



Biostratigraphy and chronostratigraphy of the Miocene Pietra Leccese in the type area of Lecce (Apulia, southern Italy)

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ABSTRACT - The Miocene Pietra Leccese formation characterizes the Salentine Peninsula in the southern Italian Apulia Region, where it crops out extensively from north of the city of Lecce to Lèuca. A biostratigraphical (planktonic foraminifera and calcareous nannofossils) and chronostratigraphical study of the Pietra Leccese formation in the Lecce type area is reported. The work is based on 186 samples collected from 19 sections and 5 boreholes. As elsewhere in the Salento area, the sedimentation of the Pietra Leccese spans about 11 Ma, from the late Burdigalian (Globigerinoides trilobus Zone of the planktonic foraminifera, Helicosphaera ampliapertura Zone of the calcareous nannofossils) to the early Messinian (Globorotalia miotumida Zone and Amaurolithus delicatus-A. amplificus Zone of the two groups of organisms respectively). The deposition was interrupted by the repeated action of marine currents, which inhibited the accommodation of the sediments and/or eroded those previously formed, resulting in hiatuses (generally testified to by the occurrence of glauconite mineralization) of different durations even in successions that are located very close each other. The Lecce area was studied by considering four geographical sectors (north-western, north-eastern, south-western, and south-eastern) and three hiatuses were recognized, which in stratigraphical order are:

- first hiatus, between the typical Pietra Leccese and the overlying weakly glauconitic Pietra Leccese. This hiatus separates the upper Burdigalian sediments of the G. trilobus Zone and H. ampliapertura Zone (Sphenolithus heteromorphus-Helicosphaera ampliapertura Subzone) from the Langhian ones of the Orbulina suturalis-Globorotalia peripheroronda Zone (O. suturalis Subzone) and S. heteromorphus Zone (S. heteromorphus-Helicosphaera waltrans Subzone). The gap is shorter in the succession of the Seminario Borehole (south-eastern sector). In fact, the first sediments above the hiatus pertain to the upper part of the Praeorbulina glomerata s.l. Zone (Paragloborotalia siakensis-Praeorbulina glomerata circularis Subzone) and the lower part of the S. heteromorphus Zone (S. heteromorphus-H. waltrans Subzone);

- second hiatus, between the weakly glauconitic and the intensely glauconitic Pietra Leccese. This hiatus separates the upper Langhian sediments of the Orbulina universa (O. suturalis-G. peripheroronda Zone) and the Helicosphaera walbersdorfensis-S. heteromorphus (S. heteromorphus Zone) subzones from the lower Tortonian ones of the Paragloborotalia siakensis and Discoaster bollii (lower part) zones. The gap is shorter in the north-eastern sector (succession of the Morello Borehole) as the sedimentation restarts in the Paragloborotalia partimlabiata (P. mayeri Subzone) and Calcidiscus macintyreii zones. In this sector, further hiatus cannot be ruled out, and it should embrace the interval P. mayeri Subzone (pars) - P. siakensis Zone (pars) of the foraminifera and C. macintyreii Zone (pars) - D. bollii Zone (pars) of nannofossils.

- third hiatus, at the top of the glauconite-rich interval. This hiatus occurs between the lowermost Tortonian sediments and the middle Tortonian ones of the Neoglobobulimina acostaensis Zone (lower part) and the Discoaster bellus Zone. The gap is longer in the north-eastern sector since the deposits immediately above the intensely glauconitic interval pertain to the Globigerinoides obliquus extremus and Discoaster surculus zones.

A fourth hiatus was also recognized, but only in the area north of Lecce. In the north-western sector, the uppermost Tortonian sediments of Globorotalia suterae and Amaurolithus primus zones directly overlie the middle Tortonian deposits of N. acostaensis and D. bellus zones. The gap is shorter in the north-eastern sector because the lowermost Messinian deposits of G. miotumida and A. delicatus-A. amplificus zones lie on those of the upper Tortonian belonging to the G. obliquus extremus and D. surculus zones.

In the south-eastern sector, the deposition was continuous from the lower Tortonian (N. acostaensis and D. bellus zones) to the lower Messinian (G. miotumida and A. delicatus-A. amplificus zones). This resulted in a greater thickness of the formation (about 90 m). However, it should be noted that in this interval the Pietra Leccese formation presents lithological features that differ from the typical ones. These features are the result of a progressive bathymetric decrease in the marine environment. The decreasing depth and lithological change led to the deposition of the Calcareni di Andrano formation, the final Miocene unit on the Salentine Peninsula.

RIASSUNTO - [Biostratigrafia e chronostratigrafia della Pietra Leccese nell'area tipo di Lecce (Puglia)] - La Pietra Leccese è una formazione miocenica, peculiare della Penisola Salentina, che ha come aree di riferimento quella di Cursi-Melpignano (presso Maglie) e quella di Lecce. In questa nota sono riportati i risultati di uno studio biostratigrafico (foraminiferi planctonici e nannofossili calcarei) e chronostratigrafico degli affioramenti della seconda area; questi risultati vanno ad aggiungersi, per un quadro stratigrafico d'insieme, a quelli recentemente proposti per la prima area da alcuni degli scriventi. I dati presentati sono risultati dallo studio di 186 campioni provenienti da 19 sezioni stratigrafiche e da 5 pozzi. Il loro esame evidenzia che, nell'area di Lecce, la Pietra Leccese giace sulla Formazione di Lecce di età aquitaniana e che, in armonia con quanto già definito in altre zone del Salento, la sua deposizione è iniziata nel Burdigaliano superiore (Zona a Globigerinoides trilobus dei foraminiferi planctonici, Zona ad Helicosphaera ampliapertura, Sottozona a Sphenolithus heteromorphus-H. ampliapertura, dei nannofossili calcarei) e si è conclusa nella parte inferiore del Messiniano (Zona a Globorotalia miotumida e Zona ad Amaurolithus delicatus-A. amplificus). Il processo sedimentario è stato interrotto a più riprese dall'azione erosiva e/o dispersiva di correnti (di intensità variabile nello spazio e nel tempo), la quale ha determinato lacune (in genere segnalate dalla presenza di glauconite) di ampiezza diversa a seconda delle località. La presenza di queste lacune giustifica il ridotto spessore complessivo della Pietra Leccese, rispetto a quello che virtualmente l'unità avrebbe potuto avere in considerazione della sua litologia e della sua estensione temporale (oltre 11 Ma).

Tre lacune possono essere generalmente riconosciute nell'intero areale leccese; in ordine dal basso stratigrafico esse sono così ubicate:

- al passaggio dalla Pietra Leccese priva di granuli glauconitici a quella debolmente glauconitica. Questa lacuna separa sedimenti burdigaliani delle zone a *G. trilobus* e ad *H. ampliaperla* (Sottozona a *S. heteromorphus*-*H. ampliaperla*), da quelli langhiani della sottozona a *Orbulina suturalis* (Zona a *O. suturalis*-*Globorotalia peripheroronda*) ed a *S. heteromorphus*-*Helicosphaera waltrans* (Zona a *S. heteromorphus*). Nel settore sud-orientale (Pozzo Seminario) essa ha un'ampiezza minore, in quanto al di sopra della tipica Pietra Leccese di colore giallo-paglierino (zone a *G. trilobus* e ad *H. ampliaperla*) vi sono conservati sedimenti langhiani della zona a *P. glomerata* s.l. (Sottozona a *Paragloborotalia siakensis*-*Praeorbulina glomerata circularis*) ed a *S. heteromorphus* (Sottozona a *S. heteromorphus*-*H. waltrans*);

- al passaggio dalla Pietra Leccese debolmente glauconitica a quella riccamente glauconitica. Questa lacuna si interpone tra i sedimenti del Langhiano superiore, appartenenti alle sottozone a *Orbulina universa* (Zona ad *O. suturalis*-*G. peripheroronda*) e a *Helicosphaera walbersdorfensis*-*S. heteromorphus* (Zona a *S. heteromorphus*), e quelli del Tortoniano basale di pertinenza delle zone a *P. siakensis* e a *Discoaster bollii* (parte inferiore). Nel Pozzo Morello (settore nord-orientale) essa mostra ampiezza minore poiché la sedimentazione riprende con le zone a *Paragloborotalia partimlabiata* (Sottozona a *P. mayeri*) ed a *Calcidiscus macintyreii*. Nello stesso settore nord-orientale però non si può escludere la presenza di un'ulteriore lacuna. Questa comprenderebbe l'intervallo Sottozona a *P. mayeri* (pars) - Zona a *P. siakensis* (pars) dei foraminiferi e Zona a *C. macintyreii* (pars) - Zona a *D. bollii* (pars) dei nannofossili.

- alla sommità dell'intervallo intensamente glauconitico. Questa lacuna è compresa tra i sedimenti del Tortoniano basale e quelli ancora tortoniani riferiti alla Zona a *Neoglobobulimina acostaensis* (parte inoltrata) ed alla Zona a *Discoaster bellus*. Nel settore nord-orientale questa lacuna presenta un'estensione maggiore, in quanto i depositi al di sopra delle biomicriti intensamente glauconitiche sono riferiti alle zone a *Globigerinoides obliquus extremus* e a *Discoaster surculus*.

Limitatamente alle sezioni ubicate nella fascia a Nord di Lecce è stata riconosciuta anche una quarta lacuna. In particolare, nel settore nord-occidentale questa è evidenziata dal fatto che i depositi del Tortoniano medio-inferiore, delle zone a *N. acostaensis* ed a *D. bellus*, sottostanno a quelli del Messiniano basale, riferibili alle zone a *G. miotumida* ed a *A. delicatus*-*A. amplificus*; in quello nord-orientale essa è di entità minore in quanto i depositi messiniani giacciono direttamente su quelli del Tortoniano superiore non sommitale delle zone a *G. obliquus extremus* ed a *D. surculus*.

Per quanto riguarda il settore sud-orientale dell'area studiata è da rilevare che la deposizione è proseguita ininterrottamente dal Tortoniano inferiore al Messiniano inferiore, con le zone a *N. acostaensis* (pars), *G. obliquus extremus*, *G. suterae* e *G. miotumida* (pars) dei foraminiferi e con le zone a *D. bellus* (pars), *D. calcaris*, *D. surculus*, *Amaurolithus primus* ed *A. delicatus*-*A. amplificus* (pars) dei nannofossili. Ciò ha portato ad uno spessore di Pietra Leccese più consistente; da notare, però, che in tale intervallo l'unità presenta caratteristiche litologiche diverse da quelle tipiche e conseguenti ad una progressiva diminuzione batimetrica.

In ragione della progressiva riduzione della profondità, nelle cronozone a *G. miotumida* ed a *A. delicatus*-*A. amplificus* i sedimenti della Pietra Leccese sono stati gradualmente sostituiti da quelli della soprastante formazione delle Calcareni di Andrano, con i quali si chiude la deposizione miocenica nella Penisola Salentina.

INTRODUCTION

The Pietra Leccese is a homogeneous planktonic foraminiferal biomicrite that is yellowish in colour. The biostratigraphy of the Pietra Leccese in both the Ionian coast area (Bossio et al., 1992) and the Adriatic area (Bossio et al., 1986, 1989a, b, 1991, 1994) has been studied by the present authors who recently continued

this research in the Cursi-Melpignano area (Mazzei, 1994; Foresi et al., 2002b), which has now been concluded by studying the type area of Lecce, where the unit crops out at its maximum thickness. Bossio et al. (1999) presented the geological mapping of the Lecce area. Unfortunately, this area is fairly flat and largely anthropised, thus lacking good exposures. Nevertheless, sampling and observation were also possible in active and abandoned quarries and from the cores obtained from several boreholes located in the built-up area of Lecce and its immediate surroundings.

Previous studies have shown that sedimentary hiatuses affected the Pietra Leccese. The duration of these hiatuses even varies between nearby zones. So as to emphasize this aspect, the area considered in this paper is divided into four sectors (Fig. 1). The main lithological features of the sections and the biostratigraphy (with particular attention to the hiatuses) are illustrated for each sector, while the overall framework and comparison with data previously obtained in the Cursi-Melpignano area are presented in the conclusions.

BIOSTRATIGRAPHY

The biostratigraphical zonation of Foresi et al. (2002c), as modified in the Langhian and in the Messinian parts by Di Stefano et al. (2008) and Iaccarino et al. (2007) respectively, is adopted here (Fig. 2). The frame in this zonal scheme (and consequently in the standard chronostratigraphical scale) of selected sections of the Pietra Leccese formation of the Lecce area is reported in Figs. 4-5 and 8. The correlation of the sections was obtained by using both the micropalaeontological data

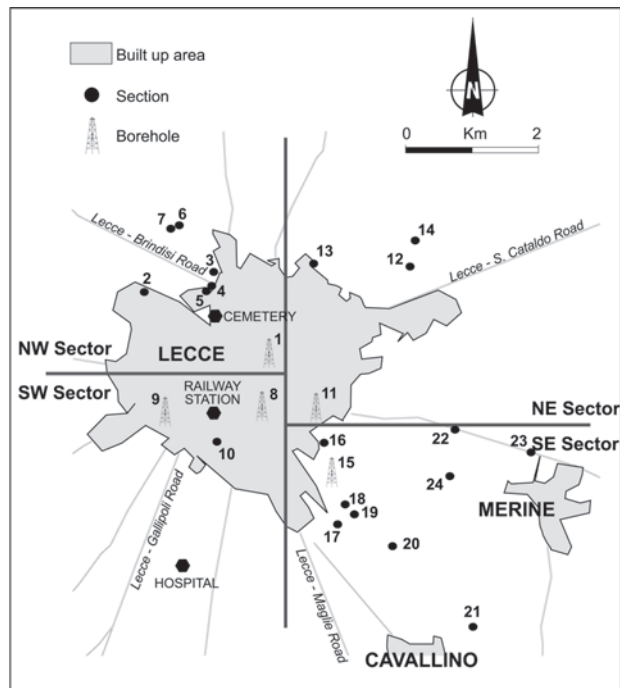


Fig. 1 - Map showing the location of the investigated sections.

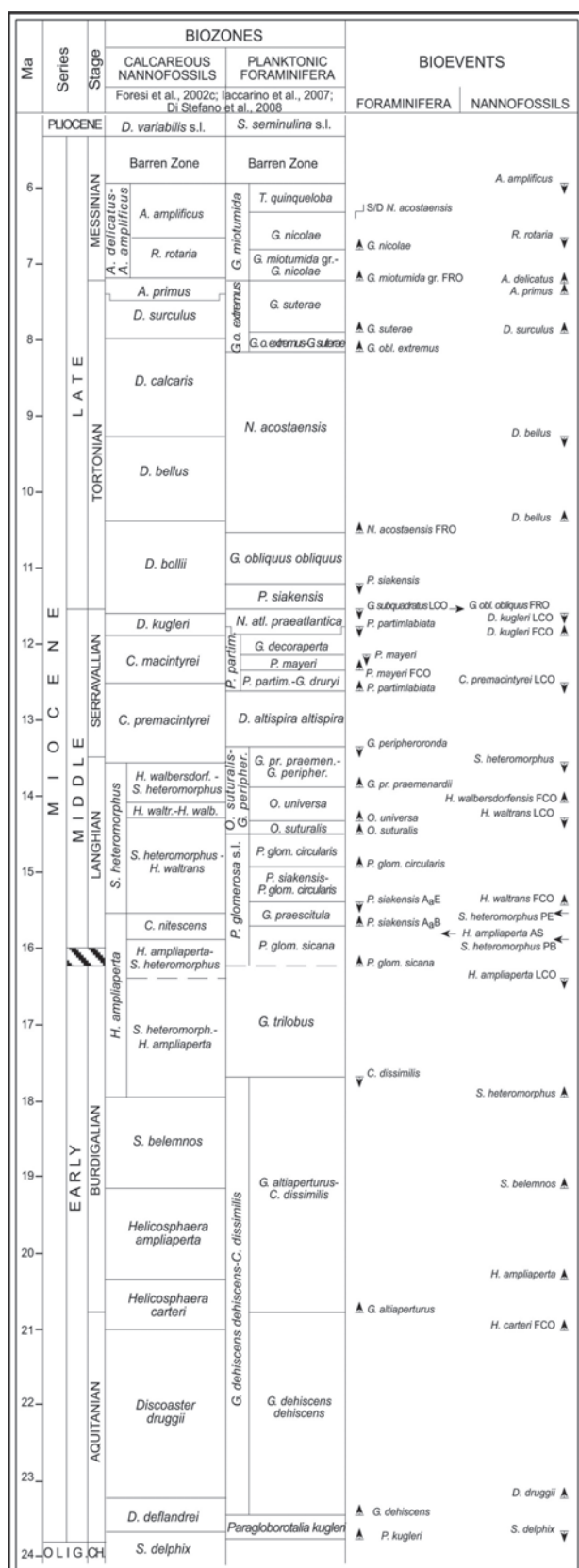


Fig. 2 - Integrated calcareous plankton biostratigraphic scheme (FCO: First Common Occurrence, LCO: Last Common Occurrence, FRO: First Regular occurrence, S/D: sinistral to dextral coiling change. AS: Acme spike, PB: Paracme Beginning; PE: Paracme End; A_aB: Beginning of Acme a; A_aE: End of Acme a).

(semiquantitative and qualitative analyses) and the mineralogical-lithological features (particularly the presence and abundance of glauconite). In spite of the low specific diversity and poor to moderate preservation, as a result of secondary dissolution or calcite encrustation, the distribution patterns of selected taxa were studied and plotted (a list of all the recognized calcareous nannofossils and planktonic foraminifera is given in Tab. 1).

NORTH-WESTERN SECTOR

Section 1 - The Sant'Oronzo Borehole (40°22'04".9 N - 18°23'48".4 E)

This borehole is located in Sant'Oronzo square (in the centre of Lecce), and was drilled using a percussion system with very low recovery. The well reached a depth of 201 m and passed through the following lithostratigraphical units: Calcareni di Andrano, Pietra Leccese, Formazione di Lecce, and Formazione di Galatone (see geological section 4 in Bossio et al., 1999). The Pietra Leccese formation is about 80 m thick (27 samples) and generally composed of a homogeneous and compact biomicrite varying in colour depending on its mineralogical content: at its base (-102 m) it has a tobacco brown colour containing small brown phosphatic nodules; from -101 m to -42 m its colour varies between straw yellow and light brown; from -42 m to -32.50 m it is greenish-yellow, and intensely greenish from -32.50 m to -26.50 m due to its glauconite content; from -26.50 m to -21 m (top of the formation) it is once again yellowish in colour because its glauconite content decreases. From -21 m to 0 m the succession in this borehole is represented by the Calcareni di Andrano formation, which ends the Miocene sedimentation.

Section 2 (40°22'35".4 N - 18°23'39".3 E)

This section is about 12 m thick and is exposed in a quarry located west of the Lecce cemetery. The Pietra Leccese formation has here the typical straw yellow colour, and it is rich in trace fossils. Six samples (SM 18-23) were taken.

Section 3 (40°22'45".9 N - 18°23'43".4 E)

This section is 20 m thick and is located in a quarry, now closed, near the Lecce cemetery. The succession is composed of typical Pietra Leccese. Nine samples, labelled IGCP 3066 to 3075, were collected.

Sections 4 (40°22'39" N - 18°23'43".6 E) and 5 (40°22'35".1 N - 18°23'43".3 E)

These two sections are also located in two quarries near the Lecce cemetery. Today the quarries are closed and partially covered. Section 4 (Fig. 3) is about 2 m thick and is composed of weakly glauconitic Pietra Leccese (sample SM 24) that unconformably underlies the intensely glauconitic Pietra Leccese (samples SM 25 and 26). Section 5 is intensely glauconitic in its lower part (samples SM 31 and 32) and weakly glauconitic in its upper (sample SM 33). The two parts are separated by an unconformity. Abundant fossils (bivalves, pteropods, brachiopods) and sparse small apatitic nodules

Calcareous nannofossils	Sector				Planktonic foraminifera	Sector			
	NW	SW	NE	SE		NW	SW	NE	SE
<i>Amaurolithus delicatus</i> Gartner & Bukry			X	X	<i>Cassigerinella chipolensis</i> (Cushman & Ponton)	X	X	X	X
<i>Amaurolithus</i> spp.	X		X	X	<i>Catapsydrax parvulus</i> Bolli, Loeblich, & Tappan* ***	X		X	X
<i>Calcidiscus leptoporus</i> (Murray & Blackman)	X		X	X	<i>Catapsydrax stainforthi</i> Bolli, Loeblich & Tappan	X			
<i>Calcidiscus macintyreii</i> (Bukry & Bramlette)	X		X	X	<i>Clavatorella sturani</i> (Giannelli & Salvatorini)	X			
<i>Calcidiscus premacintyreii</i> Theodoridis	X		X	X	<i>Dentoglobigerina altispira altispira</i> (Cushman & Jarvis)	X	X	X	X
<i>Coccolithus miopelagicus</i> Bukry	X	X	X	X	<i>Dentoglobigerina altispira globosa</i> (Bolli)	X	X	X	X
<i>Coccolithus pelagicus</i> (Wallich)	X	X	X	X	<i>Dentoglobigerina baroemouensis</i> (Le Roy)	X	X	X	X
<i>Coronocyclus</i> sp.	X				<i>Dentoglobigerina langhiana</i> (Cita & Gelati)	X	X	X	X
<i>Coronocyclus nitescens</i> (Kamptner)		X			<i>Dentoglobigerina larmei larmei</i> (Akers)	X	X	X	X
<i>Cyclargolithus floridanus</i> (Roth & Hay)	X	X	X	X	<i>Globigerina bulloides</i> d'Orbigny	X		X	X
<i>Discoaster aulakos</i> Gartner	X	X			<i>Globigerina</i> aff. <i>ciperoensis</i> (Bolli)	X	X	X	X
<i>Discoaster bellus</i> Bukry & Percival	X			X	<i>Globigerina eamesi</i> Blow	X			X
<i>Discoaster bollii</i> Martini & Bramlette	X		X	X	<i>Globigerina falconensis</i> Blow	X	X		X
<i>Discoaster brouweri</i> Bramlette & Riedel	X		X	X	<i>Globigerina foliata</i> Bolli	X	X	X	X
<i>Discoaster calcaris</i> Gartner	X		X	X	<i>Globigerina praebulloides</i> Blow	X	X	X	X
<i>Discoaster deflandrei</i> Bramlette & Riedel	X	X	X	X	" <i>Globigerina</i> " <i>venezuelana</i> Hedberg			X	
<i>Discoaster exilis</i> Martini & Bramlette	X		X	X	<i>Globigerinella aequilaterialis</i> (Brady)	X		X	X
<i>Discoaster</i> cf. <i>kugleri</i> Martini & Bramlette	X		X	X	<i>Globigerinella obesa</i> (Bolli)	X	X	X	X
<i>Discoaster mendonobensis</i> Wise				X	<i>Globigerinella pseudobesa</i> (Salvatorini)*	X		X	X
<i>Discoaster pentaradiatus</i> Bramlette & Riedel	X		X	X	<i>Globigerinita glutinata</i> (Egger)*	X	X	X	X
<i>Discoaster quinquenarius</i> Gartner	X		X	X	<i>Globigerinita uvula</i> (Ehrenberg)	X	X	X	X
<i>Discoaster stellulus</i> Gartner	X		X	X	<i>Globigerinoides altiapertura</i> Bolli	X	X		X
<i>Discoaster surculus</i> Martini & Bramlette	X		X	X	<i>Globigerinoides bollii</i> Blow	X		X	X
<i>Discoaster variabilis</i> Martini & Bramlette	X	X	X	X	<i>Globigerinoides bulloides</i> Crescenti	X	X	X	X
<i>Discoaster</i> spp.	X	X	X	X	<i>Globigerinoides diminutus</i> Bolli	X	X		X
<i>Geminilithella rotula</i> (Kamptner)	X	X	X	X	<i>Globigerinoides fragilis</i> Borsetti & Cati			X	
<i>Helicosphaera ampliapertura</i> Bramlette & Wilcoxon	X	X	X	X	<i>Globigerinoides obliquus extremus</i> Bolli & Bermúdez	X		X	X
<i>Helicosphaera carteri</i> (Wallich)	X		X	X	<i>Globigerinoides obliquus obliquus</i> Bolli	X	X	X	X
<i>Helicosphaera euphratis</i> Haq	X	X	X	X	<i>Globigerinoides quadrilobatus sacculifer</i> (Brady)	X	X	X	X
<i>Helicosphaera intermedia</i> Haq	X	X	X	X	<i>Globigerinoides quadrilobatus quadrilobatus</i> (d'Orbigny)	X	X	X	X
<i>Helicosphaera kamptneri</i> Hay & Mohler	X	X	X	X	<i>Globigerinoides quadrilobatus trilobus</i> (Reuss)	X	X	X	X
<i>Helicosphaera mediterranea</i> Müller	X				<i>Globigerinoides seigliei</i> Bermúdez & Bolli	X		X	X
<i>Helicosphaera scissura</i> Miller	X	X	X	X	<i>Globigerinoides</i> sp. (aff. <i>mitra</i>)	X		X	X
<i>Helicosphaera walbersdorfensis</i> Müller	X		X	X	<i>Globigerinoides subquadratus</i> Brönnimann	X	X	X	X
<i>Helicosphaera waltrans</i> Theodoridis	X		X	X	<i>Globigerinoides tyrrhemicus</i> Borsetti & Cati	X		X	
<i>Pontosphaera multipora</i> (Kamptner)	X	X	X	X	<i>Globigerinopsis agasayensis</i> Bolli	X		X	X
<i>Pontosphaera japonica</i> (Takayama)				X	<i>Globoquadrina dehiscens</i> (Chapman, Parr & Collins)	X	X	X	X
<i>Pontosphaera</i> spp.	X	X	X		<i>Globorotalia conoidea</i> Walters			X	
<i>Pyrocyclus</i> spp.	X	X	X	X	<i>Globorotalia conomiozea</i> Kennett*	X		X	X
<i>Reticulofenestra pseudoumbilica</i> Gartner	X		X	X	<i>Globorotalia exserta</i> Romeo			X	
<i>Reticulofenestra</i> spp.	X	X	X	X	<i>Globorotalia languensis</i> Bolli	X			X
<i>Rhabdosphaera procera</i> Martini	X		X	S	<i>Globorotalia mediterranea</i> Catalano & Sprovieri	X		X	X
<i>Scyphosphaera</i> spp.	X				<i>Globorotalia menardii</i> s.l.*	X		X	X
<i>Sphenolithus abies</i> Deflandre	X		X	X	<i>Globorotalia</i> aff. <i>menardii</i> (Parker, Jones & Brady)*	X		X	X
<i>Sphenolithus compactus</i> Backman	X		X		<i>Globorotalia miotumida</i> Jenkins			X	
<i>Sphenolithus heteromorphus</i> Deflandre	X	X	X	X	<i>Globorotalia miozea</i> Finlay	X		X	X
<i>Sphenolithus moriformis</i> (Brönnimann & Stradner)	X	X	X	X	<i>Globorotalia peripheroronda</i> Blow & Banner	X		X	X
<i>Sphenolithus</i> spp.	X	X	X	X	<i>Globorotalia praemenardii archeomenardii</i> Bolli	X	X		X
<i>Umbilicosphaera sibogae</i> (Weber-van Bosse)	X		X	X	<i>Globorotalia praemenardii praemenardii</i> Cushman & Stainforth	X		X	X
					<i>Globorotalia praescitula</i> Blow	X	X	X	X
					<i>Globorotalia saphoe</i> Bizon & Bizon			X	
					<i>Globorotalia</i> gr. <i>scitula</i> (Brady)*	X		X	X
					<i>Globorotalia suterae</i> Catalano & Sprovieri	X		X	X
					<i>Globorotalia ventriosa</i> Ogniben	X		X	X
					<i>Globoturborotalia decoraperta</i> (Takayanagi & Saito)	X	X	X	X
					<i>Globoturborotalia druryi</i> (Akers)	X		X	X
					<i>Globoturborotalia nepenthes</i> (Todd)	X		X	X
					<i>Globoturborotalia woodi</i> (Jenkins)	X	X	X	X
					<i>Hastigerina pelagica</i> (d'Orbigny)			X	
					<i>Neogloboquadrina acostaensis</i> (Blow)	X		X	X
					<i>Neogloboquadrina atlantica praetlantica</i> Foresi, Iaccarino & Salvatorini***	X		X	X
					<i>Neogloboquadrina humerosa humerosa</i> (Takayanagi & Saito)	X			
					<i>Neogloboquadrina humerosa praehumerosa</i> (Natori)	X		X	X
					<i>Orbulina bilobata</i> (d'Orbigny)	X		X	X
					<i>Orbulina suturalis</i> Brönnimann	X		X	X
					<i>Orbulina universa</i> d'Orbigny	X		X	X
					<i>Paragloborotalia acrostoma</i> (Wezel)	X	X		X
					<i>Paragloborotalia bella</i> (Jenkins)	X	X		X
					<i>Paragloborotalia birnageae</i> (Blow)	X	X		X
					<i>Paragloborotalia</i> aff. <i>birnageae</i> (Blow)	X	X		X
					<i>Paragloborotalia incognita</i> (Walters)	X	X	X	X
					<i>Paragloborotalia mayeri</i> (Cushman & Ellis)			X	
					<i>Paragloborotalia partimlabiata</i> (Ruggieri & Sprovieri)			X	
					<i>Paragloborotalia siakensis</i> (Le Roy)	X	X	X	X
					<i>Praeorbulina glomerata circularis</i> (Blow)	X		X	
					<i>Praeorbulina glomerata glomerata</i> (Blow)			X	
					<i>Praeorbulina transitoria</i> (Blow)			X	
					<i>Sphaeroidinellopsis disjuncta</i> (Finlay)**	X			X
					<i>Sphaeroidinellopsis seminulina seminulina</i> (Schwager)**	X		X	X
					<i>Sphaeroidinellopsis subdehiscens</i> (Blow)**				X
					<i>Tenuitellina angustumbilicata</i> (Bolli)	X	X	X	X
					<i>Turborotalia quinqueloba</i> Natland	X		X	X

Tab. 1 - List of all the calcareous nannofossils and planktonic foraminifera recognized in the studied sections. References for taxa marked by asterisks: * - Foresi et al. (2001); ** - Salvatorini & Cita (1979); *** - Foresi et al. (2002a).



Fig. 3 - Unconformable contact between the weakly glauconitic Pietra Leccese (bottom half of the picture), and the intensely glauconitic Pietra Leccese (upper half of the picture) of the Section 4 (North-Western Sector).

characterize the base of the intensely glauconitic Pietra Leccese.

Section 6 (40°23'08".1 N - 18°23'40".4 E)

It crops out in a quarry located near Borgo San Nicola to the North-East of Lecce cemetery and it is 6 m thick. The section is composed of slightly glauconitic biomicrites (3.5 m) in the lower part and of intensely glauconitic ones in the upper part (2.5 m). The base of the upper part is marked by a concentration of fossils (prevalently *Neopycnodonte*, *Flabellipecten*, and *Amusium*, while phosphatic moulds of other bivalves, pteropods, and brachiopods were also found) mixed with small apatitic nodules (a few millimetres to 2-3 cm in size). Widespread bioturbation can be observed on the quarry wall from which six samples (IGP 2828-2833) were taken.

Section 7 (40°23'06".8 N - 18°23'39".9 E)

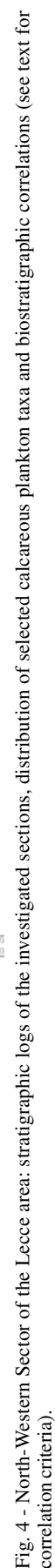
This is located in the Macello Quarry, approximately 500 m SW of Section 6. The quarry walls are 27-28 m high and are entirely composed of homogeneous compact biomicrites with sparse fossils (mainly pectinids, but some echinoids are also present) and abundant horizontal burrow trace fossils. The biomicrites in the lower 5-6 m are light brown to tobacco in colour while the remaining part has a straw yellow colour. Eleven samples (SM 1-11) were taken from this section.

Bio-chronostratigraphy - The Pietra Leccese formation of this sector belongs to the Burdigalian-Messinian interval (Fig. 4) and spans the *Globigerinoides trilobus*-*Globorotalia miotumida* and *Helicosphaera ampliaperta*-*Amaurolithus delicatus*-*A. amplificus* zones of the foraminifera and calcareous nannofossils, respectively. At least four sedimentary hiatuses can be

identified, and these are localized in the upper part of the succession where glauconite is found, a mineral indicative of condensed sedimentation or no sedimentation (see Balenzano et al., 1994, 1997).

Starting from the lowest, the first hiatus is located between samples SO 29 and SO 30 of the Sant'Oronzo Borehole and presumably corresponds to the first appearance of glauconite. The weakly glauconitic interval is referred to the *Orbulina suturalis*-*Globorotalia peripheroronda* Zone (N9 Zone in the standard zonation of Blow), specifically to the *O. suturalis* and *O. universa* subzones. The presence of the last subzone is also confirmed by the occurrence of *Globigerinopsis aguasayensis* (Foresi et al., 2001). Assemblages from sample SO 29 down to the bottom of the borehole are referred to the *G. trilobus* Zone (N7 of Blow). In fact, *Praeorbulina* (the First Occurrence of the taxon marks the base of *P. glomerata* s.l. Zone) and *Catapsydrax dissimilis* (the Last Occurrence of the species marks the base of *G. trilobus* Zone) are not present. Furthermore, other bioevents recognized in the glauconite-free interval support this reference, which from lowest to highest are: the LO of *Paragloborotalia incognita* (according to Kennett & Srinivasan, 1983, it disappears at the bottom of N7); the LOs of *Globigerinoides altiapertura* and of *Paragloborotalia acrostoma* (see comments in Bossio et al., 2002); and the FOs of *Globigerinoides diminutus* and of *Globorotalia birnageae* (according to Blow, 1969, Kennett & Srinivasan, 1983, and Bolli & Saunders, 1985, the disappearance of the two taxa occurs in N7).

The analyses of calcareous nannofossil assemblages confirm the foraminiferal biostratigraphy. In particular, sample SO 29 and those of the underlying Pietra Leccese are referred to the *H. ampliaperta* Zone (*Sphenolithus heteromorphus*-*H. ampliaperta* Subzone) due to the



common occurrence of *H. ampliaperta*, *S. heteromorphus*, and *Discoaster deflandrei* and the absence of *Discoaster exilis*. SO 30 and the overlying samples with weakly glauconitic content (up to sample SO 33) can be attributed to the middle-upper portion of the *S. heteromorphus* Zone (uppermost part of *S. heteromorphus-Helicosphaera waltrans* Subzone up to the basal part of the *Helicosphaera walbersdorfensis-S. heteromorphus* Subzone). According to Foresi et al. (2001, 2002c), Iaccarino et al. (2001), and Di Stefano et al. (2008) this biostratigraphic attribution is supported by the common occurrence of *S. heteromorphus* and *H. waltrans* (rare in samples SO 32-33), the rare occurrence of *H. walbersdorfensis* (common only in sample SO 33) and the occasional occurrence of *D. exilis*, *Calcidiscus macintyreii* (<11 µm), *C. premacintyreii*, *Helicosphaera mediterranea*, and *Sphenolithus abies*. The biostratigraphical references show that the glauconite-free biomicrites are late Burdigalian in age while the overlying weakly glauconitic biomicrites belong to the middle-upper Langhian. The hiatus between the two portions embraces at least the upper part of the *G. trilobus* Zone and all the *P. glomerosa* s.l. Zone of the foraminifera as well as the upper part of the *H. ampliaperta* Zone and the lower-middle part of the *S. heteromorphus* Zone of the nannofossils.

The second hiatus is recorded between the weakly glauconitic interval and the overlying intensely glauconitic one (between samples SO 33 and 34 of the Sant'Oronzo Borehole, SM 24 and 25 of Section 4, and IGP 2830 and 2831 of Section 6), which is marked at the base by a level with very abundant remains of mollusks (named "livello a cozze" [mussel level] by the local quarrymen).

The intensely glauconitic interval is referred to the *Paragloborotalia siakensis* Zone due to the occurrence of the nominal marker with the presence of sporadic *Globigerinoides subquadratus*, and abundant and typical *G. obliquus obliquus* (according to Sprovieri et al., 2002, the First Common Occurrence of this taxon coincides with the Last Common Occurrence of *G. subquadratus*). The biostratigraphical attribution is also confirmed by the presence of *Globoturborotalita nepenthes* (according to Foresi et al., 2001, its FO is detected at the base of the *P. siakensis* Zone), common specimens of *Neogloboquadrina atlantica praeatlantica* dx and rare *N. acostaensis* dx (Foresi et al., 2002a and the above mentioned authors). Calcareous nannofossil assemblages are not particularly rich or diversified in the samples with high glauconite content. However, the presence of rare *Discoaster bollii* and *D. cf. kugleri*, together with common *Coccolithus miopelagicus* and *H. walbersdorfensis*, are indicative of the lower part of the *D. bollii* Zone (Iaccarino et al., 2001; Foresi et al., 2002c). Biostratigraphical data indicate that the intensely glauconitic interval of the Pietra Leccese formation can be referred to the base of the Tortonian. Therefore, the hiatus between the weakly and intensely glauconitic biomicrites spans the *O. suturalis-G. peripheroronda* (upper part)-*Neogloboquadrina atlantica praeatlantica* zones, as well as the *S. heteromorphus* (highest part)-*Discoaster kugleri* zones.

The third hiatus can be identified between samples SO 37 and SO 38 of the Sant'Oronzo Borehole, SM 32

and 33 of Section 5, and IGP 2832 and 2833 of Section 6 where, compared to the underlying interval, the glauconite content of the Pietra Leccese starts to decrease. This interval (with its decreasing glauconite content) is referred to the foraminiferal *N. acostaensis* Zone for the abundance of the nominal marker (the interval is also characterized by the presence of *Neogloboquadrina humerosa praeumerosa*, *Globorotalia ventriosa*, *G. linguaensis*, and *Globigerinoides seigliei*, while *G. obliquus extremus* is absent), and to the nannofossil *Discoaster bellus* Zone for the rare occurrence of zonal marker in addition to rare *Discoaster brouweri*, *D. cf. calcaris*, and *D. pentaradiatus* (see Foresi et al., 2001, 2002c, and Iaccarino et al., 2001). The biostratigraphical attribution is also confirmed by the LO of *Globigerinopsis aguasayensis* and by the dextral/sinistral coiling change of neogloboquadrinids (Foresi et al., 2001) that occurs just above the base of the interval in which the glauconite decreases. In chronostratigraphical terms, above the basal Tortonian sediments lie those of the middle Tortonian. The hiatus between the two intervals spans at least the entire *G. obliquus obliquus* Zone and part of the *N. acostaensis* Zone, as well as most of the *D. bollii* Zone and the lower portion of the *D. bellus* Zone.

A fourth hiatus, which includes at least the Tortonian *N. acostaensis* (pars), *G. obliquus extremus*, and *G. suteri* (pars) zones, and the *Discoaster calcaris*, *D. surculus*, and *Amaurolithus primus* (pars) zones is documented between samples SO 39 and SO 40 of the Sant'Oronzo Borehole (where the glauconite becomes even rarer). The presence of *Amaurolithus* spp. (together with *Discoaster surculus* and *D. quinqueramus*) and *G. suteri* in sample SO 40 and of *Globorotalia conomiozea* in sample SO 41 (together with *G. mediterranea* and *G. suteri*) indicate that it is possible to recognize the Tortonian *G. suteri* and *A. primus* zones (sample SO 40) and the Messinian *G. miotumida* and *A. delicatus-A. amplificus* zones (sample SO 41) in the uppermost part of the Pietra Leccese formation.

SOUTH-WESTERN SECTOR

Section 8 - The Alfarano Borehole (40°21'43" N - 18°23'48".8 E)

This borehole is located in the built up area of Lecce at the crossroads for Maglie. It was drilled by the Alfarano company in 1994 using a rotation and continuous core drilling system. Samples between a depth of -40 m and -156 m were available. The Formazione di Galatone and the Formazione di Lecce are present in stratigraphical order from -156 m to -85 m while the Pietra Leccese formation occurs from -85 m up to the top of the borehole. The latter unit is represented by a compact biomicrite whose colour varies from "bruno avana" to nut brown. Eight samples (AL 85, 80, 75, 70, 65, 60, 50, 40) were taken.

Section 9 - The Acquedotto Borehole (40°21'35".6 N - 18°23'42".9 E)

This borehole is located at km 2 on the Arnesano road within Lecce. It includes the Formazione di Lecce

and the Pietra Leccese. Four samples were taken from the lower 9 m of the latter unit (IGP 3087-3090), which are composed of a biomicrite varying in colour from dark brown to straw yellow.

Section 10 (40°21'22".6 N - 18°23'46".8 E)

This is located south of the Lecce railway station and is composed of subsections 10a and 10b. Subsection 10b is located in the Marco Vito Quarry (sampling started from about 4 m above the quarry floor) and Subsection 10a corresponds to a nearby overlying artificial cutting on the road that passes along the northern perimeter of the quarry. The total thickness of the composite section is approximately 30 m. The Pietra Leccese formation is represented by a compact biomicrite and is straw yellow in colour containing sparse skeletal fossils and diffuse trace fossils. Fifteen samples were taken, eight in the quarry (SM 34-41), and seven along the road cutting where the stratification is evident (SM 42-48).

Bio-chronostratigraphy - The biostratigraphy of the Pietra Leccese in the south-western sector was obtained by analysing 27 samples (Fig. 5). Calcareous plankton is scarce in the samples at -85 m, -80 m, and -75 m of the Alfarano Borehole. Fig. 5 shows that the whole succession can be attributed to the upper Burdigalian *G. trilobus* Zone and *H. ampliaperta* Subzone (*S. heteromorphus*-*H. ampliaperta* Subzone). The biostratigraphical events recognized in this sector are the same as those in the glauconite-free biomicrite of the north-western sector. Consequently, the same considerations are applied here.

NORTH-EASTERN SECTOR

Section 11 - The Morello Borehole (40°21'33".1 N - 18°23'52".6 E)

The borehole is located at the junction of the Lecce inner ring road and Lecce-Maglie motorway. It was drilled using the percussion system and a partial recovery of the succession was obtained (from -90 m to -23 m). This succession is composed of two lithostratigraphical units: the Formazione di Lecce (from -90 m to -85 m) and the Pietra Leccese formation (from -85 m to -23 m). The lower part of the Pietra Leccese (it was not possible to examine it at the base), up to -32 m, is represented by straw yellow biomicrites. The remaining part of the unit is composed of greenish-yellow biomicrites and dark green ones from -32 m to -26 m and -26 to -23 m, respectively, ten samples (SM 3-12) were collected.

Section 12 (40°22'48".8 N - 18°23'55".7 E)

This section corresponds to a cutting on the road from the centre of Lecce to the soccer stadium between Masseria Gricella and Masseria Torricella. It is composed of 5 m of Pietra Leccese. The first metre consists of greenish biomicrites (sometimes the glauconitic granules are concentrated in lenses, which are dark green in colour), with sparse phosphatic nodules (1 to 20 mm in size), common trace fossils and skeletal fossils (especially *Flabellipecten*, *Chlamys*, *Amusium*, and *Neopycnodonte*, but also pteropods, echinoid remains, fish teeth, and vertebrate bone fragments). From 1 to 5

m the unit becomes more yellowish because of the decrease in glauconite and it contains large *Terebratula* as well as moulds of bivalves. It is more marly in the last 50 cm and shows a clear brown colour (with an ochreous shade in fresh fracture) and a fossil content composed of small pectinids (especially *Chlamys*), ostreids, and brachiopods as well as balanids, bryozoans, and serpulids. Eight samples (SM 176-184) were taken.

Section 13 (40°22'49".8 N - 18°23'49".6 E)

The section, located at SE of Masseria Frisella (on the northern outskirts of Lecce) was measured on the artificial cutting of a construction site and of the adjacent road. Approximately 6 m of Pietra Leccese and 1 m of Calcareni di Andrano are represented in this section. In the lowest two metres the Pietra Leccese is composed of a greenish biomicrite, whereas the remaining part is light brown. Five samples (GS 34-38) were taken.

Section 14 (40°23'01".5 N - 18°23'55".7 E)

This section is located along a road cut about 100 m from Section 13. It is 4.5 m thick and it is composed of weakly glauconitic Pietra Leccese in the lower part (samples SM 119-121) and of Calcareni di Andrano in the upper part (samples SM 122 and SM 167-169).

Bio-chronostratigraphy - The foraminiferal assemblages of samples SM 3-10 (Morello Borehole, Fig. 6) do not contain specimens of the *Praeorbulina-Orbulina* lineage so they were attributed to the upper Burdigalian *G. trilobus* Zone. Recognized bioevents are the FO of *G. peripheroronda* and the LOs of *Paragloborotalia incognita*, *P. acrostoma*, *G. birnageae* and *G. altiapturus*. With the common occurrence of *S. heteromorphus*, *H. ampliaperta*, and *Discoaster deflandrei*, the calcareous nannofossil assemblages of the same samples undoubtedly belong to the *H. ampliaperta* Zone (*S. heteromorphus*-*H. ampliaperta* Subzone).

Sample SM11, collected in the weakly glauconitic interval of the Morello Borehole, contains the first specimens of *O. suturalis* so it can be referred to the upper Langhian *O. suturalis* Subzone (*O. suturalis*-*G. peripheroronda* Zone). The occurrence of common *S. heteromorphus* and *H. waltrans* and rare *D. exilis*, *Helicosphaera mediterranea*, *H. walbersdorfensis*, *Calcidiscus macintyre* (<11 µm), *C. premacintyre*, *Reticulofenestra pseudoumbilica*, and *Sphenolithus abies* in this sample is indicative of the *S. heteromorphus*-*H. waltrans* Subzone (*S. heteromorphus* Zone).

Therefore, a sedimentary hiatus, which includes the upper part of the *G. trilobus* Zone and the *P. glomerata* s.l. Zone, as well as the upper part of the *H. ampliaperta* Zone and the lower part of the *S. heteromorphus* Zone, is documented between samples SM 10 and 11 (where the glauconite first appears). It should be noted that the lack of other samples from the weakly glauconitic interval makes difficult to check the presence of the *Orbulina universa*, *H. waltrans*-*H. walbersdorfensis*, and *H. walbersdorfensis*-*S. heteromorphus* subzones (Fig. 6).

The foraminiferal assemblage of sample SM 12 (intensely glauconitic interval) contains *Paraglobo-*

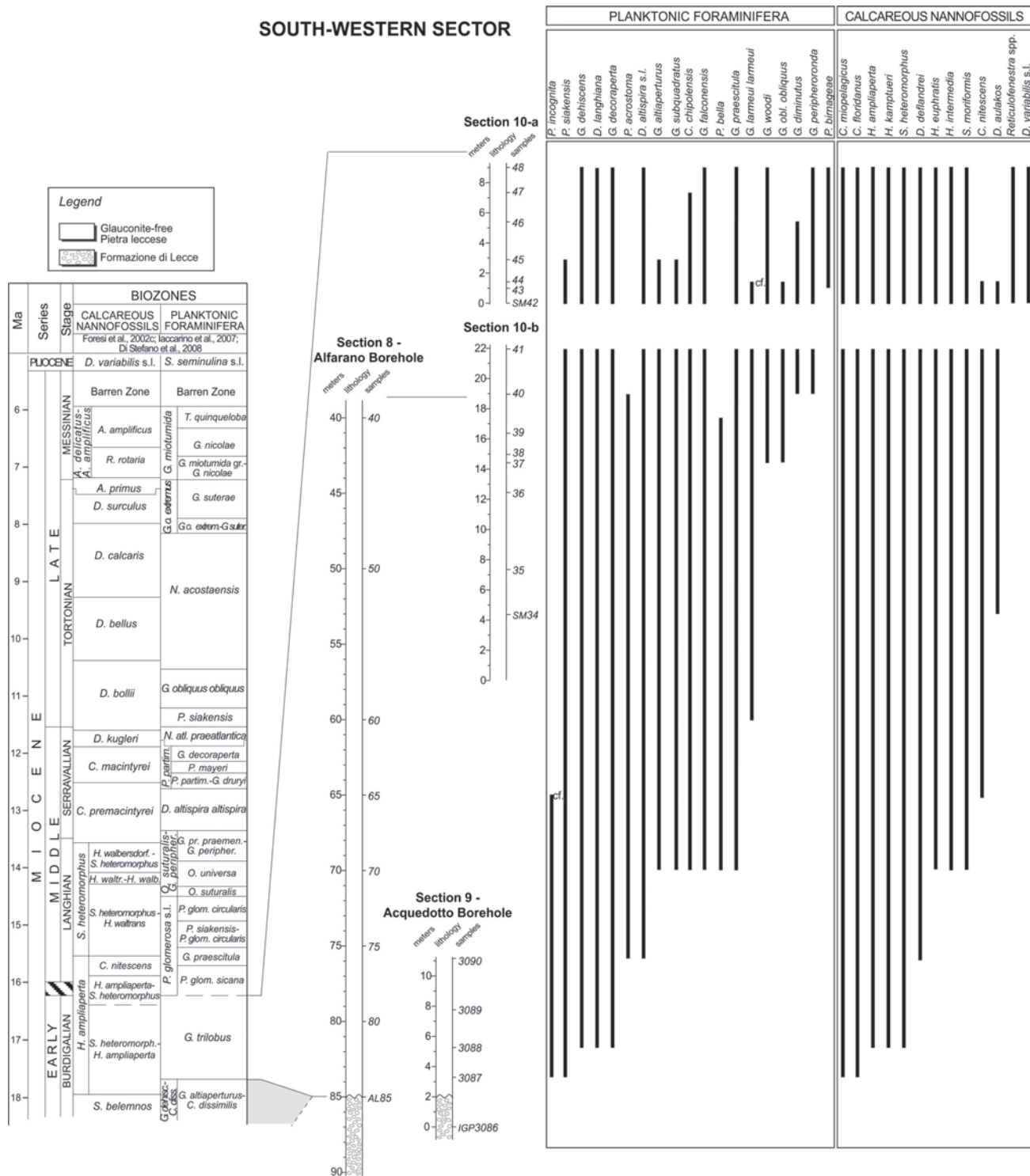


Fig. 5 - South-Western Sector of the Lecce area: stratigraphic logs of the investigated sections, distribution of selected calcareous plankton taxa and biostratigraphic correlations (see text for correlation criteria).

rotalia mayeri and *P. partimlabiata*. The presence of these taxa allows to assign sample SM 12 to the *P. mayeri* Subzone (*P. partimlabiata* Zone). The calcareous nannofossil assemblage of the same sample is characterized by the common occurrence of *C. macintyreii* (>11 μ m), *C. miopelagicus*, *H. walbersdorfensis*, and *R. pseudoumbilica* (>7 μ m), in addition to the very rare occurrence of *C. premacintyreii*,

which is indicative of the *C. macintyreii* Zone (see Foresi et al., 2002c). In chronostratigraphical terms sample SM 12 is Serravallian in age.

The attribution of sample SM 12 to the Serravallian *P. partimlabiata* and *C. macintyreii* zones means that the start of the intensely glauconitic interval (between samples SM 11 and 12) indicates a hiatus (including at least the upper part of the *O. suturalis*-*G. peripheroronda*

Zone, the *D. altispira altispira* Zone, and the lower part of the *P. partimlabiata* Zone, as well as the uppermost part of the *S. heteromorphus* Zone and the *C. premacintyreii* Zone).

The Pietra Leccese with high glauconite content occurring at the base of Section 12 (SM 176) can be referred to the lower Tortonian *P. siakensis* and *D. bollii* (lower part) zones. The first zonal attribution is due to the presence of *G. subquadratus* (rare), *G. obliquus obliquus* (typical and abundant), *G. bollii*, *P. siakensis*, *G. nepenthes* (common), *D. altispira* s.l. (rare), *N. acostaensis* (rare and dextral individuals), and *N. atlantica praeatlantica* (dextral and abundant), while the second is provided by the rare occurrence of nominal taxon in association with common *C. macintyreii* (>11 µm), *C. miopelagicus* and *H. walbersdorfensis* as well as rare specimens of *D. cf. kugleri* (see Foresi et al., 2001 for the distribution of the calcareous plankton).

A hiatus between the top of the Morello Borehole and the base of Section 12 cannot be excluded. In fact, the few metres assumed to exist between samples SM 12 and SM 176 may not be sufficient to represent to the upper part of the *P. partimlabiata* Zone (*Globoturborotalita decoraperta* Subzone) and the *N. atlantica praeatlantica* Zone, as well as the upper part of the *C. macintyreii* Zone and the *D. kugleri* Zone. On the Tremiti Islands in the Adriatic Sea, this interval (Foresi et al., 2001) is represented by sediments very similar to the Pietra Leccese, but at least 25 m thick.

Another evident hiatus is recorded between samples SM 176 and SM 177 of Section 12 because *G. obliquus extremus* and *Discoaster surculus* occur in the sample SM 177. In the absence of *G. suteri* and of the genus *Amaurolithus*, the presence of these taxa identifies the *G. obliquus extremus* and *D. surculus* zones. This hiatus includes at least the interval from the *G. obliquus obliquus* Zone to the initial part of the *G. obliquus extremus* Zone, as well as the interval from the middle-upper portion of the *D. bollii* Zone to the top of the *D. calcaris* Zone.

The *G. obliquus extremus* and *D. surculus* zones are represented up to sample SM 180 of Section 12 and sample GS 36 of Section 13. On the other hand, the samples SM 182-184 of Section 12 and GS 37-38 of Section 13 are referred to the Messinian *G. miotumida* and *Amaurolithus delicatus*-*A. amplificus* zones because they contain *G. conomiozea* (in addition to *G. miotumida*, *G. mediterranea*, and *G. exserta*) and *Amaurolithus delicatus* (in addition to *Reticulofenestra rotaria* and *Discoaster quinqueramus*). A hiatus occurs within the topmost biomicrites with a very weakly glauconite content. It includes at least the *G. suteri* Zone of the foraminifera as well as part of the *D. surculus* Zone and the *A. primus* Zone of the nannofossils. It is probable that this hiatus coincides with the decrease in glauconite content.

SOUTH-EASTERN SECTOR

Section 15 - The Seminario Borehole (40°21'07".4 N - 18°23'55" E)

This borehole is located near the Seminary to the south of the town of Lecce. It was drilled with the percussion system, and a partial recovery of the succession was obtained. The succession (from 0 to -173m) is composed of the following lithostratigraphical units from the top: the Pietra Leccese formation, Formazione di Lecce, Formazione di Galatone, and Calcari di Melissano. Based on the few samples available, the Pietra Leccese starts between samples SEM 27 (-50 m) and SEM 26 (-60 m) and occurs up to the 0 m level (SEM 33). This unit is composed of homogeneous and yellowish biomicrites, except for the uppermost 120 cm (samples SEM 32 and 33) that are slightly green in colour due to their low glauconite content. In addition, analysis of the washing residues reveals glauconite granules from -40 m level (SEM 28).

Section 16 (40°21'22".4 N - 18°23'53".7 E)

This section is about 4 m thick and is located 500 m NNW of the Seminario Borehole. The Pietra Leccese is composed of a yellowish marly biomicrite and contains abundant bivalves. Three samples (GS 1-3) were collected from this formation and two (GS 4 and IGP 2933) from the overlying Calcareniti di Andrano.

Sections 17 (40°20'44" N - 18°23'56" E), *18* (40°20'52".9 N - 18°23'56".2 E), and *19* (40°20'48".3 N - 18°23'56".8 E)

These sections represent the highest portion of walls in three quarries near the Seminary (SE Lecce). The quarries were partially filled at the time of sampling and are now totally covered. Section 17 is about 6 m thick and sections 18 and 19 are both 2 m thick. Two different lithotypes are present in these sections. The lower part (samples SM 77-79 of Section 17, samples IGP 304I-II of Section 18, and samples IGP 304E-F of Section 19) is weakly glauconitic whereas the upper (samples SM 80 and 81 of Section 17, samples IGP 304III-V of Section 18, sample IGP 304G of Section 19) is characterized by high glauconite content. The upper part lies unconformably on the lower one and is rich in fossils at the base (especially *Flabellipecten*, *Chlamys*, *Amusium*, and *Neopycnodonte*).

Section 20 (40°20'32".2 N - 18°23'59".9 E)

This section is about 22 m thick and corresponds to a wall of the "La Cisterna" Quarry, located south-east of Lecce and east of Masseria il Pino. From the bottom the Pietra Leccese formation is composed of: about 4 m (SM 66-67) of yellowish biomicrites, with sparse glauconite grains; 2 m (sample SM 68) of intensely glauconitic biomicrites; and about 4 m (SM 69-70) of weakly glauconitic biomicrites. In the remaining 12 m (samples SM 71-76 and SM 193), the unit shows a slightly larger grain size, a yellowish-orange colour, and common bivalve moulds.

Section 21 (40°19'54".3 N - 18°24'06".4 E)

The section (8.50 m thick) is located in the "I Petrari" Quarry, north of Cavallino Village. In the lower part, the Pietra Leccese is composed of fine-grained and yellowish biomicrites (in which *Amusium* and *Chlamys* are common), medium grain size and ochre



Fig 7 - Panoramic view of Section 24 from the quarry near C. Treppida (South-Eastern Sector). This section consists only of glauconite-free Pietra Leccese.

coloured biomicrites in the upper part (where several bivalves occur). Four samples (SM 82-85) were taken.

Sections 22 (40°24'01".8 N - 18°24'01".8 E) and **23** (40°24'18".5 N - 18°24'06".9 E)

Sections 22 and 23 are 1.8 m and 2.1 m thick, respectively. They are located in the cutting of the Lecce-Vernole road, NW of Merine Village. The Pietra Leccese is light brown in colour, and it contains glauconite in sparse granules and several levels with abundant bivalve remains. Six samples (SM 217-222) were taken from the Section 22, and three (SM 223-225) from the Section 23.

Section 24 (40°24'06".4 N - 18°24'02".2 E)

This section was sampled (GS 24-33) in an old quarry to the WNW of Merine Village, near C. Trappida, that is now partially filled in by detritus (Fig. 7). The thickness of Pietra Leccese formation is about 17 m and is greenish-yellow in the first metre. In the next overlying 10 m of the unit, the glauconite becomes gradually rare towards the top, until it completely disappears. In the same interval, the colour becomes increasingly light brown, the grain size changes from medium to fine, and the fossils (*Neopycnodonte*, *Amusium*, *Flabellipecten*, and other bivalves) are concentrated in levels. Samples GS 32 and 33 were collected from an outcrop at south of the quarry, where the Pietra Leccese is ochre-yellow in colour, stratified, and rich in fossils (especially bivalve moulds). The Calcareni di Andrano formation is present at the top of this section.

Bio-chronostratigraphy - The -50 m level (SEM 27) of the Seminario Borehole (Fig. 8) is representative of the glauconite-free interval of the Pietra Leccese formation. Based on the calcareous plankton, it can be referred to the upper Burdigalian *G. trilobus* (lower portion) and *H. ampliaperta* zones (*S. heteromorphus*-*H. ampliaperta* Subzone). The zonal attributions are supported by the occurrence of *Paragloborotalia bella* (according to Hornibrook et al., 1989 and Scott et al., 1990, the FO of the taxon occurs in the N7) and *P. incognita* (Kennett & Srinivasan, 1983 and Hornibrook

et al., 1989 indicate the LO of the taxon close to the N6-N7 boundary), and by the presence of common *H. ampliaperta*, *S. heteromorphus* and *D. deflandrei* (lacking *D. exilis*).

The foraminiferal assemblage of -40 m level (SEM 28, weakly glauconitic interval) is indicative of the lower Langhian *P. siakensis*-*P. glomerosa circularis* Subzone (*P. glomerosa* s.l. Zone) mainly due to the presence of *P. glomerosa glomerosa*, which first appears in this subzone (Di Stefano et al., 2008). Further steps of the *Praeorbulina*-*Orbulina* evolutionary lineage are found in the other weakly glauconitic levels of the Seminario Borehole and sections 17 and 20. In particular, the FOs of *P. glomerosa circularis* and *O. suturalis* occur in samples SM 29 and SM 30 of the Seminario Borehole, respectively; and *O. universa* first occurs in samples SM 67 of Section 20 and SM 79 of Section 17. Therefore, the whole weakly glauconitic interval is referable to the upper part of the *P. glomerosa* s.l. Zone (*P. siakensis*-*P. glomerosa circularis* and *P. glomerosa circularis* subzones) and to the lower part of the *O. suturalis*-*G. peripheroronda* Zone (*O. suturalis* and *O. universa* subzones).

According to the mannofossil biostratigraphy, samples SM 28-31 of the Seminario Borehole belong to the upper part of the *S. heteromorphus*-*H. waltrans* Subzone (*S. heteromorphus* Zone) due to the relatively common presence of *S. heteromorphus* and *H. waltrans*, in addition to the rare occurrence of *D. exilis*, *D. deflandrei*, *C. macintyre* (<11 µm), *C. premacintyre*, *H. mediterranea*, *H. walbersdorfensis*, and *S. abies*. *S. heteromorphus* and *H. waltrans* are still quite common in the weakly glauconitic interval of sections 17 and 20, while *H. walbersdorfensis* is rare. It is worth noting that *H. waltrans* becomes rarer in sample SM 70 of Section 17 so this level could be indicative of the *H. waltrans*-*H. walbersdorfensis* Subzone.

A hiatus is present between samples SEM 27 and 28, probably where the glauconite appears. This hiatus includes at least the upper part of the *G. trilobus* Zone and the lower part of the *P. glomerosa* s.l. Zone as well as the upper part of the *H. ampliaperta* Zone and the basal part of the *S. heteromorphus* Zone. The presence of the hiatus in the lower part of the Seminario Borehole is also supported by the reduced thickness (about 15 m) of the Burdigalian interval compared to that in other boreholes (about 60 m).

The intensely glauconitic biomicrites of sections 17-20 are referred to the basal Tortonian *P. siakensis* and *D. bollii* zones. The weakly glauconitic biomicrites, which lie on the intensely glauconitic ones at the top of Seminario Borehole and in Section 20 belong to the Tortonian *N. acostaensis* and *D. bellus* zones. These biostratigraphical attributions and consequent documentation of the hiatus are explained above in the paragraphs for the north-western and north-eastern sectors. Another feature of this sector is represented by a significant (at least 25 m) sedimentary development of the Pietra Leccese upwards and without interruption above its intensely glauconitic term. The bioevents recognized in this atypical Pietra Leccese interval are, the FOs of *G. obliquus extremus* (between samples GS 25 and 26 of Section 24, and samples SM 76 and 193 of Section 20),

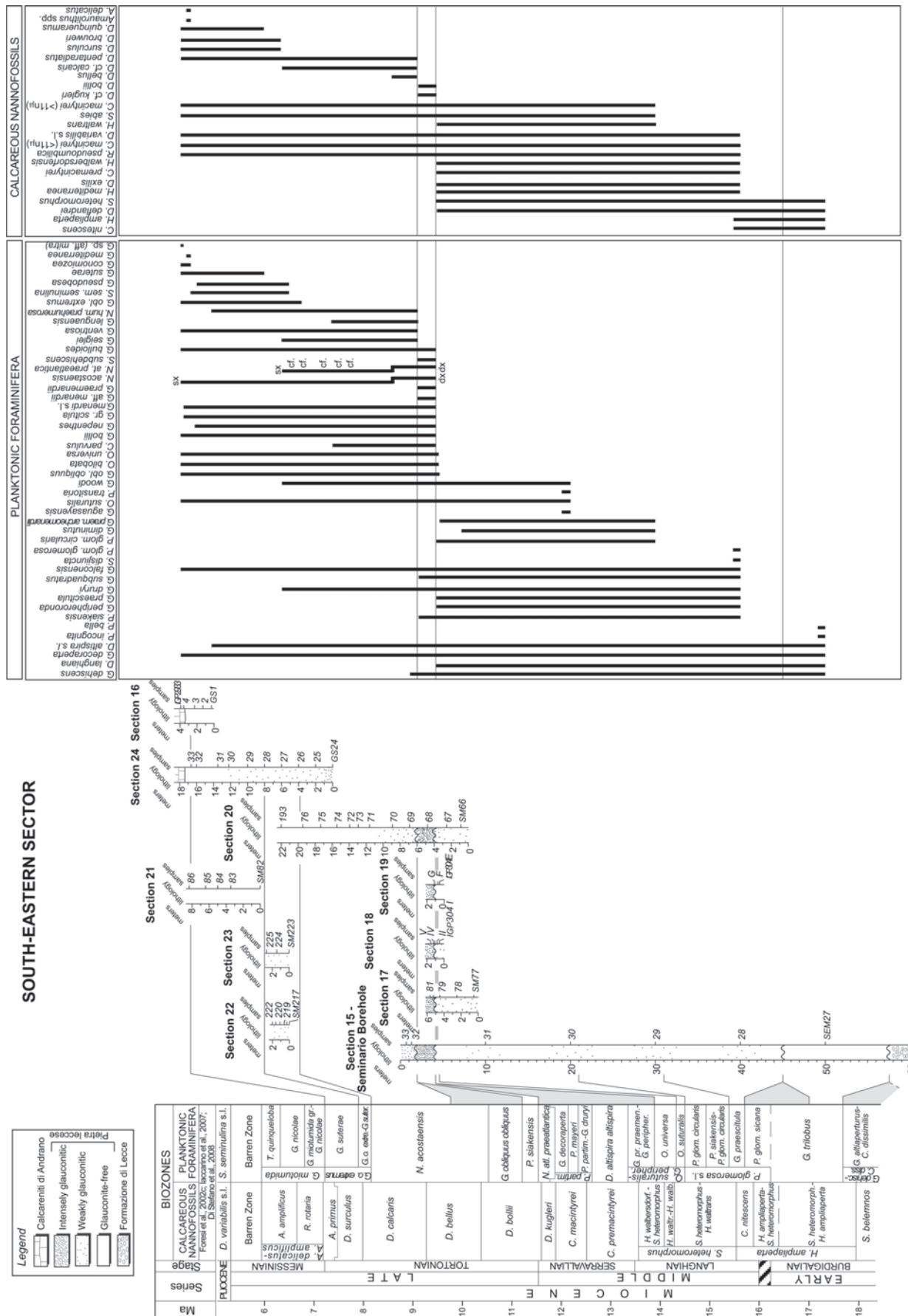


Fig. 8 - South-Eastern Sector of the Lecce area: stratigraphic logs of the investigated sections, distribution of selected calcareous plankton taxa and biostratigraphic correlations (see text for correlation criteria).

G. suterae (between samples GS 27 and 28 of Section 24) and *G. miotumida* gr., including *G. conomiozea*, (between samples GS 32 and 33 of Section 24, samples SM 85 and 86 of Section 21). Consequently, *N. acostaensis* (pars), *G. obliquus extremus*, *G. suterae*, and *G. miotumida* zones have been recorded. These biostratigraphical results are supported by the analyses of the nannofossil assemblages. In fact the LO of *D. bellus* (between sample SM 70 and 71 of Section 20), the FOs of *D. surculus* (between samples GS 26 and 27 of Section 24) and *A. delicatus* (between samples GS 32 and 33 of Section 24) are recorded in the same interval. These bioevents testify the presence of the *D. bellus* (upper part), *D. calcaris*, *D. surculus*, and *A. delicatus*-*A. amplificus* zones; due to the rarity of the genus *Amaurolithus*, the *A. primus* Zone could not be recognized.

In chronostratigraphical terms, the upper part of the Pietra Leccese formation, which is glauconite-free or weakly glauconitic, belongs to the middle Tortonian-basal Messinian interval.

CONCLUSIONS AND COMPARISON WITH THE AREA OF CURSI-MELPIGNANO

Surface and subsurface data allow to refer the Pietra Leccese formation of the Lecce type area (Figs. 4-6, 8) to the stratigraphic interval encompassing the *G. trilobus* Zone - *G. miotumida* Zone and *H. ampliapertura* Zone - *A. delicatus*-*A. amplificus* Zone. Consequently, the succession was deposited in the late Burdigalian-early Messinian, in full agreement with previous studies in other Salentine areas (Bossio et al., 1986, 1989a, 1991, 2002), including Cursi-Melpignano type area (Mazzei, 1994; Foresi et al., 2002b).

Throughout the studied area of Lecce, the Pietra Leccese formation overlies the Aquitanian Formazione di Lecce; its maximum inferred thickness is about 90 m (south-eastern sector) and it spans a time interval of approximately 11 Ma. The relatively small thickness of the unit in comparison with its duration is interpreted as a consequence of the repeated action of marine currents that inhibited the deposition, and/or eroded the previously deposited sediments. The related hiatuses are generally revealed by the presence of more or less abundant glauconite grains (a mineral typical of a dynamic marine environment). As demonstrated in the different sectors of the Lecce area (Figs. 3-6, 8), the time duration of the hiatuses varies also in successions that are very close to each other.

Three hiatuses were recognized (Fig. 9):

- the first is at the boundary between the glauconite-free (yellowish in colour) and the weakly glauconitic (greenish-yellow in colour) biomicrites. It separates the Burdigalian sediments of the *G. trilobus* and *H. ampliapertura* (*S. heteromorphus*-*H. ampliapertura* Subzone) zones from the Langhian ones of the *O. suturalis* (*O. suturalis*-*G. peripheroronda* Zone) and *S. heteromorphus*-*H. waltrans* (*S. heteromorphus* Zone) subzones. Based on the above-mentioned biostratigraphic attributions, it follows that the hiatus duration is about 2.5 Ma. In the Seminario Borehole (south-eastern sector)

the hiatus has a shorter time-span (about 1.2 Ma). In fact, it corresponds to the upper part of the *G. trilobus* Zone and the lower part of the *P. glomerosa* s.l. Zone and the upper part of the *H. ampliapertura* Zone and the basal part of the *S. heteromorphus* Zone;

- the second hiatus is at the boundary between the weakly glauconitic biomicrites and the intensely glauconitic ones (greenish in colour). It separates the Langhian deposits of the *O. universa* (*O. suturalis*-*G. peripheroronda* Zone) and *H. walbersdorfensis*-*S. heteromorphus* (*S. heteromorphus* Zone) subzones from the Tortonian *P. siakensis* and *D. bollii* (lower part) zones. Consequently, the hiatus time-span is about 2.5 Ma. In the Morello Borehole (north-eastern sector) the hiatus is shorter (about 1.8 Ma), because the deposition restarts within the *P. mayeri* Subzone (*P. partimlabiata* Zone) and the *C. macintyreii* Zone. However, in the north-eastern sector, a further hiatus cannot be excluded, spanning the interval *P. mayeri* Subzone (pars)-*P. siakensis* Zone (pars) and *C. macintyreii* Zone (pars)-*D. bollii* Zone (pars).

Furthermore, the weakly glauconitic interval in the Seminario Borehole (south-eastern sector) represents a continuous deposition during the Langhian *P. glomerosa* s.l. (pars) and *O. suturalis*-*G. peripheroronda* (pars) chronozones. This justifies the greater thickness (over 40 m) of the interval compared to that found in the other sectors (< 9 m);

- the third hiatus is at the top of the intensely glauconitic interval. It is found between the biomicrites of the basal Tortonian (*P. siakensis* and *D. bollii* zones) and those (with weak glauconite content) of the middle Tortonian (lower part of the *N. acostaensis* Zone and upper part of the *D. bellus* Zone). Accordingly, the hiatus time-span is about 1.7 Ma. In the north-eastern sector (Section 12) it shows its maximum duration (about 3.7 Ma) since the deposits immediately above the intensely glauconitic biomicrites pertain to the *G. obliquus extremus* and *D. surculus* zones.

A fourth hiatus (about 2.1 Ma) is documented only in the area north of Lecce (Figs. 4, 6, 9) and is found in the uppermost portion of the Pietra Leccese (between weakly glauconitic and glauconite-free intervals). In the north-western sector the deposition of *N. acostaensis* and *D. bellus* zones was interrupted in the middle Tortonian. Deposition restarted in the latest Tortonian (*G. suterae* and *A. primus* chronozones). In the north-eastern sector, after a short episode of deposition represented by the upper Tortonian *G. obliquus extremus* and *D. surculus* zones, the sedimentation restarted at the beginning of the Messinian.

In the south-eastern sector, the biomicrites overlying the intensely glauconitic interval were deposited without interruption from the early-middle Tortonian to the early Messinian (lower part of the *N. acostaensis* Zone - *G. miotumida* Zone and upper part of the *D. bellus* Zone - *A. delicatus*-*A. amplificus* Zone intervals), resulting in a greater thickness (about 25 m) which is quite unusual for the Pietra Leccese in the Salentine Peninsula. Moreover, it must be emphasized that, towards the top, these biomicrites gradually lose the typical characteristics of the Pietra Leccese formation (generally fine grained, yellow-straw yellow in colour, not stratified or in thick banks, and few fossils except in glauconitic levels) and

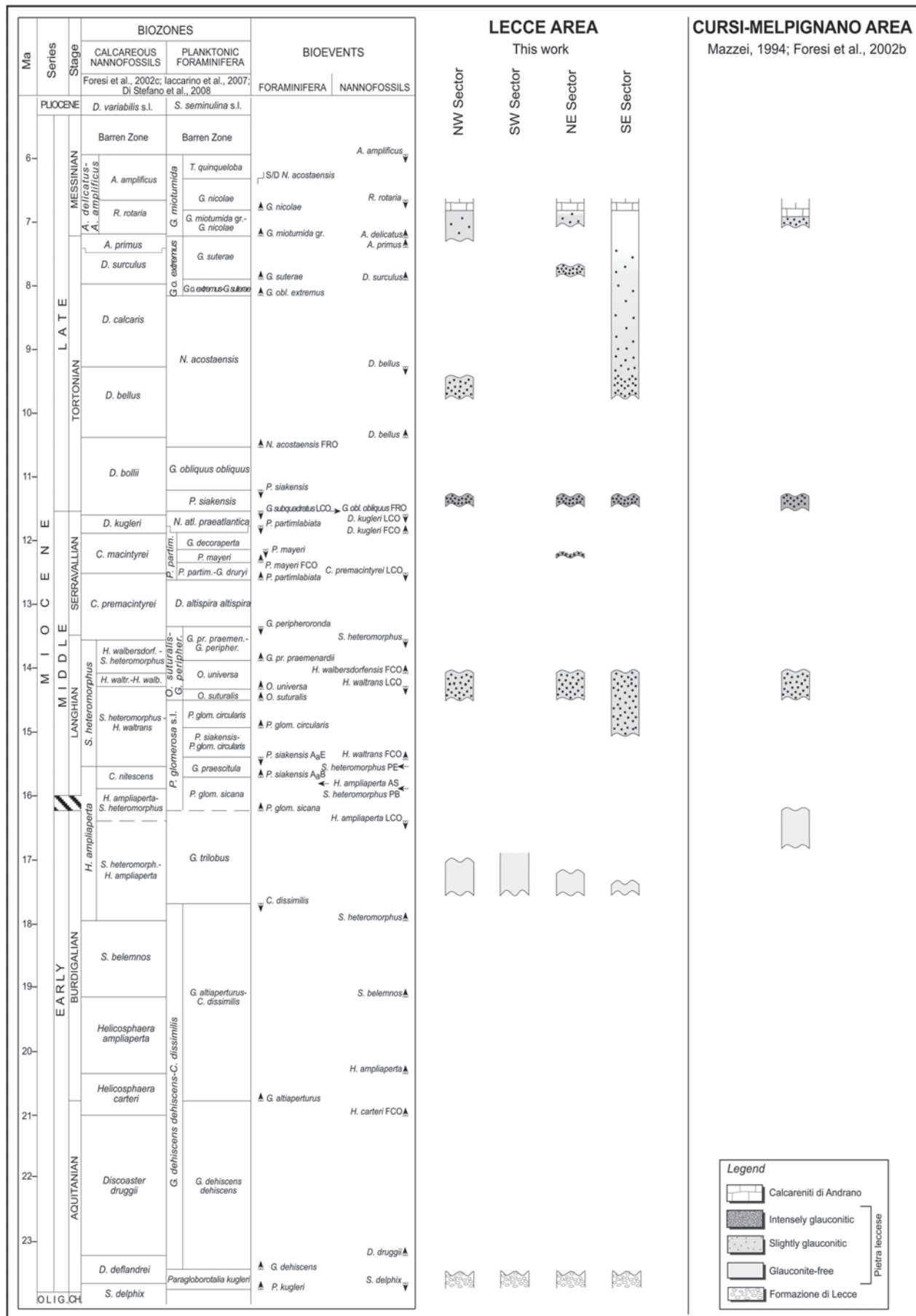


Fig. 9 - Chronological extent of the Pietra Leccese formation in the four sectors of Lecce area.

exhibit different features (coarser grained, ochreous-yellow in colour, decimetric stratification, and diffuse fossils especially bivalves). During this last depositional phase of the Pietra Leccese formation, a bathymetric decrease occurred (as documented by changes in benthonic foraminifera assemblages) leading to the deposition of the Calcareni di Andrano formation, which represents the regressive term of the Miocene sedimentary cycle of the Salentine Peninsula.

Furthermore, in the successions of the Cursi-Melpignano area (the other type locality of the formation), Mazzei (1994) and Foresi et al. (2001) described lower thicknesses of Pietra Leccese (about 35 m) compared to those ascertained in the Lecce area. It should be noted that the base of the unit is never exposed in the Cursi-Melpignano area. However, its proximity is indicated by the colour of the biomicrites, whose change is from yellowish to blackish (the "pietra nera" according to local quarrymen), is commonly considered to be the lithological evidence of the contact with the preceding units. Furthermore, the above-mentioned studies show that the lower portion of the Miocene Cursi-Melpignano succession belongs to the upper part of the *G. trilobus* and *H. ampliaperta* zones. Therefore, two hypotheses are possible: a) the Burdigalian transgression at Cursi-Melpignano occurred later than in the Lecce area; b) there is a hiatus at the base of the Cursi-Melpignano succession. In addition, the reduced thickness of the yellow-straw yellow biomicrites in the Cursi-Melpignano area could be caused by earlier or more intense erosive action of marine currents that were also responsible for the hiatus between the Burdigalian glauconite-free biomicrites and the Langhian weakly glauconitic ones (*O. suturalis*-*G. peripheroronda* Zone and upper part of *S. heteromorphus* Zone). It is likely that the restart of sedimentation at Cursi-Melpignano occurred slightly later than in Lecce, as also supported by the difference in thickness of the *O. suturalis* Subzone in the two areas (1 m at Cursi-Melpignano, 15 m at Lecce, south-eastern sector). However, this restart was short-lived since a second hiatus is recorded at the passage between the weakly glauconitic and the intensely glauconitic biomicrites. In both areas, this hiatus separates Langhian levels of the *O. universa* Subzone and *S. heteromorphus* Zone (upper part) from basal Tortonian ones of the *P. siakensis* and *D. bollii* zones (in the absence of zonal taxa, Mazzei, 1994 interpreted the few elements found, among which is *D. bollii*, as indicative of the *Discoaster hamatus* Zone of Okada & Bukry, 1980).

The early Tortonian sedimentation at Cursi-Melpignano was also short-lived due to a third hiatus in the succession (from 1 to 6 m above the previous). In fact, everywhere the *P. siakensis* and *D. bollii* zones are overlain by the Messinian *G. miotumida* and *A. delicatus*-*A. amplificus* zones. Therefore, the hiatus corresponds to the *G. obliquus obliquus* Zone-*G. suteri* Zone and the *D. bellus* Zone-*A. primus* Zone intervals.

Concluding, the uppermost levels (weakly glauconitic) of the Pietra Leccese formation (about 1 m thick) and the overlying Calcareni di Andrano formation, were deposited in the early Messinian.

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