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Neogene Stratigraphy and Sedimentology of the Gargano Promontory (Southern Italy)

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ABSTRACT

The Gargano Promontory has revealed a succession of Neogene shallow-water rocks, unconformably covering the Mesozoic substratum, of an Early Miocene to Late Pliocene age.

The lowermost unit consists of a tidal platform of poorly constrained age (Torre Mileto Fm., Chathian-Aquitanian?), topped by continental deposits, and covered by a lower Burdigalian to lower Langhian shallow-water complex (Torre Rossa Fm.). A drowning sequence separates the Torre Rossa Fm. from the overlying Langhian to Tortonian plankton-rich chalks and calcarenites, the Lauro Formation. The subsequent diatomites and tidal carbonates should be referred to lower Messinian Tripoli and Calcare di base formations. An erosional unconformity separates the latter from the Rignano Formation (Late Messinian?), mainly a conglomeratic unit of deltaic origin. Post-Miocene marine deposits consist of shallow-water calcarenites of Middle to Late Pliocene age and referred to as Gravina Calcarenite.

The sequence-stratigraphic evolution has been reconstructed. The main changes in the sedimentation are related to second and third order climato-eustatic cycles, whereas ongoing tectonics produced only local unconformities (up to 50° of tilting) with negligible effects on the sediment composition.

Pre-Miocene distribution of emerged land coupled with Miocene contractional tectonics controlled the geometry and width of the Neogene basins, which were mainly narrow and elongated, and separated by emerging ridges.

RIASSUNTO

Nel Promontorio del Gargano affiora una successione di età compresa tra il Miocene Inferiore e il Pliocene Superiore. Una superficie di disconformità separa le unità neogeniche dal substrato Mesozoico.

L'unità più antica è formata da rocce carbonatiche di piana tidale, di età poco definita (Formazione di Torre Mileto, Cattiano-Aquitaniano?). Tale unità è coperta da depositi continentali (paleosuoli, terre rosse) che passano a carbonati di piattaforma (Formazione di Torre Rossa, Burdigaliano inf.-Langhiano inf.). Una sequenza di annegamento separa la Formazione di Torre Rossa dalle micriti planctoniche e calcareniti della Formazione del Lauro (Langhiano-Tortoniano). Le sovrastanti diatomiti e tidaliti sono da riferire al Tripoli e al Calcare di base (Messiniano inf.). Una disconformità erosiva divide il Calcare di base dalla Formazione di Rignano (Messiniano sup.?). Quest'ultima è composta prevalentemente da conglomerati di ambiente alluvionale e deltizio. I depositi post-miocenici sono costituiti da calcareniti di acque basse (Pliocene Medio-Sup.), riferibili alla Calcarenite di Gravina.

E' stata ricostruita l'evoluzione stratigrafico-sequenziale delle unità neogeniche. Le principali variazioni nella sedimentazione sono riferibili a cicli climatico-eustatici di secondo e terzo ordine, mentre le disconformità locali sono legate alla tettonica compressiva miocenica. La distribuzione delle terre emerse ereditata da eventi pre-miocenici, associata alla tettonica compressiva sinsedimentaria, è stato il maggiore fattore di controllo su geometria e ampiezza dei bacini neogenici, che erano stretti ed allungati, e separati da dorsali emerse.

1. Introduction

The Tertiary, especially Neogene evolution of the Adriatic plate between the Apennines and the Dinarides is poorly known because sediments of corresponding age are typically either absent or buried under deep successions of the Apennine foredeep or under sea-level. Neogene rocks are, however, present in the Gargano Promontory (southern Italy, Fig. 1) and provide very significant constraints on the sedimentary and kinematic evolution of this portion of the Adriatic plate.

Available literature on the Gargano Neogene sediments contains only a detailed paleontological documentation (D'Alessandro et al. 1979; Borsetti et al. 1970), mainly independent from sedimentological and stratigraphical features. On the contrary, the Plio-Pleistocene sediments west of the Gargano Promontory (Apricena-Poggio Imperiale block) have been thoroughly investigated and interpreted (Valleri 1984; Abbazzi et al. 1996; Capuano et al. 1996).

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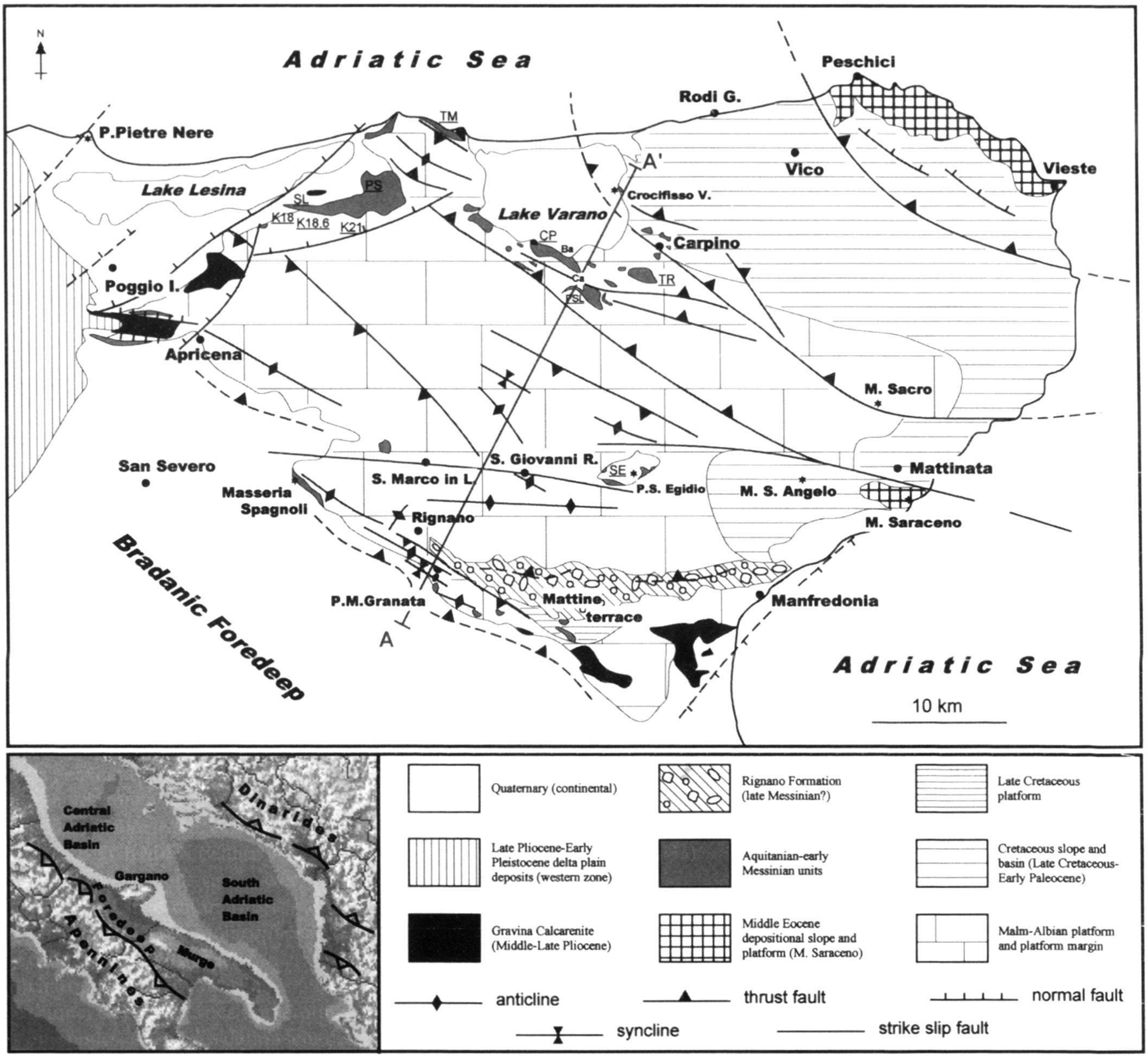

Fig. 1. Geologic map of the Gargano Promontory. Underlined abbreviations correspond to the stratigraphic sections plotted in Fig. 2. A–A' is the cross section of Fig. 3. Ca = Cagnano; Ba = Bagno locality (see text). Plain circles are villages and little towns, asterisks are small localities cited in the text. Inset map shows the major geologic elements surrounding the Gargano.

In this paper, we present a detailed sedimentological analysis of Neogene sediments from the Gargano Promontory, mainly from the central and eastern parts, where the Tertiary rocks are poorly known. The description of a nearly complete succession of Neogene sediments, integrated with many fragmentary stratigraphic sections, provides the database of this paper.

For instance, we document for the first time the existence of Burdigalian and Messinian sediments in the area, and propose the existence of a pre-Burdigalian (Chattian-Aquitanian?) carbonate platform. In addition, a large number of outcrops in the southern Gargano, previously interpreted as Quaternary continental deposits, are fan deltas and shoreline sediments of possible Messinian age. These new findings allow us to define a substantially new evolutionary scheme for the Neogene and Quaternary.

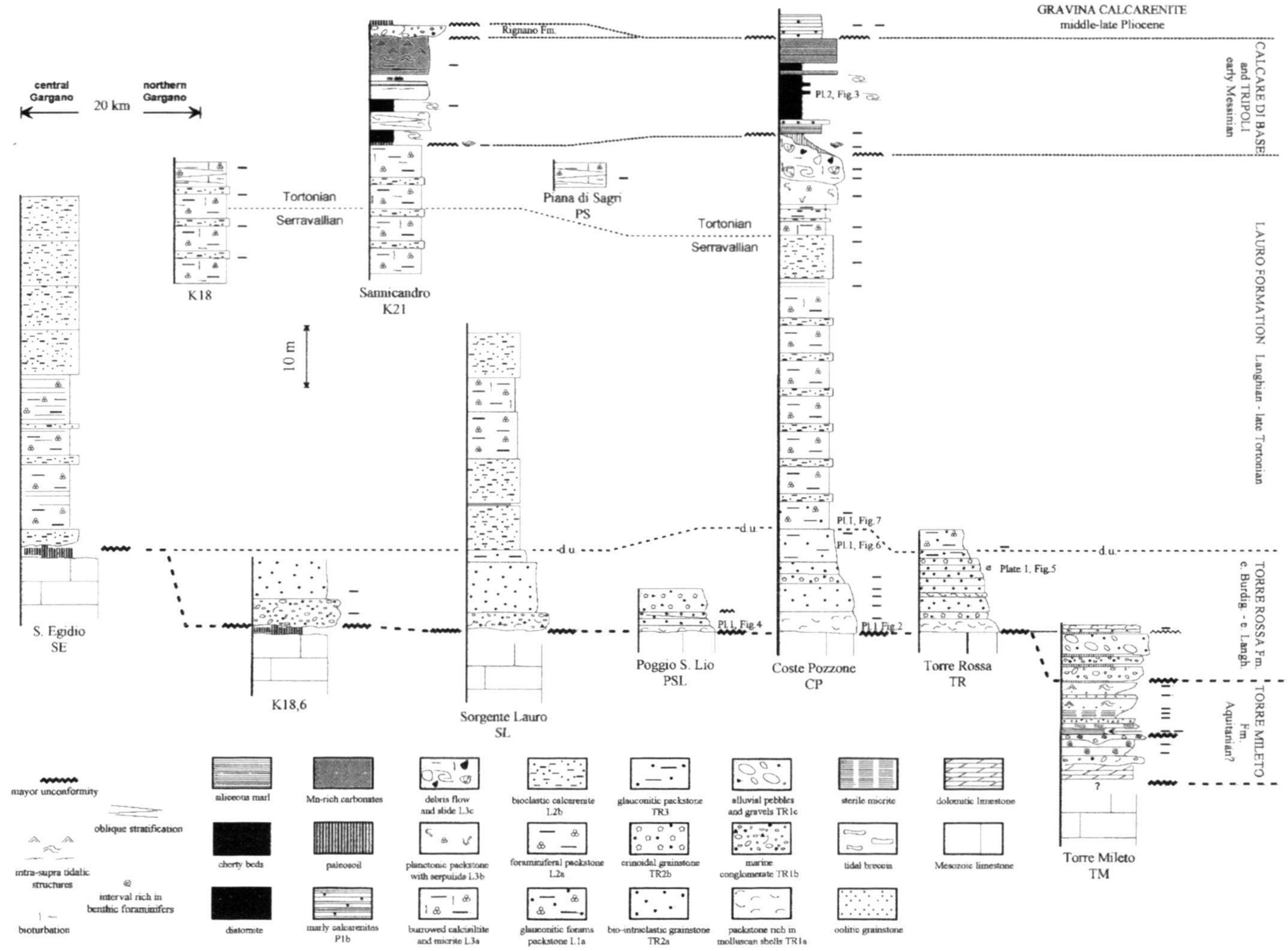

Fig. 2. Stratigraphic correlations of the measured sections, showing the main facies discussed in the text. Samples photographed in thin section are linked with corresponding plates. Other diagnostic samples are indicated with a dash. Positions of the stratigraphic sections are plotted in the geologic map of Fig. 1. The S. Egidio section is reconstructed from published borehole data (Crescenti & Vighi 1964) integrated with our observations. d.u.: drowning unconformity.

2. Geological overview

The Gargano Promontory lies on the Adriatic plate between the Dinarides and Apennine belts and associated foredeeps (Fig. 1). Traditionally, the considerable elevation of the Gargano Promontory (reaching an altitude of 1 km) is associated with the foreland bulge of the two orogenic systems (e.g. D'Argenio et al. 1973; Moretti & Royden 1988; Royden 1988; Bosellini et al. 1993). This bulge has generally been considered basically undeformed and stable (e.g. Martinis 1964), beside widespread brittle faulting generally associated with strike-slip movements (e.g. Funiciello et al. 1991). Remarkable exceptions can be found in the papers of Ortolani & Pagliuca (1987), who proposed the presence of transpressive tectonics, and Letouzey & Trémolières (1980) that mentioned an Early Miocene NE-oriented compressional stress. Winter & Tapponier (1991) stressed the importance of extensional tectonics (Cretaceous-Eocene) of the north-eastern Gargano.

Preliminary interpretations from our tectonic database point out the importance of contractional movements during the Tertiary, which deeply influenced the sedimentary evolution as well as the overall structure of the area.

The Gargano Promontory mainly consists of a thick pile (3–4 km) of Mesozoic to Eocene carbonates (with several hiatuses), overlying Permo-Triassic sedimentary rocks and a crystalline basement, known from drillhole data (D'Argenio 1976; Bosellini et al. 1993). The bulk of the Promontory consists of a Late Jurassic to Albian platform and Late Jurassic to Early Paleocene slope and basin carbonates. Late Cretaceous shallow-water limestones have been documented only in the southernmost sector of the Gargano (Fig. 1) (Crescenti & Vighi 1964; Merla et al. 1969).

The Mesozoic of the Gargano has been described as a platform-slope-basin system, deepening from SW to NE (e.g. Pavan & Pirini 1966; Masse & Borgomano 1987; Masse & Luperto Sinni 1989, Bosellini et al. 1993). This succession of carbonate rocks belongs to the wider Apulian Platform *l.s.* (D'Argenio 1976; Mostardini e Merlini 1986). Morsilli & Bosellini (1997) described in detail the Upper Jurassic-Lower Cretaceous platform margin, mainly NW-SE oriented, and separating the inner platform of the western Gargano from the basin located to the east (Fig. 1). However, the presence of Cretaceous slope facies in the south-eastern part of the Gargano suggests a more articulated paleogeography, characterized by embayments and promontories.

The Cretaceous in Gargano is usually subdivided in two main sequences, separated by a regional unconformity marked in the platform interior by bauxite horizons, encompassing the Late Albian to Turonian age.

The Middle Eocene sequence consists of slope sediments, outcropping along the NE coast between Peschici and Vieste and south of Mattinata (M. Saraceno). In Monte Saraceno, where a complete sequence is exposed, deep-water limestones pass upward to shallow water carbonates (Bosellini et al. 1993).

Neogene sediments outcrop at low-middle altitudes in large part of the Gargano, but they are absent in its eastern sectors. Miocene carbonates unconformably overlie the Jurassic-Cretaceous substratum. Pliocene calcarenites rim the present day relief, outcropping mainly along the Adriatic coast to the north and at the border of the Apenninic foredeep to the south.

3. Stratigraphy and sedimentology

3.1. Material and methods

The biostratigraphic study is based on 47 samples collected along 11 stratigraphic sections (Fig. 2), integrated with test samples (71) taken from scattered outcrops.

The preparation of samples for foraminiferal analyses followed standard micropaleontological techniques, namely preliminary disaggregation and ultrasonic treatment, when needed, in order to get clean specimens. The preservation is generally moderate to good, the fauna commonly consists of benthic foraminifers that are not diagnostic for biostratigraphic purposes. Thin sections were prepared from hard lithologies. The biostratigraphic scheme for benthic foraminifers is from Agip (1982), while for planktonic foraminifers is from Blow (1969). Calcareous nannofossil analyses were performed on smear slides mounted with Norland optical Adhesive. In order to retain their original composition, samples were not centrifuged. Preservation of nannofossils is generally poor to moderate, but a biostratigraphic attribution was possible, using the zonation of Fornaciari et al. (1996) and Okada & Bukry (1980). Biochronology and correlation to standard stages are according to Berggren et al. (1995).

3.2. Description of the units

The Miocene rocks are here subdivided in six lithostratigraphic units replacing the poorly defined formational names adopted in the literature of the Gargano Promontory. This is the case, for instance, of the Miocene "Calcareniti di Apricena" (Cremonini et al. 1971).

The ages of the Miocene succession have been substantially revised, documenting at least a Burdigalian to Messinian time span. Cremonini et al. (1971) proposed a Langhian-Serravallian age, whereas D'Alessandro et al. (1979) dated at the Late Tortonian the whole Miocene rocks of the Gargano. The Pliocene rocks are grouped in the well-known Gravina Calcarenite formation.

Hereinafter, we will indicate facies associations with capital letters (mainly the initials of the unit), followed by a number representing its vertical position. In the case of heteropy, a small-cap letter will follow the numbers. For example, TR1a of the Torre Rossa Formation is heteropic with TR1b and both facies associations pass vertically to TR2.

3.2.1. Torre Mileto Formation (Chattian-Aquitanian?)

Rocks assigned to the Torre Mileto Formation outcrop only along the northern coast of the Gargano, between Torre Calarossa and Torre Mileto (Fig. 1). In previous studies (e.g. Cremonini et al. 1971; Bosellini et al. 1993) they have been mapped as Mesozoic rocks. Two different members, whose total thickness is around 15 m, can be identified both characterized by a shallowing upward trend (Torre Mileto section, Fig. 2).

The outcropping base of the lower member consists of few meters of whitish dolomitic limestones with *Heterostegina*, followed by a deeply incised layer of a dolomitized conglomerate. Upsection, a roughly channellized floatstone-rudstone follows. At the top of the lower member, a hard-ground occurs, consisting of ochraceous dolosiltites and Fe-Mn crusts with rare foraminiferal ghosts.

The base of the upper member is a structureless, sterile micrite, followed by oolitic-bioclastic grainstones (Pl. 1, Fig. 1), and then by breccias and coarse sands (tidal channel deposits). The rest of the member is formed by alternating peritidal facies interpreted as migration of various sedimentary sub-environments in a carbonate inner shelf.

An unconformity topped by paleosoils divides this unit from the conglomerate and paleosoils forming the base of the Torre Rossa Formation in this sector (facies TR1c, see section 3.2.2.).

No significant microfauna or nannoflora has been found in the Torre Mileto Formation and a precise biostratigraphic attribution is, therefore, impossible. A Chattian-Aquitanian age is proposed, based on correlation with offshore stratigraphy and on the stratigraphic position of the Torre Mileto Formation, underlying the Early Burdigalian Torre Rossa Formation.

3.2.2. Torre Rossa Formation (Early Burdigalian- Early Langhian)

The Torre Rossa Formation consists of strongly cemented limestones, mainly biodetrital wacke-packstones, deposited in shallow-water environments. Peculiar characters are the abundance of benthic foraminifers (*Miogypsina* at the base, *Amphistegina*, and *Heterostegina*) and the diffuse presence of glauconitic grains.

This unit lies unconformably on the Mesozoic substratum, except for a little stretch of the northern coast, where it overlies older Miocene carbonates of the Torre Mileto Formation. The thickness of the formation varies between few centimetres and 25–30 meters.

The base of the Torre Rossa Formation

The basal contact varies from sharp and planar (Pl. 1, Fig. 3) to strongly irregular over an eroded Mesozoic substratum. The most common basal facies (TR1a) recognized in the whole northern Gargano, consists of roughly graded, bio-intraclastic pack-wackestones with abundant molluscan shells (Pl. 1, Fig. 2). The sand-sized grains consist of a mixing of rounded Mesozoic clasts, glauconitic grains and bioclasts, including benthic and rare planktonic foraminifers. In the Torre Mileto section (Fig. 2) the basal part of the unit (TR1b) consists of two thick bodies of matrix-supported conglomerates with large unsorted clasts floating in a sandy matrix, alternated with brown and red paleosoils. In the northern Gargano another basal facies (TR1c) consists of matrix-supported, *Ostrea*-bearing conglomerates, with sub-angular clasts derived from the Mesozoic substratum. The matrix is poorly sorted and consists of foraminiferal bio-intraclastic pack-grainstone.

Benthic macroforaminifers (mainly *Miogypsina, Amphistegina, Heterostegina*) are present at the base of the Torre Rossa Formation. *Miogypsina* has been found only in the two basal beds of the unit. A sample collected at the base of the unit in the northern Gargano (Poggio S. Lio, sample 21–09b in Fig. 2) yields *Miogypsina* cf. *intermedia* Drooger (Pl. 1, Fig. 4). This species has been found and described by Schiavinotto (1985) in the southern Apennines and by Schuttenhelm (1976) in the Piedmont basin. Both Authors correlate the distribution of *Miogypsina* cf. *intermedia* to the lower part of the N6 Zone of Blow (1969), Early Burdigalian in age. In addition, this form occurs in the higher part of the Burdigalian stratotype (Drooger 1993, Fig. 61). According to Poignant et al. (1997), the stratotype spans the NN2 nannofossil biozone of Martini (1971) of Early Burdigalian age.

The middle-upper part of the Torre Rossa Formation

This portion consists of 10 to 25 meters of crudely stratified wacke-packstones, with a general shallowing-upward trend. The first facies association (TR2a) consists of coarse grain-packstones passing upward to fine-grained pack-wackestones, sometimes displaying low-angle to planar lamination. The main sandy components are rounded micritic Mesozoic clasts, glauconitic and phosphatic grains, angular oxidized clasts, peloids, bioclasts and shallow-water foraminifers. The facies association TR2b overlies or is partly heteropic with the previous one. It consists of roughly graded beds of crinoidal and glauconitic limestone, containing corals, calcareous sponges, bivalves and shallow-water foraminifers. Two characteristic foraminifera-rich intervals (each about 1 m thick) occur toward the top, providing a useful marker interval in the field (Pl. 1, Fig. 5). The uppermost facies (TR3) consists of 2–3 meters of well-bedded, poorly cemented yellowish packstone-grainstone, rich in glauconitic grains. The main components are planktonic and benthic foraminifers, crinoids, lithothamns, bryozoans (Pl. 1, Fig. 6). This facies is interpreted as drowning sequence of the Torre Rossa platform (see section 5.1.).

3.2.3. Lauro Formation (Langhian-Late Tortonian)

The Lauro Formation forms the main body of the Miocene sediments in the Gargano area. At the outcrop scale, the base of the formation lies para-conformably on the drowned Torre Rossa platform (TR3 facies) in correspondence of morphostructural lows (marine onlap), whereas a pronounced angular unconformities and reduced successions are observed on the tilting limbs of the growing basin margins (coastal onlap).

In small outcrops in the northern Gargano (Crocifisso Varano) and in the central Gargano (S. Egidio basin), the Lauro Formation lies directly on Mesozoic carbonates (Fig. 1).

The formation is vertically arranged as a basal interval of glauconitic calcisiltites with abundant plankton (foraminiferal packstones), followed by alternating chalks and bio-calcarenites, mainly interpreted as storm deposits. The upper part of the unit consists of intensively burrowed chalks, alternating with foraminiferal calcisiltites, showing large-scale, low-angle oblique stratification (K18 and PS sections of Fig. 2).

The lower-middle part of the Lauro Formation

The common basal facies of the Lauro Formation (L1a in Fig. 2) consists of poorly stratified planktonic foraminiferal packstones rich in glauconitic grains, and rare fragments of bivalves, lithothamns and shallow-water benthic foraminifers (Pl. 1, Fig. 7).

At Crocifisso Varano (Fig. 1), the Lauro Formation lies directly on the Cretaceous limestones and the Torre Rossa Formation is missing. Here, the basal facies (L1b, not plotted in Fig. 2) consists of a few decimetres of thinly laminated whitish chalks, very rich in planktonic foraminifers. Facies association L2a (Fig. 2) consists of poorly bedded chalks, including abundant planktonic foraminifers, ostracods and mollusc fragments. Some intervals are characterized by skeletal concentrations (pectinids, ostreids, brachiopods, echinoids, bryozoans, crustaceans), structureless or roughly fining-up, interpreted as storm deposits (Pl. 1, Fig. 8). In some outcrops, bio-intraclastic calcarenites are prevalent (L2b). Usually this facies, containing clasts of the Mesozoic substratum, is characteristic of the internal Sant'Egidio basin. Here, the macrofauna (mainly internal moulds) is dominated by an assemblage of shallow-water molluscs, echinoids, crustaceans and pteropods (Checchia Rispoli 1915; D'Alessandro et al. 1979).

The upper part of the Lauro Formation

Intensively burrowed calcisiltites and micrites with high contents of plankton (L3a) outcrop in the Lesina Lake area. The sediment is characterized by large-scale, low-angle oblique stratification (Pl. 2, Fig. 1), topped by large wave-length hummocky, but structureless or discontinuous flat-bedded intervals also occur. Macrofossils are quite scarce and consist of crinoids, lithothamn fragments, echinoids, pteropods and rare pelecypods *(Amussium)*. In some intervals, fine-grained storm layers show concentrations of pteropods and crinoid articles. A peculiar facies (L3b) discontinuously outcrops along the southern coast of Lake Varano (CP section, see Figs. 1 and 2). It consists of strongly cemented and structureless *Globigerina* packstones rich in reworked serpulids. Well sorted crinoid articles and pelecypod fragments are recognized in thin section. Finally, facies L3c is a mud-supported breccia in lateral contact with L3b. The clasts are either angular, often consisting of lithified L3b limestones, or sub-angular (5–15 cm large), derived from reworked calcarenitic/bioclastic intervals (similar to L2 facies). Clasts are embedded in strongly burrowed lime-muddy sands.

Integrated biostratigraphic results

In the Coste Pozzone section (CP in Fig. 2), samples collected in the L1 and L2 facies of the Lauro Formation, yielded a microfauna that consists of both benthic and planktonic foraminifers. *Orbulina suturalis*, *Orbulina universa*, *Globigerinoides trilobus*, *Globoquadrina* spp. have been recognized in the planktonic assemblage whereas the benthic one mainly consists of *Uvigerina* spp. This indicates an open marine environment that can be referred to Zone N9 of Blow (1969). In the Torre Rossa section (TR) a sample collected at the base of the unit (L1) also yielded *Orbulina* spp.

The calcareous nannofossil assemblage of this interval (L1 and L2 facies), although poorly to moderately preserved, shows since the base of the unit the presence of *Sphenolithus heteromorphus* and the absence of *Helicosphaera ampliaperta*, which refer to Zone MNN5 of Fornaciari et al. (1996). According to the Subcommission on Neogene Stratigraphy (cf. Rio et al. 1997), the integrated biostratigraphic result suggests a Late Langhian-Early Serravallian age for the base of the Lauro Formation.

In the previously described Lauro facies L1b, resting on Cretaceous substratum at the Crocifisso Varano locality, the abundant planktonic foraminifers consists of *Globoquadrina dehiscens*, *Globorotalia mayeri*, *Globorotalia siakensis*, *Globigerinoides bisphericus*, *Globigerinoides trilobus*, *Globigerina bulloides*. No *Orbulina* or *Preorbulina* spp. have been observed. Benthic foraminifers are abundant and well represented, and mainly consists of *Uvigerina* spp. and *Siphonina reticulata*. Such an assemblage suggests a pre-Langhian age.

Chalks of Crocifisso Varano contain moderately preserved, abundant calcareous nannofossils. The assemblage consists of *Calcidiscus leptoporus*, *Coccolithus miopelagicus*, *Coccolithus pelagicus*, *Helicosphaera carteri*, *Helicosphaera mediterranea*, *Calcidiscus premacintyrei*, *Sphenolithus heteromorphus* and *Sphenolithus moriformis*. No *H. walbersdorfensis* and *H. ampliaperta* have been observed. The presence in the calcareous nannofossil assemblage of *S. heteromorphus* in the absence of *H. ampliaperta* clearly indicate the Zone CN4 of Okada & Bukry (1980) biostratigraphic scheme, corresponding to the first part of Zone MNN 5 of Fornaciari et al. (1996), which is Langhian in age.

Samples from the higher part of the L2 facies in the Coste Pozzone section, where a pure micritic interval occurs, yield a calcareous nannofossil assemblage that consists of *H. walbersdorfensis* and *Reticulofenestra pseudoumbilicus*, whereas *C. premacintyrei* is lacking. This assemblage can be referred to the Zone MNN 7 of Fornaciari et al. (1996). The presence of *Orbulina* spp. in the planktonic foraminiferal assemblage refers the samples to an interval younger than the N9 Zone of Blow (1969). Both foraminifers and nannofossils are thus indicating a Serravallian age for this facies.

Samples from facies L3a yielded a moderately preserved calcareous nannofossil assemblage. The presence of *R. pseudoumbilicus*, *C. premacintyrei*, *C. leptoporus*, *Syracosphaera pulchra* and *H. carteri* indicate the zone MNN 8b of Fornaciari et al. (1996).

Samples from the matrix of facies L3c (Fig. 2) yielded rich and moderately preserved planktonic foraminiferal microfauna consisting of *Globigerina bulloides*, *Globigerina decoraperta*, *Globigerinoides bulloideus*, *Globigerinoides gomitulus* and *Globigerinoides fragilis*. Benthic microfauna, rich as well, contains *Uvigerina rutila*, *Florilus boueanum*, *Bolivina* spp., *Asterigerinata planorbis*, *Robulina rotulata*. Such an assemblage can be referred to a general Tortonian age. The calcareous nannofossil assemblage consists of a poorly preserved nannoflora with *R. pseudoumbilicus*, *Discoaster pentaradiatus*, *Calcidiscus leptoporus*, *Calcidiscus macintyrei*, *Syracosphaera pulchra*. Based on the absence of *Amaurolithus* spp. and *Discoaster hamatus*, these samples can be referred to the CN8–CN9a Zones of Okada and Bukry (1980) of Tortonian age.

Both foraminifers and nannofossils data are in good agreement with the previous finding by D'Alessandro et al. (1979; sample MS3, p. 102, Tab. 1), who observed a planktonic foraminiferal assemblage consisting of *Globigerina apertura*, *Globigerina decoraperta*, *Globigerina falconensis*, *Globigerina nephentes*, *Globigerina quinqueloba*, *Globigerinoides obliquus*, *Globigerinoides ruber*, *G. trilobus*, *Globoquadrina altispira*, *Neogloboquadrina acostaensis*, *Globorotalia humerosa*, *G. mayeri*, *Globorotalia obesa*, *Globorotalia tumida plesiotumida*, *Neogloboquadrina pseudopachyderma*, *Globorotalia scitula*, *Globorotalia suterae*, *Hastigerina siphonifera*, *Orbulina universa*. Such an assemblage, observed in an interval corresponding to the upper part of the unit (Masseria Spagnoli, southern Gargano) can be referred to the *Globorotalia suterae* subzone of Iaccarino (1985), corresponding to Zone N17 of Blow (1969) (Late Tortonian).

3.2.4. Lower Messinian

Beside some very short remarks (Ricchetti et al. 1988), Messinian rocks have never been previously described in the Gargano Promontory. Lower Messinian sediments outcrop at low altitudes (5–100 m) bordering the Gargano relief to the north and to the south, and consist of a basal continental interval, followed by lagoonal-tidal sediments. Where the continental interval is lacking, Messinian unconformably lies on the upper Tortonian sediments. The sediment composition and organization closely recall the lower Messinian "Tripoli" and "Calcare di base", well-known formations of the Apennines and Sicily (Selli 1954, 1973). For this reason, we have adopted the same formational names.

Tripoli Fm. and Calcare di base Fm.

Complete successions outcrop in the northern Gargano (sections K21 and CP, Figs. 1 and 3). Here the Tripoli Formation consists of diatomites, microbialites, marls, argillites, porcellanites, chert, limestones and dolostones, alternating within (ca. 20 m).

The basal interval (ca. 7 m) overlies the Lauro Formation through a deeply incised erosional unconformity. An erosional pocket in the Coste Pozzone section (Fig. 2) is filled by a thin layer of ochraceous sands, followed by varicoloured pelites alternating with nodular and strongly cemented calcilutites with small gastropods and serpulids.

Overlying diatomites are cream coloured, porous, finely laminated and scarcely cemented and are alternated with porcellanites and microbialites (Pl. 2, Fig. 2 and 3). Marly intervals, coupled with fine-grained dolomitic grainstones, are present. Layers in the uppermost part of the unit are calcarenites rich in bivalves (mainly Pectinids). Thin chert beds (2–6 cm) occur in the middle part of the unit, hosted by diatomaceous calcarenites. In the Sannicandro section (K21 of Fig. 2), bioclastic sand bodies are organized as migrating dunes or sand waves. These carbonates are highly vacuolar due to dissolution of mollusc shells. Skeletal concentrations occur also as thin tempestites interbedded with sterile dolomicrites.

Flat-lying lower Messinian rocks are patchily exposed in a terraced area of the southern Gargano (Mattine terrace, Fig. 1). The main facies consist of silicified calcarenites with abundant ostreids, passing upward to fine grained diatomaceous calcarenites with chert nodules, containing small-sized gastropods and ostracods. The entire succession reaches about 2 m in thickness.

The Tripoli Formation passes upward, with a gradual and conformable transition, to the Calcare di base Formation. This unit consists of whitish to brownish limestones/dolostones arranged in up to 150 cm-thick, poorly defined beds. The succession is subdivided in two different facies associations.

The lower one is 5–7 m thick and consists of lime/dolostones with rare slightly undulated laminations in the lower part, evidenced by brown oxide concentrations. In the upper part, wave ripples and small- to medium-scale sand waves are common. The overlying facies association is 10–12 m thick and consists of peritidal lime/dolostones with inter-supratidal structures, as stromatolites, dessiccation cracks and mini-tepee (Pl. 2, Fig. 4).

No diagnostic nannoflora and microfauna have been observed in this succession and thus biostratigraphic attribution was impossible. An Early Messinian age is suggested by the stratigraphic position and by correlations with similar characteristic lithofacies.

3.2.5. Rignano Formation (Late Messinian?)

At the foot of the Gargano Promontory in the southern zone, there is a wide terrace (Mattine terrace, Fig. 1). This feature consists of an eroded and peneplained Cretaceous substratum, unconformably covered by lower Messinian sediments and by a younger unit, the Rignano Formation, described for the first time in the present paper. The Rignano Formation spreads over the whole northern margin of the Mattine terrace, up to the border of the slope connecting the terrace with the adjacent Gargano highland.

The Rignano Formation consists of conglomerates, which are interpreted as nearshore fan deposits. In the available geological maps (Cremonini et al. 1971; Merla et al. 1969), this succession has been mapped as Quaternary continental deposits.

The main facies consists of conglomerates in reddish sandy matrix, interbedded with whitish ostracod-bearing mudstones and microbialites. In some places, a ten-meter thick interval of well-bedded grey calcarenites occurs. Conglomerates are always sand-supported, polymodal and poorly organized, except some roughly graded intervals. Clasts are well rounded and derive from the Mesozoic substratum of the Gargano relief. The sands are partly derived from the substratum and partly by contribution of benthic organisms such as foraminifers (*Elphidium crispum* predominant), regular echinoids, gastropods and red algae (Pl. 2, Fig. 5). Most grains are cemented by isopacous marine phreatic cement, whereas micritic matrix is scarce. Microbialites with laminoid fenestral fabric and ostracod mudstones form thin (10–20 cm) lenticular layers, possibly deposited in ephemeral ponds along the strandplain. Passing upslope, this unit pinches out and interfingers with subaerial talus breccias derived from the bedrock riser.

In a peculiar outcrop near Rignano, a sump related to a deep drainage channel is exposed. The sump is infilled by conglomerates, cemented by continental crusts. This feature indicates the transgressive character of the Rignano Formation, post-dating a period of very low base level, characteristics of the Late Messinian in the Mediterranean.

Few remnants of conglomerates, resting on the Calcare di base Formation, have been recognized also at Sannicandro in the northern Gargano (Fig. 2; Pl. 2, Fig. 6).

3.2.6. The Pliocene shallow-water deposits of the Gargano

During the Pliocene the Gargano relief was already formed and continuously uplifting. During the Middle Pliocene, the lower flanks of the relief were flooded and the Gargano Promontory became an elongated island. This is demonstrated by preserved coastal onlap and shallow-water deposits, outcropping mainly at low elevation around the Promontory. To the south, the coastline was facing the Bradanic basin (foredeep of the Apennines); to the north, the coastline of the Adriatic basin was located few meters above the present-day sea level. To the west, the transition to a deeper basin connected with the Bradanic trough occurred *via* the shallow basins of the Apricena-Poggio Imperiale zone (see Par. 4.1.); to the east, in correspondence of the present-day Adriatic Sea, Pliocene marine sequences piled up, as documented by seismic profiles and wells. Along the two major borders of the Pliocene Gargano island the morphology of the coast was very different. In the southern Gargano, the coastline was confined by steep, south-verging flanks of folds, whose erosion produced talus breccias and conglomerates. In the northern Gargano, the substratum was gently north dipping, favouring the development of a shallow carbonatic-siliciclastic shelf. These morpho-structural differences produced different facies assemblage. The western and the eastern successions will not be described here, because the coastal onlap geometries on the Gargano are not outcropping. However, a brief evolution of the western area (Apricena-Poggio Imperiale) has been depicted below (Par. 4.1).

Gravina Calcarenite

In the Gargano Promontory, we adopted the same formation name used for the better-known Pliocene sediments of the southern Apulia region. In fact, the age and the lithofacies are quite similar, and other formation names are not required (Lago di Varano Formation of Cremonini et al. 1971).

Northern Gargano

The Gravina Calcarenite outcrops discontinuously between the Varano and Lesina lakes. Two different basal contacts with the Miocene substratum have been observed. 1) sub-horizontal Pliocene calcarenites onlapping the folded substratum (N-dipping); 2) para-conformable Pliocene marly calcarenites resting on top of the Messinian.

The first type of contact is characteristic of inherited structural highs, as demonstrated by reduced Miocene sediments (few meters), and by the lack of the Messinian terms. In such setting, the Pliocene transgression produced a basal interval (P1a, not plotted in Fig. 2) of yellowish, massive, bio-intraclastic packstones. The main fossils consist of corallinacean algae, bryozoans, corals, bivalves, crinoid plates, echinoid spines, serpulids and gastropods. The benthic foraminifers, especially consisting of epiphyte forms, are common, whereas planktonic foraminifers are very rare. The fossil assemblage suggests a shallow-water environment with a winnowed and hardened substrate, necessary for attachment of fixosessile epibenthos. The high concentration of frame builders suggests also the proximity of patch reefs.

The second type of contact is more common and developed both on slightly deformed or undeformed substratum. The basal facies (P1b, Fig. 2) consists of yellow marly calcarenites, thin bedded and strongly burrowed. The fossil assemblage, dominated by calcareous epibionts, suggests a shallow, slightly agitated environment, rich in sea grasses.

The middle-upper part of the unit (P2) consists of calcarenites with a variable content of marl, arranged in thick beds (1–2 m), structureless or roughly cross-laminated (large scale, low angle). Thin (2–3 cm) layered bivalves-rich tempestites are common.

The top of the unit (P3) consists of poorly cemented clayey sandstones, containing bioclasts, shallow-water bivalves and calcareous algae. The total thickness of the unit (top has been eroded) ranges between 10 and 30 m.

Southern Gargano

The Gravina Calcarenite outcrops discontinuously along a NW-SE trending belt from Apricena to Manfredonia, bordering at very low altitudes (10–30 m a.s.l.) the steep flanks of the southern Gargano, at the junction with the Apennine foredeep (Bradanic Foredeep in Fig. 1).

The base of the Gravina Calcarenite is well exposed in the southwesternmost part of the Gargano Promontory (Posta Monte Granata). Here, Mesozoic beds form a large SW-vergent anticline, which passes towards the south (ancient seaward) to a more symmetrical syncline. Despite their overall flat position, Pliocene sediments display significant facies variations. Adjacent to steep flanks of the anticlines they form a body of coarse talus breccias in sandy matrix, deriving from the erosion of the Jurassic layers. These deposits constitute a back-shore facies, the rockfall and talus slope debris that accumulated at the margin of the bedrock riser (see Gupta & Allen 1999). The breccias pass laterally towards the SW to a tapering wedge of pebbly calcarenites. Several tens of meters to the south (seaward), the coarse-grained bodies interfinger with well-sorted bio-calcarenites, which are interpreted as distal shoreface-inner shelf facies. Calcarenites display an erosional base on the folded Jurassic beds and contain abundant clasts deriving from it. In addition, the flattened upper surface of the Mesozoic rocks is sometimes reddished and strongly bored by lithodoms. Thus, a shallow-water environment established on a Mesozoic substratum previously subaerially exposed and then terraced by wave-cut.

These facies pass upsection to bio-intraclastic calcarenites rich in shallow-water foraminifers and bioclasts, indicating the establishment of a carbonate shelf, similar to those depicted in the northern Gargano. In the upper part of the succession, the contribution of sterile micrite becomes higher, leading to the deposition of poorly cemented wackestone. Both bioclasts and intraclasts display micritic envelopes, suggesting a low-energy and shallow environment. The top of the outcropping succession consists of non-cemented subaerial microbial tufas and micritic algal boundstones, showing undulated calcrete exposure surfaces. The total thickness of the unit ranges between 20 and 30 meters.

Samples from the Gravina Calcarenite (Coste Pozzone, CP section in Fig. 2) yielded a rich benthic microfauna consisting of *Cibicides lobatulus, Hopkinsina bononiensis, Bulimina* aff. *corsiniana, Textularia sagittula, Elphidium crispum, Elphidium macellum, Florilus boueanum, Ammonia beccarii, Ammonia inflata, Cancris* spp. *Bolivina placentina* has been observed very rarely. This suggests a Middle to Late Pliocene age in agreement with the previous study of Borsetti (in Cremonini et al. 1971) and D'Alessandro et al. (1979).

4. Sedimentary evolution

In the Lower Miocene (Chattian-Aquitanian?), a tide-dominated carbonate platform (Torre Mileto Formation) developed along the northern border of the Gargano Promontory (Fig. 1 and Fig. 2). These *Heterostegina* and *Miogypsina* bearing carbonates are the oldest Neogene rocks of the entire Gargano Promontory. The remnants of this unit are confined to a short stretch of the northern coast (1 km).

After a break in carbonate sedimentation, transgressive continental deposition took place. A succession of alluvial conglomerates and greenish to reddish palaeosoils discontinuously cover the previous platform.

Marine conditions were re-established from the Burdigalian to the Early Langhian, when a carbonate shoal-water complex (Torre Rossa Formation) rich in *Amphistegina* developed in the northern and southern Gargano over an irregular Mesozoic substratum.

A drowning sequence recognized at the top of the Torre Rossa Formation records important paleoceanographic changes, and the demise of the Torre Rossa platform. Subsequently, the planktonic foraminiferal packstones of the Lauro Formation sedimented on the top of the drowned platform, encroaching wide areas of the northern and southern Gargano. The Lauro carbonate shelf was characterized by mixed bioclastic calcarenites and planktonic foraminiferal packstones. In the central Gargano, the Lauro carbonates sedimented within a perched basin (S. Egidio basin), whose margins established in correspondence of a reactivated Mesozoic structure (Mattinata fault auct.).

The Lauro Formation displays a winnowing- and shallowing-upward trend with some subaerial exposures toward the top, which has been dated to the latest Tortonian. This decrease of accommodation space is related to the combined effect of the aggradation of the shelf and the long term lowering of sea level (Haq et al. 1987). A sea level drop occurred in the Late Tortonian, as suggested by the occurrence of subaerial exposure surfaces, passing to a deeply incised unconformity, which separates the Lauro Formation from the overlying Messinian rocks.

After all, the maximum ingression of Miocene sediments was still controlled by inherited morpho-tectonic setting, and the coastal onlap established in correspondence of a pre-existing relief (possibly generated from the Late Eocene to the Early Burdigalian).

At the base of the Messinian units, a transitional environment developed, characterized by continental ponds and shallow-water deposits. The overlying lower Messinian sediments consist of diatomites, calcareous marls and cherty layers (Tripoli Formation), grading to skeletal packstones and peritidal carbonates (Calcare di base Formation). In the northern Gargano the lagoon-tidal sediments are scoured at the top by conglomeratic bodies or subaerially exposed until the deposition of the transgressive Pliocene deposits. In the southern Gargano, the Tripoli lies over a wide marine terrace which is covered by a complex of upper Messinian fan deltas (Rignano Formation).

Post- Miocene marine deposits are of Middle/Late Pliocene age and generally referable to as Gravina Calcarenite as already suggested by D'Alessandro et al. (1979). They consist of biocalcarenites interfingering upslope with breccias and conglomerates. In the southern Gargano, the coarser sediments are found adjacent to steep flanks of partially eroded anticlines, which formed steep cliffs indicating that the position of the coastline was essentially controlled by the previous structures.

4.1. The Apricena-Poggio Imperiale block: a different evolution

The Apricena-Poggio Imperiale block is located west of the Gargano relief (Fig. 1) and corresponds to a flat, gently NW-dipping area. It is made up of Late Cretaceous limestones (Coniacian-Santonian, Laviano & Marino 1996), unconformably covered by a thin succession of Plio-Pleistocene rocks. Paleogene rocks are absent. The Neogene evolution of this block is quite different with respect to the adjacent Gargano, and requires a brief overview. Data presented are mainly derived from the available literature (Valleri 1984; Abbazzi et al. 1996; Capuano et al. 1996) integrated with our own observations.

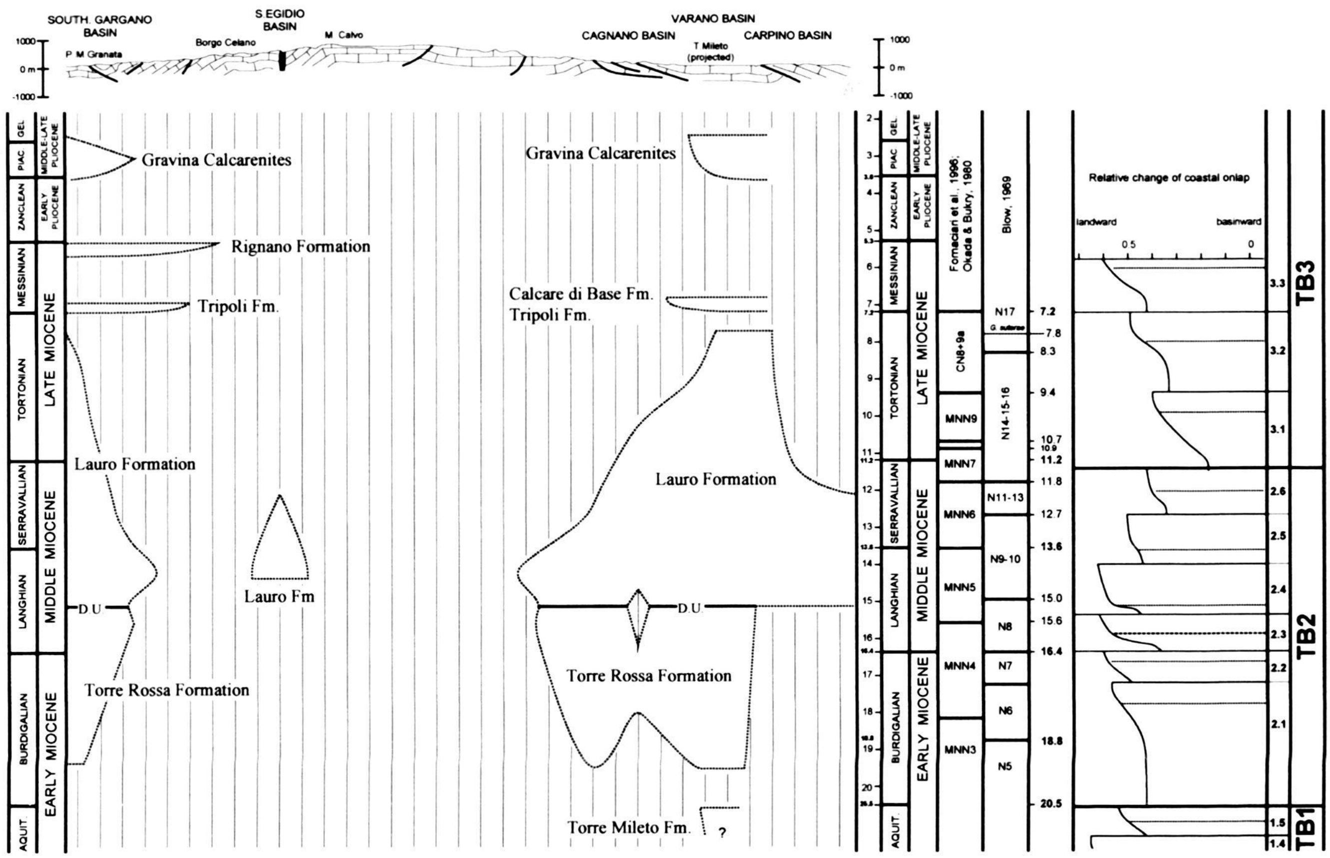

Fig. 3. SSW-NNE chronostratigraphic scheme of Gargano Miocene units, linked to a regional cross section across the whole Promontory. The main sub-basins are mentioned on the cross section (southern Gargano basin, S. Egidio b., Cagnano b., Varano b., and Carpino basin). The trace of the section is reported in Fig. 1. Vertical lines are *hiatus*, due to non-deposition and/or erosion. Dotted lines are unconformable contacts. D.U.: drowning unconformity. Age corresponding to the base of the Lauro Fm. is plotted in correspondence of the base of the 2.4 3rd cycle, whereas our biostratigraphic results indicate generically part of the Langhian (15–13.6 Ma). The extended *hiatus* corresponds to the actual relief (center) and is interpreted as *non-depositional* area, suggesting a pre-Miocene onset of the tectonic uplift (?Late Eocene to Oligocene). Note the S. Giovanni sub-basin, which developed during the strong Langhian trangression in a deeply incised embayment of the SW Gargano.
Calcareous nannofossil zonations after Fornaciari et al. (1996) and Okada & Bukry (1980). Planktonic foraminiferal zones after Blow (1969), Agip (1982). Biochronology and correlation to standard stages are according to Berggren et al. (1995) and Subcommission on Neogene Stratigraphy (SNS) (see Rio et al. 1997). Relative changes of coastal onlap after Haq et al. (1987). The timing of the Haq et al. (1987) cycles has been updated (see text for discussion).

During the Miocene the Apricena-Poggio Imperiale block formed a morphological high elongated in E-W direction as documented by the pinch-out of Miocene sediments in correspondence of the high. This structural high could be related to the compressional tectonic activity in the whole southern border of the Gargano Promontory.

The Late Messinian to Early Pliocene paleosoils document the continental deposition over a karstified and peneplained Mesozoic substratum. The paleosoils consist of ferrallitic soils very rich in endemic continental vertebrate fauna (Freudenthal 1985; Abbazzi et al. 1996).

During the late Early Pliocene (according to Valleri 1984, *Globorotalia puncticulata* Zone of Colalongo et al. 1982), this block subsided and was flooded. The main active structures were E-W and NE-SW trending normal faults. In the initial stages of the transgression, organic matter-rich, lagoonal greenish clays sedimented in the morphological lows of the inherited karst landscape. This environment was periodically connected with the open sea, as revealed by the abundant plankton content of the rocks. Subsequently, a carbonate shallow-water complex established on the articulated substratum. Reduced succession developed on the highs, and consists of nodular micrites or clean, winnowed calcarenites, depending from their position with respect to the dominant winds and currents. Thicker sand bodies with current structures were deposited in the more depressed areas. The characteristic pattern was a structural high connected with deeper lows *via* steep slopes. The steep upper slopes and the verticalized, early cemented strata slabs on the hangingwall, were often colonized by Cirripeds *(Balanus)* and corals. Debris flows and slides, often consisting of metric boulders moved downward along the slopes. Detritic intervals were also characteristic facies of the tectonically controlled morphological depressions.

During the Middle Pliocene the partial inversion of normal faults combined with a general sea level lowering, induced a diffuse unconformity.

A renewal of the subsidence re-established the carbonate production with high-energy subtidal condition during the Late Pliocene (*Globorotalia inflata* Zone of Colalongo et al. 1982). The sediments mainly consist of bioclastic sands arranged in mobile sand bodies. A filter-feeding community (pectinids and bryozoans) dominated the faunal assemblage.

Between the latest Pliocene and the Early Pleistocene, during the eastward migration of the Appenninic front, the Apricena-Poggio Imperiale block was tilted to the north and was incorporated in a deltaic clastic coast with regressive trend (Capuano et al. 1996). During the Pleistocene, the area was part of a braided alluvial system, draining the Appenninic chain.

In the Late Villafranchian the area definitively emerged, as revealed by a rich continental fauna discovered in the rejuvenated karst network (Abbazi et al. 1996).

5. Morpho-tectonic control and Sequence Stratigraphy

The hierarchy of the recognized unconformities results from the different scales of the active processes, from basin wide to local. Climato-eustatic fluctuations controlled the sedimentary cycles and, therefore, the evolution of stratigraphic units: the main unconformities of the Gargano Promontory are correlatable with unconformities recognized in wide areas of southern Italy, unless their different tectonic settings. Pre-Miocene morphology controls the horizontal (landward) extent of onlapping marine sediments and, therefore, the basin shape. Local tectonic structures, active during sedimentation, influenced the geometry of the sub-basins, and produced a number of minor unconformities, imposing strong lateral variation on the facies at the basin margins. This results in the narrowing of the sub-basins, separated by emerging ridges.

5.1. Sequence stratigraphic evolution

In Figure 3 we have correlated the described sedimentary cycles to a chrono- and sequence-stratigraphic framework. The chronostratigraphic scheme is according to Berggren et al. (1995), except for the Langhian/Serravallian boundary, approximated by the Last Occurrence of *S. heteromorphus*, which is the closest biostratigraphic event (see Rio et al. 1997). In Figure 3 the relative changes of coastal onlap by Haq et al. (1987) are also plotted. We recalibrated the sequence boundary ages *via* first order calibration of the biostratigraphic events to the Cande & Kent (1995) magnetostratigraphy according to Berggren et al. (1995). Thus, numerical ages of cycle boundaries and therefore their duration are different with respect to the one of Haq et al. (1987).

Since we are dealing with sedimentary cycles in a platform environment, the sedimentary archive recorded only the late transgressive and the highstand periods. Early transgressive intervals have been only patchily preserved.

1) The base of the Torre Rossa cycle is characterized by the presence of *Miogypsina* cf. *intermedia*. This means that the transgressive interval can be referred to the Burdigalian (higher part of the N5 and lower part of N6 zones of Blow 1969). This transgression is very important not only for the Gargano area, where the coastal onlap shifted at least 50 km landward, but also in other areas of the southern Apennines (Schiavinotto 1985; Mutti et al. 1997). Despite its extent, this transgression does not correlate to the Haq et al. (1987) curve. We can suggest two different hypotheses. The first one is that the observed transgression is a local event, while a second hypothesis envisages an additional eustatic fluctuation. In the first case, the marine ingression could be related to a subsidence pulse possibly associated to foreland subsidence. This is in contrast with the wide occurrence of this transgression in different realms (many platforms of the southern Apennines, Selli 1957; Piedmont Basin, Bicchi et al. 1994). Our second hypothesis appears more suitable because the discussed interval is poorly constrained and condensed in the type areas considered by Haq et al. (1987) (as remarked also by the authors in note 25 p. 1166). We thus suggest that the 2.1 third order cycle of Haq et al. (1987) can include two different cycles. The top of the Torre Rossa Formation is characterized by a drowning sequence, recorded only in the deepest portion of the basin. Although most of platform drowning has been usually referred to periods of fast sea level rise (e.g. Mutti et al. 1997), in our experience this is not a rule (e.g. Picotti & Cobianchi 1996). Because the drowning sequence is absent at the basin margins, we suggest that the sea level was possibly low during this event (see Fig. 3).
2) The base of the Lauro cycle in the eastern sector lies directly over the Mesozoic substratum, whereas in the other basins this base overlies the Torre Rossa Formation. Our biostratigraphic data document a Langhian age (not older than MNN5 zone of Fornaciari et al. 1996). For this reason, the base of the cycle correlates to the 2.4 3rd order cycle of Haq et al. (1987). The rise of sea level was intense during the deposition of this cycle, as revealed by the presence of the Lauro Fm. in internal domains of the Gargano (S. Egidio basin), directly on the Mesozoic substratum. In the Lauro unit, the third order fluctuations are not clearly recognizable in the field while the 2nd order trend is evident and regressive. This regressive trend culminates in the Late Tortonian, resulting in subaerial exposure surfaces and erosional scours at the top of the unit.
3) The base of the Tripoli Formation is correlated to the base of the 3.3 cycle of Haq et al. (1987), whereas the Calcare di Base Formation is not calibrated and possibly falls within the 3.3 highstand system tract.

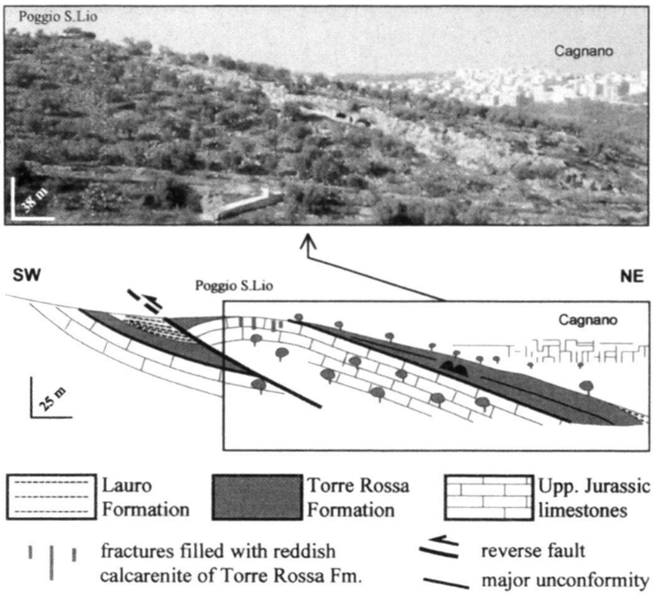

Fig. 4. Panoramic view of Poggio S. Lio outcrop and schematic cross section. The emerging ridge, corresponding to a contractional structure, separated two different Miocene sub-basins. Note the thickening of the Torre Rossa layers toward the NE sub-basin. Box indicates the part of the section corresponding to the picture (top).

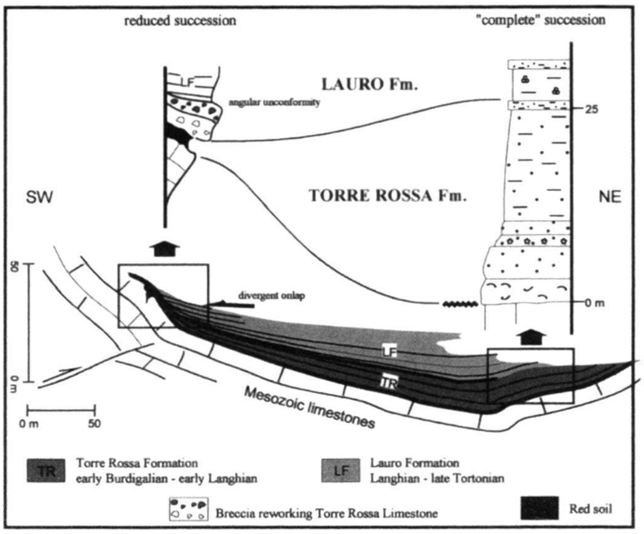

Fig. 5. Example of tectonic control on the basin margins: SW-NE cross section (vert. exagg. 2 ×) showing the Miocene complete and reduced succession of Bagno locality (northern Gargano). Note the growing stratal pattern, mainly related to active tectonics, and the physical correlation between Torre Rossa Formation and red soils. Symbols of the complete succession as in Fig. 2.

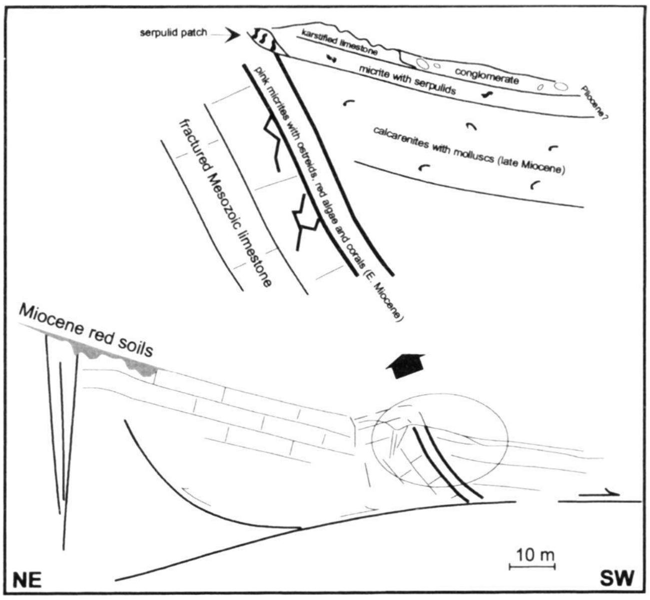

Fig. 6. Schematic section (bottom) and close up (top) on Miocene discordances in Masseria Spagnoli outcrop (southern Gargano). Note the relevant angular unconformity between lower Miocene and Tortonian layers (see text). Heavy lines corresponds to major unconformities.

After the Messinian drop in sea level, the marine terraces rimming the southern Gargano were overlain by tapering wedges of conglomerates and sands (Rignano Formation). The Early Pliocene sediments, however, never reached the fast uplifting Gargano relief, and were confined to downfaults (e.g. Apricena-Poggio Imperiale block). A new subsidence pulse produced the Middle-Late Pliocene cycle, where the absence of biostratigraphic markers prevented a better definition.

5.2. Tectonic control on the basin margins

A brief description of particular settings recognized in the field allows to better explain the difference between local unconformities and major sedimentary cycles recorded by Miocene rocks.

In Poggio S. Lio locality (northern Gargano, Fig. 1), the beds of the Torre Rossa Formation close toward a SW-verging ramp anticline (Fig. 4). At the top of the structure a diffuse karstification of the Mesozoic carbonates occurred, associated to a network of fractures filled with the chemically weathered Torre Rossa calcarenites. In front of the structure (SW), another Miocene sub-basin developed. These features indicate that the sub-basins were separated by ridges corresponding to growing structures.

In Bagno locality (southern shore of the Lake Varano) we have constructed a section across the basin margin, in order to correlate the different successions. The marginal succession consists of red soils covered by conglomerates and coarse sands, whose clasts derive from the eroded Torre Rossa Formation (Fig. 5). This interval (1.5 m thick) dips 50° to the north and is unconformably covered by sub-horizontal layers of the Lauro Formation, representing the local coastal onlap. Few tens of meters to the NE of this reduced succession, a complete succession outcrops. Here, the Torre Rossa Formation is well developed and the transition with the Lauro Formation is gradual and interpreted as drowning unconformity (marine onlap).

In Masseria Spagnoli locality (southern Gargano, Fig. 1) at the foot of a wide SW verging fold, a relevant angular unconformity separates the lower Miocene layers from the Tortonian ones (Fig. 6). Moving toward the more elevated part of the structure (NE), Miocene marine layers are replaced by red soils infilling the fractures of the Mesozoic substratum. This implies that the first Miocene sediments were chemically weathered under continental conditions, whereas at the foot of the structure the marine sedimentation continued. Thus, the compressional structure grew during the Miocene.

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REFERENCES

ABBAZZI, L., BENVENUTI, M., BOSCHIAN, G., DOMINICI, S., MASINI, F., MEZZABOTTA, C., PICCINI, L., ROOK, L., VALLERI, G. & TORRE, D. 1996: Revision of the Neogene and Pleistocene of the Gargano region (Apulia, Italy). The marine and continental successions and the mammal faunal assemblages in the area between Apricena and Poggio Imperiale (Foggia). Mem. Soc. Geol. It. 51, 383–402.

AGIP 1982: Foraminiferi Padani, Seconda Edizione (Ed. by AGIP S.p.A.).

BERGGREN, W. A., KENT, D. V., SWISHER, C. C., AUBRY, M. P. 1995: A revised Cenozoic geochronology and chronostratigraphy. SEPM spec. publ. 54, 129–212.

BICCHI, E., FERRERO, E., NOVARETTI, A., PIRINI, C. & VALLERI, G. 1994: Biostratigraphy of the Oligo-Miocene sequence of Torino Hill and Monferrato. Atti Tic. Sc. Terra 1 (ser. spec.), 215–225.

BLOW, W. H. 1969: Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. Proc. 1st Internat. Conf. Plakt. Microfoss., Geneva, 1967. Leiden: E.J. Brill, 1, 199–442.

BORSETTI, A., CREMONINI, G. & MONESI, A. 1970: Ricerche su alcuni affioramenti miocenici del Gargano. Giorn. Geol. 36, 581–598.

BOSELLINI, A., NERI, C., LUCIANI, V. 1993: Guida ai carbonati cretaceo-eocenici di scarpata e bacino del Gargano (Italia Meridionale). Ann. Univ. Ferrara, Sez. Scienze della Terra, 4, Suppl.

CANDE, S. C. & KENT, D.V. 1995: Revised calibration of the geomagnetic polarity time scale for the Late Cretaceous and Cenozoic: J. geophys. Res. 100, 6093–6095.

CAPUANO, N., PAPPAFICO, G. & AUGELLI, G. 1996: Ricostruzione dei sistemi deposizionali plio-pleistocenici del margine settentrionale dell'avanfossa pugliese. Mem. Soc. Geol. It. 51, 273–292.

CHECCHIA RISPOLI, G. 1915: Il Miocene nei dintorni di S. Giovanni Rotondo. Boll. Soc. Geol. It. 34, 277–282.

COLALONGO, M. L., DONDI, L., D'ONOFRIO, S. & IACCARINO, S. 1982: Schema biostratigrafico a Foraminiferi per il Pliocene e il basso Pleistocene nell'Appennino settentrionale e nella Pianura padana. In: Guida alla geologia del margine appenninico padano (Ed. by CREMONINI, G. & RICCI LUCCHI, F.). Mem. Soc. Geol. It. 24, suppl. D, 121–122.

CREMONINI, G., ELMI, C. & SELLI, R. 1971: Note illustrative della Carta Geologica d'Italia. Foglio 156 "San Marco in Lamis". Serv. Geol. It. 88, 5–51.

CRESCENTI, U. & VIGHI, L. 1964: Caratteristiche, genesi e stratigrafia dei depositi bauxitici del Gargano e delle Murge; cenni sulle argille con pisoliti bauxitiche del Salento (Puglie). Boll. Soc. Geol. It. 83, 285–338.

D'ALESSANDRO, A., LAVIANO, A., RICCHETTI, G., SARDELLA, A. 1979: Il Neogene del Monte Gargano. Boll. Soc. Geol. Paleont. It. 18, 9–116.

D'ARGENIO, B. 1976: Le piattaforme carbonatiche periadriatiche. Una rassegna di problemi nel quadro geodinamico mesozoico dell'area mediterranea. Mem. Soc. Geol. It. 13, 137–159).

D'ARGENIO, B., PESCATORE, T. & SCANDONE, P. 1973: Schema geologico dell'Appennino Meridionale. Acc. Naz. Lincei 183, 49–72.

DROOGER, C. W. 1993: Radial Foraminifera: morphometrics and evolution. Verhandelingen der Koninklijke Nederlandse Akademie van Wetenschappen, Afd. Natuurkunde, Eerste Reeks, deel 41. Amsterdam.

FORNACIARI, E., DI STEFANO, A., RIO, D., NEGRI, A. 1996: Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region. Micropaleontology 42(1), 37–63.

FREUDENTHAL, M. 1985: Cricetidae (Rodentia) from the Neogene of Gargano (prov. of Foggia, Italy). Scripta Geologica 77, 29–75.

FUNICIELLO, R., MONTONE, P., PAROTTO, M., SALVINI, F., TOZZI, M. 1991: Geodynamical evolution of an intra-orogenic foreland: the Apulia case history (Italy). Boll. Soc. Geol. It. 110, 419–425.

GUPTA, S. & ALLEN, P. A. 1999: Fossil shore platforms and drowned gravel beaches: evidence for high frequency sea level fluctuations in the distal Alpine foreland basin. J. Sed. Res. 69 (2), 394–413.

HAQ, B. U., HARDENBOL, J. & VAIL, P. R. 1987: Chronology of fluctuating sea levels since the Triassic. Science 235, 1156–1167.

IACCARINO, S. 1985: Mediterranean Miocene and Pliocene planktic foraminifera. In: Plankton Stratigraphy (Ed. by BOLLI, H. M., SAUNDERS, J. B. & PERCH-NIELSEN, K.). Cambridge Univ. Press, 283–314.

LAVIANO, A. & MARINO, M. 1996: Biostratigraphy and paleoecology of Upper Cretaceous carbonate successions in the Gargano Promontory. Mem. Soc. Geol. It. 51, 685–701.

LETOUZEY, J. & TRÉMOLIÈRES, P. 1980: Paleostress fields around the Mediterranean since the Mesozoic from microtectonics. Comparison with plate tectonic data. Rock Mech. 9, 173–192.

MARTINI, E. 1971: Standard Tertiary and Quaternary calcareous nannoplankton zonation. Proc. II Planktonic. Conf., Roma 1970, 2, 739–785.

MARTINIS, B. 1964: Osservazioni sulla tettonica del Gargano meridionale. Boll. Serv. Geol. It. 85, 45–93.

MASSE, J. P. & BORGOMANO, J. 1987: Un modèle de transition plateforme-bassin carbonatés controlé par des phénomènes tectoniques: le Crétacé du Gargano (Italie Méridionale). C.R. Acad. Sc. (Paris) 304, Série II, 10, 521–526.

MASSE, J. P. & LUPERTO SINNI, E. 1989: A platform to basin transitional model: the lower Cretaceous carbonates of the Gargano Massif. Mem. Soc. Geol. It. 40, 99–108.

MERLA, G., ERCOLI, A. & TORRE, D. 1969: Note illustrative della Carta Geologica d'Italia. Foglio 164 "Foggia". Serv. Geol. It. 22 pp.

MORETTI, I. & ROYDEN, L. 1988: Deflection, gravity anomalies and tectonics of doubly subducted continental lithosphere: Adriatic and Ionian Seas. Tectonics 7 (4), 875–893.

MORSILLI, M. & BOSELLINI, A. 1997: Carbonate facies zonation of the Upper Jurassic-Lower Cretaceous Apulia Platform margin (Gargano Promontory, Southern Italy). Riv. It. Paleont. Strat. 103, 193–206.

MOSTARDINI, F. & MERLINI, S. 1986: Appennino centro-meridionale. Sezioni geologiche e proposta di modello strutturale. Mem. Soc. Geol. It. 35, 177–202.

MUTTI, M., BERNOULLI, D. & STILLE, P. 1997: Temperate carbonate platform drowning linked to Miocene oceanographic events: Maiella platform margin, Italy. Terra Nova 9, 122–125.

OKADA, H. & BUKRY, D. 1980: Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). Marine Micropaleontology 5, 321–325.

ORTOLANI, F. & PAGLIUCA, S. 1987: Tettonica transpressiva nel Gargano e rapporti con le catene appennica e dinarica. Mem. Soc. Geol. It. 38, 205–224.

PAVAN, G. & PIRINI, C. 1966: Stratigrafia del Foglio 157 "Monte S. Angelo". Boll. Serv. Geol. It. 86, 123–189.

PICOTTI, V. & COBIANCHI, M. 1996: Jurassic periplatform sequences of the eastern Lombardian Basin (Southern Alps). Mem. Sci. Geol. 48, 171–219.

POIGNANT, A., PUJOL, C., RINGEADE, M. & LONDEIX, L. 1997: The Burdigalian historical stratotype. In: Miocene stratigraphy: an integrated approach. (Ed. by MONTANARI, A., ODIN, G. S. & COCCIONI, R.). Elsevier Science B.V.

RICCHETTI, G., CIARANFI, N., LUPERTO SINNI, E., MONGELLI, F. & PIERI, P. 1988: Geodinamica ed evoluzione sedimentaria e tettonica dell'avampaese apulo. Mem. Soc. Geol. It. 41, 57–82.

RIO, D., CITA, M. B., IACCARINO, S., GELATI, R. & GNACCOLINI, M. 1997: Langhian-Serravallian and Tortonian historical stratotypes. In: Miocene stratigraphy: an integrated approach (Ed. by MONTANARI, A., ODIN, G. S. & COCCIONI, R.). Elsevier Science B.V.

ROYDEN, L. 1988: Flexural behavior of the continental lithosphere in Italy: constraints imposed by gravity and deflection data. J. geophys. Res. 93, 7747–7766.

SCHIAVINOTTO, F. 1985: Le Miogypsinidae alla base della trasgressione miocenica del Monte Camposauro (Appennino Meridionale). Boll. Soc. Geol. It. 104, 53–63.

SCHUTTENHELM, R. T. E. 1976: History and modes of Miocene carbonates deposition in the interior of the Piedmont basin, NW Italy. Utrecht Micropal. Bull. 14, 1–207.

SELLI, R. 1954: Il bacino del Metauro. Descrizione geologica, risorse minerarie, idrogeologia. Giorn. Geol. 24, 3–300.

– 1957: Sulla trasgressione del Miocene nell'Italia meridionale. Giorn. Geol. 26, 1–54.

– 1973: An outline of italian Messinian. In Drooger, Messinian events in the Mediterranean. K. ned. Akad. Wetensch., 150–171.

VALLERI, G. 1984: New data on planktic foraminifera biostratigraphy from the Neogene of the Gargano peninsula (Foggia, Southern Italy). Riv It. Paleont Strat. 90, 375–406.

WINTER, T. & TAPPONIER, P. 1991: Extension majeure post-Jurassique et ante-Miocène dans le centre de l'Italie: données microtectoniques. Bull. Soc. géol. France 162, 1095–1108.

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Plate 1

Fig. 1. Oolitic grainstone passing to bioclastic grainstone with high-angle, low-scale cross lamination. Upper member of the Torre Mileto Formation. Torre Mileto section, Northern Gargano. Scale bar is 20 cm.
Fig. 2. Transgressive bio-intraclastic packstone with abundant mollusc shells (moulds). Base of the Torre Rossa Formation, Coste Pozzone section, northern Gargano. Sample PU1. Scale bar is 0.5 cm.
Fig. 3. Sharp and planar unconformity between the Mesozoic substratum and the Torre Rossa Formation. Poggio S. Lio section, northern Gargano. Hammer in vertical position as a scale.
Fig. 4. Equatorial section of *Miogypsina* cf. *intermedia* Drooger. Base of the Torre Rossa Formation, Poggio S. Lio section. Sample 21–09b. Scale bar is 0.1 mm.
Fig. 5. Benthic foraminiferal-rich interval toward the top of the Torre Rossa Formation. Torre Rossa section, sample 28–09. Scale bar is 0.5 mm.
Fig. 6. Poorly cemented packstone showing an assemblage of planktonic and benthic foraminifers. Uppermost facies of the Torre Rossa Formation, interpreted as drowning sequence (see text). Coste Pozzone section, sample 98–21. Scale bar is 0.5 mm.
Fig. 7. Planktonic foraminiferal packstone, chalk-like, at the base of the Lauro Formation. Rare fragments of benthic foraminifers are present. Coste Pozzone section, sample 98–23. Scale bar is 0.5 mm.
Fig. 8. Shell concentration, mainly storm deposit, in the middle part of the Lauro Formation. Northern Gargano, K18 section.

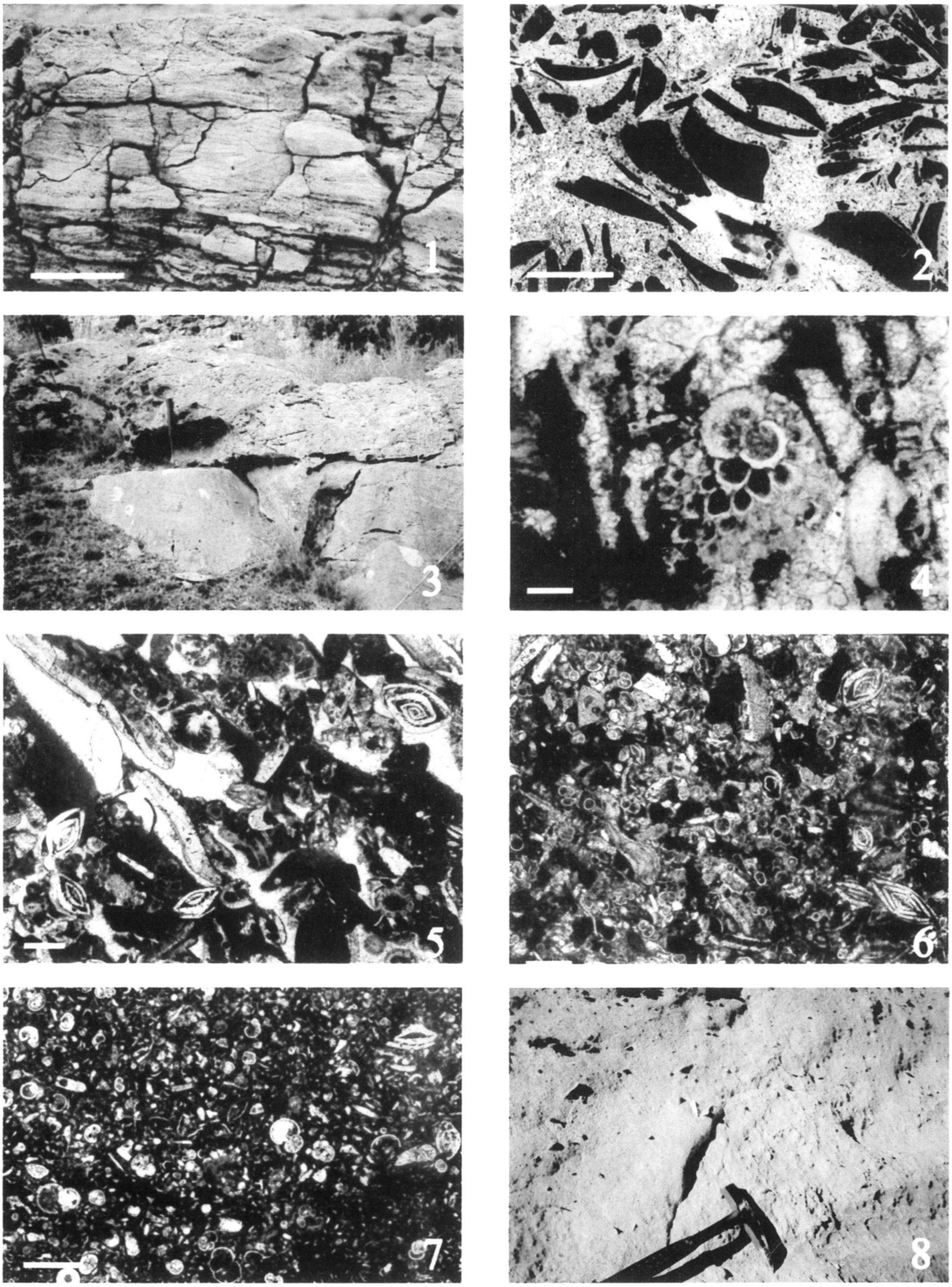
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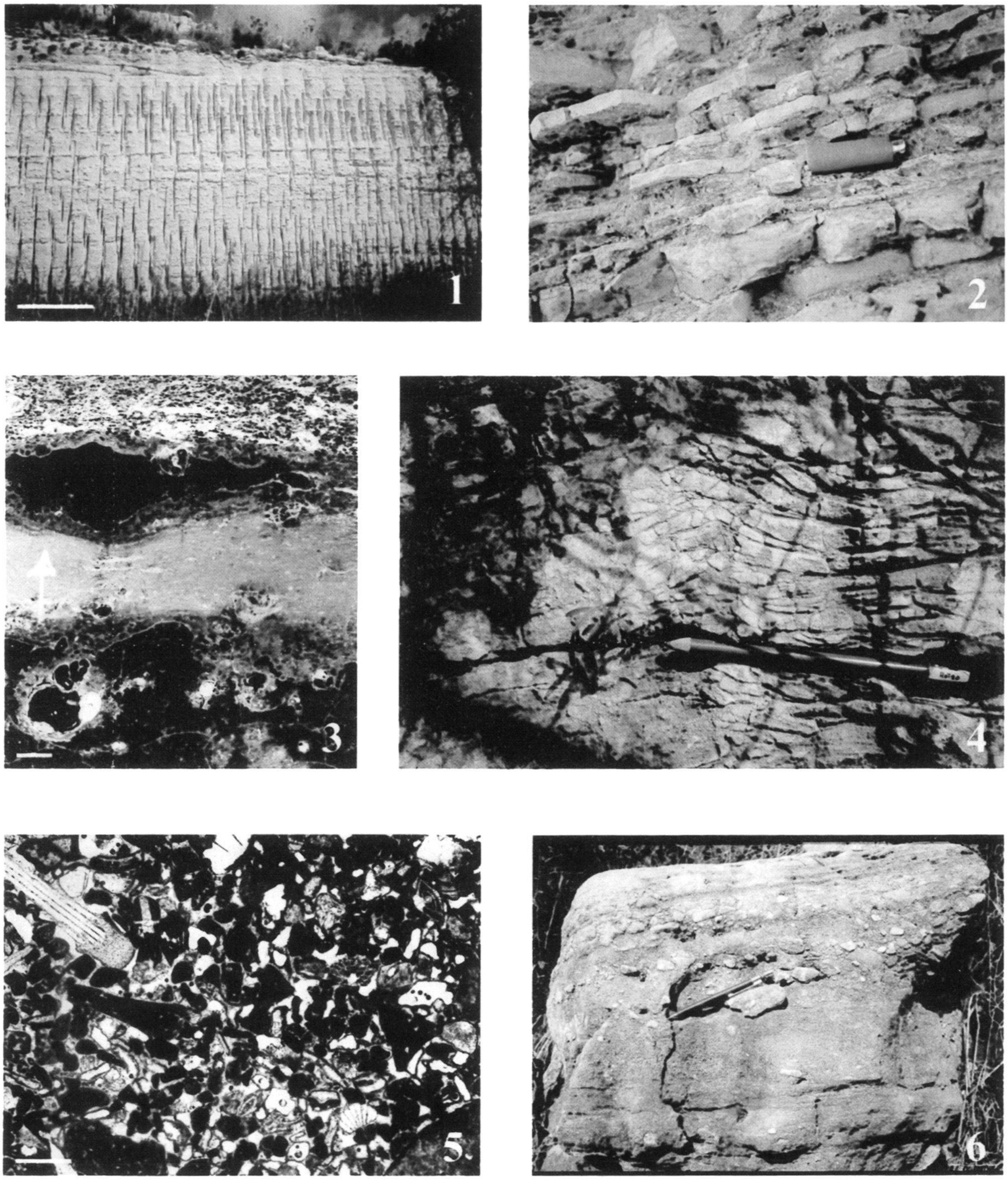
Plate 2

Fig. 1. Burrowed calcisiltites and planktonic foraminiferal packstones in the upper part of the Lauro Formation. Note the large-scale, low-angle oblique stratification, passing upward to hummocky cross bedding. Northern Gargano, a quarry in Lake Lesina zone (Piana di Sagri section). Scale bar 1 m.
Fig. 2. Chert beds comprised within diatomaceous calcarenites and thinly laminated diatomites. Tripoli Fm. (Early Messinian) of the Coste Pozzone section.
Fig. 3. Biogenic opaline chert containing gastropods, covered by thin microbialites. Tripoli Fm. (Early Messinian age) of the Coste Pozzone section. Sample PU12. Scale bar is 2 mm.
Fig. 4. Mini-tepee in the peritidal limestones of the Calcare di base Fm. (lower Messinian). Sannicandro section.
Fig. 5. Microphotograph of the calcarenitic matrix of the Rignano Formation. Note the mixing of lithoclasts deriving from the eroded Mesozoic substratum with the benthic foraminifers and echinoid fragments. Sample RCON. Scale bar is 0.5 mm.
Fig. 6. Coarse calcarenite grading to sand-supported conglomerates. Rignano Formation (lower Messinian). Sannicandro section.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