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MEDITERRANEAN PLIOCENE EVENTS IN THE SALENTO GEOLOGICAL RECORD

ABSTRACT

During the Pliocene age, the past Mediterranean sea became similar to the present and the European and African continents progressively acquired their present-day contours. The species turnover accelerated as high latitude temperatures dropped, the ice sheets gathered and the sea circulation changed their form patterns.

In the lower Pliocene, the Salento peninsula was the central sector of an isolated carbonate platform far from the continent. On the contrary, at the beginning of the Quaternary age the platform was just connected to the Apennines Chain by means of a shallow interposed basin (the Bradanic Trough). These paleoenvironmental and paleogeographic changes, occurred between 5.3 and 1.6 My, have been the local setting reorganisation in a context of large-scale Mediterranean evolution marked by a number of geological events.

The Salento Pliocene Series is represented by the follow lithological facies: (1) chaotic assemblage, (2) marlstones, (3) glauconitic siltstones, (4) phosphatized calcirudite, (5) calcarenites and limestones containing, at the top, the first appearance of *Arctica islandica*. They can be respectively linked to: (1) the late Messinian Mediterranean drawdown, (2) the deepest paleo-depth of the early Pliocene inundation, (3) a lower-middle Pliocene stage of very low rate of sedimentation, (4) the about 2.5 My cooling phase as well as southern Apennines middle-upper Pliocene tectonic strain, and (5) the Neogene/Quaternary boundary arrival of the “northern guests”.

RIASSUNTO

A scala globale, il Pliocene costituisce la parte finale di un fase di raffreddamento e inaridimento, iniziata durante l’Eocene, che prelude all’inizio dei periodi glaciali e influenza particolarmente l’avvicendamento delle specie viventi (RAYMO *et al.*, 1989; TIEDEMANN *et al.*, 1994; SERRANO *et al.*, 1999). Nel dominio

mediterraneo, il tardo Miocene era stato caratterizzato da notevoli mutamenti paleogeografici, quali la chiusura dei collegamenti con l'Atlantico, che causò un drastico abbassamento del livello marino, e la successiva apertura dello stretto di Gibilterra, con conseguente nuova inondazione (RIDING *et al*., 1998; KRIJGSMAN *et al*., 1999; GRIFFIN, 2002). Durante il Pliocene, il mar Mediterraneo assunse contorni progressivamente più simili a quelli attuali, mentre la Piattaforma Apula passò da condizioni insulari a quelle odierne di avampaese collegato alla catena appenninica da una avanfossa emersa (ARNOUX *et al*., 1985; TROPEANO *et al*., 2002; PATACCA and SCANDONE, 2004).

Nel Salento, parte centrale della Piattaforma Apula, si formarono depositi di ambienti neritico e batiale, nel cui ambito vengono in questa nota analizzate, con metodi della sedimentologia e dalla stratigrafia sequenziale, cinque facies litologiche riferibili ad eventi mediterranei. La facies più antica ricopre con contatto discordante varie unità preplioceniche ed è formata da blocchi, brecce e conglomerati contenuti in matrice prevalentemente calcarenitica. La sua sedimentazione è riferibile al Pliocene basale (circa 5.3 M di anni fa) e rappresenta l'accumulo di materiali prodotti dall'intensa erosione conseguente ai mutamenti paleogeografici tardo miocenici. La seconda facies è costituita da depositi prevalentemente marnosi, formati durante la massima inondanzione del Mediterraneo (da 5 a 4.5 M di anni fa). La terza è formata da depositi siltosi, con abbondanti minerali glauconitici, che indicano una bassa velocità di sedimentazione, riscontrata peraltro in vari depositi del dominio mediterraneo del Pliocene inferiore-medio (da 4.5 a 2.5 M di anni fa) (CITA *et al*., 1999). Un livello di clasti fosfatizzati, con granulometria prevalentemente grossolana, costituisce la quarta facies sedimentologica della serie pliocenica salentina. La sua sedimentazione può essere riferita a eventi tettonici e climatici avvenuti al passaggio Piacenzano-Gelasiano (circa 2,5 M di anni fa). La quinta facies, costituita da calcareniti e calcilutiti, è correlabile con le Calcareniti di Gravina, che ricoprono estesamente ed in più luoghi la Piattaforma Apula, la cui età è riferita al Pliocene superiore - Pleistocene inferiore (da 2.5 a 1.5 M di anni fa). In essa vi è la comparsa di "ospiti nordici", ed in particolare di *Arctica islandica*, che convenzionalmente marca il passaggio con il Quaternario (da 1.8 a 1,6 M di anni fa).

INTRODUCTION

The Pliocene is the uppermost subdivision of the Tertiary period and represents the final stage of a global cooling and drying trend started in the Eocene and that led up to the Quaternary Ice Ages. A large-scale paleogeographic reorganisation of the western Thetys occurred during the late Miocene (KRIJGSMAN *et al.*, 1999), as a consequence of a tectonic phase (DUGGEN *et al.*, 2004) that caused the closure of the Betic and Rif corridors (fig. 1), which allowed several Miocene species to migrate eastward from the Atlantic ocean (SERRANO *et al.*, 1993). The isolation led to a drastic sea level drawdown, causing the Messinian Salinity Crisis (MSC) that represents one of the most dramatic events occurred during the Cenozoic (HSÜ *et al*., 1973).

An existing river system flowed down into some residual basins, the largest one was the Lake Cyrenaica which had been a water level about 2000 m below the present day Mediterranean sea level (GRIFFIN, 2002). The Apulia platform and the frontal Balkan area were probably connected by land bridges. Investigated sites drilled by Agip on the continental shelf South of Gargano, in fact, show Pliocene deposits prograded on Miocene and Cretaceous by means of a wide spread erosional surface (DELLE ROSE, 2001).

With the late Miocene drawdown of the sea, a northward shift of the African humid and desert zone occurred; within such a context, according to a desert/monsoon system, aridity and humidity can be occurred in close proximity (GRIFFIN, 2002). The wet phase would ameliorated and, around 4.6 My, North Africa and Mediterranean began to experience drier climates.

The end of the MSC has been envisaged as a rapid event involving a terminal Messininan-earliest Pliocene inundation from the Atlantic by means of the opening of the Gibraltar Strait (HSÜ *et al.*, 1973). The flooding could be resulted from an eustatic rise in global sea level (MCKENZIE *et al.*, 1999). From a hydraulic point of view, only 10 years could be enough to fill up the Mediterranean (BLANC, 2002). Nevertheless, the transgression could last about 200 KA and followed by a subdued Pliocene influx of oceanic water (VAN LAER *et al*., 1994; RIDING *et al*., 1998).

During the early Pliocene, the Apulia carbonate platform (RICCHETTI *et al.*, 1988), whose central sector was the present Salento Peninsula (fig. 2), experienced insular conditions (ARNOUX *et al.*, 1985). The open marine environment was a heritage of the Miocene age, during which the Salento lithological facies recorded a number of geological events (DELLE ROSE, 2001). The central and southern Apennines were interested by tectonic events which strongly changed the paleogeography arrangement (DE FEYTER and DELLE ROSE, 2002; PATACCA and SCANDONE, 2004). An entire pile of nappes began to overthrust the subdued western Apulia platform, reversing its sense of migration at 2.5 My, and a terrigenous sedimentation in-filled the Bradanic foredeep (TROPEANO *et al*., 2002).

In Europe, the early Pliocene sea covered large areas around the present day Mediterranean and parts of the continent which were, in turn, colonized by species adapted to temperate or subtropical climates and open woodlands. At about 3.0 My, occurred a transition from a climatic regime with low amplitude oscillations to a typical climatic regime with high amplitude variation (TIEDEMANN *et al.*, 1994). This climatic change probably culminated in a strong expansion of the Arctic Ice Sheet at about 2.5 My. Since that time, the Earth's climate has generally been in a glacial mode marked by over 50 repetitive cycles (RAYMO *et al.*, 1989). As a matter of fact, there was a turnover of vertebrates between the lower Villafranchian substages (*Mastodon, Hipparion*) and the upper Villafranchian substages (*Elephas, Equus*), the transition took place just around 2.5 My.

In North Africa, the general picture for the early to mid Pliocene is of a bigger moisture than the present conditions. Before 3 My, semi-arid vegetation covered the present-day Sahara belt, and tropical forest and moist savanna extended at times nearly as far as Tropic of cancer (PRISM Project Members, 1996). Around 3 My ago, African environments have shifted more toward a drier and somewhat cooler state (DEMENOCAL and BLOEMENDAL, 1995).

The Pliocene marine series

During the Pliocene epoch, the Mediterranean Sea was characterised by a number of periods of subtropical and subpolar conditions. These latter were frequent in the middle-upper Pliocene, presaging the entry of polar fauna (the so called northern guests), such us the molluscan *Arctica islandica*, that conventionally marks the beginning of the Pleistocene (SERRANO *et al*., 1999). Three mollusc extinction events throughout the Mediterranean Pliocene suggest the definition of four faunistic units (MONEGATTI and RAFFI, 2001). The boundaries of these units approximate the major climatic changes of the Northern Hemisphere, respectively at 3.2-3.0, 2.6-2.4 and 2.1.-1.8 My (LOURENS *et al.*, 1992; RAYMO *et al.*, 1992; TIEDEMANN *et al.*, 1994). At 2.5-2.4 My, also occurred in the Mediterranean the extinction of a number of foraminifers (SPROVIERI, 1986).

In the marine successions, the base of the first Pliocene stage, the Zanclean, is defined as the lowest stratigraphic surface of the Trubi Formation (VAN COUVERING *et al.*, 2000) at Eraclea Minoa (fig. 1), which is near at the First Occurrence (FO) of *Ceratolithus acutus* (MARTINI, 1971) calibrated at 5.37 My.

The subdivision of the Pliocene has been object of several passionate debates. Even if numerous stages have been proposed over the years for subdividing the epoch, at present, a three-folded subdivision is commonly accepted (Tab. I).

The Piacenzian, the second Pliocene stage, has been initially defined in the middle of XIX centuries at Castell'Arquato (PC). Since in this type area a hiatus was proved to be present at the base, the middle Pliocene unit was re-defined by Castradori *et al.* (1998) along the SW coast of Sicily.

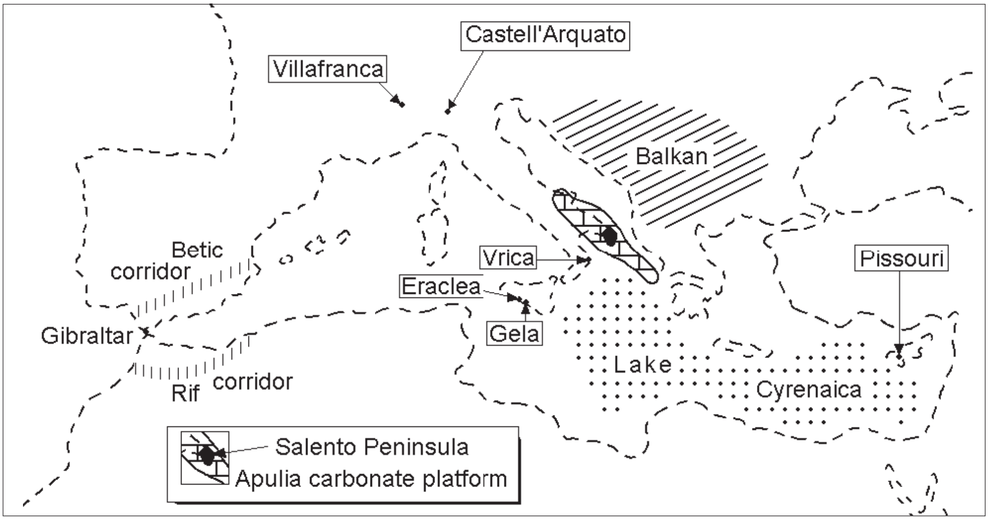

Fig. 1 - Diachronous paleogeographic late Miocene - late Pliocene domains of Mediterranean (present-day contours of continental masses must be considered as generic indications) and some of the most important sites (see text) of the Mediterranean Pliocene record.

Tab. I - Pliocene geochronological and biostratigraphic scheme related to Mediterranean biological events (after Martini, 1971; Cita, 1975; Colalongo and Sartoni, 1979; Okada and Burry, 1980; Iaccarino and Salvatorini, 1982; Spaak, 1983; Bonadonna and Alberdi, 1987; Castradori *et al.*, 1998; Rio *et al.*, 1998; Patacca and Scandone, 2004). FO = First Occurrence; LO = Last Occurrence; FCO = First Common Occurrence; LCO = Last Common Occurrence; FAD = First Appearance Data in Mediterranean domain; BP = Before Present.

PLEISTOCENE		**My BP**
FAD of *Arctica islandica*		1.64?
Gelasian	LO of *Discoater brouweri*	1.95
(UPPER PLIOCENE)	FO of *Globorotalia Inflata*	2.13
	LO of *Globorotalia bononiensis*	2.45
LO of *Discoater pentaradiatus*		2.53
	FCO of *Bulimina marginata*	2.63
Piacenzian	LO of *Discoaster surculus*	2.63
(MIDDLE PLIOCENE)	LO of *Discoaster tamalis*	2.81
	LO of *Sphaeroidinellopsis spp*	3.21
FO of *G. crassaformis* - LO of the *Globorotalia puncticulata*		3.57
Zanclean	LCO of *Globorotalia margaritae*	3.94
(LOWER PLIOCENE)	FO of *Globorotalia puncticulata*	4.52
	Sphaeroidinellopsis Acme Zone	5.2-5.3
FO of *Ceratolithus acutus*		5.33
MIOCENE		

Furthermore, none of the proposed upper Pliocene standard stages before the formalisation of the Gelasian (RIO *et al.*, 1998) at Gela, covered the entire interval of time between the Piacenzian and the Pliocene/Pleistocene boundary. The erection of the Gelasian as uppermost chronostratigraphic unit of the Pliocene Series, seems settled the controversies concerning the upward extension of the previous stage.

Several problems of the middle-upper Pliocene subdivision are related to some species whose taxonomic significance are not clear. As an example, the plankton foraminifer *Globoratalia aemiliana* (Colalongo and Sartori, 1967) has been chosen to represent a zone in the IACCARINO and SALVATORINI (1982) and BOSSIO *et al.* (1991) schemes, whereas it is not to acknowledge by CITA (1975) and SPAAK (1983), whose zonation-scale is commonly used in the Mediterranean domain. The taxon *Globorotalia hirsuta aemiliana* was initially considered as transitional between *G. hirsuta* and *G. crassaformis*, and in a second time identified as a separate species. According to BYLINSKAYA (2005), *Globorotalia aemiliana* closely resembles *G. crassaformis crassaformis* and *G. crassaformis viola*, whose FO data was during the earliest Pliocene within the Atlantic Ocean (see, as an example, MCKENZIE *et al.*, 1999), whereas it was at Zanclean/Piacenzan boundary within the Mediterranean domain (see plankton zones in PATACCA and SCANDONE, 2004). As a consequence the use of this taxon to chronostratigraphic evaluations appears to be controversial.

The Vrica section (Calabria, S Italy), in spite of the lack of *Arctica islandica*, officially represents the Pliocene/Pleistocene boundary. The relative absolute age is 1.64 My (AGUIRRE and PASINI, 1985), obtained by controversial sedimentological and magnetostratography interpretations, that implicitly furnish to the floral and faunal events a temporal resolution of 10 Ky (BONADONNA and ALBERDI, 1987), against a real resolution for biostratigraphical datum of 10^5 years (FLYNN *et al.*, 1984). In this way, the Pliocene/Pleistocene stratotype could be few suitable for paleontological, chronological, and paleoclimatic viewpoints.

Lithological facies related to Mediterranean events

Pliocene is probably the most questionable Series of the whole Salento geological record. Its main lithological features have been recognized by DE GIORGI (1922), but the sedimentological arrangement of the deposits has been not yet defined. Actually, two lithostratigraphic units have recognized: Leuca Formation and Uggiano la Chiesa Formation (BOSSIO *et al.*, 1987a, b, 1991; D'ALESSANDRO and MASSARI, 1997; BOSELLINI *et al.*, 1999; MASSARI and D'ALESSANDRO, 2000; D'ALESSANDRO *et al.*, 2004). Nevertheless, their chronostratigraphic context as well as their relationships with younger quaternary deposits, are object of several interpretations that don't allow to correlate stratigraphic features of the Pliocene

Salento with other coeval sediments. A geological survey of four areas was performed (fig. 2), using tolls and methodologies of the sedimentology and sequential stratigraphy, to recognize lithological facies linked to Mediterranean paleoenvironmental and paleoclimatology changes or events. The use of not conventional units (the lithological facies), defined on the base of sedimentological and paleontological features, showed a useful tools in the study of the Salento Miocene (DELLE ROSE, 2001). This approach contrasts with the lithostratigraphic analyses (VAIL *et al.*, 1977) dealing with the reconstruction of the modality of the deposition in a chronostratigraphic context. The Pliocene lithological facies described in this study are summarised in table II.

SALENTO PLIOCENE LITHOLOGICAL FACIES

Chaotic assemblage

This unit has been recognized by DE GIORGI (1876) at Leuca and initially described as calcarenites with large calcareous blocks and macrofossils. The unit will be identified and mapped later in the surrounding of Otranto (GIANNELLI *et al.*, 1965; LARGAIOLLI *et al.*; 1966). It lies disconformably on different Cretaceous to Miocene units and shows a maximum thickness of about 30 m (BOSSIO *et al.*, 1987b, 1991). At Canale Muscio (fig. 2) this facies overlies a paleosol including blocks of Cretaceous and thin lens of limestone and fine calcarenite containing gastropods, ostracods and molluscs (MASSARI and D'ALESSANDRO, 2000).

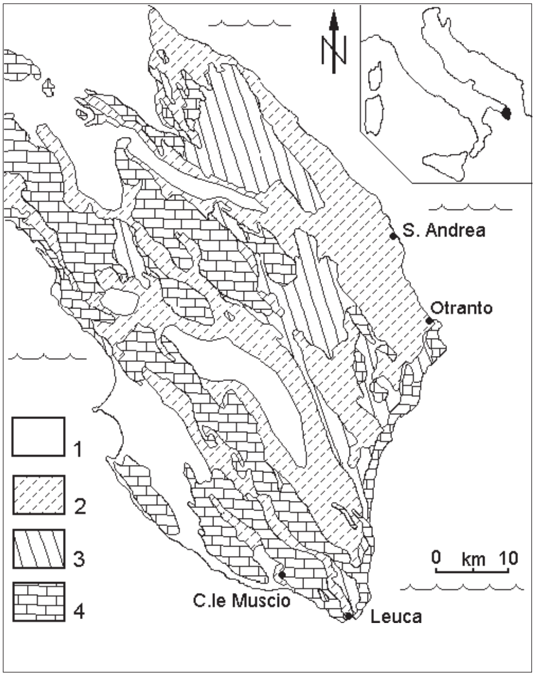

Fig. 2 - Salento geological scheme and ubication of investigated areas. 1 - Pleistocene (Emilian-Crotonian) units; 2 - Pliocene and early Pleistocene (Zanclean-Santernian) units; 3 - Oligocene and Miocene units; 4 - Cretaceous and Eocene units.

The chaotic assemblage essentially consists of megablocks, breccias and pebbles, coming from the decay of older units, within calcarenitic or calciruditic matrix. Frequently lens of thin bedded limestones occurred in the chaotic mass. *Ostrea* shells have been observed, as well going upwards, the matrix is finer and silty-marly in composition; at the top, the chaotic assemblage is locally draped by the marlstones and glauconitic siltstone facies. Usually the marine thalassinoid systems included within the chaotic assemblage cannot be used to perform through biostratigraphic considerations. Remarkable results have been obtained by BOSSIO *et al.* (1991) at Casamassela (few km west of Otranto), where the planktonic foraminifer *Sphaeroidinellopsis seminulina seminulina* and *S. seminulina penedehiscens*, and the nannofossil *Discoaster variabilis* have been detected. This last taxon forms the zone *Discoaster variabilis* s.l. belonging to the earliest Pliocene (according to BOSSIO *et al.*, 1991) or to the terminal Miocene (according to PATACCA and SCANDONE, 2004). It is useful to remember that the *Discoaster variabilis* is also considered a non-diagnostic taxa (see, as an example, DI STEFANO *et al.*, 1999). *Sphaeroidinellopsis* spp. could be related to the *Sphaeroidinellopsis seminulina* s.l. zone of IACCARINO and SALVATORINI (1982). About the paleo-depth of the sedimentation, on the basis of rare benthic taxa identified by BOSSIO *et al.* (1991), it can be referred to the inner mid shelf. For the origin of the chaotic assemblage, considering its stratigraphic position, its sedimentological character and relationships with underlying and overlying units, BOSELLINI *et al.* (1999) asserted that it is derived from subaerial dismantling of exposed ridges (Fig. 3).

Fig. 3 - Chaotic assemblage out crop (Port of Otranto). Note the heterogeneous pattern of clasts distribution and the presence of a megablock longer than 0.5 m (in the circle).

Marlstones

The marlstone facies has been recognized by BOSSIO *et al.* (1987a, b, 1991) in the S-E sector of Salento (tab. II). The boundary between chaotic assemblage and this facies is well exposed at Casamassella where it shows the features of a gradual passage. Marlstone facies can also directly mantle pre Pliocene deposits. Its maximum observed thickness reaches 4-5 m.

The marlstones are massive or poorly stratified, they present variable amount of silt and, especially at the basal portion, sandy and pebbly inclusions.

The outcropping successions are usually characterized by several hiatus and by microfossil assemblages containing a number of species reworked from older deposits (BOSSIO *et al.*, 1987a, 1991). The thalassinoid systems that can be identified are usually incompatible each other. As a consequence, biostratigraphical screening is hard task. In any case, *Sphaeroidinellopsis* spp., whose LO was at 3.2 My are frequently present. Some nannofossils (*Discoaster tamalis*, *D. surculus* and *D. pentaradiatus*), whose disappearance attest 2.8-2.5 My (Tab. I), have been recognized (BOSSIO *et al.*, 1991).

These Authors, by means of several recognized benthic taxa assemblage, referred the deposition of marlstones at a depth comprised between the outer neritic (100-200 m depth) and the upper epibathyal (200-300 m) environment.

Glauconitic siltstones

Also the glauconitic siltstones has been recognized by BOSSIO *et al.* (1987a, b, 1991) in the S-E sector of Salento. Other outcrops have been noticed by D'ALESSANDRO and MASSARI (1997), and MASSARI and D'ALESSANDRO (2000) nearly along the S-W Salento coast in the surrounding of Canale Muscio (Fig. 2).

Where the glauconitic siltstones directly overlies the chaotic assemblage, the boundary appears sharp (BOSSIO *et al.*, 1987b). The glauconitic siltstones, that in some places overlie the marlstones, consist of massive bioturbated calcareous silty-sand beds that are, as a whole, few meters thick. Macrofossils occur and are mainly represented by *Pseudamussium* and *Pycnodonte*.

At Aparo di Valentini, 1,5 km W of Canale Muscio (fig. 4), bioturbated glauconitic siltstones are about 6 m thick (MASSARI and D'ALESSANDRO, 2000). Due to the large amount of glauconitic grains, formed under reducing conditions in sediments, the deposits are distinctly greenish and its upper surface is bound by a decimetres phosphatized breccia. The top of siltstones is characterized by thalassinoid piping downwards from younger deposits (D'ALESSANDRO and MASSARI, 1997).

The thalassinoid assemblages useful to chronostratigrapy are closely similar to those recognized within the marlstones, while the benthic taxa, and some sedimentological features, reflect an outer shelf setting (BOSSIO *et al.*, 1991; D'ALESSANDRO and MASSARI, 1997).

Phosphatized calcirudite

Marlstones and glauconitic siltstones are usually truncated by a 0.1-1 m thick phosphatized calcirudite that is, in turn, overlied by the younger calcarenites and limestone facies (BOSSIO *et al.*, 1987a; D'ALESSANDRO and MASSARI, 1997).

At Otranto, along the well exposed Bastione Pelasgi section (fig. 4), the phosphatized calcirudite covers an erosive marlstone surface (the paleo-bottom of the sea), that shows several filled irregular holes (BOSSIO *et al.*, 1987b). At the lower portion of the phosphatized calcirudite a number of squashed marly inclusions are present. This contact represents an unconformity. As a matter of fact, it marks a substantial break or gap in the geological record related to an interruption in the continuity of the depositional sequence.

The phosphatized clasts are usually angular broken pre-Pliocene rock fragments and show a three-folded partition: a basal portion (0.2-0.3 m) with a reverse grain-size grading, a middle one (about 0.25 m) that presents the maximum amount of greater detritus component, and an upper portion (about 1 m) where the angular clasts have a normal grain-size grading.

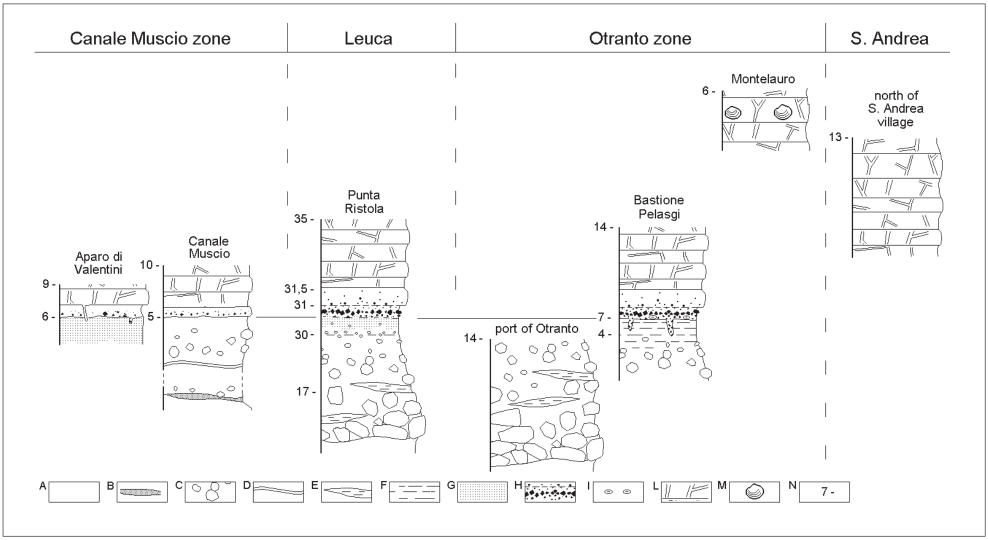

Fig. 4 - Geological sections of the investigated areas. A - pre Pliocene; B - paleosol; C - Chaotic assemblage; D - undulated calcarenite beds; E - limestone and calcarenite lens; F - Marlstones; G - Glauconitic siltstones; H - Phosphatized calcirudite; I - squashed marly inclusions; L - bioturbated calcarenites and limestones; M - *Arctica islandica* shells; N - meters from section base.

These above mentioned features, suggest intra-platform grain flow re-sedimentation processes.

Along Canale Muscio, this unit directly overlies the chaotic assemblage, shows a reduced thickness, and does not present remarkable gradations features, whereas noticeable is the presence of glauconitic silty-sand pebbles. The interval time of deposition of the phosphatized calcirudite is bounded by the age of previous and further facies.

Calcarenites and limestones

A first accurately description of this facies was performed by BOSSIO *et al.* (1985) along the central E coast of Salento (S. Andrea village, fig. 2). Calcarenites and limestones are a few tens of meters thick and consist of intensively bioturbated coarse to fine-grained beds bounded by diastems. They are rich in macrofossils and, in some place, contain well conserved decapods (VAROLA, 1965). At S. Andrea coast (Fig. 9), the finer beds (calcilutites-marlstones) contain a relatively high amount of clay (BOSSIO *et al.*, 1985).

At Montelauro, S of Otranto, the top beds of the calcarenites and limestones present several shells of *Arctica islandica* (fig. 5). These strata have been related to the early Pleistocene (BOSSIO *et al.*, 1987a).

The fossil assemblages of this facies, especially the nannofossils, are frequently scarce and abraded. As a consequence, the biostratigraphic analyses can lead to questionable results. As an example, along the Palmariggi-Otranto road, BOSSIO *et al.* (1991) referred the calcarenites and limestones to the upper part of middle Pliocene, *Discoaster brouweri* zone (MARTINI, 1971; OKADA and BURRY, 1980) and *Globoratalia aemiliana* zone (IACCARINO and SALVATORINI, 1982). Nevertheless, according to MAIORANO (in D'ALESSANDRO *et al.*, 2004) the

Fig. 5 - *Arctica islandica* fossil, marked by circle, within a calcarenitic bed at Montelauro (south-east of Otranto).

nannofossil content of the Palmariggi-Otranto section, did not yield any key species supporting the aforementioned attribution.

Taking into account the constraints about the biostratigraphic analyses, it seems noticeable the absence of *Discoaster tamalis*, *D. surculus* and *D. pentaradiatus* (Bossio *et al.*, 1985, 1987a, b, 1991), whose Last Occurrence (LO) are bioevents respectively dated at 2.81, 2.63 and 2.53 My (PATACCA and SCANDONE, 2004). On the other hand, the presence of *Globorotalia bononiensis* (LO at 2.45 My, Tab. 2) at the basal part of the facies, and of *G. inflata* (First Occurrence (FO) at 2.13 My) at the upper one, can form important constraints to set the sedimentation of calcarenites and limestones in the geochronological scale. Remarkable seems to be also the recognition of transitional forms from *Globorotalia bononiensis* to *G. inflata* (BOSSIO *et al.*, 1991). These elements can suggest a Gelasian age for the calcarenites and limestones lithological facies. Nevertheless, the presence of *Bulimina marginata*, a benthic foraminifer whose First Common Occurrence (FCO) nearly precedes the Piacenzian-Gelasian boundary (PATACCA and SCANDONE, 2004), within the calcarenites and limestones of S. Andrea succession (Bossio *et al.*, 1985) strengthens the aforementioned suggestion.

The stratigraphic and paleontological features, especially the thalassinoid assemblages of benthic foraminifers (BOSSIO *et al.*, 1991), lead to sketch the depositional conditions that mainly evolved within the inner-middle neritic environment (around 50 m or shallower paleo-depth). Some taxa related to deepest

Tab. II - Salento Pliocene lithological facies related to Mediterranean events.

<table>
<tr><th>FACIES</th><th colspan="4">LITERATURE NAMES AND REFERENCES</th></tr>
<tr><td>Calcarenites and limestones</td><td colspan="2">Uggiano la Chiesa Fm at Lago Mangiovino (BOSSIO et al., 1987b)</td><td colspan="2">subunit 2ª (D’ALESSANDRO et al., 2004)</td></tr>
<tr><td>phosphatized calcirudite</td><td colspan="2">basal conglomerate of Uggiano la Chiesa Fm (BOSSIO et al., 1987a, b, 1991; BOSELLINI et al., 1999)</td><td colspan="2">terrestrial conglomerate (D’ALESSANDRO and MASSARI, 1997)</td></tr>
<tr><td>Glauconitic siltstones</td><td rowspan="2">upper member of Leuca Fm (BOSSIO et al., 1987a, b, 1991)</td><td colspan="2">glauconitic mudstone (BOSELLINI et al., 1999)</td><td>glauconitic silty sand (MASSARI and D’ALESSANDRO, 2000)</td></tr>
<tr><td>Marlstones</td><td colspan="3">Trubi (BOSELLINI et al., 1999)</td></tr>
<tr><td>Chaotic assemblage</td><td>basal member of Leuca Fm (BOSSIO et al., 1987a, b, 1991)</td><td colspan="2">Leuca Breccia (BOSELLINI et al., 1999)</td><td>subunit 1ª (D’ALESSANDRO et al., 2004)</td></tr>
</table>

environments, such as *Bulimina costata* and *Uvigerina peregrina*, also occur, and they could be transported by sea water currents. During the deposition of this facies, the transport of sediment within the shelf (intrabasinal reworking) must be a major factor of physiographic evolution of the platform environment.

DISCUSSION AND CONCLUSION

The sedimentological features of the chaotic assemblage clearly indicate that it is derived from subaerial dismantling of exposed ridges (fig. 6). In any case, the uppermost facies of the early Messinian pre-evaporitic deposits of the S Salento, clearly show regressive features (BOSELLINI *et al.*, 2001), supporting the hypothesis that a tectonic uplift of Salento could precede the dried up Mediterranean event (BOSSIO *et al.*, 1987b).

The Salento chaotic assemblage is similar to several upper Messinian units of the Mediterranean domain (IACCARINO *et al.*, 1999). For an example, the Calcare di Base formation, a carbonate autobreccia outcrops in Sicily, shows abundant clasts and evidence of reworking that indicate humid climate (GRIFFIN, 2002). At Pissouri area (Cyprus), the upper Messininan breccia underlies mixed fresh-salt water deposits as is testified by the occurrence of *Cyprideis pannonica*, *Laxoconca diaffarovi* and *L. variesculpta* (DI STEFANO *et al.*, 1999). These data confirm that

Fig. 6 - At Punta Ristola (Leuca), the chaotic assemblage (CA) uncoformably overlies the pre Pliocene (pP) which according to BOSELLINI *et al.* (1999) consists of early Messinian calcarenites.

the terrestrial environments took place in the Mediterranean surrounding areas during the MSC. In this view, on the basis of the late Messininan features of a number of S Adriatic sea drilling (DELLE ROSE, 2001), the Mediterranean drawdown could lead to the presence of land bridges between the Apulia foreland and the Balkan area, by means of which terrestrial animals and plants could expand their distribution.

The megablocks, breccias and pebbles within the chaotic assemblage have been eroded from the ridges at time of the salinity crisis and later on, probably during the earliest Pliocene age, deposited within long shore topographic depressions. The nearly lack of continental deposits between Miocene and Pliocene Salento geological records can be due to the short interval time of the gap. Nevertheless, ravinement process, namely a time transgressive near-shore marine and shoreline strong erosion of coastal deposits, during the early Pliocene transgression can explain this features.

The lens of thin bedded limestones within the chaotic assemblage could represent deposits of a very shallow transitional continent-sea basins subject to intense evaporation under warm, dry climatic conditions (MASSARI and D'ALESSANDRO, 2000). In the Salento, during the early Pliocene, aridity and humidity could occur in close proximity according to the climate model of GRIFFIN (2002).

In someplace, as at Canale Muscio (Fig. 7), the chaotic assemblage contains large-scale undulated calcarenite beds that, according to MASSARI and D'ALESSANDRO (2000) and by virtue of the presence of *Strombus coronatus* (an extinct species before of 3 My, see MONEGATTI and RAFFI, 2001) can represent early Piacenzian tsunami-generated deposits. The above exposed features of the chaotic assemblage seem to indicate the presence of a shelf environment intensely supplied by dismantled ridges, with life-adverse environmental conditions.

The early Pliocene Mediterranean inundation could make deeper the

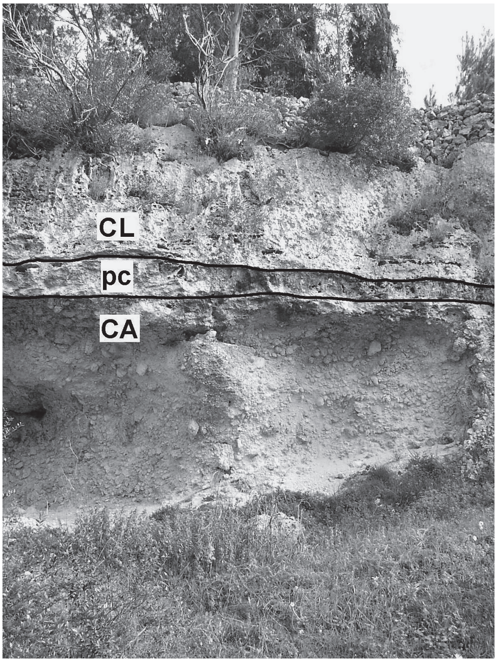

Fig. 7 - Upper Canale Muscio section (see. figure 4). CA - Chaotic assemblage; pc - phosphatized calcirudite; CL - calcarenites and limestones.

Salento shelf environment and, as a consequence, leaded to the marlstone deposition that can be related to the Trubi formation crops out on Sicily and Calabria (BOSSIO *et al.*, 1991; BOSELLINI *et al.*, 1999). During that phase the Salento, or at least the southern part of it, was at epibathyal paleo-depth.

Below the Global Standard Stratotype section and Point (GSSP) of the Gelasian Stage, the LO of *Sphaeroidinellopsis* spp. is fixed at the boundary between Trubi and Monte Narbone formations (RIO *et al.*, 1998), and the deposition environment is inferred to be an open marine slope-basin setting, whose water depth was from 800 to 1.000 m (CASTRADORI *et al.*, 1998), clearly deepest of the sea bottom of Salento's marlstones and glauconitic siltstones.

Glauconitic siltstones attest a relatively long stage of very low rate of sedimentation (at epibathyal or outer neritic paleo-depth), in accordance with the general sedimentological conditions of the whole Mediterranean sea during the lower-middle Pliocene (CITA *et al.*, 1999). According to a re-interpretation of the paleontological literature, the deposition of these facies could be stopped not before than the upper Piacenzian.

Shallowing of sea bottom is not recorded within the marlstones and glauconitic siltstones sedimentation, so that the coming to the surface of the Salento could be a "fast" geological phenomenon related to eustatic fall and/or tectonic movement. In any case, a wide inner-middle neritic environment could be placed before the phosphatized calcirudite sedimentation, but the shelf sedimentary condition were not able to lead to geological record.

The features of the unconformable contact between the marlstones and glauconitic siltstones and the phosphatized calcirudite, consisting in an erosive and burrowed thalassia paleosubstratum, allow to some paleoenvironmental considerations (Fig. 8). Hardened surfaces similar to the aforementioned unconformity, namely hardgrounds, frequently occur at sea bottom as the result of longer time disposable for cement precipitation in favourable chemical and environmental conditions. Cold environmental conditions occurred during the upper Piacenzian - lower Gelasian times, could have reduced the carbonate precipitation and forbidden the hardening of the sediments below the unconformity.

In any case, the interpretation of the contact between the Salento facies as an unconformity appears reinforced by the occurrences of this kind of stratigraphic features in the cool-water carbonate systems at the middle-outer shelf environment and in response of a sea-level fall (e. g. BOREEN and JAMES, 1995).

The phosphatized calcirudite interpretation needs, at least, the identification of: the area subject to subaerial exposure that have supplied the sediments; the intrabasinal environment where the phosphatization process occurred and the mechanism of deposition of the phosphatized clasts.

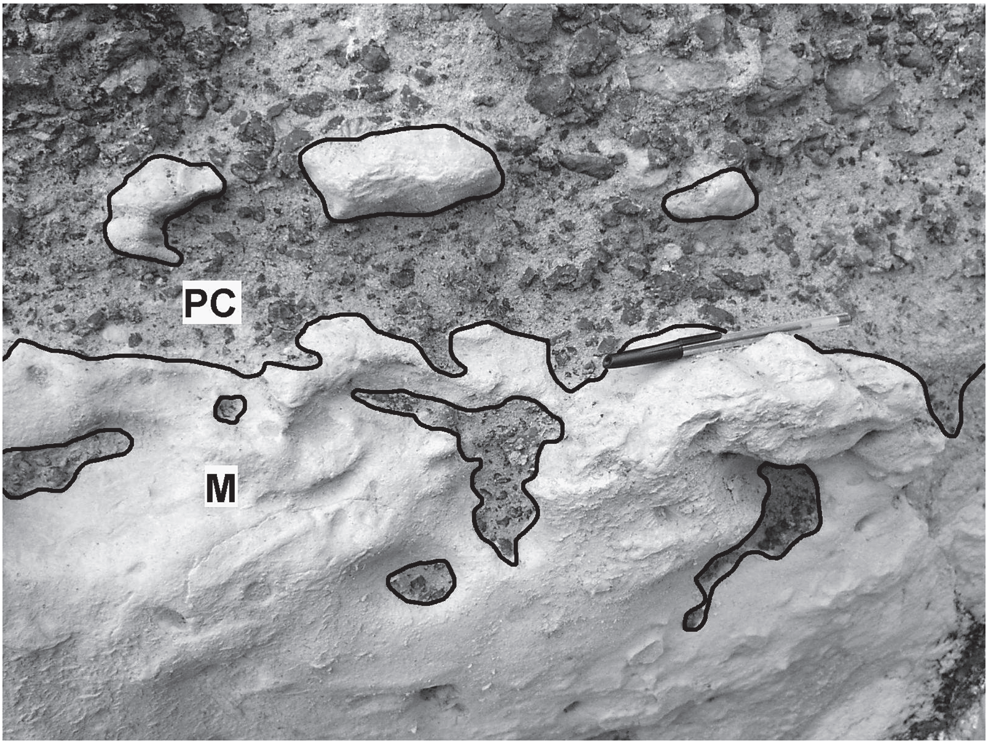

Fig. 8 - Marlstones (M) and phosphatized calcirudite (PC) contact at Bastione Pelasgi (Otranto village). Irregular erosive holes are filled by coarser clasts.

About the intrabasin environment, the phosphatization process could be developed probably below the euphotic zone being the phosphate concentrations rather poor within it, mainly because the plankton extraction of nutrients. Below the euphotic zone (that typically reachs some tens of meters in platform environment) and within the thermocline depths, decay of organic matter in subsurface waters can sufficiently concentrate phosphates to precipitate nodules or crusts. Consequently the zone between the deepest inner shelf and the shallowest middle shelf seems to be the probable phosphatization’s environment. For what concern the mechanism of deposition of the phosphatized calcirudite, the presence of filled irregular holes at the top of the marlstones, of squashed marly inclusions at the base and the grain-size grading features suggest an erosive basal contact and a re-sedimentation process by means of grain flow.

The calcarenites and limestones (Fig. 9) were supplied from an expansive subtidal source area located to the north west of Salento as far as the Murge. Sediments were piled toward Salento where they were reworked, sorted and transported by currents within the shelf. During the Gelasian, the present day flat

Fig. 9 - Calcarenites and limestones succession outcrops at S. Andrea. Arrows indicate the finer in grain-size beds.

land between the Salento and the Murge have been probably a inner shelf/ramp where rates of erosion and off shore sediment transport was higher than those of carbonate production. Very thin sequences of inner shelf/ramp can be draped some local sub basin, such as the Novoli graben, probably also before Gelasian stage (D'ALESSANDRO *et al.*, 2004).

The depositional environment of the calcarenites and limestones was a middle shelf/ramp where the sediments derived from the inner zone and relict ones were reworked by waves and bioturbated.

The calcarenites and limestones of the Salento could be related the Calcarenite di Gravina Formation, a mixed bioclastic-lithoclastic unit widespread all over the Murge and the Bradanic areas (TROPEANO and SABATO, 2000). A major limitation on this correlation consists of the lack of detailed biostratigraphic and chronological researches. Nevertheless, some outcropping sections (as an example at Cerignola, northwestern Murge, see TADDEI RUGGERO, 1996) are similar in thalassinoid assemblages to the Salento calcarenites and limestones.

At Murge area, the lower boundary of upper Pliocene - early Pleistocene

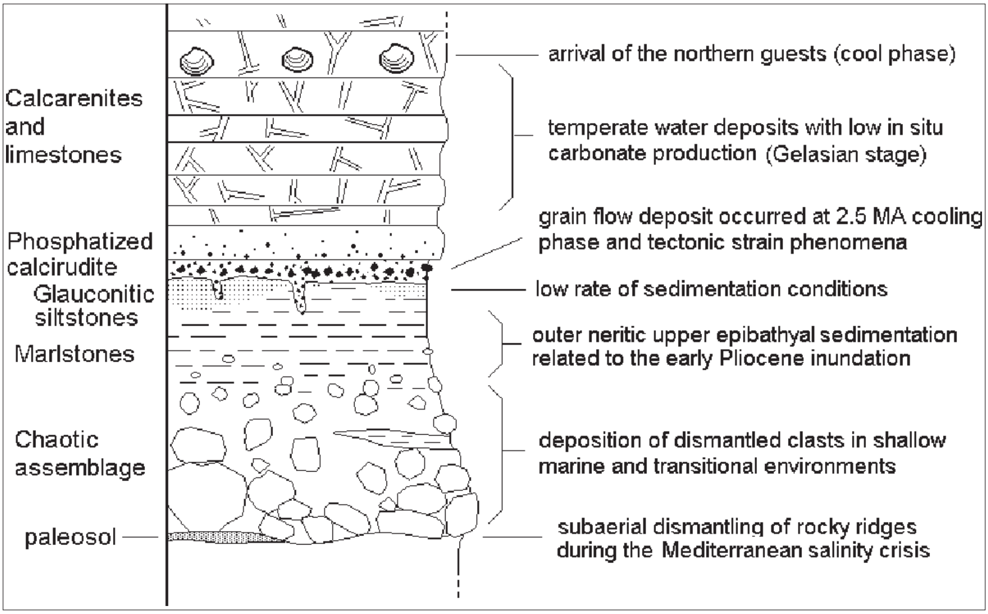

Fig. 10 - The Salento Pliocene Series related to Mediterranean events.

Calcarenite di Gravina formation has considered as a ravinement surface (TROPEANO and SABATO, 2000). The Authors, by means of the thalassinoid systems, interpreted the Calcarenite di Gravina as a temperate water deposit where carbonate production rates was low. These environmental conditions can be applied also about the coeval deposits of the Salento.

The sedimentation of the calcarenites and limestones continued at least until the deposition of the strata containing *Arctica islandica*. According to the general conventions, at this level the Neogene/Quaternary boundary must be fixed. Nevertheless, a number of data supports a large range of diachronicity of the first appearance within the Mediterranean domain (BONADONNA and ALBERDI, 1987), so much that the occurrence record westward Otranto can have an age comprise between 2.1 and 1.6 My.

In conclusion, the Salento Pliocene Series records at least five stratigraphic levels that can be related to paleogeography and paleoenvironmental changes (fig. 10). From the bottom to the top, the levels are: (1) chaotic assemblage, (2) marlstones, (3) glauconitic siltstones, (4) phosphatized calcirudite and (5) bed containing the first appearance of *Arctica islandica* at the top of calcarenites and limestones. The levels 1, 2, 3 and 5 can be respectively linked to the late Messinian Mediterranean drawdown, the deepest paleo-depth of the early Pliocene inundation, the lower-middle Pliocene stage of very low rate of sedimentation (at epibathyal or outer neritic paleodepth) and the Neogene/Quaternary boundary arrival of the "northern guests". The stratigraphic level 4 could be related to the about 2.5 My cooling phase as well as southern Apennines middle-upper Pliocene tectonic strain.

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