The Aptian–Albian of the Apulia Carbonate Platform (Gargano Promontory, southern Italy): evidence of palaeoceanographic and tectonic controls on the stratigraphic architecture of the platform margin

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Impressive megabreccia levels that were deposited mainly on by-pass, steep margins of carbonate platforms have usually been linked to syn-sedimentary tectonics and, more recently, to other mechanisms including sea-level low-stands. The Apulia Carbonate Platform, a main palaeogeographic domain of the Mediterranean Tethys, is characterized by huge megabreccia bodies which were deposited along its flank at various intervals during the Cretaceous. This paper deals with the stratigraphy and the genetic meaning of a peculiar early Cretaceous megabreccia level occurring on the Apulia platform margin exposed in the southern Gargano Promontory (southern Italy). The stratigraphic implications of the megabreccias within the tectonic evolution of the Apulia platform are also discussed along with a comparison with previous models. A sub-vertical blind contact separates a tectonized Berriasian shallow-water succession (Lower S. Giovanni Rotondo Limestones) from a thick rock-fall megabreccia succession pertaining to the Late Aptian–Albian Posta Manganaro Megabreccias. The contact, which is interpreted as a syn-sedimentary fault plane, is sealed by undeformed late Albian slope bioclastic sediments (lower Monte S. Angelo Rudist Limestones). Tensile tectonics downfaulted an external sector of the platform generating an articulated, steep, retreating margin. Field analysis and stratigraphic reconstructions show that the syn-tectonic wedge-shaped megabreccias partly filled an asymmetric depocenter (half-graben) resulting from the activity of a normal fault system located behind the previous prograding, low-energy, leeward margin (Montagna degli Angeli Limestones). Nevertheless, syn-sedimentary tectonics severely conditioned the composition, depositional processes and dispersal pattern of sediments supplied towards the original platform-to-basin transition (Upper Mattinata Bioclastic Limestones). This stratigraphic framework is believed to reflect a local response of the sedimentation to a late Early Cretaceous syn-sedimentary tectonic phase representing an important turning point in the evolution of the Apulia Carbonate Platform. It is supposed here that the observed tectonics, which are assumed to be related to the onset of the Austrian orogenic phase at the distant Adria plate margin, could only control the extension of the down-faulted platform. More probably, its drowning was decisively caused by the coeval global-scale Selli palaeoceanographic event (OAE 1a), which reduced the healing power of the platform by poisoning the shallow-water, sediment-donor communities. As a major causal mechanism, the OAE Selli event controlled the development of a rapid facies evolution during the late Early Aptian within the shallow-water successions of the Apulia and many other Tethyan carbonate platforms through the onset of nutrient-enriched water conditions. In this light, a stratigraphic correlation between the bases of the late Early Aptian shallow-water Orbitolina Level and the basinal Fucoid Marls is proposed. Their deposition within distinctive tracts of many platform-to-basin transitions on the southern Tethyan margin is viewed as the response of a previously pure carbonate sedimentation to the onset of environmental control on a global scale during the late Early Aptian.

KEY WORDS: Apulia Carbonate Platform; Gargano Promontory; Lower Cretaceous; syn-sedimentary tectonics; megabreccias; drowning unconformity; late Early Aptian global event.

1. Introduction

Sedimentary and stratigraphic analyses of carbonate successions deposited on platform margins and flanks represent a particularly sensitive tool in order to delineate the evolutionary trends of carbonate platforms and basins (e.g., Hine & Neumann, 1977; Enos & Moore, 1983; James & Mountjoy, 1983; Eberli & Ginsburg, 1989; Schlager, 1992). Many studies regarding the carbonate successions of the central-southern Apennines (central-southern Italy) have been carried out in this light and several parameters controlling the development of carbonate depositional systems have been recognized (e.g.,
Within the various slope deposits occurring in the Italian Mesozoic sequences, impressive megabreccia levels showing variable internal organizations, sedimentary features and stratigraphic relationships with the embedding successions have been interpreted as the ultimate results of syn-sedimentary tectonic events (e.g., Castellarin, 1972, 1982; Colacicchi et al., 1978; Bernoulli et al., 1990). More recent geological models consider the megabreccia events as a response of carbonate margins to a number of genetic processes driven by a variety of eustatic and dynamic controlling factors (Freeman-Lynde & Ryan, 1985; Paull & Neumann, 1987; Mullins & Hine, 1989; Hine et al., 1992; Grammer et al., 1993; Spence & Tucker, 1997, and references therein; Bosellini, 1998).

Owing to the slight deformation of the Apulia foreland exposed in the Gargano Promontory, the local Cretaceous megabreccias have largely preserved their original stratigraphy and depositional geometry. In spite of this and the extensive studies carried out on them (e.g., Masse & Luperto Sinni, 1987; Bosellini & Neri, 1993; Neri & Luciani, 1994; Graziano, 1994a), different age assignments, palaeoenvironmental interpretations and correlation patterns have resulted in alternative genetic and stratigraphic models (Masse & Borgomano, 1987; Bosellini et al., 1993a, b, 1994; Graziano, 1994a–c).

The present paper aims to: (1) improve the sedimentologic and stratigraphic knowledge of the meaningful late Early Cretaceous megabreccias exposed at Posta Manganaro, a key-area of the debated Gargano geology; (2) discuss and interpret the peculiar stratigraphy of the Cretaceous Apulia Carbonate Platform margin exposed in the southern Gargano Promontory; and (3) provide some stratigraphic and palaeoenvironmental elements linking the dynamics of the Apulia platform margin to the regional evolutionary trend of adjoining carbonate depositional systems within the Mediterranean Tethys.

2. Geologic framework and previous work on the investigated area

The Gargano Promontory (southern Italy) represents the north-eastern, slightly deformed sector of the Mesozoic–early Tertiary Apulia Carbonate Platform, which starting from the Neogene, acted as the main foreland of the growing Apennine thrust belt (D’Argenio, 1974; Doglioni et al., 1994) (Figure 1A). It is the only region of the Apulia foreland in which carbonate platform-to-basin transgressions ranging in time from Late Jurassic to mid Eocene are exposed on land (e.g., Pavan & Pirini, 1965) (Figure 1B).

Several lithostratigraphic schemes have been proposed for the Cretaceous of the Gargano Promontory. Some of them differ considerably as regards both the age assignments and the palaeoenvironmental interpretations of the margin-to-slope successions. A preliminary comparison was reported by Laviano & Marino (1996, fig. 2). The lithostratigraphic organization of the early Cretaceous successions adopted in this paper is based on Graziano (1994a) and subsequent studies (Figure 2).

The studied stratigraphic architecture, which is described and interpreted in Sections 3 and 4 respectively, crops out at Posta Manganaro a few km north of Manfredonia (Figure 1), along the southern edge of the low plateau that borders the regional crustal structure of the west-east trending Mattinata Fault (e.g., Doglioni et al., 1994). At Posta Manganaro, along the bends of the Manfredonia–Ruggiano road, the early Cretaceous shallow-water succession of the Apulia platform is bounded by thick megabreccias, the stratigraphy of which has been variously interpreted by authors (Figure 3).

According to Masse & Borgomano (1987) and Masse & Luperto Sinni (1987) the margin of the platform was affected by the long-lasting activity of a pre-Cenomanian syn-sedimentary normal fault, which obliterated the marginal facies and led to the deposition during the Albian of a thick syn-tectonic megabreccia body (Figure 3A). By contrast, Bosellini et al. (1993a, b, 1994), Bosellini & Neri (1993), and Neri (1993) stated that the same megabreccias, which they assumed to be Cenomanian in age, were deposited on a crudely erosive surface that originated as a gravity-collapse slide scar during a main low-stand of relative sea level (Figure 3B). According to this interpretation, the Cenomanian platform margin evolved in a manner similar to the scalloped margins described by Mullins et al. (1986) and Mullins & Hine (1989) for the Miocene–Quaternary of the Florida-Bahamas region.

Further studies have led to almost the same conclusions of those of Masse & Borgomano (1987) and Masse & Luperto Sinni (1987), but within a more articulated sedimentary and structural framework which includes, among others, the persistence of syn-tectonic marginal facies on the hinge line of a half-graben structure (Graziano, 1994a).

3. Stratigraphic and sedimentologic data

The original stratigraphy of the local early Cretaceous platform-to-slope transition may be observed along the cliff which separates the Gargano plateau from the
coastal plain (Figure 1). Only weak tectonic deformation by normal and transcurrent faults has occurred subsequently. Posta Manganaro is located where the early Cretaceous shallow-water deposits (S. Giovanni Rotondo Limestones of Luperto Sinni & Masse, 1986) laterally pass abruptly to a very coarse grained Aptian–Albian slope succession (Posta Manganaro Megabreccias of Graziano, 1994a). Both of these units are abruptly overlain by the sandy slope sediments belonging to the lower Monte S. Angelo Rudist Limestones of Graziano (1994a). This stratigraphic geometry is highly anomalous if one considers that it occurs at the back of the early Cretaceous platform margin that crops out some km eastward, at Montagna degli Angeli (Figure 1). Previous geological models dealing with this stratigraphic anomaly are illustrated in Figure 3.

A close-up view of the stratigraphy at Posta Manganaro and the location of the sampled sections are shown in Figure 4. Detailed field mapping of lithofacies associations has revealed the occurrence of a sharp sub-vertical and blind contact between a thick massive and chaotic, almost undeformed megabreccia horizon (Posta Manganaro Megabreccias) and a strongly tectonized, faintly bedded, shallow-water succession (S. Giovanni Rotondo Limestones). The contact, which locally shows a roughly erosive feature and an irregular dip with an average value of about 75°, is abruptly sealed in the field by a completely undeformed and well-bedded slope succession made up mostly of bioclastic grainstones rich in rudist and Orbitolina debris belonging to the lower Monte S. Angelo Rudist Limestones (Figure 4).

3.1. Section A

The studied section, which is about 60 m thick (Figures 4, 5), has been sampled west of the sharp
contact described above (Figure 4). Faint bedding is only locally evident in the lower 40 m which have suffered intense tectonization. By contrast, the upper 20 m are well bedded and poorly fractured. The attitude of the beds is irregular only at the base of this upper interval because of the tectonized and eroded nature of the underlying rocks.

**S. Giovanni Rotondo Limestones.** This unit consists of an almost monotonous lithofacies association made up largely of fine to medium white–greyish grainstones–packstones and subordinate greyish wackestones–packstones. Oolitic, peloidal and oncoidal fossiliferous grainstones and packstones mostly predominate; microbial and bioclastic packstones bearing small gastropods, benthic foraminifers and nodular thalli of *Porostromata* are particularly common in some levels. Despite the complex and almost pervasive fracturing, field analyses have revealed the occurrence of even and small-scale planar cross-lamination in some well-sorted medium–coarse grained sands. Grain textures and sedimentary structures clearly suggest active winnowing by traction currents above wave-base level. Early cementation by an isopachous crust of bladed to acicular crystals partly occludes the intergranular porosity filled by a later mosaic of equant crystals.

In some cases, within the peloidal and microbial lithofacies, large dissolution cavities up to 5 mm high and 10 mm wide have been found with an internal filling made up of brownish vadose silt in thin, even and graded laminations (Figure 6a). Vertical stacking of different lithofacies seems not to follow a well-defined depositional trend.

On the whole, both the sedimentary and diagenetic features suggest for these sediments relatively high
energy, open, normal marine settings locally influenced by nearby paralic environments, the occurrence of which may be inferred from early freshwater diagenetic imprinting. According to Masse & Borgomano (1987) and Bosellini et al. (1993b) this lower interval is Berriasian in age.

These deposits, which underlie a Valanginian drowning unconformity, have been attributed recently to the Monte Spigno Formation (Bosellini & Morsilli, 1997), an informal unit introduced by Cremonini et al. (1971). The nearly identical sedimentary features of the successions across the drowning unconformity and the basically older stratigraphic interpretation of the Monte Spigno Formation suggests the need to maintain the attribution of the Berriasian shallow-water deposits to the S. Giovanni Rotondo Limestones as originally defined by Luperto Sinni & Masse (1986) (Figure 2).

Monte S. Angelo Rudist Limestones. The Berriasian shallow-water facies association is erosionally overlain by an undeformed and well-bedded succession (beds are 0.1–3 m thick) showing a marked angular unconformity (Figure 7). No lithic megabreccia intercalation overlies the unconformity.

The unconformable succession is made up of an intercalation of two main lithofacies. Fine to coarse bioclastic grainstones and rudstones rich in rudists (mostly radiolitids and some caprinids), echinoids and orbitolinids debris (Figure 6b, c) largely prevail; a generally limited intraclastic fraction consisting of usually well-rounded chips up to 1 cm in diameter of chalky pelagic/hemipelagic wackestones may be present locally. The second lithofacies is made up of a thin intercalation of finely laminated bioclastic grainstones–packstones and pelagic wackestones bearing planktonic foraminifers (Rotalipora sp.) (Figure 6d); the grains usually range in diameter from silt to medium sand. Coarse bioclastic sands and gravels are frequently bioeroded and usually show micrite envelopes. Morphoscopic features indicate variable, locally high sorting and roundness values.

Even laminations (average thickness is 2 mm, but may reach 2 cm) with sharp, locally erosive bottoms and slightly graded tops were observed in the finest bioclastic sediments. Coarse sands and gravels made up of large rudist debris, show generally massive facies; the occurrence of a laminar flow regime is suggested locally by the imbricated fabric of elongate grains. The rare occurrence of sutured (stylolitic)
grain contacts strongly suggest that these sediments have essentially preserved their depositional features (e.g., scarce original content of lime mud, and grain fabric).

In the thickest beds, intraclastic rudstones in a matrix of bioclastic sands deposited as sharp-based lens-shaped levels up to 40 cm thick and 4 m long show weak normal grading in the uppermost part. The observation of both these levels and sudden vertical grain-size variations within some beds strongly suggest the occurrence of amalgamation processes, which are locally associated with small-scale channelling.

The stacking pattern of these gravitational lithofacies clearly shows the occurrence of five distinct coarsening and thickening upward cycles ranging from 1.5 to about 8 m thick (Figure 8). Thicker cycles (the first and fifth) are typically asymmetrical, being almost 80% of the whole of the cycle constituted by coarse-grained levels; by contrast, thinner cycles are typically symmetrical, showing a more gradual increase both in grain size and bed thickness (Figure 5).

Planktonic foraminiferal associations found in many thin pelagic/hemipelagic levels in the lower part of the cycles indicate a Late Albian–Cenomanian age (total range of the genus *Rotalipora*). This age is consistent with the stratigraphic implication of the caprinid-*Orbitolina* association in the coarse skeletal lithofacies. More particularly, the finding of *Rotalipora balernaensis* (Gandolfi) (Figure 9a, b) and *R. cf. ticinensis* (Gandolfi) at the base of the fifth cycle suggests the presence of the Late Albian *R. appenninica* Zone of Premoli Silva & Sliter (1995). No planktonic foraminifer indicative of younger biozones has been found.

The skeletal sands of the Monte S. Angelo Rudist Limestones were deposited during the Late Albian–Cenomanian in a gentle slope setting. This was located along an inferred leeward sandy platform margin and fed by a shallow-water source in which rudist-dominated communities proliferated (Graziano, 1994a).

### 3.2. Section B

The section investigated is about 150 m thick (Figure 10) and located about 100 m east of section A and the concealed vertical contact (Figure 4).

*Posta Manganaro megabreccias.* The lowest 110 m of the section sampled constitute the upper part of this
informal slope unit (Figure 2). It is essentially made up of chaotic, coarse, lithic megabreccias in its western outcrops (Posta Manganaro area), and of poorly stratified litho-intraclastic megabreccias and shallow-water bioclastic debris in those of the east (Montagna degli Angeli area) (Graziano, 1994a).

Lithic megabreccias at Posta Manganaro appear as chaotic deposits that lack any internal organization. Lithoclasts are poorly sorted and constituted by white or light grey angular–subangular cobbles, blocks and boulders up to 3 m across (Figure 11). Some of these show striations on their surface and are interpreted as tectonites. Matrix is virtually absent and only a small fine fraction made up of lithic floatstones in detrital packstones may occur locally. The lithoclasts often have sutured contacts and packed fabric.

Very rare and discontinuous intercalations up to 20 cm thick of fine, light brown detrital packstones barren of fossils occur within the breccias. These levels, which appear to have locally suffered plastic deformation at a later date, seem to have draped what presumably was the irregular surface of originally protruding large lithoclasts, or filled irregular open spaces within the breccias.

By contrast, the correlatable finer breccias that crop out less than 1 km to the east (i.e., basinward) of the tilted Berriasian platform assume in an apparently gradual manner both faint stratification and a detectable muddy matrix content (Figure 12). Some specimens of *Ticinella* sp. have been found in the latter.

Thin section analysis of a representative population of lithoclasts has shown that all are composed of two largely prevailing shallow-water classes of lithofacies with some minor variations: (1) oolitic and bio-peloidal grainstones, which sometimes appear laminated and/or graded; (2) bioclastic grainstones and packstones bearing cyanophytes, benthic foraminifers and small gastropods. In some cases peloids are the only constituents of grains; in others, oncoliths may occur along with some intraclasts. In a few instances, cryptalgal bindstones showing some early dissolution features have been found. Micritization processes affecting both skeletal and non-skeletal grains are quite usual, and diagenetic features suggest some distinct evolutionary paths of primary porosity which was occluded by later precipitation of equant calcite mosaics.

As regards the stratigraphy of the lithoclasts, their Early Cretaceous age assignment is well constrained by biostratigraphic (Luperto Sinni & Masse, 1987; Masse & Borgomano, 1987) and lithostratigraphic (Graziano, 1994a) data. The first in particular establishes quite a wide range of stratigraphic reworking owing to the occurrence of Berriasian clasts in (middle?) Albian slope deposits. More recently, the finding of Early Berriasian open-platform diceratid-rich limestones as large megabreccia clasts at Posta Manganaro (Cestari & Sartorio, 1995) confirm this interpretation. These stratigraphic data are relevant to the determination of the geometric reconstruction of the studied platform margin (see below).
Overall, the sedimentary and stratigraphic features of the lithoclasts suggest that megabreccias derived by the erosion of Early Cretaceous platform successions (S. Giovanni Rotondo Limestones), being open sub-tidal and possibly the peri-marginal sandy successions, are the most likely source of the clasts. Depositional features indicate that the megabreccias were deposited in a base-of-slope apron setting by repeated rock-falls and avalanche transport mechanisms. This is suggested by the almost total lack of matrix content and stratification. Lateral facies variation is thought to represent a distinct proximal to distal trend within the megabreccias which buried the retreating steep cliff cut into the Lower Cretaceous platform succession. As regards the timing of their deposition, the lack of a fossiliferous matrix prevents direct dating. Only a few specimens of *Ticinella* sp. have been found in the uppermost levels, which may be attributed to the Albian (see below).

**Monte S. Angelo Rudist Limestones.** The top of the Posta Manganaro Megabreccias is overlain by the lowermost Monte S. Angelo Rudist Limestones (Figure 10). The boundary is easy to recognize in the field (Figure 13). Megabreccias are onlapped by a well-bedded interval about 6 m thick composed of rudist and *Orbitolina*-rich amalgamated grainstones and rudstones (individual beds are up to 80 cm thick). Skeletal sands are locally graded and variously sorted and rounded. These are capped by an erosion surface, above which are channelized, lens-shaped, lithic breccias up to 8 m thick (Figure 10). These are...
Figure 7. Angular unconformity (heavy line) between the eroded Berriasian shallow-water succession of the Lower S. Giovanni Rotondo Limestones (a) and the overlying Upper Albian slope succession of the lower Monte S. Angelo Rudist Limestones (b); cliff edge south of Posta Manganaro.

Figure 8. The tilted and eroded Lower S. Giovanni Rotondo Limestones (a) is unconformably overlain (heavy line) by the lower Monte S. Angelo Rudist Limestones (b); the latter unit is organized in five distinct coarsening- and thickening-upward cycles (1–5 in figure) up to some 8 m thick. Cliff edge south of Posta Manganaro.
compositionally similar to those beneath but show faint stratification, locally normal grading, and an abundant matrix of unsorted, mostly angular rudist sands and pebbles (radiolitids and caprinids) (Figure 14).

These deposits are abruptly overlain by a succession of about 35 m of bioclastic sediments. These are completely correlatable with those in the upper part of the succession described in Section 3.1 with respect to biostratigraphy, bed attitude and compositional and sedimentary features. The stacking pattern of five coarsening- and thickening-upward cycles may also be identified, but single cycles are thicker. On the whole these sediments onlap the top of the Posta Manganaro Megabreccias (Figure 15) and, together with those unconformably overlying the shallow-water Berriasian succession, form a large scale, pinch-out geometry (see Figure 16).

Both the overall depositional geometry and the transitional, possibly conformable, boundary between the lithic megabreccias and the overlying upper Albian bioclastic deposits suggest a late Albian age for the uppermost Posta Manganaro Megabreccias.

4. Stratigraphic analysis and interpretation

4.1. Evidence of Early Cretaceous tectonics at the margin of the Apulia Platform

The physical stratigraphy of the Posta Manganaro successions and their sedimentary, palaeoenvironmental and stratigraphic features, clearly indicate that syn-sedimentary tensional tectonics controlled the evolution of the margin of the Apulia platform in the Gargano Promontory. There are several lines of evidence (see Figure 16):

(1) The occurrence of a blind, strongly tectonized sub-vertical surface cut into a Berriasian platform succession (Lower S. Giovanni Rotondo Limestones) which is tilted and bounded basinward by Aptian p.p. (?)-Upper Albian coarse megabreccias (Posta Manganaro Megabreccias) forming a wedge-shaped body at the base of a slope-apron setting.

(2) The megabreccias above, which are almost undeformed, show a distinct proximal to distal trend in a coherently oriented basinward direction. They are uniquely formed by lithoclasts derived from older Early Cretaceous shallow-water facies associations, thus implying the exhumation of deeply buried successions belonging to the Lower S. Giovanni Rotondo Limestones.
(3) The blind surface above is clearly sealed by completely undeformed Upper Albian slope deposits (lower Monte S. Angelo Rudist Limestones), which unconformably overlie the tilted Berriasian platform and conformably onlap the Albian megabreccias.

4.2. Palaeofault dip-slip calculation

Palaeo-fault mapping is hindered by both the widespread extent of the overlying Upper Albian–
Figure 15. Large-scale, low-angle onlap of the well-bedded lower Monte S. Angelo Rudist Limestones (1) on the upper Posta Manganaro Megabreccias (2); note the distinct coarsening- and thickening-upward cycles within the onlapping deposits. The tectonized S. Giovanni Rotondo Limestones (3) is present in the foreground.

Figure 16. Schematic model of the tectonically-induced stratigraphic architecture at Posta Manganaro (see text for discussion). a, shallow-water oolitic grainstones and bioclastic packstones; b, rock-fall lithic megabreccias without matrix; c, channelized debris-flow megabreccias with rudist-rich bioclastic matrix; d, rudist- and Orbitolina-rich bioclastic grainstones-rudstones and hemipelagic wackestones; e, asymmetrical coarsening and thickening upward cycles; f, symmetrical coarsening and thickening upward cycles. Apart from minor differences regarding the stratigraphy of the rudist-rich bioclastic deposits, the model fits well with that proposed by Masse & Borgomano (1987) (see Figure 3a).
Cenomanian slope deposits and an articulated array of Neogene and Quaternary normal and strike-slip faults. In spite of this, stratigraphic investigations on the successions that crop out northwest of Posta Manganaro (Figure 1) indicate that the buried fault trends about N140° (Graziano, 1994a). Field estimations of the hangingwall downthrow suggest a value of about 140 m, corresponding to the maximum measured thickness of the Posta Manganaro Megabreccias. Nevertheless, this is likely to be a conservative value because the lower boundary of the megabreccias deposited on the hangingwall is not exposed in this section.

A more accurate estimation may be attempted by integrating the procedure of Castellarin (1972, 1982), which is based on the stratigraphy of clasts derived from the footwall of rifted carbonate margins and the physical geometry observed in the field. Lithoclast stratigraphy of the Posta Manganaro Megabreccias demonstrates that towards the end of the fault activity (Middle–Late Albian; see below) the footwall source rock was exposing early Berriasian shallow-water successions (see Section 3.2 and Figures 4, 16). At that time, these had to be tectonically and erosionally exhumed from a burial depth which, at the onset of the fault activity (late Early Aptian; see below), was of the order of 700 m. This value corresponds to the thickness of the Berriasian p.p.–Early Aptian p.p. succession of the S. Giovanni Rotondo Limestones measured by Luperto Sinni & Masse (1986, fig. 4) a few km west of the location of the fault. By adding to this value the thickness of the megabreccia exposed on the hangingwall (140 m; the deposits are assumed not to be decompacted), a conservative estimation of the Posta Manganaro palaeofault downthrow is about 850 m.

4.3. Age of inception and termination of fault activity

The physical stratigraphy of the Posta Manganaro succession suggests that the fault was active during the Berriasian–Albian and abruptly deactivated before or coincident with the accumulation of the earliest rudist-rich slope deposits (Figures 4, 16). Some stratigraphic constraints allow a more precise age determination.

A distinct set of sedimentary and stratigraphic evidence recorded by correlatable successions of the Early Cretaceous platform-to-basin transition suggests that the Posta Manganaro palaeofault was active from the late Early Aptian:

(1) The prograding ‘Urgonian’ leeward margin of Montagna degli Angeli (Graziano, 1992, 1994a) (Figure 1) rapidly drowned and retreated within the Triploporella mariscana Praturlon and Palorbitolina lenticularis (Blumenbach) association Zone, being buried by the coarse deposits of the lowermost Posta Manganaro Megabreccias (Figure 2).

(2) The coeval prograding slope was suddenly drowned and draped by a wedge of basinal pelagites (a lime succession of the lowermost Fucoid Marls) which were deposited beginning in the late Early Aptian (upper part of the Chiastozygus litterarius Zone) according to the biostratigraphic studies of Luciani & Cobianchi (1994) (Figure 2).

(3) The composition of the slope sediments evolved from an almost pure pre-drowning bioclastic end-member to a successive mixed litho-bioclastic one (lower and upper members of the Mattinata Bioclastic Limestones, respectively).

These stratigraphic features identify the late Early Aptian as a major turning point in the evolution of the Apulia platform; the evolution of the Posta Manganaro palaeostructure is assumed to be strictly consistent with this. Hence, it is proposed that the Posta Manganaro palaeofault (1) was activated during the late Early Aptian (see Graziano, 1994a, c), and (2) represented one of the causal mechanisms that triggered the stratigraphic evolution of the platform-to-basin transition (e.g., the late Early Aptian drowning unconformity).

The stratigraphic features of the bioclastic deposits sealing the Posta Manganaro palaeostructure and the age of the underlying megabreccias are quite controversial points (see Figure 3). Nevertheless, as discussed below (Section 5), the effective age of these deposits has important implications with respect to the reconstruction of the Cretaceous evolution of the Apulia Carbonate Platform. In this regard, it is worth noting that the fault plane is sharply sealed by slope deposits of the Late Albian Rotalipora appenninica Zone (see Section 3.1). They correlate with similar bioclastic deposits that unconformably overlie the platform-to-slope transition through a possible erosional hiatus. This latter is associated with a major sequence boundary, the age of which is derived from conformable pelagic basinal successions and considered to be Late Albian (Planomalina buxtorfi/Rotalipora appenninica Zone of Premoli Silva & Sliter, 1995) (Graziano, 1992, 1994a) (Figure 2).

The Late Albian dating of the lowermost Monte S. Angelo Rudist Limestones provides a new biostratigraphic timing of palaeofault deactivation which is earlier than the mid Cenomanian date determined by Masse & Borgomano (1987, p. 525); furthermore it pre-dates the Middle Turonian–Early Coniacian age.
assignment given to the same deposits by Bosellini et al. (1993a) and Bosellini & Neri (1993) (see Figure 3b).

4.4. Tectonic structure of the faulted platform margin

The Upper Albian slope deposits unconformably overlying the tilted and eroded Berriasian platform (Figure 7) indicate that the late Early Aptian–Albian (i.e., syn-tectonic) shallow-water source retreated to the west of the Posta Manganaro fault escarpment. The occurrence of a master fault (or system of faults), presumably located between S. Giovanni Rotondo and Posta Manganaro, may be thus inferred, in agreement with Masse & Borgomano (1987). Stratigraphic analysis of several mid Cretaceous successions which crop out extensively to the west of Montagna degli Angeli (Figure 1) allows the occurrence of another syn-sedimentary normal fault trending almost orthogonally to that of Posta Manganaro to be inferred.

The combined action of these possibly listric growth faults resulted in the formation of a rapidly subsiding half-graben where the coarse deposits of the Posta Manganaro Megabreccias and a thick section of the overlying Monte S. Angelo Rudist Limestones could be deposited. The persistence of syn-tectonic aggrading marginal facies mainly constituted by coral boundstones (Casa Calcarulo Limestones of Graziano, 1994a) on the previous prograding margin (Figure 2) suggests that the latter acted as the crest of a tilting hangingwall block (Graziano, 1994a).

Syn-tectonic shallow-water deposits are actually poorly exposed owing to their extensive erosion. According to Claps et al. (1996), the shallow-water succession of Borgo Celano (i.e., only few km west of the Posta Manganaro palaeofault) records an abrupt shallow-upward evolution during the late Early Aptian. It is assumed here that these sediments, which were deposited near the fault, suggest a relative uplift of the footwall-tilted block, the crest of which possibly recorded ephemeral to persistent subaerial exposures. Overall, this stratigraphic framework closely resembles the facies architecture predicted by the structural models of Leeder & Gawthorpe (1987) and Bosence et al. (1998) for fault-block carbonate platforms.

5. Discussion and results

5.1 Comparison with previous models

The stratigraphic and structural interpretations of the Posta Manganaro facies architecture largely agree with those of Masse & Borgomano (1987) and Masse & Luperto Sinni (1987). Nevertheless, a more detailed chronostratigraphic estimation of the palaeofault activity (Section 4.3) and some differences regarding the general palaeogeographic assumptions have been determined. It is assumed that the late Early Aptian–Albian faults cut into the platform interior and not into its margin, and that marginal facies effectively persisted during the syn-sedimentary tectonic phase (see Section 4.4.). Furthermore, it is believed that the northwestward palaeogeographic continuation of the fault to the northern Gargano Promontory, as hypothesized by Masse & Borgomano (1987, fig. 1), needs to be treated with caution because it is well established only in the southern Gargano Promontory.

The stratigraphic framework (Section 3) and model (Section 4) presented here are to be considered alternative to those proposed by Bosellini (1989), Bosellini et al. (1993a, b, 1994), Bosellini & Neri (1993), Neri (1993), and Neri & Luciani (1994). These authors have considered the megabreccias exposed at Posta Manganaro to be Cenomanian in age. They were correlated with the Cenomanian megabreccias belonging to the Monte S. Angelo Megabreccia (Figure 3b) which crop out in many sections both in the northern (Vico del Gargano and Ischitella areas) and southern Gargano Promontory (between Posta Manganaro and Monte S. Angelo). The resulting impressive composite megabreccia body was considered to be the final product of repeated collapses of a mappable scalloped margin induced by a Cenomanian low-stand of relative sea level which Bosellini (1989), Bosellini et al. (1993a, b, 1994) and Neri (1993) genetically linked to the well-known Apulia bauxitiferous unconformity.

However, as pointed out by Graziano (1994a), the megabreccias at Posta Manganaro bounding the tilted Berriasian platform cannot be correlated with the Cenomanian Monte S. Angelo Megabreccias for the following reasons:

1. Chronostratigraphy: the top of the former is regarded as (middle–?) Late Albian in age, either within or below the R. appenninica Zone, whereas the bottom of the latter is early–mid Cenomanian in age being within the Orbitolina (Conicorbitolina) conica Zone (Figure 2).

2. Sequence stratigraphy: the former and the latter lithostratigraphic units are respectively below and above the late Albian sequence boundary of Graziano (1992, 1994a) (Figure 2).

3. Clast composition and provenance: the Posta Manganaro Megabreccias are uniquely composed of lithoclasts derived from an older, exhumed Early Cretaceous platform succession whereas the Monte
S. Angelo Megabreccias are uniquely composed of early–mid Cenomanian intraclasts derived by a pencontemporaneous bioclastic sandy margin.

Thus the Cenomanian Monte S. Angelo Megabreccias constitute a distinctive unit that interferes with the prevailing skeletal rudist-rich grainstones of the Monte S. Angelo Rudist Limestone (Figure 2).

In addition, the Cenomanian age assignment of Bosellini (1989, 1998), Bosellini et al. (1993a, b, 1994), Bosellini & Neri (1993), Neri (1993) and Bosellini & Morsilli (1994) for the relative low-stand of sea level controlling both the Apulia bauxite formation and the deposition of the related low-stand wedge of megabreccias is not in agreement with the biostratigraphic and regional data that are relevant to the argument. The papers of Crescenti & Vighi (1964), Iannone & Laviano (1980), Ricchetti et al. (1988), Simone et al. (1991), Reina (1992), Mindszenty et al. (1995), Luperto Sinni (1996) and Luperto Sinni & Reina (1996), among others, unequivocally state that the Cretaceous Apulia bauxitiferous unconformity is Turonian in age. As a result, the formation of the Cenomanian Monte S. Angelo Megabreccias cannot be genetically linked to any long-term exposure of the Apulia Platform. Rather, according to Graziano (1992, 1994a) both the Monte S. Angelo Megabreccias and the Monte S. Angelo Rudist Limestones mark the pronounced basinward migration of an unstable sandy margin during the onset of a compressive tectonics which deactivated the previous tectonics regime within the framework of the geodynamic eo-alpine evolution of the Adria plate.

5.2. Lithostratigraphy of the Early Cretaceous slope successions

According to Masse & Borgomano (1987) and Masse & Luperto Sinni (1987), the thick and massive megabreccia level that crops out at Posta Manganaro pertains to the Early Cretaceous Mattinata Limestones. This assumption is consistent with the age determination of the megabreccias but their genetic meaning and peculiar physical stratigraphy call for a distinctive lithostratigraphic attribution.

The Mattinata Bioclastic Limestones are made up of various sediment types that were re-deposited along the platform-flank by means of gravitational transport mechanisms including turbidites and debris flows. The typical intercalation of bioclastic deposits and pelagic fines characterizing the lower member of the Mattinata Bioclastic Limestones (Valanginian p.p.–late Early Aptian) reflects a slope that was being discontinuously fed with loose skeletal debris coming from the shallow-water carbonate source. On the other hand, the upper member of the Mattinata Bioclastic Limestones (Late Aptian–Albian) is characterized by, among others things, an abundant lithic fraction that is mainly organized as discrete megabreccia beds which typically pinch out basinward.

The massive megabreccias exposed at Posta Manganaro accumulated by means of rock-fall and rock-avalanche transport mechanisms at the toe of the syn-sedimentary fault plane cut into the Early Cretaceous platform succession. As noted in Section 4, these megabreccias and their lateral equivalents deposited west of Montagna degli Angeli, constitute a large wedge-shaped body. This partly fills an intra-platform half-graben structure about 6 km long, which formed at the back of the previously prograding platform margin.

Owing to the stratigraphic characteristics noted above, the Posta Manganaro Megabreccias constitute a distinct unit which correlates well with the upper member of the Mattinata Bioclastic Limestones according to both chronostratigraphic (Figure 2) and genetic stratigraphic approaches. Similarly, the pelagic tongue (Lower Fucoid Marls) which abruptly overlies the lower member of the Mattinata Bioclastic Limestones (Figure 2), possibly reflects starvation of the previously prograding clinoforms at the onset of the platform fragmentation.

5.3. Interpreting the drowning of the Apulia Platform: the global late Early Aptian event

The impact of syn-sedimentary tectonics, eustasy and environmental changes on the stratigraphic evolution of carbonate depositional systems has been widely discussed (e.g., Kendall & Schlager, 1981; Schlager, 1991, 1992; Handford & Loucks, 1993; Bosence et al., 1998). In agreement with Schlager (1992) and Bertotti et al. (1993), it is believed that a block-faulting mechanism of the type discussed in Section 4, would not drown a healthy carbonate platform. Its activity would, in fact, typically result in a growth fault bounded by a thicker section of shallow-water sediments deposited on the hangingwall with no facies change (e.g., Doglioni et al., 1999). Rather, following the basic assumptions of Schlager (1981) and Hallock & Schlager (1986) on the environmental processes leading to drowning events, a net reduction of the healing power of carbonate platforms during fault activity may produce a major lateral facies change associated with a detectable change in bathymetry on the sea floor. It is believed that this process may well explain the drowning event of the Apulia Carbonate Platform in the late Early Aptian (Section 4.3).
Several lines of evidence strongly suggest that an important environmental change affected the Apulia carbonate depositional system during this period. Some of the effects may be easily observed in both platform and basin settings. A rapid shifting from open to restricted marine conditions has been recorded from several shallow-water successions of late Early Aptian age (Luperto Sinni & Masse, 1982, 1993; Claps et al., 1996) while the platform margin retreated in the Gargano Promontory (upper part of the Palorbitolina lenticularis Zone; see Section 4.3). The marly or shaly ‘Palorbitolina’ level represents a late Early Aptian marker horizon of many Tethyan carbonate platforms (e.g., Cherchi et al., 1978; Vilas et al., 1995), which is indicative of mildly eutrophic (e.g., stressed) oceanic water (Vilas et al., 1995).

Its correlatable basinal counterpart is exposed in eastern and northern Gargano where deposition of a marly and shaly succession (Fucoid Marls) abruptly retreates the pelagic cherty limestones of the Maiolica Formation within the upper part of the Chiastozygus litterarius Zone (Cobianchi et al., 1997). This facies change is clearly associated with the globally synchronous ‘Nannoconid crisis’ event of Erba (1994) (Cobianchi et al., 1997) and is strictly coeval with the drowning of the late Early Aptian cliniforms in the southern Gargano Promontory (Section 4.3).

The basinal pelagites of the Fucoid Marls are mostly indicative of fluctuating eutrophic conditions in the sea-water (e.g., Premoli Silva et al., 1989) and typically overlie the widespread black shale ‘Selli’ level described by Coccioni et al. (1989), which is the Tethyan equivalent of the Oceanic Anoxic Event (OAE) 1a of Arthur et al. (1990) according to the biostatigraphic data of Bralower et al. (1994).

These data suggest that the late Early Aptian drowning unconformity recorded in the Gargano successions (Section 4.3) is coeval with the global palaeoceanographic event which led to the widespread drowning of many Tethyan carbonate platforms, as noted by Schlager & Philip (1990). This has been described by Föllmi et al. (1994) in the Helvetids and Castro & Ruiz Ortiz (1995) in the Prebetic Zone (south-eastern Spain), and by many others.

This late Early Aptian environmental control exerted a great influence on carbonate shallow-water as well as pelagic ecosystems, driving one of the most important global Cretaceous bio-events recognized by Kauffman & Hart (1996). According to Masse (1989), the successions of late Early Aptian age clearly show the fingerprints of a drastic environmental perturbation in the oceanic waters and several genetically linked signals may be detected in the world-wide geologic record as geochemical (e.g., major trace element spikes, rapid δ13C excursions) sedimentary (onset of black shale and phosphorite deposition) and biotic events (diversification and diversity reduction bio-events).

Following the basic assumptions above, a physical correlation between the late Early Aptian shallow-water Orbitolina-rich level and the lowermost Fucoid Marls may be proposed by means of both biostratigraphic and event-stratigraphic approaches. Bréhère & Delamette (1989) came to the same conclusion by examining the evolutionary meaning of coeval phosphorites and black shales deposited along the platform-to-basin transitions of the Western Alps.

The OAE 1a is assumed to have promoted and/or supported the accumulation of black shales in the anoxic basins, and of phosphorites or green marls, locally black organic-rich muds, on the nutrient enriched platforms. Ferreri et al. (1997) established a carbon isotope curve for an Early Cretaceous shallow-water succession of the southern Apennines. This shows that a major δ13C spike, equated to the ‘Selli’ event, occurs at the base of a marly and clayey horizon which is possibly correlatable to the Orbitolina-rich level belonging to the uppermost S. Giovanni Rotondo Limestones exposed in the Gargano.

These stratigraphic elements suggest that the environmentally stressed Apulia Carbonate Platform could have provided only a reduced amount of sediment to fill the subsiding half-graben prior to drowning. This would have resulted in the preservation of the growing fault scarp from which a considerable amount of megabreccia (Posta Manganaro Megabreccias) was delivered to the adjacent deepening intra platform basin. It is worth noting that the age of platform drowning might not necessarily correspond to the beginning of the recorded extensional tectonics, the latter possibly being older than the onset of the environmental crisis.

Many carbonate depositional systems in the Tethyan domain seem to have recorded a general instability at the onset of the Austrian orogenic phase (Graziano, 1994a). This is suggested partly by the accumulation from the late Early Aptian onwards, of widespread and almost coeval breccia horizons in distant carbonate platforms of the Adriatic plate (e.g., Sartorio, 1992; Bravi & De Castro, 1995; Fumanti, pers. comm., 1997).

It seems possible to infer that the regional to global onset of both environmental (oceanographic) and tectonic events at the end of the Early Aptian may represent a twofold impact on sedimentation of a large scale geodynamic peak linked to Earth’s endogenic dynamics. This assumption is based largely on the
observation that the global late Early Aptian event affecting both the oceans and the climate may have been caused by the well-known mid-Pacific superplume of Larson (1991a), the timing of which has been well established by Bralower et al. (1994). The environmental impact of oceanic waters containing polluting volcanogenic products on carbonate shallow-water ecosystems has been demonstrated by Vogt (1989) and Larson (1991b). Recent investigations by Weissert et al. (1998) on the carbon isotope stratigraphy of northern Tethyan carbonate platforms strongly confirm the causal link between the environmental deterioration and the Early Cretaceous platform drowning events. Their model, including marked positive $\delta^{13}C$ spikes at drowning events, suggests a different ultimate cause: an increased nutrient transfer from the continent to the northern Tethyan coastal system during intensified greenhouse climatic conditions.

It is worth noting that distinctive drowning unconformities possibly developed, as in the case of the eastern margin of the Apulia Platform, only where carbonate shoals faced upwelling currents or oceanic waters enriched by a sufficient charge of polluting products. Comparative analyses of how the westward path of the Tethyan oceanic currents (e.g. Lloyd, 1982) impacted the Lower Cretaceous palaeogeography of the Tethyan carbonate platforms seem to be particularly relevant.

The proposed scenario is that the productivity of carbonate platforms was reduced by an episode of environmental deterioration triggered on a worldwide scale by a geodynamic peak. This could have occurred several times during the Mesozoic, and might, for example, have controlled the widespread unconformities associated with the Liassic drowning event within the Mediterranean Tethys. This event is undoubtedly linked to an intense positive shift of the $\delta^{13}C$ observable in pelagic successions (Bartolini et al., 1996), to deteriorated conditions in the shallow-water environments, and to intense, coeval syn-sedimentary tectonics (e.g., Bice & Stewart, 1990; Zempolich, 1993; Santantonio, 1994) associated to the opening of the Mediterranean Tethys.

Geologic investigations dealing with the impact of eutrophic, ‘polluted’, waters on carbonate shallow-water environments during the development of Cretaceous OAEs are scarce (e.g., Jenkyns, 1991, 1995; Baudin, 1996; Drzewiecki & Simo, 1997). Nevertheless, there is much evidence (drawn from the regional geology of Tethyan carbonate platforms) to suggest that during the late Early Aptian global-drowning event, different specific responses in terms of vertical facies succession may be noted along distinctive tracts of the northern and southern Tethyan margins respectively. A similar palaeogeographic partition has been noted by Carannante et al. (1997) in the Senonian rudist-bearing foramol-type open shelves that developed along the opposite margins of the Tethyan domain. This suggests the occurrence of a persistent, time-independent driving control affecting the carbonate facies successions during the Cretaceous.

6. Conclusions

Stratigraphic analysis of the Lower Cretaceous facies architecture exposed in the Gargano sector of the Apulia Carbonate Platform margin has enabled the recognition of a twofold driving control on its evolutionary development. At the end of the Early Aptian, syn-sedimentary tensile tectonics, possibly related to the onset of the Austrian orogenic phase on the distant Adria plate margin, severely affected the platform margin. This event, coupled with a decisive coeval global-scale palaeoceanographic crisis, the OAE ‘Selli’ event, triggered the development of a marked drowning unconformity by reducing the ‘healing power’ of the shallow-water source of sediments.

This turning point in the evolution of the Apulia Platform correlates well with a marked environmental deterioration of oceanic waters, which led to a rapid turnover of marine biotas and a world-wide temporary or permanent termination of many carbonate depositional systems. In this light, the widespread deposition, beginning in the late Early Aptian, of black shales, phosphorites and marly, sometimes black, bituminous sediments in the Tethyan realm may be viewed as a response of the carbonate platforms and basins to major ‘pollution’ by fertile, nutrient enriched and/or anoxic conditions in the water column.

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