Rivista Italiana di Paleontologia e Stratigrafia | volume 110 | no. 1 | 1 pl. | pp. 345-355 | April 2004

TRANSITION FROM CARBONATE PLATFORM TO PELAGIC DEPOSITION (MID JURASSIC-LATE CRETACEOUS), VOURINOS MASSIF, NORTHERN GREECE

NICOLAOS CARRAS[1], MILVIO FAZZUOLI[2] & ADONIS PHOTIADES[1]

Received December 19, 2002; accepted October 23, 2003

Key-words: carbonate platform, neptunian dyke, laterite, unconformity, pelagic sediments, ophiolites, radiolarites, Jurassic, Cretaceous, Vourinos, Greece.

Abstract. A Jurassic-Cretaceous carbonate succession crops out along the Zyghosti Rema, Kozani (Northern Greece). The substratum consists of the ophiolitic succession of the Vourinos Massif (Pelagonian Domain): serpentinites tectonically overlain by basalts, with thin lenses of radiolarian cherts of middle Bathonian age. The contact with the overlying Jurassic limestones is tectonic. Eight informal units have been distinguished within the Mesozoic limestones, from the base upwards. (A) bioclastic, intraclastic and oolitic packstone (Callovian-Oxfordian). (B) bioclastic packstone and coral boundstone (Oxfordian). (C) bioclastic and oncoidal wackestone with *Clypeina jurassica* (Oxfordian-Upper Kimmeridgian). (D) (Upper Kimmeridgian- Portlandian): oncoidal packstone and rudstone (facies D1); intraclastic and bioclastic grainstone and packstone (facies D2); neptunian dykes with intraclastic and bioclastic wackestone and packstone filling (facies D3); neptunian dykes with Fe-Mn rich laterite filling and with pink silty filling of early Late Cretaceous age.

An unconformity surface, due to emersion and erosion of the platform during the latest Jurassic-Early Cretaceous, is overlain by (E) intraclastic, bioclastic packstone and grainstone (Cenomanian). (F) massive body of debrites with coral, echinoderm, algae and rudist large clasts (facies F1) (Cenomanian); turbiditic beds of bioclastic, intraclastic and lithoclastic rudstone and grainstone (facies F2). (G) thin bedded bioclastic mudstone and wackestone with planktonic foraminifers and radiolarians, alternating with turbiditic beds of bioclastic, intraclastic packstone and rudstone and with conglomeratic levels and slumped beds of the previous turbidites (upper Santonian-lower Campanian). (H): bioclastic packstone with planktonic foraminifers (facies H1) (lower Campanian - ?Maastrichtian); amalgamated turbiditic beds of bioclastic wackestone and packstone with planktonic foraminifers (facies H2); turbiditic beds of bioclastic packstone and rudstone (facies H3).

These features allow to recognise the following sequence of events: 1) development of a carbonate platform in the Middle and Late Jurassic; 2) its overthrusting onto the ophiolites and its emersion starting from latest Jurassic time, with erosion and deposition of laterites; 3) marine transgression on the Jurassic platform and on the ophiolites during the early Late Cretaceous, and 4) extensional tectonism and platform demise starting in the Cenomanian, with sedimentation of gravity flows and turbidity currents deposits from the Cenomanian to the Campanian-?Maastrichtian.

Riassunto. Nella regione di Kozani (Grecia settentrionale) lungo il corso dello Zyghosti Rema affiora una successione calcarea del Giurassico e Cretaceo. La successione poggia tettonicamente sulle serpentiniti del Massiccio del Vourinos e su livelli lenticolari di radiolariti del Bathoniano medio. La successione calcarea è stata suddivisa in otto unità informali hanno permesso di evidenziare: lo sviluppo di una piattaforma carbonatica nel Giurassico medio e superiore, il suo sovrascorrimento sulle ofioliti e la sua emersione a partire dal Giurassico sommitale, con erosione e deposizione di lateriti, una trasgressione marina all'inizio del Cretaceo superiore sui calcari giurassici e sulle circostanti ofioliti, una tettonica distensiva a partire dal Cenomaniano, che ha portato alla deposizione di depositi grossolani da flussi gravitativi e di torbiditi dal Cenomaniano al Campaniano-?Maastrichtiano.

Introduction and geological setting

In the Vourinos area near Kozani, in Western Macedonia (Northern Greece), the metamorphic "Para-autochthonous unit" (mainly marbles of Late Triassic-Early Jurassic age) of the Pelagonian Nappe is overthrust by the ophiolitic unit of the Vourinos Massif (Celet & Ferrière 1978; Mountrakis 1984; Vergely 1984, Bonneau et al. 1988), consisting of an ultramafic subunit at the base, overthrust by a basaltic subunit with scattered lenses of radiolarian cherts at its top.

In the study area, Zyghosti Rema and surroundings near the Lefkopighi Village, a carbonate platform succession of Late Jurassic age crops out above the basaltic subunit. Upper Cretaceous neritic limestones un-

1 I.G.M.E., Messoghion 70, 11527 Athens, Greece. E-mail: nicarras@in.gr; fotiadis@igme.gr
2 Dipartimento di Scienze della Terra, Università di Firenze Via La Pira, 4, 50121 Firenze, Italy. E-mail: milvio@dicea.unifi.it

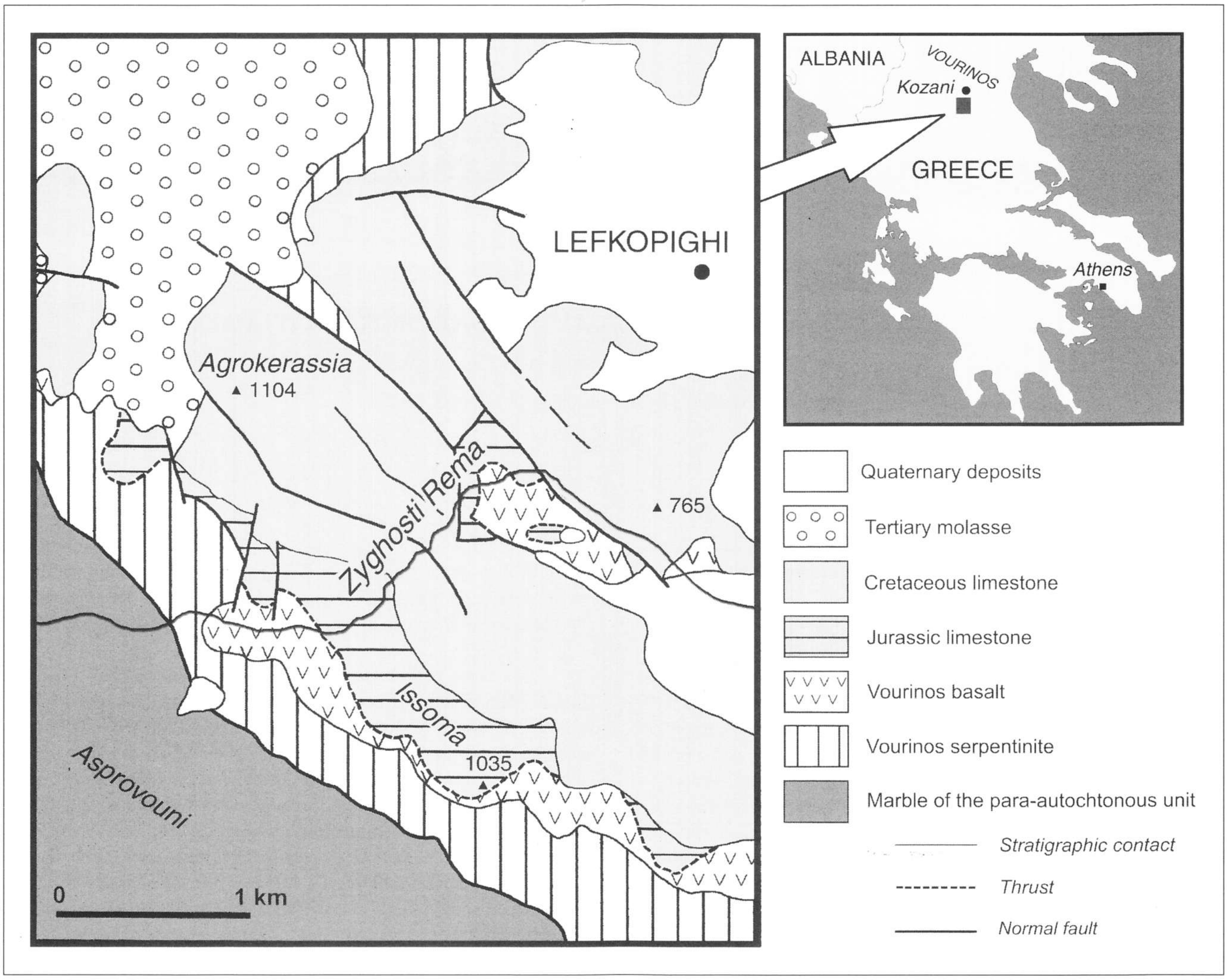


Fig. 1 - Geological sketch map of the Zyghosti Rema area, Kozani District.

conformably overlie both the ophiolitic sub-units and the Upper Jurassic succession (Brunn et al. 1972; Bortolotti et al. 2000; 2001; 2002) (Fig. 1). The contact between ophiolites and radiolarites and the overlying shallow water Jurassic limestones is intensely tectonised. The contact has been considered as stratigraphic, because of the inferred Middle Jurassic age of the radiolarites, the inferred conformable contact with the overlying limestones and the Middle -Late Jurassic age of corals occurring at the base of the carbonate succession (Brunn et al. 1972; Anastopoulos et al. 1980; Mavridis & Kelepertzis 1993). According to Brunn et al. (1972), the deposition of the radiolarites was followed by emersion of the ophiolites and then by marine transgression and deposition of the shallow-water limestones.

The aim of this paper is to describe the stratigraphy of the Jurassic-Cretaceous carbonate succession in the Zyghosti section and to trace the evolution of the carbonate platform with the main focus on its formation and demise.

The stratigraphic succession

A stratigraphic section of carbonate rocks, several hundred metres thick, is well exposed on the road running along the northern side of the Zyghosti Rema (Fig. 1). From the analysis of 92 rock samples, eight main informal lithostratigraphic units are defined, namely (from base upwards): A, B, C, D of Jurassic age, unconformably overlain by E, F, G, H of Cretaceous age (Fig. 2). The ophiolitic substratum is well exposed north of the road, where it consists of a few metres of radiolarites on top of a thick succession of MOR basalts.

The ophiolite unit

In this unit, we analysed only the radiolarian cherts, that stratigraphically overlie the basalts.

Radiolarian chert

The radiolarian chert crops out for a maximum thickness of 6 m and consists of bioclastic siliceous pack-

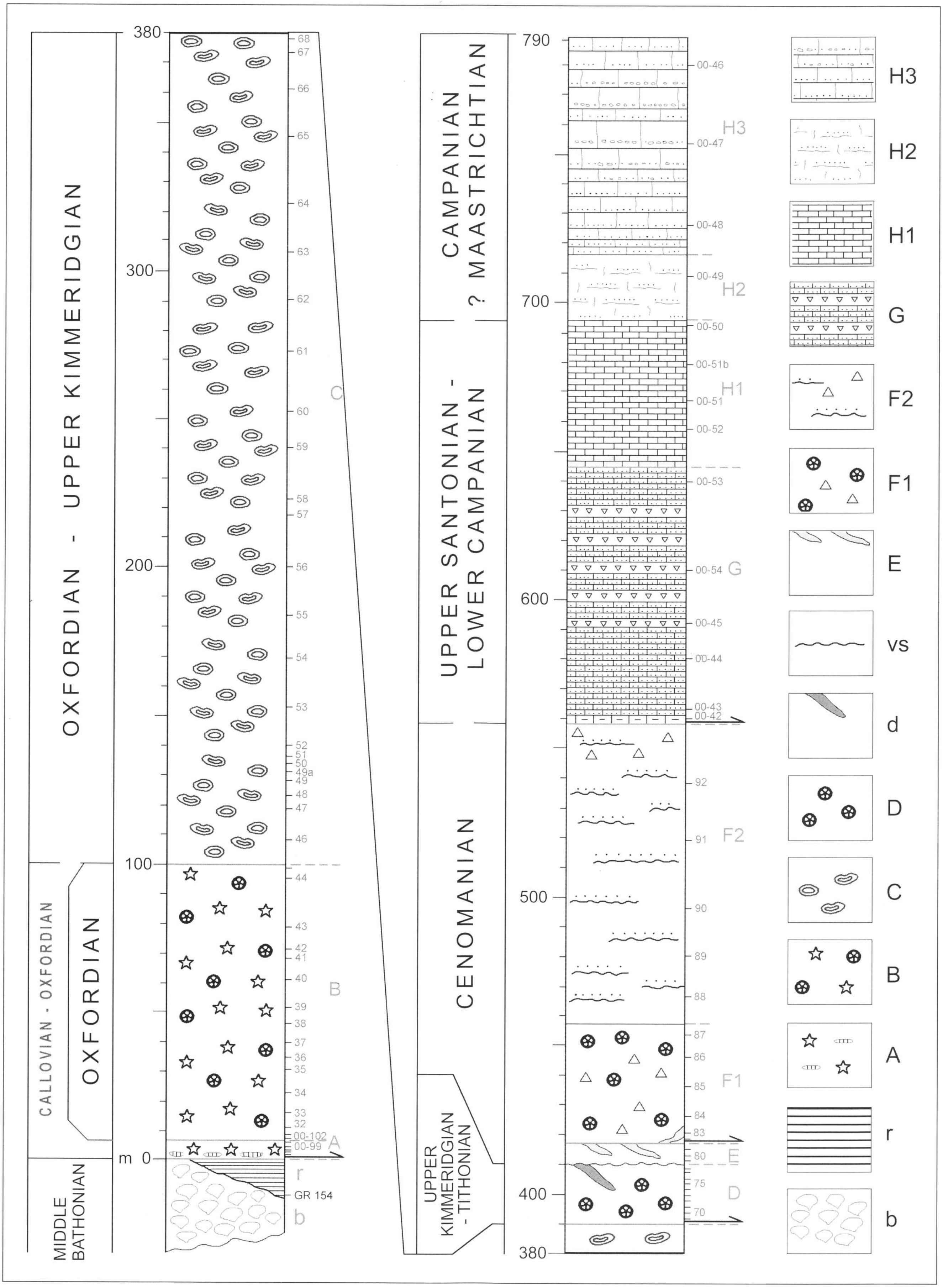


Fig. 2 - Stratigraphical section of Zyghosti Rema: b - MOR basalts; r - radiolarian chert; A - Unit A; B - Unit B; C - Unit C; D - Unit D ; d - neptunian dyke with lateritic filling; US - unconformity surface; E - Unit E with neptunian dykes ; F1 - facies F1 of the Unit F ; F2 - facies F2 of the Unit F; G - Unit G; H1 - facies H1 of the Unit H; H2 - facies H2 of the Unit H; H3 - facies H3 of the Unit H.

stone. The beds are 2-5 cm thick, red in the lower part and greenish at the top of the succession. The age is mid Bathonian (sample GR 154) based on the presence of the radiolarians *Stylocapsa oblongula* (Kocher) and *Stylocapsa tecta* Matsuoka (Chiari & Marcucci, in press). The deposition setting was a relatively deep ocean basin, below the local carbonate compensation depth (CCD) (Garrison & Fischer 1969; Bosellini & Winterer 1975). Variations in the rates of biological productivity and local redeposition of calcareous and siliceous sediment may have strongly influenced the sedimentary pattern (Baumgartner 1987; Aiello & Hagstrum 2001).

The contact of ophiolites with the Jurassic limestones

The contact of the Jurassic limestones with the underlying ophiolites and radiolarites is always a thrust surface with shear structures. This is confirmed also by observations in the area surrounding the Zyghosti section (Bortolotti et al. 2002). Here, along the contact between the ophiolites and the overlying limestone, the unit A is present only in some places, elsewhere it was tectonically removed and the ophiolites are overlain by the units B or C.

The Jurassic succession

Unit A. Consists of decimetre-thick bedded, bioclastic and oolitic packstone and grainstone; the limestone is light grey and slightly recrystallised; rare chert nodules are present near the base and chert concretions occur scattered at the contact with the underlying radiolarites. The maximum thickness is about 10 m. The fossil assemblage is characterised by the foraminifers *Protopeneroplis striata* Weynschenk, "*Conicospirillina*" *basiliensis* Mohler, *Trocholina gigantea* Pelissiè & Peybernès, solenoporacean algae and echinoderms, commonly with syntaxial cement (Pl. 1, fig. A). The age is Callovian-Oxfordian. The depositional textures and the faunal characters are indicative of a shallow water, subtidal environment, winnowed by waves and currents, probably an oolitic-type margin of a pericratonic isolated platform (Tucker 1985; Read 1985). Locally the underlying radiolarian unit tectonically includes thin tectonic slivers of fenestral oolitic packstone, possibly detached from the overlying carbonate thrust sheet during the overthrusting on the ophiolitic unit, of deposition setting similar to that of A. The contact with the overlying unit B is conformable.

Unit B. The facies of unit B consists of grey massive bioclastic packstone and boundstone with branched corals, some in life position, bivalves and echinoderms (Pl. 1, fig. B). Millimetre- to cm-sized dissolution cavities filled with films of sparry cement and laminated siltstone rarely occur. The unit is about 90 m thick. The fossil association is represented by corals (Brunn et al. 1972 quoted the presence of *Lochmaeosmilia* Wells), the complex *Tubiphytes morronensis* Crescenti, the worm ?*Mercierella dacica* Dragastan, the benthic foraminifer "*Conicospirillina*" *basiliensis* Mohler, echinoderms, bivalves, algae ("*Thaumatoporella*", etc.). The age is Oxfordian. The sedimentary and faunal characters point out to the development of a reef-type margin of a pericratonic isolated platform (Tucker 1985; Read 1985). The contact with the overlying unit C is conformable.

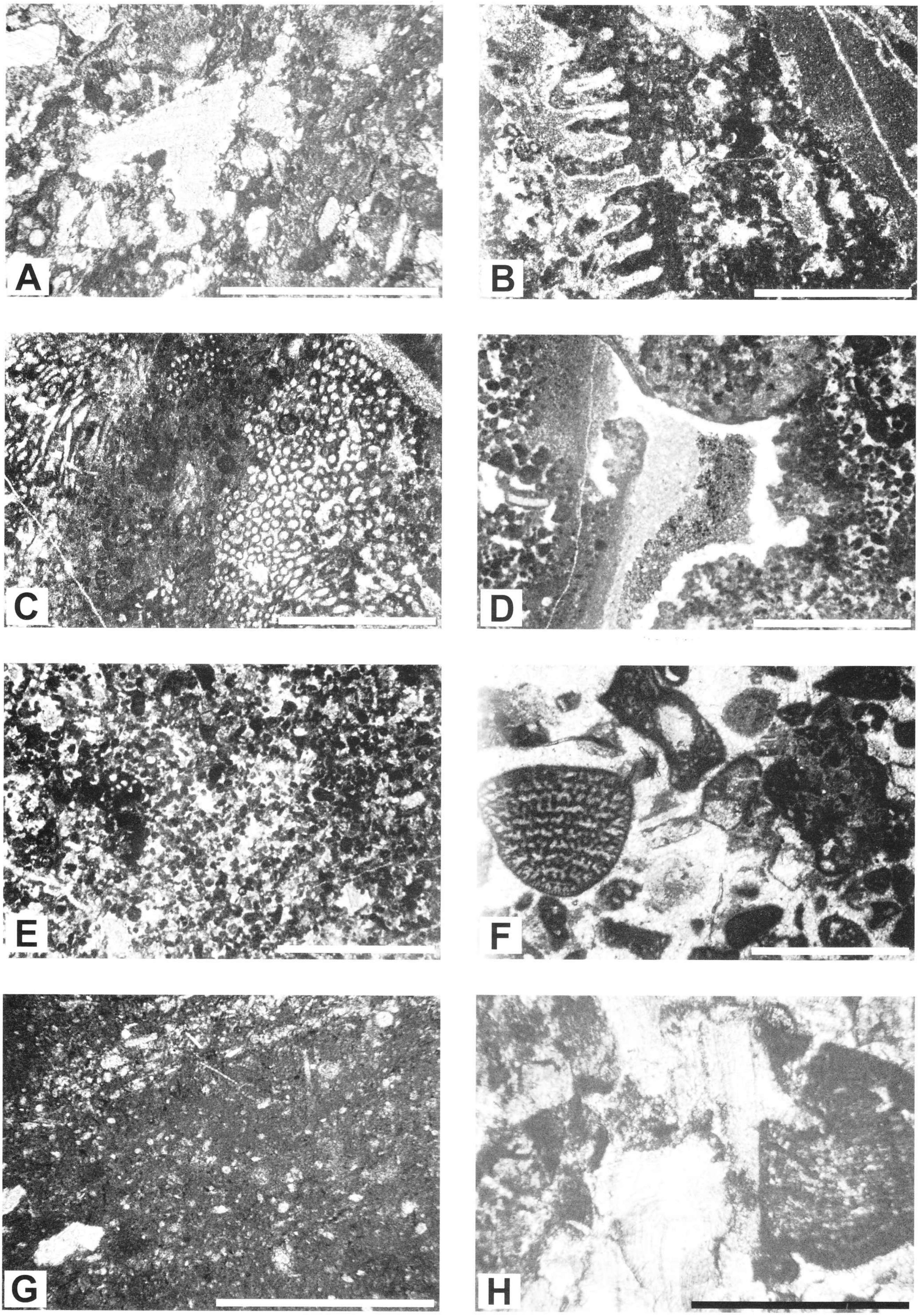
Unit C. The facies of this unit is very monotonous and consists of dark grey, massive bioclastic and oncoidal wackestone and algal boundstone (Pl. 1, fig. C). The thickness is about 290 m. Regarding the fossil association, the lower part of the unit is characterised by the alga *Salpingoporella annulata* Carozzi, the foraminifers *Parurgonina caelinensis* Cuvillier, Foury & Pignatti Morano, *Kurnubia palastiniensis* Henson, *Labyrinthina mirabilis* Weynschenk, ?*Alveosepta jaccardi* (Schrodt), the hydrozoan *Cladocoropsis mirabilis* Felix and bivalves. Some intercalations of boundstone with the algae "*Bacinella*" and "*Thaumatoporella*" are present. In the upper part, bioclastic packstone and grainstone also occur; the fossil assemblage is characterised by mixing of the previous forms with the algae ?*Clypeina delphica* Carras and *Salpingoporella* gr. *pygmaea* (Guembel), the foraminifer "*Conicospirillina*" *basiliensis* Mohler, algae Rivulariaceae and echinoderm fragments. Moreover, the alga *Clypeina jurassica* Favre appears in the uppermost part of the unit. The age is Oxfordian-Kimmeridgian in the lower and middle part of the unit and late Kimmeridgian in its upper part. The depositional textures in the lower part indicate a subtidal, restricted shelf lagoon within a pericratonic isolated platform (Tucker 1985; Read 1985; Accordi & Carbone 1992), whereas the occurrences of higher energy textures and microfossils in the upper part indicate a transitional setting between the lagoon and the platform margin. The contact with the overlying unit D is conformable.

Unit D. Within unit D three facies are distinguished; they are, from the bottom upwards:

Facies D1, about 15 m thick. It consists of whitish or pale grey, massive, locally brecciated, bioclastic, intraclastic and oncoidal packstone and rudstone with fragments of corals, echinoderms, gastropods and bivalves; some dissolution cavities with geopetal filling are present (Pl. 1, fig. D). The fossil assemblage is dominated by the algae "*Thaumatoporella*", encrusting algae "*Bacinella*", and by coral and echinoderm fragments . Facies D2 consists of light-grey, laminated grainstone and packstone with intraclasts, pellets, bioclasts (algae as *Clypeina jurassica* etc.) and small oncoids; the rock is fractured and crossed by dm- to m-wide neptunian dykes. The filling of these fractures (Facies D3) consists of dark-grey intraclastic, bioclastic and oncoidal wackestone and packstone; according to the occurrence of *Clypeina jurassica* and "*Bacinella*", its age is Late Jurassic. The facies D2 with the neptunian dykes D3 is about 5 m thick. The age of the whole unit D is late Kimmeridgian-Portlandian. Both facies D2 and D3 are crossed by mm- to cm-wide neptunian dykes; the filling is made up of Upper Cretaceous, red or pink marly mudstone and bioclastic wackestone.

PLATE 1

Microfacies of Jurassic and Cretaceous units in the Zyghosti Rema section. Bar = 1 mm. Fig. A - bioclastic, intraclastic packstone with echinoderms, foraminifers and Solenoporaceae (unit A, 00GR99); Fig. B - bioclastic boundstone with corals (unit B, 99GR44); Fig. C - bioclastic and oncoidal wackestone and algal boundstone (unit C, 99GR55); Fig. D - laminated peloidal, intraclastic and bioclastic grainstone and packstone. A dissolution cavity with geopetal filling can be seen in the centre of the photograph (unit D, facies D1, 99GR73); Fig. E - intraclastic, peloidal, bioclastic packstone and grainstone with echinoderm and rudist fragments (unit E, 99GR79); Fig. F - bioclastic grainstone with orbitolinids, foraminifers, gastropods and rudist fragments (unit F, facies F2, 99GR84); Fig. G - bioclastic mudstone and wackestone with planktonic foraminifers and radiolarians (unit G, 00GR43); Fig. H - bioclastic packstone with rudist fragments (unit H, facies H1, 00GR51).


A
B
C
D
E
F
G
H

Facies D1 originated during a short interlude of high energy reefoidal conditions; subsequently low-energy, lagoonal conditions were again established (Facies D2), as the reef margin migrated seawards. Tectonic movements, possibly heralding the latest Jurassic-earliest Cretaceous major tectonic phases (Vergely 1984; Bonneau et al. 1988) resulted in the formation of the fractures and irregularities of the sea bottom in which the wackestone and packstone of facies D3 were deposited. The dyke cavities are likely of tectonic origin, as palaeokarst features, like speleothems, have not been observed. The contact with the overlying unit E is marked by an unconformity surface.

The unconformity surface

On top of unit D is marked by the occurrence of dm–deep and m-decametre-large irregular cavities with steep walls and flat bottoms coated by mm to cm-thick films or thin pockets of reddish marly siltstone. The sharp boundaries and the rounded shape of the cavities point to a karst origin (Choquette & James 1988). This karst surface likely formed during the emersion of the carbonate platform starting in the latest Jurassic.

The Cretaceous succession

Cretaceous neptunian dyke systems

The Upper Jurassic limestones of the unit D are crossed by at least two generations of neptunian dykes, which differ in their composition; geometrical relationships between the two are not visible. The system which we consider older, for considerations at a regional scale (see later), consists of some thin fractures and reddish spots, stained by Fe-oxide and by a single cm- to dm-wide and some metres deep fissure, filled by a dark red-violet, Fe-rich (37%), lateritic silty matrix. The filling material is homogeneous, is directly adjacent to the walls of the dyke, contains small fragments of the host rock, but without gravity-driven structures. A chemical analysis of this matrix (sample 99GR74) gave the following values: SiO_2: 4.3%; Al_2O_3: 1.3%; Fe_2O_3: 37%; CaO: 33.5%; MnO: 0.75%; TiO: <0.01%; K_2O: <0.01%; Na_2O: <0.01%; MnO: <0.01%; Cr_2O_3: <0.05; NiO: <0.05 %; Co: <0.05; loss: 21.6%.

The other neptunian dyke system consists of cm to dm-large fissures filled with early Upper Cretaceous pink or greenish calcareous marine siltstone.

Unit E. This facies consists of massive, brecciated, dark grey intraclastic, peloidal, bioclastic, packstone and grainstone (Pl. 1, fig. E), with echinoderm and rudist fine-grained fragments, the foraminifer *Rotalia* sp., etc. It is crossed by abundant centimetre-thick neptunian dykes with a reddish, calcareous-marly mudstone filling. The age is (?)Late Cretaceous (Cenomanian?). The thickness is about 7 m. The textural features and fossils indicate a rather fine-grained, partly pelagic deposit in an under wave base, foreslope setting (Read 1985).

The contact of unit E with the overlying facies F1 of unit F consists of a sharp and high angle surface that could be a tectonic surface; however, some features, in particular the lack of evident shear structures and the occurrence of a mm- to cm-large dyke, made up of red, greenish and brown marly mudstone ad wackestone with some undetermined pelagic foraminifers, sandwiched between the footwall and the hangingwall, may indicate the injection of pelagic sediment within an extending palaeofault.

Unit F. Two facies can be distinguished, on the basis of grain size and sedimentary structures, within unit F; from the base:

Facies F1. It consists of a massive body of breccia. The smaller fraction of the clasts consists of bioclastic, intraclastic, lithoclastic grainstone and rudstone. The larger fragments consist almost entirely of unsorted, angular, cm-to dm-sized clasts of Jurassic limestones, fragments of Jurassic corals, gastropods and rudists. The matrix is scarce and consists of greenish, yellowish and pink intraclastic and bioclastic wackestone. The thickness is about 40 m. The fossil assemblage includes the algae *Salpingoporella pygmaea* (Guembel) and "*Bacinella*" sp., the foraminifers "*Conicospirillina*" *basiliensis* Mohler, *Rotalia* sp. and Orbitolinidae, the complex *Tubiphytes morronensis* Crescenti, coral, echinoderm, algal and rudist small fragments, gastropods, annelids: it consists of Upper Cretaceous forms mixed with Upper Jurassic forms. According with the very poor sorting and grading and to the clast-dominated texture, this facies is considered a debris flow deposit (Stow 1986); the deposition took place in a slope setting .

The occurrence of clasts originated from Jurassic rocks suggests the collapse of the platform margin, probably due to tectonics (Bosellini 1989; Accordi & Carbone 1992; Bosellini et al. 1999). The contact with the overlying facies F2 is stratigraphic.

Facies F2. It consists of dark grey, dm– to m–thick, graded, laminated and sometimes amalgamated beds of bioclastic, intraclastic, lithoclastic grainstone and rudstone (Pl. 1, fig. F). The thickness is about 110 m. The fossil association includes the foraminifers *Orbitolina (Conicorbitolina) conica* (D'Archiac), "*Valdanchella*" *dercourti* Decrouez & Moullade, rudist (Radiolitidae) and echinoderm fragments. The age is Cenomanian. Some lithoclasts may be fragments of Upper Jurassic corals. According to the sedimentary structures, the facies consists of high density turbidity current deposits, in a base of the slope setting (Stow 1986). The contact with the overlying Unit G is marked by a tectonic surface.

Unit G. This unit consists of an alternance of three facies. The first and prevailing facies consists of dark grey, dm- to m-thick, graded and laminated beds of bioclastic, intraclastic, lithoclastic wackestone and packstone (Pl. 1, fig. G) with fragments of rudists, algae, echinoderms, benthic foraminifers, planktonic foraminifers and radiolarians. The second facies consists of cm- to dm-thick beds of pink or grey, marly bioclastic wackestone with planktonic foraminifers and radiolarians. The third facies is represented by several m-thick bodies of conglomerates, sometimes with the lower part constituted by slumped beds of the first facies. Smaller clasts of conglomerates are generally angular and consist of bioclastic packstone and rudstone with colonial organisms, fragments of rudists, echinoderms and planktonic foraminifers. Larger clasts are generally rounded, up to 30 cm-large and are made up of the same dark grey bioclastic wackestone and packstone of the first facies. The yellowish matrix is calcilutitic to marly. The thickness is about 85 m. The fossils association is characterised by the planktonic foraminifers *Marginotruncana pseudolinneiana* Pessagno, *Marginotruncana* cf. *coronata* (Bolli), *Marginotruncana* cf. *angusticarinata* (Gandolfi), *Globotruncana* gr. *linneiana* (D'Orbigny), *Globotruncana arca* (Cushman), *Globotruncana bulloides* Vogler, *Rosita fornicata* (Plummer), *Dicarinella* cf. *asymetrica* (Sigal), *Globigerinelloides* sp., *Pseudotextularia* sp., *Rugoglobigerina* sp. and Heterohelicidae, the Calcisphaerulidae "*Stomiosphaera*" *sphaerica* (Kaufmann) and *Pithonella ovalis* (Kaufmann), the benthic foraminifers *Cuneolina pavonia* D'Orbigny and *Minouxia* sp. The age is late Santonian-early Campanian. Given the depositional textures, the sediments consist of an alternance of fine– to coarse–grained turbidites, sometimes deformed by slumps, of paraconglomerates (i.e. with partially consolidated clasts) (Bosellini et al. 1999), of coarse–grained debrites (Stow 1986) and of pelagic deposits; the succession was deposited at a base of the slope setting.

According to Bosellini (1989), Accordi & Carbone (1992) and Bosellini et al. (1999), similar sedimentary features suggest a platform margin retreat by downfaulting and local tectonically–induced collapse. The paraconglomerates, made up of intrabasinal turbidites, derive from the re-mobilization (cannibalisation sensu Bosellini et al. 1999) of the slope to basin deposits. The contact with the overlying unit H is conformable.

Unit H. Within the unit H three facies are distinguished; they are from the bottom upwards:

Facies H1: This facies consists of grey and pink bioclastic packstone and wackestone (Pl. 1, fig. H) in cm- to dm-thick beds, sometimes laminated, with pseudo-nodular structures marked by stylolithes. The thickness is about 48 m. The fossil association includes the foraminifers *Marginotruncana pseudolinneiana* Pessagno, "*Stomiosphaera*" *sphaerica* (Kaufmann), *Pithonella ovalis* (Kaufmann), *Minouxia* sp., Heterohelicidae, rare small undetermined benthic foraminifers, fragments of rudists and echinoderms. The age is late Santonian-early Campanian. The succession, consisting mostly of fine-grained turbidites within pelagic lime mudstones, deposited on a slope and at the base of the slope setting (Stow 1986).

Facies H2. It consists of graded and amalgamated beds, 1-3 m thick, of grey to pink, slightly recrystallised bioclastic packstone with pseudo-nodular structures marked by stylolithes. The thickness is about 20 m. The fossil assemblage includes planktonic foraminifers, the Calcisphaerulidae "*Stomiosphaera*" *sphaerica* (Kaufmann) and *Pithonella ovalis* (Kaufmann) and rare small undetermined benthic foraminifers. The age is Late Cretaceous, not older than Campanian. According to the sedimentary structures, the succession consists of high density turbidity current deposits, in a slope and base of slope setting (Stow 1986; Bosellini et al. 1999).

Facies H3. This facies consists of dm- to m-thick, graded and/or laminated beds of bioclastic packstone and rudstone (in particular with large fragments of rudists); the maximum exposed thickness is about 75 m. The fossil assemblage consists of the algae "*Thaumatoporella*", abundant rudist and rare, small undetermined benthic foraminifers. The age is Late Cretaceous, not older than Campanian. Also this succession was deposited on a slope and base of the slope setting by high density turbidity currents (Stow 1986; Bosellini et al. 1999).

Sedimentary evolution

The contact between ophiolites and Jurassic limestones

The nature of this contact is a crucial point to reconstruct the evolutionary model of the carbonate platform. From the field observations and the laboratory data, some conclusions may be drown also about the age of thrusting. The contact of the Jurassic limestones with the underlying ophiolites and radiolarites is always a thrust surface. Both Jurassic limestones and surrounding ophiolites are unconformably overlain by the early Upper Cretaceous sediments; therefore the Jurassic limestones are sandwiched between a (paleo)tectonic surface at the base and an unconformity surface on the top. The overthrusting is thus younger than the top of the carbonate platform limestones (late Kimmeridgian–Tithonian) and older than the base of the Cretaceous neritic transgressive sediments (early Aptian, see later). Regarding the provenance of the tectonic wedge constituted by the carbonate platform, this problem must be considered at a regional scale and it is beyond the aim of this paper: it will be object of a forthcoming paper (Bortolotti et al., in press).

The development of the platform: Callovian-late Kimmeridgian

The tectonic truncation at the base of the Jurassic carbonate succession does not allow to know the older units, but some informations come from some decimetre-thick calcareous tectonic slices near the top of the radiolarites, tectonically detached from the overlying carbonates. The facies consists of fenestral oolitic packstones with large, broken and recoated ooids, suggesting deposition in hyperhaline lagoons (Simone 1981; Carras & Fazzuoli 1992); this facies locally characterises the well-known Middle Jurassic "oolitic facies" of the Parnassus carbonate platforms and a late Mid-Jurassic age may be inferred (Carras & Tselepidis 2001). According to the regional features of the Tethyan platforms (D'Argenio 1976; Bosellini 1989), Units A and B represent a high energy, oolitic and then reefal, margin of a pericratonic isolated platform (Read 1985). The water depth of unit A was possibly slightly deeper than that of unit B, where small patches of branching corals in life position occurred close to the sea level, possibly indicating the progradation of the reefal margin above the oolitic bars. Upwards (unit C), this progradational trend becomes aggradational. Unit C represents the maturity of the Jurassic carbonate platform; it consists of a long-lived, thick, massive body of dark grey subtidal deposits of a shallow marine shelf. Quiet lagoonal deposition developed, as the sedimentation rate kept pace with the rate of accommodation resulting in platform aggradation. According to Sarg (1988), this geometry characterizes a Highstand System Tract. From the ages obtained for units A, B and C, we conclude that the evolution of the Zyghosti carbonate platform lasted at least 20 Myr and it can be framed into the Callovian-upper Kimmeridgian eustatic rise (Haq et al. 1987); the sequence can be considered as a Composite Sequence (sensu Mitchum & Van Wagoner 1991) or a Second-order Cycle (sensu Duval et al. 1992).

The onsetting of tectonic movements: Late Kimmeridgian -Tithonian

Facies D1 represents a short onset of high-energy reefoidal conditions: the backstepping of the high energy margin facies may be due to the small eustatic rise at the end of the Tithonian (Haq et al. 1987), but more probably was due to the first tectonic collapse of the margin and slopes of the platform (Bosellini 1989), possibly heralding the latest Jurassic-earliest Cretaceous major tectonic phases. Tectonic movements triggered also the formation of neptunian dykes and the irregularities of the sea bottom, in which calcarenites of facies D3 were deposited. Subsequently the reef margin migrated seawards, and low-energy, lagoonal conditions were re-established again (Facies D2).

The crisis of the Jurassic platform: latest Jurassic - late Early Cretaceous

The highly irregular unconformity surface reflects emersion of the carbonate platform, starting from the latest Jurassic into the Early Cretaceous. Emersion of the platform may be due either to eustasy, or to tectonism (see later) or both. In fact a marked eustatic fall may have occurred during the Valanginian (Haq et al. 1987). The prolonged emersion and subaerial erosion, possibly extended over large areas including also the ophiolites, gave origin to "terra rossa" and to lateritic deposits. This karst surface, formed during emersion of the carbonate platform, is possibly analogous to that of the Parnassus Zone, where subaerially originated cavities (up to 30 m deep) are the substratum of the economically important b2 Bauxite Horizon (Papastamatiou 1960; Combes 1979; Carras 1995; Carras & Tselepidis 2001). According to D'Argenio & Mindszenty (1991), the bauxites of the internal Hellenides zones, occurring within carbonatic nappes of collisional belts near the obducted ophiolites, are surface transported weathering products of adjoining emergent non carbonate areas (including ophiolites). Those bauxites mark regional unconformity surfaces originated by lithospheric arching and uplift, due to the propagation towards plate-interior of the collision-generated stresses (Ziegler 1987). Another possibility is that emersion of the platform was due to overthrusting of the carbonate body onto the ophiolites of the Vourinos area during the so called Paleohellenic tectogenetic phases, when the ophiolites were obducted (Vergely 1984; Bonneau et al. 1988). The emersion lasted about till the late Early Cretaceous.

The Lower Cretaceous neptunian dyke systems

The two generations of neptunian dykes that cross the Upper Jurassic limestones of unit D have different fillings. The age of unit D is late Kimmeridgian - Tithonian. The Fe-rich filling material of the older dyke system may have been derived from the lateritic horizons, originated from the nearby subaerially exposed ophiolites (D'Argenio & Mindszenty 1991; 1992). At present such horizons are absent in the Zyghosti area, possibly eroded, but they crop out few kilometres from Zyghosti, where, according to the age of the overlying sediments (see later), they were deposited during the Early Cretaceous. At that time seismotectonic events caused the opening of the fractures, which were contemporaneously infilled by the already deposited and yet soft lateritic material. The second neptunian dyke system consists of centimetre to decimetre-large fissures filled with early Upper Cretaceous, pelagic, pink or greenish calcareous siltstone. The formation of neptunian dykes is due to submarine fractures that opened during repeated seismotectonic events, related to extensional deformations (Fuechtbauer & Richter 1983; Winterer et al. 1991; Fazzuoli et al. 2002) and were contemporaneously filled by soft mud from the sea bottom. The neptunian dykes preferably develop along the margins of the platform (Lehner 1991; Fazzuoli et al. 2002); they are thought to indicate the first phases of platform drowning, when the margins underwent flexural deformations, induced by extensional tectonics (Fuechtbauer & Richter 1983).

The Cretaceous marine transgression: Aptian-Cenomanian

According to the age of Unit E, the onset of the marine transgression across the Jurassic platform limestones and the surrounding ophiolites occurred at Zyghosti during the early Late Cretaceous, possibly Cenomanian; but at Protochori, only 500 m far from Zyghosti, the sediments that overlie a body of laterites have an early Aptian age (Bortolotti et al. in press). Sedimentary textures of the oldest transgressive deposits (unit E) are indicative of a deepening of the sea bottom, that favoured development of a foreslope setting, where fine-grained, partly pelagic deposition occurred. This period of deposition came to an end when more and more violent, extensional tectonic phases originated the neptunian dyke systems cutting both unit E and the underlying Jurassic unit D and gave origin to the abrupt collapse of large portions of the shallow water platform.

The platform tectonic drowning: Cenomanian-?Maastrichtian

During Cenomanian, major, possibly extensional, tectonic activity resulted in strong basin subsidence and backstepping of the platform margins, that become highly productive of calcareous debrites. Facies F1, which has an abrupt contact with the facies E through a probable palaeofault, represents mass deposition on the slope or at the base of the slope of an apron constituted of shallow water grains, derived from the contemporaneous reef margin, of coarse-grained reefoidal clasts derived from a fault scarp cutting also the underlying Jurassic rocks (Accordi & Carbone 1988; 1992; Bosellini et al. 1999) and of reddish, fine, pelagic material. The fine-grained turbiditic deposits of the facies F2 may reflect a temporary decrease in the tectonic activity.

During the late Santonian - early Campanian, collapse of a large part of the previously formed slopes increased the steepness of the bottom, as indicated by the occurrence in unit G of several very coarse-grained gravity flow deposits within the turbidites and the fine-grained pelagic sediments. The collapse was due to a phase of tectonic activity possibly in connection with a marked sea-level fall near the boundary Santonian-Campanian (Haq et al. 1987). Clasts of Jurassic carbonates are missing, whereas many slumps and conglomerates with coarse clasts of the same lithology and age of the underlying turbidites and pelagites are present. In the earliest Campanian, the tectonic activity was very mild and fine-grained pelagic sediments and turbidites were deposited; subsequently, during the Campanian, a thickening and a coarsening upwards trend in the turbidites occurred; the turbidites mainly consist of shallow water bioclasts, as rudist fragments. This possibly indicates an important increase in the biological productivity along the margins of the surviving carbonate platforms.

Considerations on the Platform sedimentary evolution

The lithostratigraphy of the Zyghosti succession is indicative of the development of a carbonate platform with steep slopes, probably fault-controlled, analogous to other Periadriatic platforms (Channell et al. 1976; Bosellini et al. 1999) and quite different from the pericratonic platforms which are widespread in space and bounded by gentle slopes (Read 1980). According to Bosellini (1973), Bernoulli & Jenkyns (1974) and D'Argenio (1976), the Periadriadriatic (Southern Tethys) continental margin, during the Mesozoic, was " a belt, several hundred kilometres wide, along which carbonate platform and seamounts areas alternated with basins, trending parallel to the continent-ocean boundary" (Channell et al. 1979). Even if recent palaeogeographic reconstructions (i.e. Fourcade et al. 1993) give a more articulated palaeogeographic framework, there are remarkable analogies in the evolution of the Tethyan platforms and adjoining basins (Bosellini 1989). According to Zappaterra (1990), there are three main "Carbonate Paleogeographic Sequences", that reflect a specific palaeogeographic evolution from the Late Triassic to the Tertiary: a) the Platform Sequence, that indicates stable sedimentation and platform growth under rather uniform environmental conditions (i.e. Apennines Platform: Accordi & Carbone 1988; Apulia platform: Bosellini et al. 1999; Parnassus platform: Carras & Tselepidis 2001); b) the Platform to Basin Sequence that reflects the breakup and foundering of carbonate platforms (generally Lower Jurassic) and the development of a new palaeogeography, characterised by a platform to basin morphology (i.e. the Ionian Zone: Bernoulli & Renz 1970; the Pelagonian Zone: Celet & Ferriere 1978; Baumgartner 1985); c) the Basin Sequence that represents continuous sedimentation in deep water basins with slow deposition. It is difficult to frame the evolution of the Zyghosti platform within this oversimplified model, in particular because the time of platform foundering is too young for the Platform to Basin Sequence and too old for the Platform Sequence. Some analogies are present with the Lefkas-Central Kephalonia (Pre-Apulian) platform (Accordi & Carbone 1992), i.e. the foundering of the platform in the early Late Cretaceous, but also some differences (an hiatus including the whole Early Cretaceous in the Zyghosti platform).

Conclusions

This study on the stratigraphic succession of Zyghosti Rema provides information about the sedimentary and structural evolution in the Vourinos area from the Middle Jurassic to the Late Cretaceous. Main results, according to field and laboratory observations, are:

a) The radiolarites at the top of the ophiolites are of middle Bathonian age.

b) The age of the present base of the platform limestones is Middle Jurassic.

c) The contact between the ophiolites and the overlying limestones of the Jurassic Zyghosti carbonate platform is always tectonic.

e) The carbonate platform developed during the Late Jurassic; sedimentological features indicate a high energy platform margin evolving into a low energy shallow marine shelf and again back to high energy platform margin.

f) Emersion of the platform started in the Late Jurassic, probably due to eustatic fall and possibly in connection with tectonic causes, like a lithospheric arching and uplift, due to the propagation towards the plate-interior of the collision-generated stresses, or, alternatively, to the thrusting of the carbonate body above the ophiolites of the Vourinos area.

g) During latest Jurassic-Early Cretaceous time in nearby areas lateritic horizons were deposited, originating from the ophiolites. At Zyghosti, laterites are present only as filling of a neptunian fissure.

h) Starting in the Early Cretaceous the marine transgression spread over the emerged and eroded Jurassic platform limestones and the surrounding ophiolites.

i) Starting in the Cenomanian, extensional tectonic phases, heralded by development of neptunian dyke systems, gave origin to an abrupt collapse of the platform. Very coarse-grained gravity flow deposition developed, including fault-derived Upper Jurassic reefoidal clasts.

j) During the Cenomanian deposition of turbidites with shallow water bioclastic grains occurred.

k) During the late Santonian-early Campanian an increase in the bottom slope, due to a tectonic extensional phase, resulted in several very coarse-grained gravity flows with cobbles of pelagic and turbiditic rocks and slumps within pelagic fine-grained sediments and turbidites.

l) During the Campanian sedimentation consisted of pelagic fine-grained sediments and turbidites.

Acknowledgements. We wish to thank M. Chiari and B. Treves for technical assistance and G. Principi for useful discussions. The constructive suggestions of F. Surlyk (Copenhagen) and of V. Bortolotti (Fireze) are gratefully acknowledged. This study was financed by C.N.R., Istituto di Geoscienze e Georisorse, Sezione di Firenze and M.U.R.S.T. 60% (1999, 2000 G. Principi), COFIN 1998 (V. Bortolotti). Publ. n° XXX. Administrative support was also provided by I.G.M.E. (Athens).

REFERENCES

Accordi G. & Carbone F. (1988) - Sequenze carbonatiche meso-cenozoiche. In : Accordi et al. - Note illustrative alla Carta delle litofacies del Lazio-Abruzzo ed aree limitrofe. *C.N.R. Quaderni della Ricerca Scientifica*, 114: 11-92, Roma.

Accordi G. & Carbone F. (1992) – Lithofacies Map of the Hellenide Pre–Apulian Zone (Ionian Islands, Greece) – Scale 1:200.000. Explanatory notes. *Centro di Studio per la Geologia dell'Italia Centrale, Sp. Publ.*: 27 pp., Roma

Aiello I.W. & Hagstrum J.T. (2001) - Paleomagnetism and paleogeography of Jurassic radiolarian cherts from the northern Apennines of Italy. *GSA Bulletin*, 113: 469-481, Boulder

Anastopoulos I., Faugères L & Koukouzas K. (1980) - Geological Map of Greece, 1:50.000: Kozani Sheet, I.G.M.E., Athens.

Baumgartner P.O. (1985) - Jurassic sedimentary evolution and nappe emplacement in the Argolis peninsula (Peloponnesus, Greece). *Mém. Soc. Helv. Sci. Nat.*, 99: 111 pp., Basel.

Baumgartner P.O. (1987) - Age and genesis of Tethyan Jurassic radiolarites. *Ecl. Geol. Helv.*, 90: 831-879, Basel.

Bernoulli D. & Jenkyns H.C. (1974) - Alpine, Mediterranean, and Central Atlantic Mesozoic facies in relation to the early evolution of the Tethys. In: Dott R.H. & Shaver R.H. (eds.) -Modern and ancient geosynclinal deposition. *S.E.P.M. Sp. Publ.*, 19: 129-160, Tulsa.

Bernoulli D. & Renz O. (1970) - Jurassic carbonate facies and new ammonite faunas from Western Greece. *Ecl. Geol. Helv.*, 63: 573-607, Basel.

Bonneau M., Celet P., Clément B. & Ferrière (1988) – La crise cretacèe dans les Hellenides orientales. *Bull. Soc. Geol. Grèce*, 20: 207-213, Athens.

Bortolotti V., Carras N., Chiari M., Fazzuoli M., Marcucci M., Photiades A. & Principi G. (2000) - Decline and fall of an Upper Jurassic-Cretaceous carbonate platform, born (possibly) over wedging Pindos ophiolites: Vourinos area, Northern Greece - Preliminary results. *80a Riunione Estiva Soc. Geol. It., September 2000, Trieste. Abstr.*: 203, Trieste.

Bortolotti V., Carras N., Chiari M., Fazzuoli M., Marcucci M., Photiades A. & Principi G. (2001) - Characteristics of the Upper Cretaceous transgression in the Kozani area (Pelagonian Domain, Northern Greece). *Geoitalia 2001, September 2001, Abstr.*: 547, Chieti.

Bortolotti V., Carras N., Chiari M., Fazzuoli M., Marcucci M., Photiades A. & Principi G. (2002) - The Late Jurassic carbonate platform of Zyghosti, Vourinos-Pindos Zone, Northern Greece. *6th Intern. Symp. of Jurassic System, September 2002, Abstr.*: 21, Palermo

Bortolotti V., Carras N., Chiari M., Fazzuoli M., Marcucci M., Photiades A. & Principi G. (in press) - Geological frame of the North-eastern Vourinos area (Lefkopygi -Rodiani): palaeogeographic and geodynamic implications. *Ofioliti*, Firenze

Bosellini A. (1973) - Modello geodinamico e paleotettonico delle Alpi Meridionali durante il Giurassico-Cretaceo. Sue possibili applicazioni agli Appennini. *Acc. Naz. Lincei. Quaderni*, 183: 163-205, Roma.

Bosellini A. (1989) – Dynamics of Tethyan carbonate platforms. In: Controls on Carbonate Platforms and Basin Development, *SEPM Sp. Publ.* 44: 3-11, Tulsa.

Bosellini A. & Winterer E.L. (1975) - Pelagic limestones and radiolarites of the Tethyan Mesozoic: a genetic model. *Geology*, 3: 279-282, Amsterdam.

Bosellini A., Morsilli M. & Neri C. (1999) - Long–term event stratigraphy of the Apulia Platform margin (Upper Jurassic to Eocene, Gargano, Southern Italy). *Journ. Sedim. Research*, 69: 1241- 1252, Boulder.

Brunn J.H., Faugères L & Robert P. (1972) - Une nouvelle série du Jurassique moyen - Crétacé inférieur surmontant les ophiolites dans le détroit de Kozani (Macédoine, Gréce). *C.R. Somm. Soc. Géol. Fr.*, (1): 26-28, Paris.

Carras N. (1995) – La piattaforma carbonatica del Parnasso durante il Giurassico superiore-Cretaceo inferiore: Stratigrafia ed evoluzione paleogeografica. (In Greek, with Italian summary). Ph. D. Thesis, University of Athens., V. of 232 pp., Despina Mavrommati Editions, Athens.

Carras N. & Fazzuoli M. (1992) - La Formation des "Calcaires de Amfissa" ("Intermediate Limestones" Auctt.), Cretacé inferieur, Zone du Parnasse (Grèce continentale). *Ann. Géol. des Pays Helléniques*, 35: 43-101, Athènes.

Carras N. & Tselepidis V. (2001) – Stratigraphy of the Alpine formations of the Parnasse zone and some allochtonous sequences in the Distomon area (Boeotia, Greece). In: Solakius N. & Kati M.(Eds) – The Parnassus Zone, Central Greece. *Meddelanden Fran Lunds Univ.*, 139: 17-36, Lund.

Celet P. & Ferrière J. (1978) - Les Hellénides internes: Le Pélagonien. *Eclogae geol. Helv.*, 71: 467-495, Basel.

Channell J.E.T., D'Argenio B. & Horvat F. (1979) - Adria, the African Promontory, in Mesozoic Mediterranean Palaeogeography. *Earth-Science Rev.*, 15: 213-292, Amsterdam.

Chiari M. & Marcucci M. (in press) – Jurassic radiolarian assemblages from the cherts on top of Vourinos ophiolite. *Ofioliti*, Firenze.

Choquette P.V. & James N.P. (1988) – Introduction. In : James N.P. & Choquette P.V. (Eds.) – Palaeokarst, 1-21, Springer Verlag, New York.

Combes P.J. (1979) – Observations sèdimentologiques, paléogéographiques, minèralogiques et géochimique sur les bauxites du deuxième horizon dans la zone du Parnasse (Gréce). *Bull. Soc. Géol. France*, 7: 485-494, Paris.

D'Argenio B. (1976) - Le piattaforme carbonatiche periadriatiche - una rassegna di problemi nel quadro geodinamico Mesozoico dell'area Mediterranea. *Mem. Soc. Geol. It.*, 13: 1-28, Roma.

D'Argenio B. & Mindszenty A. (1991) – Karst bauxites at regional unconformities and geotectonic correlation in the Cretaceous of the Mediterranean. *Boll. Soc. Geol. It.*, 110: 85-92, Roma.

D'Argenio B. & Mindszenty A. (1992) – Tectonic and climatic control on paleokarst and bauxites. *Giorn. Geologia*, 54: 207-218, Bologna.

Duval B., Cramez C. & Vail P.R. (1992) - Types and hierarchy of stratigraphic cycles. In: Mesozoic and Cenozoic Sequence Stratigraphy of Europeans Basins International Symposium (Dijon, France). Abstracts: 44-45, Dijon.

Fazzuoli M., Sani F. & Covelli S. (2002) - Structural evolution of Liassic platform margins documented by neptunian dyke systems, Northern Tuscany, Italy. *Boll. Soc. Geol. It., Vol. Sp.*, 1: 539-549, Roma.

Fourcade E., Azéma J., Cecca F., Dercourt J., Bellion Y., Ricou E., Sandulescu M & Vrielynck B. (1993) - Atlas de la Tethys Palaeoenvironmental Maps. In: Dercourt J. et al., (eds.), BEICIP-FRANLAB, Rueil-Malmaison, France.

Fuechtbauer N. & Richter D. (1883) – Carbonate internal breccia: a source of mass flow at early geosynclinal platform margins in Greece. *S.E.P.M. Sp. Publ.*, 33: 207-215, Tulsa.

Garrison R.E. & Fischer A.G. (1969) - Deep water limestones and radiolarites of the Alpine Jurassic. In: G.M. Friedman (ed.) - Depositional Environments in Carbonate Rocks. *S.E.P.M. Sp. Publ.*, 14: 20-56, Tulsa.

Haq B.U., Hardenbol J. And Vail P.R. (1987) - Chronology of fluctuating sea-levels since the Triassic. *Science*, 235: 1156-1167, Washington D.C.

Lehner B.L. (1991) – Neptunian dykes along a drowned carbonate platform margin: an indicator for recurrent extensional tectonic activity. *Terra Nova*, 3: 593-602, Oxford.

Mavridis A. & Kelepertzis A. (1993) - Geological Map of Greece, 1:50.000: Knidhi Sheet, I.G.M.E., Athens.

Mitchum R.M. & Van Wagoner J.C. (1991) - High frequency sequences and their stacking patterns: sequence stratigraphic evidence of high frequency eustatic cycles. *Sedimentary Geology*, 70: 135-144, Amsterdam.

Mountrakis D. (1984) - Structural evolution of the Pelagonian zone in Northwestern Macedonia, Greece. In : Dixon J.E. & Robertson A.H.F. (Eds.) - The geological evolution of the Eastern Mediterranean. *Geol. Soc. London, Spec. Publ.*, 17: 581-590, London.

Papastamatiou J. (1969) – La géologie de la région montagneuse du Parnasse-Kiona-Oeta. *Bull. Soc.Géol. France*, 7, 11: 398-409, Paris.

Read (1980) - Carbonate ramp-to-basin transitions and foreland basins evolution. Middle Ordovician, Virginia Appalachians. *Am. Ass. Petrol. Geol. Bull.*, 62: 1-60. Tulsa.

Read J.F. (1985) - Carbonate Platform Facies model. *Am. Ass. Petrol. Geol. Bull.*, 69: 1-21, Tulsa

Sarg. J.F. (1988) – Carbonate sequence stratigraphy. In: Wilgus C.K., Hastigs B.S., Kendall C.G.St.C., Posamentier H.W., Ross C.A. & Van Vagoner J.C., eds., Sea Level Changes: an integrated approach. *S.E.P.M., Sp. Publ.*, 42: 155-181, Tulsa.

Simone L. (1981) - Ooids: A Review. *Earth-Science Rev.*, 16, 319-355, Amsterdam.

Stow D.A.V. (1986) - Deep clastic seas In: Reading H.G. (ed.) - Sedimentary Environments and facies: 399-444, Blackwell, Oxford.

Tucker M.E. (1985)- Shallow-marine carbonate facies and facies models. In: Brenchley P.J. & Williams B.P.J. eds. - Sedimentology: Recent Developments and Applied Aspects. *Spec. Publ. Geol. Soc. Lond.*, 18,:139-161, London.

Vergely P. (1984)- Tectonique des ophiolites dans les Hellénides internes (déformations, métamorphismes et phénomènes sédimentaires). Conséquences sur l'évolution des régions téthysiennes occidentales. Thése d'Etat Sc. Naturelles, Univ. Paris Sud, V. of 649 pp., Orsay.

Winterer E.L., Metzler C.V. & Sarti M. (1991) - Neptunian dykes and associated breccia (Southern Alps, Italy and Switzerland): role of gravity in open and closed systems. *Sedimentology*, 38: 381-404, Amsterdam.

Zappaterra E. (1990) - Carbonate paleogeographic sequence of the Periadriatic region. *Boll. Soc. Geol. It.*, 109: 5-20, Roma

Ziegler P.A. (1987)-Late Cretaceous and Cenozoic intraplate compressional deformation in the alpine foreland - a geodynamic model. *Tectonophysics,* 137: 389-420, Amsterdam.