed biostratigraphic analyses carried out in the same area (MEROLA, 2007), confirm this chronological attribution: the base of the *Lithothamnium* Limestone has a Tortonian age not older than the N16 Zone, as established by the identification of the First Regular Occurrence of *Neogloboquadrina acostaensis* in the upper portion of the underlying *Orbulina* Limestone (about 15 m beneath the base of the *Lithothamnium* Limestone). This bioevent has been astronomically dated at 10.554 Ma (HILGEN *et alii*, 2005 and references therein). It follows that the basal portion of the *Lithothamnium* Limestone and consequently the entire vertebrate-bearing Scontrone Member are surely Tortonian and date back at about 10 Ma.

2. THE SCONTRONE MEMBER OF THE *LITHOTHAMNIUM* LIMESTONE

The Scontrone Member of the *Lithothamnium* Limestone was deposited in the inner portion of a wide carbonate homoclinal ramp that in Tortonian time constituted the foreland of the middle-upper Miocene Apennine mountain chain. The ramp included the not yet deformed Scontrone, Morrone-Porrara, Queglia, Majella and Gargano-Murge-Salento depositional domains (see fig. 8). The inboard zone of this carbonate ramp possibly measured thousands of square kilometres in size and had to reach trophic resource levels sufficient for enabling the development and endemization of the terrestrial vertebrates. The Scontrone Member represents the remainder of a tide-influenced coastal deposit widespread over the inner portion of the homoclinal ramp. It is overlain by marine offshore bars, a higher-energy lithofacies that usually constitutes in Abruzzi the transgressive basal portion of the *Lithothamnium* Limestone forming a widespread and quite uniform calcareous sand sheet directly above the Cretaceous substrate. An important ravinement surface at the base of this generalized transgressive episode accounts for the almost complete removal of the peritidal carbonates of the Scontrone Member.

A detailed stratigraphic and sedimentological analysis of the Scontrone Member allowed us to identify a second-order short-lived episode of coastal progradation in the overall deepening-upward sequence of the Scontrone Member (coastal-tidal-flat deposits evolving upwards into subtidal-lagoon deposits). This episode of coastal progradation is clearly related to a temporary increase in the sediment supply determined by a landward transport and inward accumulation of nearshore sediments swept by strong tidal currents. In modern low-gradient seaward-sloping coastal flats with weak subsidence, absence of alluvial drainage systems and negligible fresh-water input

Plate 3 - Characteristic microfacies of the marsh deposits of the Scontrone Member (SMc facies interval in fig. 7). Fig. a. Dark nodular mudstone showing a characteristic reticulate fabric produced by root activity (crescentic to circular spar-filled veins) and syneresis. A well preserved root cast is evident in the upper left corner of the picture, outlined by a spar-filled circumgranular crack. High intertidal to supratidal marsh. Scontrone Fossil Site stratigraphic section, facies interval SMc in fig. 7. Fig. b. Thinly laminated dark brown to pale yellow mudstone. The laminar structure, locally clearly crinkled, is related to alternating lighter laminae of calcified root mat and darker laminae of microbial mat. The former (upper side) consist of irregular spar/microspar-filled voids lined by concentric micrite; the latter (lower side) 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, facies interval SMc in fig. 7. Fig. c. Detail of a calcified root mat showing transverse (center of the picture) and oblique sections of root moulds filled with sparry calcite or microspars. A geopetally-filled void of decayed root can be seen in the center of the picture. The root casts are evidenced by an external coat of dark micrite. Supratidal marsh. Scontrone Fossil Site stratigraphic section, facies interval SMc in fig. 7. Fig. d. Intracellularly calcified root still retaining quite well preserved and recognizable anatomical features. The dark central hollow filled with micrite corresponds to the vascular cylinder. Epidermis 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 stratigraphic section, facies interval SMc in fig. 7. Fig. e. Detail of a root petrifaction showing transverse (lower left corner) and oblique sections of roots with a perfectly preserved cellular structure. The calcified cortical cells are recognizable by their typical isodiameter monocrystalline structure and their cloudy yellow appearance. Supratidal marsh. Scontrone Fossil Site stratigraphic section, facies interval SMc in fig. 7. Fig. f. Color-mottled (yellow to brownish green) ostracod-bearing mudstone with a flushed bone fragment still recognizable by the Havers structure. Tidal marsh. Scontrone Fossil Site stratigraphic section, facies interval SMc in fig. 7.

– Microfacies caratteristiche dei depositi palustri del Membro di Scontrone (intervallo di facies SMc in fig. 7). Fig. a. Mudstone nodulare scuro mostrante il caratteristico reticolato prodotto da attività di radici (fessure circolari o semicircolari riempite da sparite) e da sineresi. Nell'angolo in alto a sinistra della foto è visibile una crepa di forma circolare riempita da calcite prodotta da radici. Ambiente palustre da intertidale a sopratidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7. Fig. b. Mudstone bruno con sottili lamine giallastre. La struttura laminare è data dall'alternanza di lamine giallastre prodotte da tappeti radicali calcificati e lamine brune legate alla presenza di tappeti microalgali. I primi sono evidenziati da cavità irregolari marcate da micrite concentrica e riempite da cemento spatico e da microsparite; i secondi sono rappresentati da letti discontinui di micrite peloidica. Crosta calcarea pedogenetica legata ad un suolo idromorfico. Ambiente palustre sopratidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7. Fig. c. Dettaglio di un tappeto di radici calcificate mostrante diverse sezioni di cavità di radici riempite da sparite o microsparite. Nel centro della foto è visibile la sezione trasversale di una cavità riempita geopetalmente. I calchi delle radici sono messi in evidenza da un rivestimento di micrite scura. Ambiente palustre sopratidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7. Fig. d. Radice calcificata con caratteri anatomici ancora ben preservati e riconoscibili. La cavità centrale scura, riempita da micrite, corrisponde al cilindro vascolare. Le cellule epidermali e corticali appaiono interamente sostituite da singoli cristalli di calcite che mostrano, a nicols incrociati, estinzione uniforme od ondulata. Tappeto di radici calcificate. Ambiente palustre sopratidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7. Fig. e. Dettagli di una sezione trasversale e di sezioni oblique di radici calcificate con struttura cellulare ben preservata. Le cellule corticali calcificate sono rese riconoscibili dalla loro struttura monocristallina equidimensionale e dal loro colore giallastro. Ambiente palustre sopratidale. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7. Fig. f. Mudstone ad ostracodi con un piccolo frammento di osso reso ancora riconoscibile dalla presenza dei canali di Havers. Il colore disomogeneo di questo deposito, da giallastro a bruno-verdastro, è imputabile ad una discreta bioturbazione del sedimento. Ambiente palustre. Sezione stratigrafica Scontrone Giacimento, intervallo SMc in fig. 7.

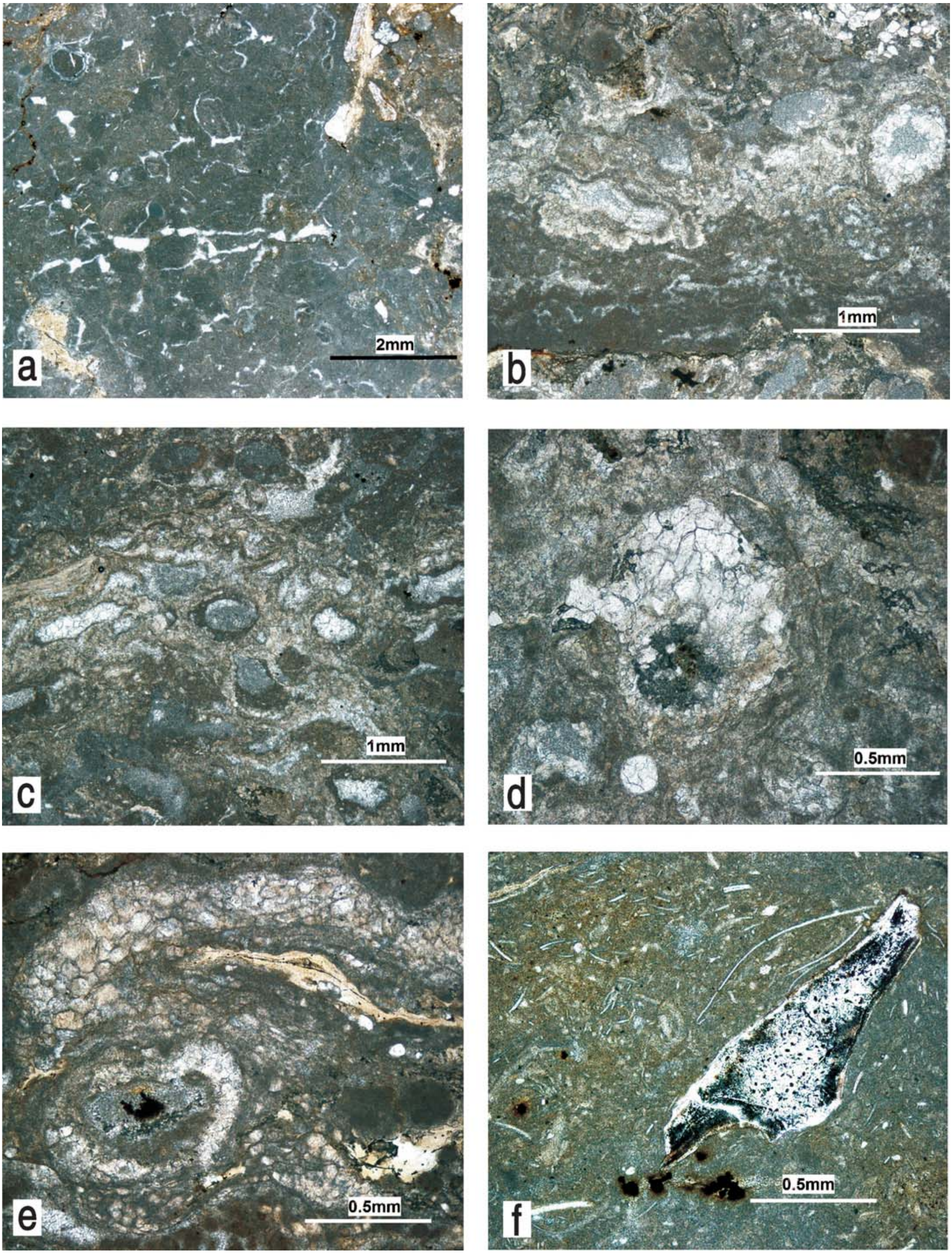


Plate 3.

(as expected in the Apennine Tortonian foreland carbonate ramp) such flooding processes induce a rapid expansion of the intertidal flat and a consequent seaward translation of the subtidal channels and surrounding subenvironments. The depositional events between the basal transgression and the ravinement upper surface are very well recorded in sections where the Scontrone Member reaches its maximum thickness (8-10 meters). In the most favorable cases, five facies intervals have been distinguished (SMa-SMe intervals in fig. 7). The identification of these intervals, based on major shifts in the depositional settings and on concomitant changes in the biotic associations, has provided a very useful tool for high-resolution correlations between the stratigraphic sections surveyed in the Scontrone area. In the following pages, we shall provide a brief description of the lithofacies characterizing the different intervals in some selected sections (Scontrone North, Scontrone Fossil Site and Scontrone South stratigraphic sections in figs. 6 and 7). The Scontrone Cemetery section exemplifies the most common case in which the lack of the Scontrone Member at the base of the *Lithothamnium* Limestone is related to the precence of a ravinement surface. Actually, peritidal deposits at the base of the *Lithothamnium* Limestone are unusual in the Central Apennines since they have been recognized only in the Scontrone area and along the eastern flank of the Majella anticline in a small outcrop sandwiched between the *Orbulina* Limestone and the overlying *Lithothamnium* Limestone. The Scontrone fossil fauna represents an isolated case of land-vertebrate finding related to the unusual presence of low-energy tidal flat deposits, rarely preserved at the base of the higher-energy transgressive Miocene deposits of the Central Apennines. Tidal flats are environments in which favourable conditions of life match up with optimal conditions for fossilization. The vertebrate remains of Scontrone have been recovered in sediments characterized by a depositional setting comparable with the modern tidal wetlands, which are among the most productive and biologically-rich ecosystems. The maximum fossil concentration has been found in tidal creek deposits. In modern coastal flat environments, tidal creeks represent efficient waterways where the intermittent flooding induced by high tidal exchanges allows flushing and considerable biotic accumulation over the flanking areas. In the case of Scontrone, a rapid burial below oxygen-depleted marsh deposits and the subsequent sealing by shaly lagoon deposits provided optimum conditions for preservation and fossilization.

2.1. The coastal tidal flat

The lower portion of the Scontrone Member is everywhere represented by fine-grained calcarenites showing quite good winnowing and locally well-preserved low-angle cross bedding (SMa facies interval in fig. 7). This grainy lithofacies, representative of mainland beach ridges accumulated during the initial transgression of the Miocene deposits, shows at the top evidence of subaerial exposure. In the Scontrone North and Scontrone Fossil Site sections, the relatively high-energy granular carbonates are substituted upward by intertidal-supratidal muddier deposits (SMb and SMc facies intervals in fig. 7). The latter are replaced, moving towards the Scontrone South section, by a dark-stained, fine-grained calcarenite showing a fossilized deep root penetration. In the Scontrone fossil site, the bulk of the vertebrates are embedded in

Plate 4 - Characteristic microfacies of the tidal flat and lagoon deposits of the Scontrone Member (SMb-SMd facies intervals in fig. 7). Fig. a. Fine to very fine-grained, well-sorted bioclastic calcarenite consisting of well-rounded abraded shell fragments and sparse comminuted vertebrate remains (pale-brown grains). The size and sorting of the framework grains, the lack of any coarser material and the concomitant absence of autochthonous marine shells point to a wind-blown deposit. This calcarenite is characterized by root-induced borings filled with black organic material. Rooted sand sheet accumulated by storm in a supratidal marsh. Scontrone South stratigraphic section, heteropic facies of the SMb and SMc intervals in fig. 7. Fig. b. Bioclastic packstone with crushed cerithids, large-sized *Ammonia*, ostracods and subordinate oyster shell fragments. Storm layer accumulated in a coastal lagoon. Scontrone North stratigraphic section, facies interval SMd in fig. 7. Fig. c. Bioclastic wackestone with a flattened and crushed specimen of gastropod filled with biodetritus and problematic microspherules. These microfossils, recognizable by a dark central hole, appear also dispersed in the brown-colored marly matrix, associated with mollusk fragments, small rounded calcareous lithoclasts and micritized bioclasts. Marly deposit in a coastal lagoon with dysaerobic bottom-water conditions. Scontrone North stratigraphic section, base of the SMd interval in fig. 7. Fig. d-f. Enlarged views of the bioclastic wackestone of fig. c. The pictures show deeply micritized bioclasts and spherical to ovoidal problematic microfossils likely representing calcareous resting cysts of algae or calcitized sporomorphs. These calcitic bodies display a thick calcareous wall made up of welded microspheres of radially arranged fibrous calcite separated by darker subtle sutures (figs. d-e), by an external brown-stained organic coat (fig. e) and by a large central cavity filled by dark micrite, microspar or sparry cement. A cracked algal cyst (?) with its dark-stained organic coat, is clearly visible in the left side of fig. f. Also clearly evident in the same figure are the radially arranged aggregates of calcite fibers making up the thick calcareous wall of these microorganisms (transverse and oblique sections in the center of the picture). Marly deposit in a restricted coastal lagoon with dysaerobic conditions. Scontrone South stratigraphic section, base of the facies interval SMd in fig. 7.
– *Microfacies caratteristiche dei depositi tidali e lagunari del Membro di Scontrone (intervalli di facies SMb-SMd in fig. 7). Fig. a. Calcarenite bioclastica a granulometria da fine a molto fine, ben classata, costituita da frammenti conchigliari molto ben arrotondati ed abrasi, nonché da frammenti di vertebrati (piccoli granuli di color marrone). La granulometria e la classazione del sedimento, la totale mancanza di clasti più grossolani e l'assenza di fossili marini suggeriscono un trasporto ad opera del vento. La calcarenite mostra anche microperforazioni riempite da materiale bituminoso legate all'attività di radici. Deposito da tempesta in un ambiente palustre. Sezione stratigrafica Scontrone Sud, facies eteropica degli intervalli SMb e SMc nella fig. 7. Fig. b. Lumachella a cerizi con grossi esemplari di* Ammonia, *ostracodi e gusci frammentati di ostree. Deposito di tempesta in una laguna costiera. Sezione stratigrafica Scontrone Nord, intervallo SMd in fig. 7. Fig. c. Marna calcarea scura con un esemplare di gasteropode deformato e riempito da microsfere calcaree di origine incerta. Questi microfossili, riconoscibili per avere una cavità centrale più scura, appaiono anche dispersi nel sedimento marnoso circostante, associati a frammenti di molluschi, litoclasti calcarei arrotondati e bioclasti micritizzati. Deposito marnoso scuro di ambiente lagunare. Sezione stratigrafica Scontrone Sud, base dell'intervallo SMd nella fig. 7. Fig. d-f. Dettaglio del wackestone bioclastico di fig. c. Le foto mostrano bioclasti fortemente micritizzati associati alle microsfere di origine incerta, forse attribuibili a cisti algali o a spore calcitizzate. Questi microfossili, di forma variabile da sferica a leggermente ovoidale, presentano una parete calcarea spessa, costituita da piccole microsfere saldate fra loro, appena individuabili dalle sottili linee suturali. Le cisti algali (?) presentano un evidente rivestimento organico bruno scuro e un'ampia cavità centrale riempita da fango micritico scuro, spesso ricristallizzato in microsparite, o da cemento di calcite a struttura pavimentosa. In fig. f è visibile a sinistra una ciste algale (?) in fase di apertura e alcune sezioni di questi organismi problematici con le pareti calcaree costituite da fibre di calcite disposte radialmente e con un rivestimento organico più esterno di colore bruno. Deposito marnoso scuro di ambiente lagunare. Sezione stratigrafica Scontrone Sud, base dell'intervallo SMd nella fig. 7.*

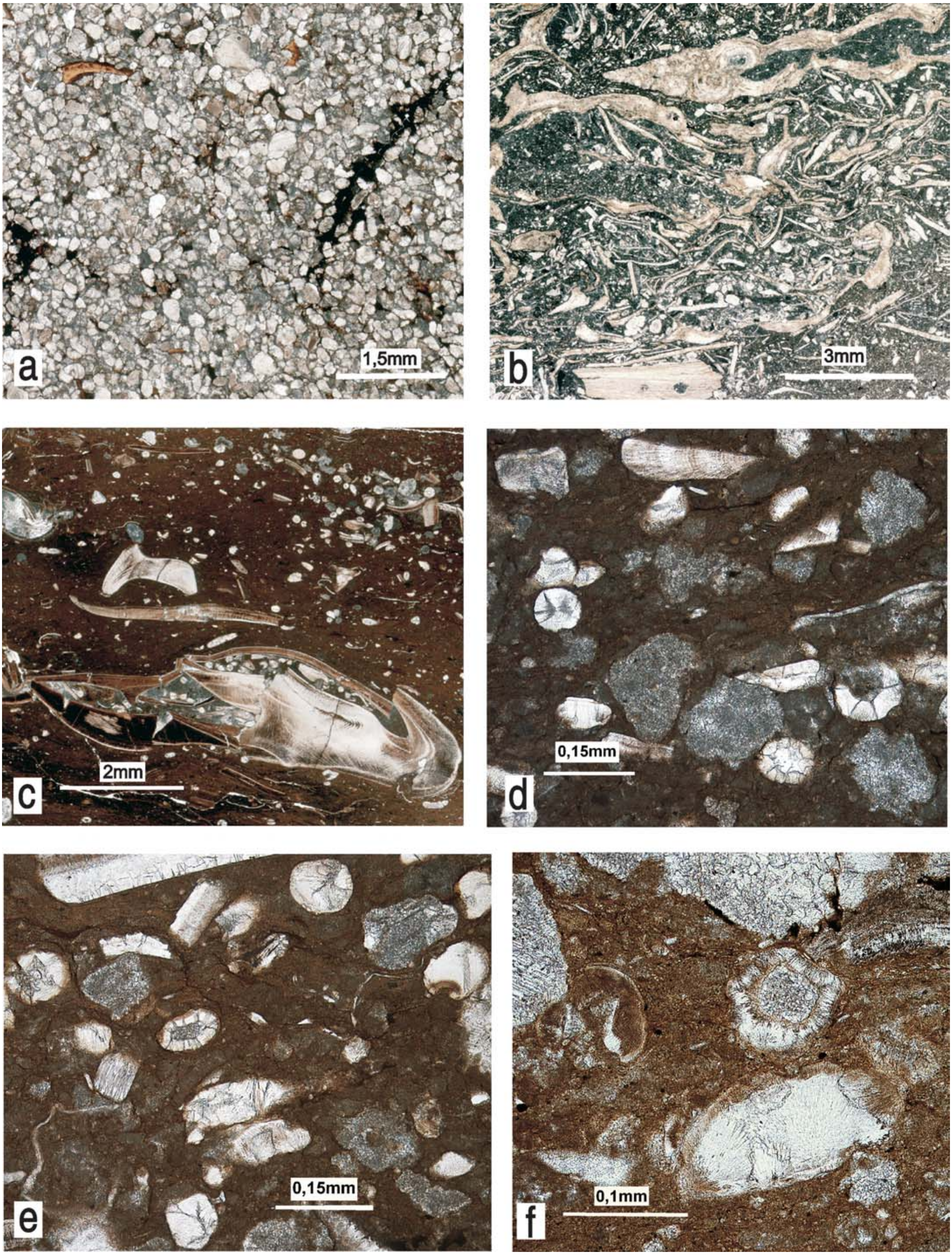


Plate 4.

tidal creek deposits belonging to the SMb facies interval. Scarce and badly preserved vertebrate remains have also been recovered at the top of the underlying carbonate coastal bars (SMa facies interval) and in the overlying marsh deposits (SMc facies interval). The latter testify to a deposition under humid climate conditions.

Coastal bars (SMa facies interval)

The SMa facies interval is represented by 2-3 m of off-white to buff litho-bioclastic calcarenites interpreted as high-energy sandbars encroaching a well-lithified older substrate. The microfacies is represented by highly bioturbated, fine to medium-grained litho-bioclastic grainstones/packstones with abundant large-sized *Ammonia* sp. and scattered specimens of *Elphidium crispum*. Glauconite grains, fish scales, echinoderm and oyster debris, as well as fragments of barnacles, are quite frequent components. The *Ammonia-Elphidium* association indicates near-shore setting and clean hard substrate. The common occurrence through the interval of very well-rounded and frequently bored oversized lithoclasts derived from older carbonates (plate 1, figs. a-c), together with deeply abraded and micritized skeletal fragments (the latter including Paleogene-early Neogene large foraminifers) indicates a strong subaerial erosion and an intense physical reworking and winnowing. The youngest abraded skeletal fragments recovered in the sandbars, i.e. worn *Miogypsinoides* (large benthic foraminifer ranging in age from the latemost Oligocene to the earliest Miocene) shown in plate 1, fig. c, suggests that the area was exposed starting from the earliest Miocene. Well-rounded, fine-grained quartz grains scattered in very well-sorted bioclastic calcarenites (plate 1, fig. d) indicate sporadic episodes of wind transport. North of Scontrone village, the basal calcarenites of the SMa facies interval overlie upper Albian-lowermost Turonian slope-apron detrital limestones. South of Scontrone, the same litho-bioclastic calcarenites, with unchanged facies, biotic content and thickness, overlie Neocomian platform-edge carbonates referable to the upper portion of the Terratta Formation.

The top of the calcareous sandbars is everywhere capped by a thin layer (20-25 cm) of very fine-grained rooted calcarenite (plate 1, fig. e), typically yellow to pinkish in color, rich in very well-rounded comminuted fragments of bones. The framework grains consist of fine-grained, well-sorted and well-rounded, wind-blown (?) calcareous skeletal fragments frequently bored and lined by a FeO rim. This calcarenite horizon contains sparse large-sized vertebrate remains (lower bonebed in fig. 7, see plate 1, fig. f). Southwest of the village of Scontrone, the SMa coastal bars pass laterally to a «terra-rossa» soil that directly covers the lower Cretaceous limestones of the Terratta Formation. The red soil, containing large-sized FeO-rich pisoids, suggests a long-lasting subaerial exposure. This layer is abruptly overlain by dark muddy deposits indicative of dysaerobic conditions in wetland areas.

Tidal creeks (SMb facies interval)

The coastal bar calcarenites are followed by about 2 m of very coarse-grained fining-up pebbly calcarenites organized into two beds ending with cross-bedded oyster lumachellas. This deposit, well exposed along the Sangro gorge and characterized by a rapid lateral pinch-out, has been interpreted as a blanket of migrating tidal-creek deposits developed in a low-gradient seaward-sloping coastal flat. In the Scontrone North and Scontrone Fossil Site stratigraphic sections, only the marginal facies of the tidal creek carbonates crop out. In the Scontrone North section, in fact, the coastal bar calcarenites are followed by about 1 m of gray oyster-rich calcarenites forming a sort of bank of disarticulated, overturned and deeply

Plate 5 - Characteristic microfacies of the lagoon and tidal flat deposits of the Scontrone Member (SMd and SMe facies intervals in fig. 7). Figs. a-b. Algal cysts (?) with different arrangements of minute spheres (serially arranged in fig. a, spherically arranged in fig. b) clearly recognizable by their delicate structure of calcite fibers radiating from a central brown-stained hole. An external brownish coat of organic matter is also visible. Marly deposit in a restricted coastal lagoon. Scontrone South stratigraphic section, base of the facies interval SMd in fig. 7. Fig. c. Dark porous calcisiltite with a thin discontinuous layer of cerithid shell fragments. The unusual clotted fabric of the calcisiltite is related to a dense aggregate of calcareous microspheres (details in figs. d and e). The abundance of these spherical microorganisms (calcispheres) in this layer may be related to a phytoplankton bloom in waters with a high level of eutrophication. Restricted coastal lagoon. Scontrone South stratigraphic section, lower portion of the facies interval SMd in fig. 7. Figs. d-e. Detail at higher magnification of the calcispherulid aggregates in fig. c. Single and clustered calcispheres, frequently displaying multiple overgrowths, testify to several growth generations and to a complex multi-stage process of calcification. The greatest part of the calcispheres shows concentric lobate layers of botryoidal fibrous calcite (former aragonite or high-Mg calcite) radiating from a central hole featured by isopachous thin calcite rings (fig. e). The sparry cement, revealed by evident interference growth boundaries enhanced by later dark solution seams, and the dense packing of the calcispheres are indicative of their in-situ accumulation. Restricted coastal lagoon deposit. Scontrone South stratigraphic section, lower portion of the facies interval SMd in fig. 7. Fig. f. Recrystallized litho-bioclastic packstone with *Ammonia* (equatorial section in the upper left corner) and *Elphidium* (right of the benthic foraminifer in the center of the picture). The picture also shows a very well-rounded oversized lithoclast derived from the erosion of well-lithified older carbonates and from the successive reworking in a high-energy contiguous environment. Tidal channel deposit. Scontrone North stratigraphic section, SMe facies interval in fig. 7.

– *Microfacies caratteristiche dei depositi lagunari e dei canali tidali del Membro di Scontrone (intervalli di facies SMd-SMe in fig. 7). Figg. a-b. Cisti algali (?) costituite da diversi tipi di impalcature di piccole sfere, ben riconoscibili dalle delicate fibre di calcite a disposizione radiale. In tutte è ben visibile un rivestimento organico marrone. Deposito marnoso scuro di laguna costiera. Sezione stratigrafica Scontrone Sud, base dell'intervallo SMd nella fig. 7. Fig. c. Calcisiltite scura, porosa, con frammenti di gusci di cerizi accumulati da tempesta. La facies è caratterizzata da un aggregato di microsfere calcaree (si veda il dettaglio in fig. e). L'abbondanza di questi microrganismi sferici (calcisfere) in certi livelli può essere messa in relazione ad improvvise fioriture di fitoplancton in acque con alto grado di eutrofizzazione. Deposito di laguna costiera non ben ossigenata. Sezione stratigrafica Scontrone Sud, parte bassa dell'intervallo SMd nella fig. 7. Figg. d-e. Dettaglio a più alto ingrandimento della fig. c. Le calcisfere, singole o riunite a grappoli, mostrano strati multipli di rivestimento testimonianti numerosi stadi di accrescimento e calcitizzazione. La gran parte delle calcisfere mostra involucri esterni lobati di calcite fibrosa (originariamente aragonite o calcite alto-magnesiaca) che si irradiano da una cavità centrale messa in evidenza da rivestimenti più sottili di calcite (fig. e). La tessitura compatta del sedimento e la presenza di cemento, rivelato dalle strutture di interferenza nella crescita della calcite, testimoniano un accumulo in situ delle calcisfere. Deposito di laguna costiera non ben ossigenata. Sezione stratigrafica Scontrone Sud, parte bassa dell'intervallo SMd nella fig. 7. Fig. f. Calcarenite litobioclastica ricristallizzata con* Ammonia *(una sezione equatoriale è visibile nell'angolo in alto a sinistra) ed* Elphidium *(in alto a destra del foraminifero bentonico porcellanaceo al centro della foto) associati a litoclasti calcarei ben arrotondati, provenienti da un ambiente limitrofo di alta energia, probabilmente di spiaggia. Deposito di canale tidale. Sezione stratigrafica Scontrone Nord, intervallo SMe nella fig. 7.*

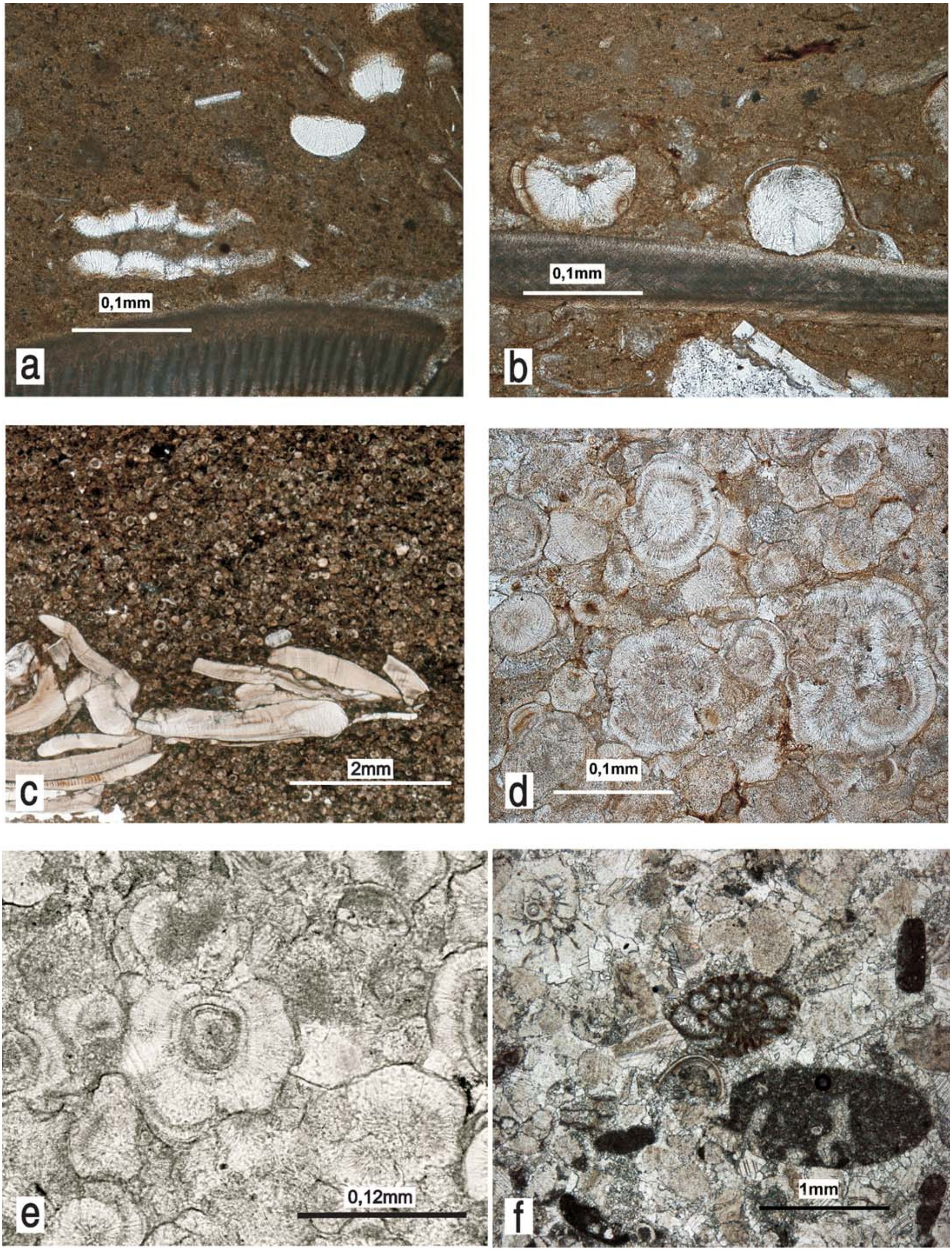


Plate 5.

bored shells (plate 2, fig. a) identical to the lumachellas developed in the Sangro gorge at the top of the pebbly channel deposits. At the fossil site, this unit is represented by 20-25 cm of a yellow-pinkish pebble calcarenite with characteristic nodular or mottled appearance. This layer typically contains rooted soft-clasts derived from FeO-stained high-intertidal sandy deposits (plate 2, fig. b), as well as pieces of soil crusts (plate 2, fig. c) dispersed in an ostracod-bearing dark muddy matrix. This deposit, representative of the upper reach of a tidal creek, forms the principal bonebed from which the bulk of the vertebrates derive. It yielded abundant and well preserved fragments of bones and of marsh-turtle carapaces together with isolated teeth of artiodactyls and crocodiles. The SMb facies interval is laterally substituted, south of the Scontrone village, by a soil profile in which a deep root penetration marks the top of the underlying calcareous coastal bars (see Scontrone South stratigraphic section in fig. 7).

In modern tide-influenced settings, oyster accumulation is typically linked to tidal creek systems. In such environments oyster banks develop in the high-energy side of the creeks. A fringe of dead oyster shell banks often separates the marsh from the main channel. This oyster accumulation, dissipating wave energy, acts as a protective barrier for the marsh. Being the oyster suspension feeders, they require quite strong water currents able to transport the organic detritus that is their primary food source. In modern coastal wetlands, normal salinity conditions (such as conditions developed in proximity of open-marine settings, dominated by diverse mollusk faunas), together with the lack of significant fresh water discharge, determine an increase in the oyster predation and parasitism activity (Meeder *et alii* 2001 and references therein). The winnowing of strong currents generated by ebb and flood tides in self-sustaining drainage channels of tidal creeks, therefore, 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 of dense vertebrate teeth.

Tidal marsh (SMc facies interval)

In the Scontrone North Section, intertidal marsh deposits are represented by about 2 m of gray marly limestones and marls rich in gastropods (mostly cerithids and hydrobiids, see plate 2, fig. d), ostracods and numerous charophyte gyrogonites. Small planar fenestrae and desiccation cracks are quite common features. In the middle portion and at the top of the interval, quite important episodes of subaerial exposure are attested by rooted limestones and pedogenic crusts (plate 2, fig. e).

At the fossil site, the SMc facies interval is represented by about 20 cm of crudely laminated dark mudstone showing discontinuous millimetric intercalations of pink to yellow fine-grained calcarenite. The yellowish calcarenite laminae, consisting of very well-sorted, abraded and FeO-stained marine skeletal grains (small bryozoan fragments, scattered planktonic foraminifers, small *Elphidium* and *Ammonia*), are related to episodic land-directed storms flushing protected inward muddy settings. Towards the top of the interval, the pink/yellow laminae, crinkled and disrupted by root activity, form a sort of «flake breccia» characterized by flattened, irregular soft intraclasts (plate 2, fig. f). The dark mudstone, characterized by a brown to green mottled appearance, shows at high magnification syneresis structures associated with well preserved calcified roots and with thin, discontinuous microbial mats (plate 3, figs. a-e). Processes causing root calcification of terrestrial plants on carbonate substrates are extensively described in Košir (2004).The marsh deposit contains quite numerous bone lags (plate 3, fig. f) poorly preserved compared with those present in the underlying deposit.

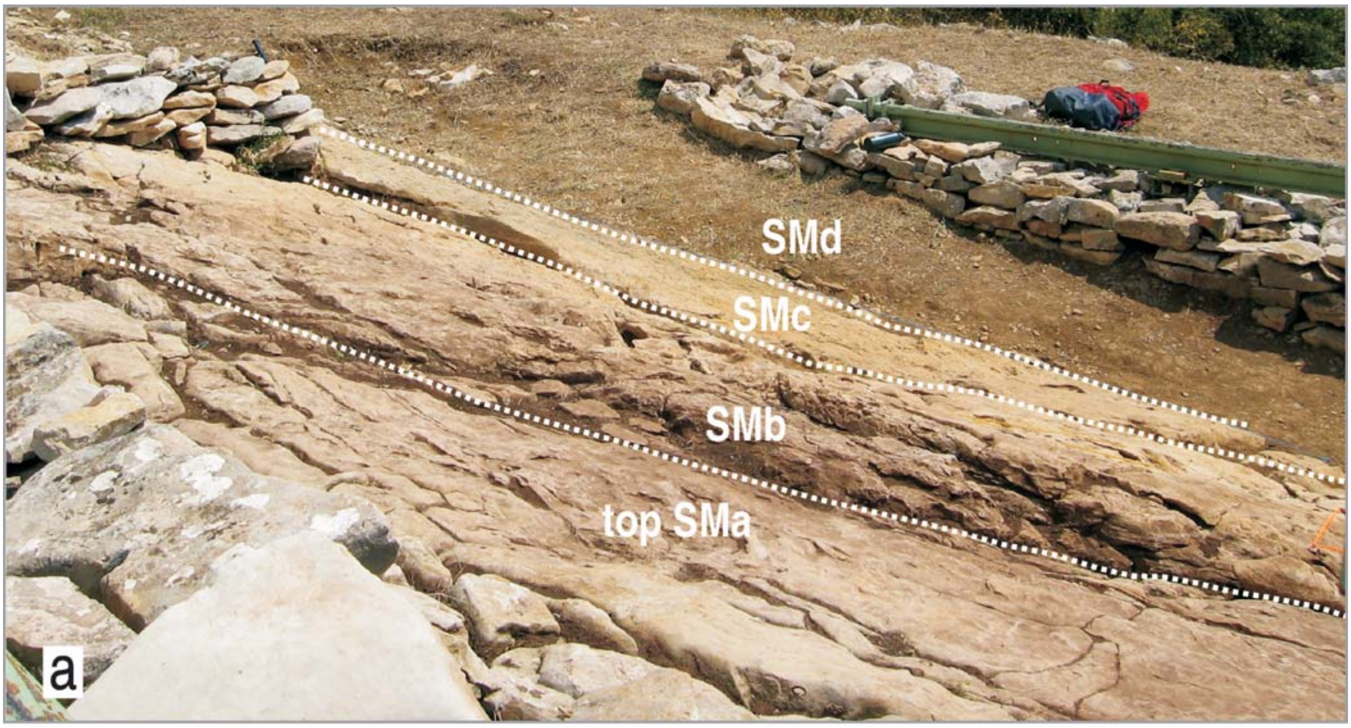
In the Scontrone South section, both the tidal creek and salt marsh deposits are replaced by a layer, a few centimetres thick, of a very fine-grained black calcarenite made up of well-sorted and very well-rounded calcareous grains, mostly abraded skeletal debris, associated with dispersed wood fragments and very small, comminuted vertebrate remains. This black-stained calcarenite veneer, extensively intersected by small vertical root tubules filled with bitumen (plate 4, fig. a), directly covers the FeO-stained rooted top of the underlying carbonate sandbars. The occurrence of this thin carbonate sandy veneer trapped in a low-energy muddy environment can be justified by storm-derived surges and/or by tide-influenced flooding events.

2.2. Coastal lagoon and tidal channels

In the Scontrone North Section, the SMc marsh deposits are abruptly overlain by about 2 m of subtidal lagoon deposits represented by marls and marly limestones containing sparse complete shells of *Cerithium* (SMd facies interval in fig. 7). They are followed by marls with intercalated centimetric-thick nodular beds of fine-grained tan calcarenites with abundant fragmented cerithids and sparse disarticulated oyster shells (SMe facies interval of fig. 7). In thin section, the lower-energy muddy deposits with complete *Cerithium* shells appear as gastropod-bearing wackestones with variable amounts of large-sized *Ammonia*, subordinate small *Elphidium* and thin-shelled sparse ostracods. In this facies the cerithids, usually preserving their original aragonite shell, appear unbroken and only flattened by burial compaction. The overlying *Cerithium*/oyster-rich beds (plate 4, fig. b) are characterized by packstones with *Ammonia* and *Elphidium* containing variable amounts of Cerithids and of fragmented, bored large mollusk shells set in a fine-grained open-marine biodetritus (echinoid spines, serpulid and barnacle debris). These bioclastic deposits have been interpreted as storm layers possibly accumulated in a coastal lagoon.

In the Scontrone fossil site section, the upper bonebed is followed by dark-grey to green marls and clayey marls rich in ostracods that are exposed only for a few tens of centimetres. After a gap of about two meters, just a few decimetres of tan-colored marls with intercalations of thin oyster banks crop out.

In the Scontrone South section, the coastal-lagoon deposits of the SMd facies interval are represented at the base by 15 cm of fetid dark shaly marls and limey marls containing scattered micritized bioclasts, crushed smooth-shelled gastropods and bivalves, sparse ostracods and numerous unidentified calcareous bodies of uncertain origin and affinity (plate 4, figs. c-f; plate 5, figs. a-b). These enigmatic microfossils, likely calcitized cysts and/or calcitized sporomorphs, are represented by spherical and more or less flattened ovoidal forms ranging in



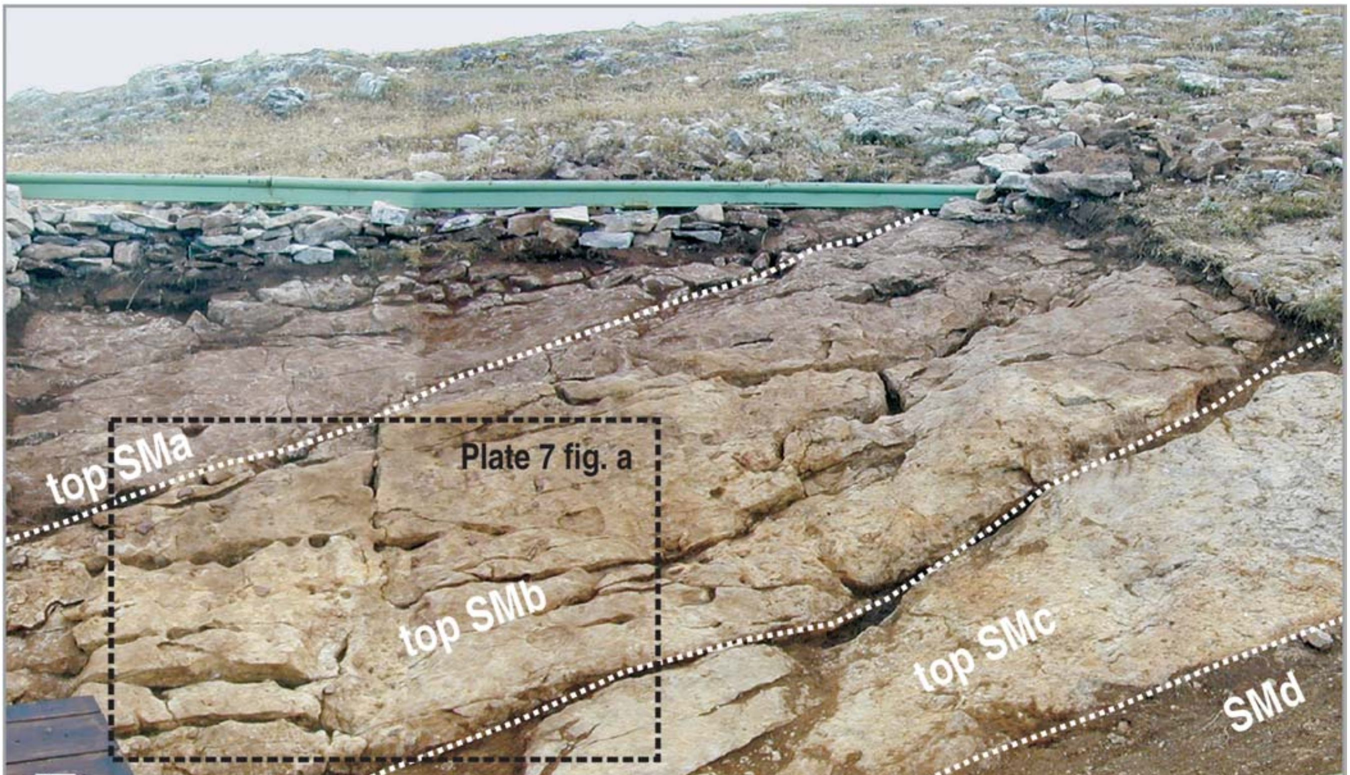


Plate 6 - Panoramic view of the Scontrone fossil site. Fig. a. View from the west of the Scontrone fossil site showing the three bonebeds (facies intervals SMa-SMc in fig. 7) and the overlying coastal lagoon deposits (facies interval SMd in fig. 7). The rucksack in the background indicates the scale. Fig. b. View from the east of the Scontrone fossil site. The picture shows the upper surfaces of the three beds yielding vertebrate remains (courtesy S. Agostini and A. Rossi). The bulk of the vertebrates derive from the top of the SMb interval (see fig. 7). Close-up views of this surface are shown in plate 7.

– Veduta d'assieme del giacimento fossilifero di Scontrone. Fig. a. Sito fossilifero di Scontrone. Panoramica da ovest sui tre livelli a resti di vertebrati (intervalli SMA-SMc in fig. 7) e sui soprastanti depositi di laguna costiera (intervallo SMd in fig. 7). Lo zaino sul muretto dà un'idea della scala. Fig. b. Veduta da est della faccia superiore dei tre strati fossiliferi del giacimento di Scontrone (foto S. Agostini e A. Rossi). Il grosso dei resti di vertebrati deriva dal livello SMb (v. fig. 7). Alcuni particolari di questo livello sono mostrati nella tav. 7.

size between 80 and 150 μm. At high magnification they reveal a quite complex microstructure resulting from serial or spherical arrangements of welded smaller microspherules highly variable in shapes and sizes made up of radial fibrous calcite (former aragonite or high-Mg calcite). Some of these problematic microfossils disclose remnants of organic walls (evidenced by the yellowish-brown color in transmitted light) and a large central hollow frequently filled by dark micrite or cemented by diagenetic microspar and/or equant calcite.

The basal marls are followed upward by a thin bed (30 cm) of fetid dark-brown calcisiltite containing scattered crushed cerithid shells. In thin section the calcisiltite shows an evident and characteristic clotted texture (plate 5, figs. c-e) related to a dense aggregate of isolated and clustered calcispheres. The peculiar fabric of this calcisiltite, deposited at the margin of a lagoon, can be related to an unusual in-situ accumulation of calcitized cysts following an abnormal phytoplankton growth in a high trophic water body. The calcispherulid-rich layer, crossed by several bitumen-filled fissures, is overlain by about 2 m of thinly laminated dark marls containing abundant calcified peloids together with sparse cerithids, hydrobiids and scattered plant remains.

In all studied sections, the uppermost portion of the Scontrone Member is represented by crudely bedded lithobioclastic calcarenites that reach the maximum thickness of about 3 m in the Scontrone North stratigraphic section (SMe facies interval in fig. 7). These calcarenites, everywhere associated with discontinuous oyster accumulations, are organized in fining-up parasequences starting with evident cross-bedding and ripple cross-lamination. Sedimentary structures suggest relatively high-energy settings such as those related to channelized tidal belts. The microscopic fabric of the calcarenites (plate 4, fig. e), characterized by a grain-supported framework, occurrence of oversized well-rounded lithoclasts and biotic association still dominated by *Ammonia* and *Elphidium,* support this interpretation. The presence of well-rounded, coarse-grained calcareous clasts, in addition, suggests overwash in proximity to higher-energy settings. In the Scontrone South stratigraphic section, the SMe interval is represented by about 40 cm of burrowed fine-grained grey calcarenite rich in gastropods that still contains abundant *Ammonia* and *Elphidium*.

In the Scontrone North, Scontrone Fossil Site and Scontrone South stratigraphic sections, the described tidal channel deposits are overlain by cross-bedded lithobioclastic grainstones with euryhaline fossil associations interpreted as transgressive offshore bars (see fig. 7). This interpretation is strengthened by the systematic occurrence of the ravinement surface at the base of these high-energy deposits

3. THE MAMMALIAN COLLECTION

Since discovery, excavations at the Scontrone fossil site (*plates 5 and 6*) have been conducted on a yearly basis. The 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 and 142 indeterminate specimens) all referable to six species, the classification of which is under way. The six species can be attributed to the genus *Hoplitomeryx*, a puzzling ungulate until now represented 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 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 bones are well fossilized, but most are broken. They are all disarticulated, unsorted and randomly scattered in every layer. However, no bone shows evidence of reworking since all fragments 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 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 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, together with sparse crocodile ossicles, 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 fit very well the environment reconstructed on the base of lithological criteria

4. THE PROVENANCE OF THE SCONTRONE VERTEBRATES

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 (FREUDENTHAL, 1971, 1972; DE GIULI & TORRE, 1984; VAN DER GEER, 2005). 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, the Apulia Platform domain, before the Scontrone depositional realm was reached by compressional deformation and incorporated in the Apennine thrust belt (see figs. 2 and 3).

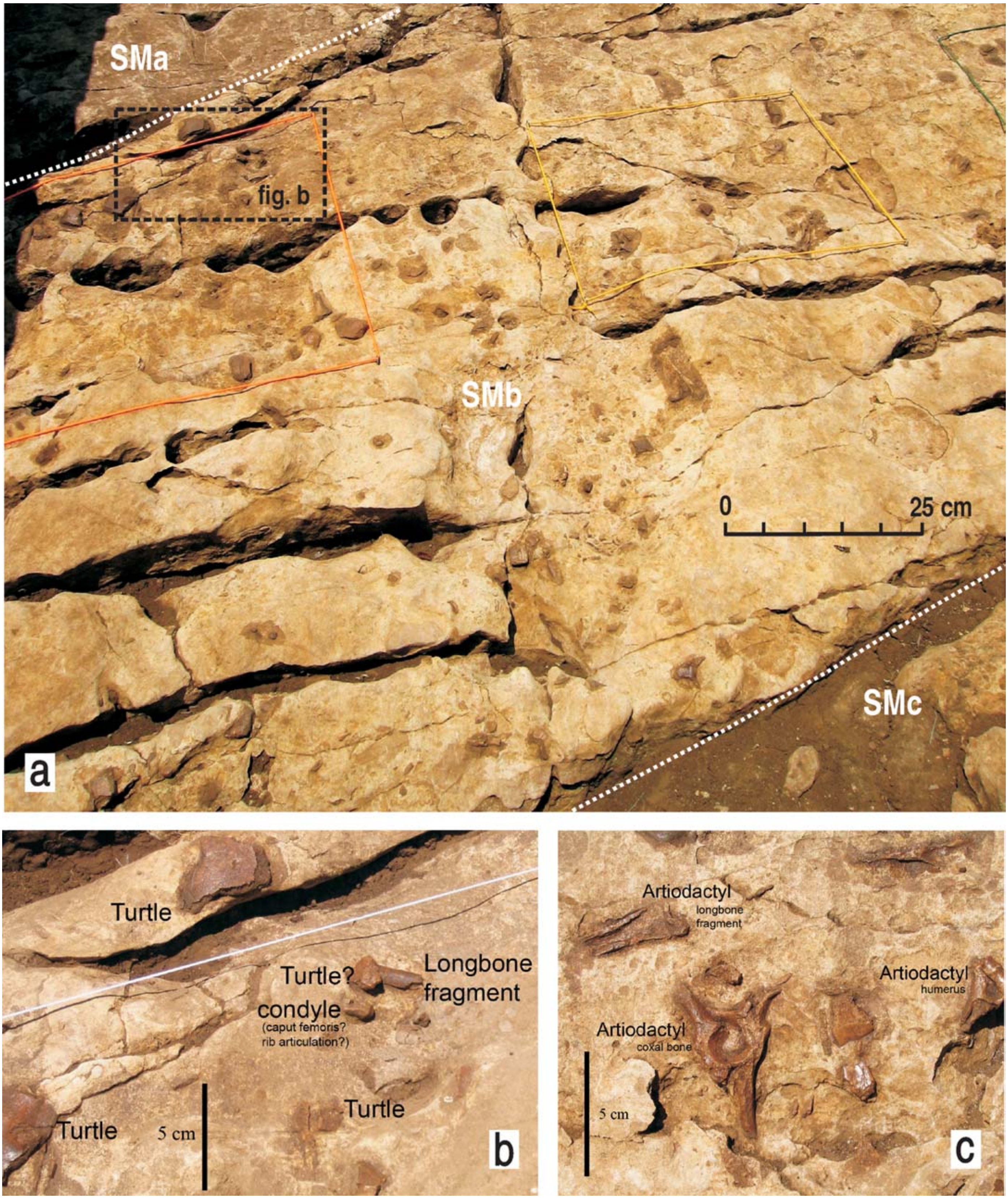


Plate 7 - Details of the top of the principal bonebed (facies interval SMb in fig. 7). Fig. a. Close-up view of the upper surface of the principal bonebed SMb showing numerous vertebrate remains (courtesy S. Agostini and A. Rossi). Fig. b. Detail of vertebrate remains (courtesy S. Agostini and A. Rossi). The picture is a close-up view of the boxed area in fig. a. Fig. c. Artiodactyl remains spectacularly exposed on the upper surface of the major bonebed (courtesy S. Agostini and A. Rossi).

– Faccia superiore di strato del principale livello fossilifero (intervallo SMb in fig. 7) mostrante numerosi resti di vertebrati (intervallo SMb in fig. 7). Fig. a. Particolare della faccia superiore di strato del livello SMb mostrante numerosi resti di vertebrati (foto S. Agostini e A. Rossi). Fig. b. Dettaglio di resti di vertebrati che sporgono dalle faccia superiore di strato del livello SMb (foto S. Agostini e A. Rossi). La foto fornisce un'immagine ingrandita dell'area marcata da un rettangolo nella fig. a. Fig. c. Resti di artiodattili esposti in modo spettacolare sulla superficie superiore del livello SMb (foto S. Agostini e A. Rossi).

The mammal colonization of the Scontrone-Gargano paleogeographic province took probably place around the early Oligocene-late Oligocene boundary, i.e. at 29-30 Ma, when an important drop in the sea level at a global scale (see HAQ *et alii*, 1988) caused the emergence of the Apulia Platform together with the central Adriatic region, creating a landbridge from Dalmatia to Gargano via the Tremiti Islands (PATACCA *et alii*, 2006). Through this filtering route and in this specific lapse of time representatives of the ancestor stock of the Hoplitomerycids spread into the Abruzzi-Apulia realm together with the forerunner of the giant insectivore *Deinogalerix*.

The landbridge connecting Dalmatia and Gargano was created by the occurrence of three combined circumstances:

– Existence in the Central Adriatic region of prominent structural highs interrupting the continuity of the former middle Liassic basinal areas created between the Apulia Platform and the Adriatic Platform by the Jurassic extensional tectonics;

– Occurrence of an important sea level drop around the end of early Paleocene which caused everywhere in the peri-Adriatic platforms an extensive erosional truncation at the top of the underlying deposits and determined in the Central Adriatic area, north of Gargano, a widespread seaward progradation of shallow-water carbonates over older deeper-marine sequences. During the subsequent transgression, upper Paleocene-Eocene ramp carbonates were deposited all 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 separating two basinal domains (Northern Adriatic and Southern Adriatic basins);

– Occurrence of the major global sea-level drop at 29-30 Ma, which caused a generalized subaerial exposure of the Apulia and Adriatic platforms together with the bulk of the intervening shallow-water plateau, thus creating a sort of isthmus between Dalmatia and Gargano.

In Langhian times, i.e. between 16.4 and 14.8 Ma (see GRADSTEIN *et alii*, 2004), the Dalmatia-Gargano isthmus was completely submerged and 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, allowing the development of a fairly varied landscape where relatively few taxa flourished, endemized and diversified. The lack of dispersion of the Scontrone-Gargano faunal population towards the Apennine mountain chain is testified by the remarkable differences between the characters of the Scontrone-Gargano assemblage and the characters of the coeval fossil fauna recovered at Baccinello in the lower portion of the «*Oreopithecus* Zone Faunas» of BERNOR *et alii* (2001). Any contact between foreland and mountain-chain faunal populations was precluded by the foredeep basin developed during Neogene times along the front of the Apennine thrust belt (PATACCA *et alii*, 1990) which acted as a major natural barrier (see the paleogeographic reconstruction in fig. 8 showing the configuration of the Apennine thrust belt and of the Adriatic-Ionian foreland in early Tortonian times). The seclusion of the Abruzzi-Apulia paleobiogeographic province ended with the Messinian salinity crisis, when a new and wider landbridge re-emerged allowing several micromammalian taxa, namely rodents, to colonize the area from the Balkans.

5. FINAL REMARKS

Scontrone, with its Tortonian fauna, represents a turning point in the investigations on the Abruzzi-Apulia paleobioprovince and its colonization. The fossil vertebrates are embedded in deposits dated at about 10 Ma. Colonization of the Abruzzi-Apulia province is much older, as it dates back at 29-30 Ma, in concomitance with a major sea level drop, when the Apulia Platform was a vast continental area connected with the Dalmatian coast via the present-day Tremiti area. During the Langhian, a marine transgression submerged the Dalmatia-Gargano landbridge isolating the Abruzzi-Apulia paleoprovince for several millions of years. The presence, both at Scontrone and Gargano, of *Deinogalerix* and *Hoplitomeryx*, with their weird endemic features, is perfectly consistent with these reconstructions. In addition, the combined investigations on the Abruzzi-Apulia paleogeographic setting and on the paleontological characteristics of this paleoprovince suggest a possible common origin of *Deinogalerix*, spread over the Abruzzi-Gargano paleoprovince, and some insectivores distributed in the Balkan region during the second half of the Oligocene.

ACKNOWLEDGMENTS

The authors thank Barbara Taccini for picture drawing and Daniela Bianchi for the careful preparation of the thin sections utilized in this study.

The authors are also indebted with Daniela Esu for her constructive critical review of the manuscript.

Patrizia Melone, mayor of Scontrone, is warmly acknowledged for the cultural initiatives aimed at the fossil site valorization and at the preservation of the precious paleontological heritage by Centro di Documentazione Paleontologico of Scontrone. An acknowledgment is also addressed to Adelaide Rossi and Silvano Agostini (Direzione Regionale per i Beni Culturali e Paesaggistici dell'Abruzzo) for their precious and enthusiastic effort to valorize and protect the numerous paleontological sites of Abruzzi.

Finally, the authors thank Fiorenzo Iacobucci for information on some interesting outcrops of the Scontrone Member of the *Lithothamnium* Limestone not yet explored in terms of paleontological contents.

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Received 20 December 2006; revised version accepted 1 June 2007.