

<i>Bollettino della Società Paleontologica Italiana</i>	23 (2)	1984	395-412	2 pls.	Modena, Settembre 1985
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Miocene foraminifera of several sections of the Marmilla area (central western Sardinia)

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KEY WORDS — *Foraminifera, Miocene, Sardinia.*

ABSTRACT — *The micropaleontological study based on the planktonic and benthic foraminifera indicates that the sediments of the investigated sections are Burdigalian to Serravallian in age (Globigerinoides altiapertura - Catapsydrax dissimilis Subzone to Orbulina universa Subzone). The benthic assemblage is indicative of lower epibathyal environment.*

RIASSUNTO — [I foraminiferi miocenici di alcune sezioni della Marmilla (Sardegna centro-occidentale)] — *Vengono esposti i risultati dello studio micropaleontologico condotto sui foraminiferi bentonici e planctonici di cinque sezioni (Sardara-Villanova-forru, Tuili-Gesturi, Giara-Gesturi, Sestu e Ales). Sulla base dei foraminiferi planctonici è stato riconosciuto che nell'area in esame i sedimenti marini che si trovano nella parte orientale del rift oligo-miocenico hanno un'età compresa tra il Burdigaliano e il Serravalliano. Infatti sono state riconosciute le seguenti unità biostratigrafiche: Subzona a Globigerinoides altiapertura - Catapsydrax dissimilis, Zona a Globigerinoides trilobus, Zona a Praeorbulina glomerata s.l., Subzona a Orbulina suturalis e Subzona a Orbulina universa. L'unico limite zonale individuato nelle sezioni è quello che separa la zona a Globigerinoides trilobus dalla zona a Praeorbulina glomerata s.l. (limite Burdigaliano/Langhiano). Il Serravalliano è stato riconosciuto solo in un campione isolato sulla base della presenza di Orbulina universa.*

I risultati biostratigrafici ottenuti, sono stati confrontati con quelli del Site 372 e con quelli del Pozzo Oristano 1.

Le associazioni a foraminiferi bentonici rinvenute nelle varie sezioni studiate si sono rivelate molto significative per l'interpretazione paleoambientale, infatti esse sono indicative di un ambiente di deposizione epibattiale inferiore.

INTRODUCTION

This research represents a further contribution to the biostratigraphy of the Miocene of Sardinia. It deals with the micropaleontological study of some sections outcropping in the Marmilla area (central western Sardinia) (Text-fig. 1). This area is located on the eastern side of the Oligocene-Miocene graben which crosses all the Sardinia from south to north and which has been interpreted as a rift by Cherchi & Montadert (1982, 1984) and Cherchi (1985).

This peculiar paleogeography of the basin must have played a remarkable control on the nature and

deposition of sediments, the water circulation and as a consequence on the faunal distribution. This narrow trough originated during the Oligocene in a continental environment and later was progressively invaded by the sea. The marine transgression appears to have proceeded from south to north. The oldest open marine sediments, late Oligocene in age, have been recovered in the axial part of the rift (Pomesano Cherchi, 1968). The distribution of the sediments along the rift is therefore controlled both by the paleobathymetry and the paleotopography.

The investigated sections which were sampled and measured by A. Cherchi and M. Murru are:

1) the SARDARA-VILLANOVAFORRU (SV) section, located along the road from Sardara to Villanovaforru. This section is mainly characterized by silty marls and marls alternated with tuffitic layers which are very common in the upper part of the section, and testify to a strong explosive volcanic activity during the sedimentation of the marls. The total thickness of the section is about 600m of which, the lowermost 90m belong to the continental deposits of the Ussana Formation. The beginning of the transgression is marked by an *Ostrea* layer (see Cherchi, 1985) located in the stratigraphic log above the sample SV-1 ter. The sedimentary sequence was affected by tectonic movements as testified by the dipping of the layers. (Létouzey *et al.* 1982; Cherchi & Tremolières, 1984).

2) the TUILI-GESTURI (TG) section located along the road from Tuili to Giara, is 317m thick. It is characterized by whitish marls. The tuffitic layers are less frequent and the setting of the strata is horizontal.

3) the GIARA-GESTURI (GG) section which shows the same lithology and setting as the Tuili-Gesturi

section, is 246m thick. It outcrops along the road Gesturi to Giara.

4) the SESTU (S) section outcropping in a quarry close to the Sestu village, is about 30 m thick and mainly constituted by whitish marls.

5) the ALES (AC) section, which outcrops near the Ales village, contains within the marly sediments a layer of biogenic calcarenite.

ADOPTED BIOSTRATIGRAPHIC ZONAL SCHEME AND CORRELATION WITH STANDARD ZONATIONS

The biostratigraphic zonal scheme of Jaccarino & Salvatorini (1982) and Iaccarino (in press) which has been established for the Mediterranean Neogene has been adopted (Text-fig. 2).

In this scheme the lower boundary of the Miocene has been tentatively placed at the first occurrence of *Globoquadrina debiscens debiscens* (Pl. 1, figs. 5, 15). The choice of this event has been based on the following considerations:

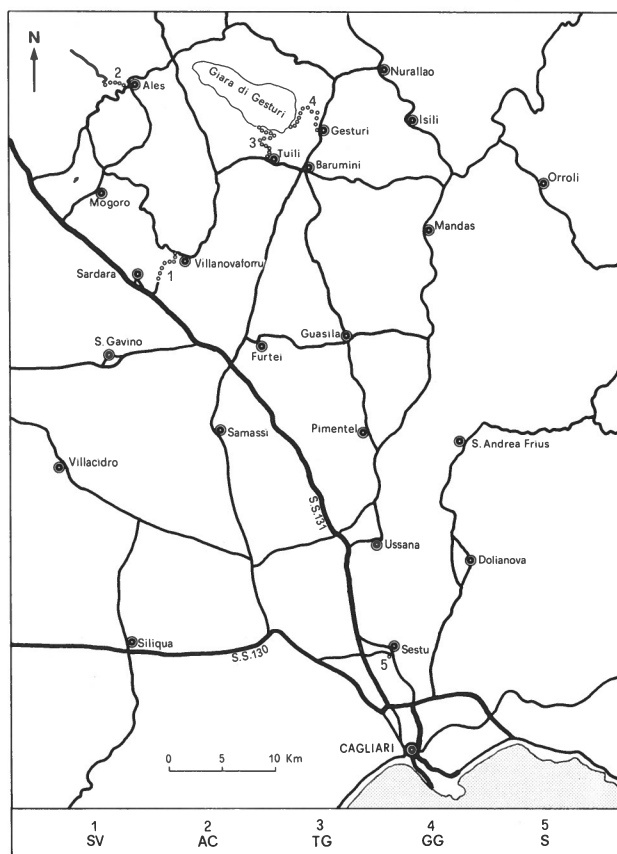
1) *G. debiscens debiscens* occurs in the Aquitanian stratotype from the lowest sample.

2) *G. debiscens debiscens* is an easily recognizable taxon, resistant to dissolution, and is widespread from low to middle latitudes.

3) the first occurrence of *G. debiscens debiscens* falls within the range of *Globorotalia kugleri* as documented in low and middle latitudes; it precedes the entrance of *Globigerinoides altiapertura* and *Globigerinoides trilobus* s.s. and follows the entrance of *Globigerina woodi*, *Globigerinoides primordius*, and other primitive forms of *Globigerinoides trilobus* s.l..

However, there is no general agreement in using this bioevent for defining the P/N boundary. According to Jenkins (1981), the first appearance of *G. debiscens debiscens* is diachronous: in the upper Oligocene in New Zealand and later at the middle and low latitudes.

For this reason some authors (Bizon & Bizon, 1972; Bizon, 1979; Berggren *et al.*, 1983; Borsetti *et al.*, 1983, 1984; Biolzi, doctoral thesis, 1984) are in favour of adopting, as a bioevent for recognizing the P/N boundary, the FAD of *G. kugleri*. This taxon is, in fact an excellent marker of the tropical areas where it is common and well documented. In the Mediterranean, on the contrary, it is rare and randomly distributed; therefore its real first occurrence is difficult to detect. According to Keller (1984) the first occurrence of *G. debiscens debiscens*, for the definition of the P/N boundary, is more suitable because « the datum is isochronous in tropical, subtropical and temperate regions », it occurs within an interval character-



Text-fig. 1 - Location of the investigated sections: SV = Sardara-Villanovaforru Section, AC = Ales Section, TG = Tuili-Gesturi Section, GG = Giara-Gesturi Section, S = Sestu Section.

ADOPTED BIOSTRATIGRAPHIC SCHEME AND CORRELATION WITH STANDARD ZONATIONS

IACCARINO and SALVATORINI (1982) IACCARINO (1984 in press)		BLOW (1969)		BOLLI and SAUNDERS (1984 in press)			
CHRON	BIOZONES	DATUM EVENTS	CHRON	BIOZ.	DATUM EVENTS	BIOZONES	
MIOCENE	SERRAVAL Orbulina suturalis	↑ G. praemenardii	MIDDLE	N 10 -----	↑ G. foehsi G. peripheroacuta	G. foehsi foehsi	
							LANGHIAN Globorotalia peripheroronda Orbulina universalis
	PRAEORBULINID Praeorbulina glomerosa s. l.	↑ P. glomerosa	N 8	↑ P. glomerosa G. sicanus	P. glomerosa		
						BURDIGALIAN Globigerinoides trilobus	↑ C. dissimilis
	BURDIGALIAN Globoquadrina d. dehiscens Catapsydrax dissimilis	↑ G. altiapterturus	EARLY	N 6 ----- N 5	↑ G. insueta G. kugleri		
						AQUITANIAN Catapsydrax dissimilis Globoquadrina d. dehiscens	↑ G. d. dehiscens
	OLIG.						

Text-fig. 2 - Biostratigraphic scheme and correlation with standard zonations.

alized by many other bioevents, whereas *Globorotalia kugleri* appears to be restricted to the tropical and subtropical regions and no other bioevents occur close to this datum.

The International Working Group (IUGS) which has been nominated to define this boundary will solve this problem but, at the moment, no conclusion has been reached.

The first occurrence of *G. debiscens debiscens* is well correlatable with the FAD of the same species as reported by Blow (1969). According to him it falls in the upper part of Zone N4 within the range of *G. kugleri*. Therefore the *Globoquadrina debiscens debiscens* Subzone of Iaccarino (in press) is correlatable with the upper part of N4 and the basal part of N5.

The FAD of *G. altiapturus* which marks the lower boundary of the *G. altiapturus-C. dissimilis* Subzone is taken to indicate the Aquitanian/Burdigalian boundary (Bizon & Bizon 1972; Demarcq *et al.* 1974; Bizon 1984; Iaccarino & Salvatorini 1982; Iaccarino, in press). Pognant & Pujol (1976, 1978) who previously documented the planktonic foraminifera of the stratotypes, recognized in the type Aquitanian the upper N4 and early N5 (without *G. altiapturus*), and in the type Burdigalian the N5 with *G. altiapturus*. Müller & Pujol (1979) recognized Zone NN1 of Martini (1971) in the type Aquitanian and NN2 in the type Burdigalian. The distinction of the two zones is based on the absence and the occurrence of *H. ampliaptura*, respectively. Therefore the *G. altiapturus-C. dissimilis* Subzone correlates with part of N5 of Blow and with NN2 of Martini (Müller & Pujol, 1979).

The *Praeorbulina glomerosa* s.l. Zone correlates with Zone N8 of Blow (1969) and with the *P. sicana-G. miozea* Zone of Berggren *et al.* (1983). As documented by Jenkins *et al.* (1981), *Globigerinoides sicanus* is not a *Globigerinoides* but belongs to the genus *Praeorbulina* and was renamed as *P. sicana*. Later, Iaccarino & Salvatorini (1982) recognized that *P. sicana* is a senior synonym of *P. glomerosa curva*, then they called it *P. glomerosa sicana*, the FAD of which marks the base of N8.

The lower boundary of *G. praemenardii-G. peripheroronda* Subzone has been correlated with that of Zone N10 on the basis of the first appearance of *G. praemenardii*, which, according to Blow virtually coincides with the top of Zone N9.

GEOCHRONOLOGY (Text-fig. 3)

In the recent geochronological time scale, for the Atlantic Ocean, Berggren *et al.* (1983) estimated the Oligocene-Miocene boundary at 23.7Ma. For determining the position of the P/N boundary, these authors chose as biostratigraphic events the FAD of *G. kugleri* and the LAD of *R. bisecta*. The estimated age of the FAD of *G. kugleri* at 23.6, by Keller (1984) in the equatorial Pacific is in good agreement.

On the basis of the early Miocene plankton foraminiferal datum events by Berggren *et al.*, in the south Atlantic (Leg 72, site 516), the ages of the zones and/or subzones here adopted have been extrapolated as follows: - *G. debiscens debiscens* Subzone from 23.2 Ma to 20.9Ma; *G. altiapturus - G. dissimilis* Subzone from 20.9Ma to 17.6Ma; *G. trilobus* Zone from 17.6Ma to 16.6Ma; *Praeorbulina glomerosa* s.l. Zone from 16.6Ma to 15.5Ma; *Orbulina suturalis* Subzone from 15.5Ma to 15.1Ma.

Since in this paper the O/M boundary is equated to the FAD of *G. debiscens debiscens* and the Aquitanian-Burdigalian boundary to the first appearance of *G. altiapturus*, the estimated age of those two boundaries are at 23.2Ma, and at 20.9Ma respectively; the Burdigalian-Langhian boundary at 16.6Ma as in Berggren *et al.*, and the Langhian/Serravallian boundary at 15.1Ma. This last age is based on the extrapolated age of the first occurrence of *O. universalis*.

Finally, on the basis of the sedimentation rate calculated for Site 616, the age of the *G. trilobus* s.s. datum event is extrapolated at 20.0Ma.

MICROPALAEONTOLOGIC AND BIOSTRATIGRAPHIC REMARKS (Text-fig. 4)

The distribution charts of planktonic foraminifera from the investigated sections are reported in Cherchi (1985).

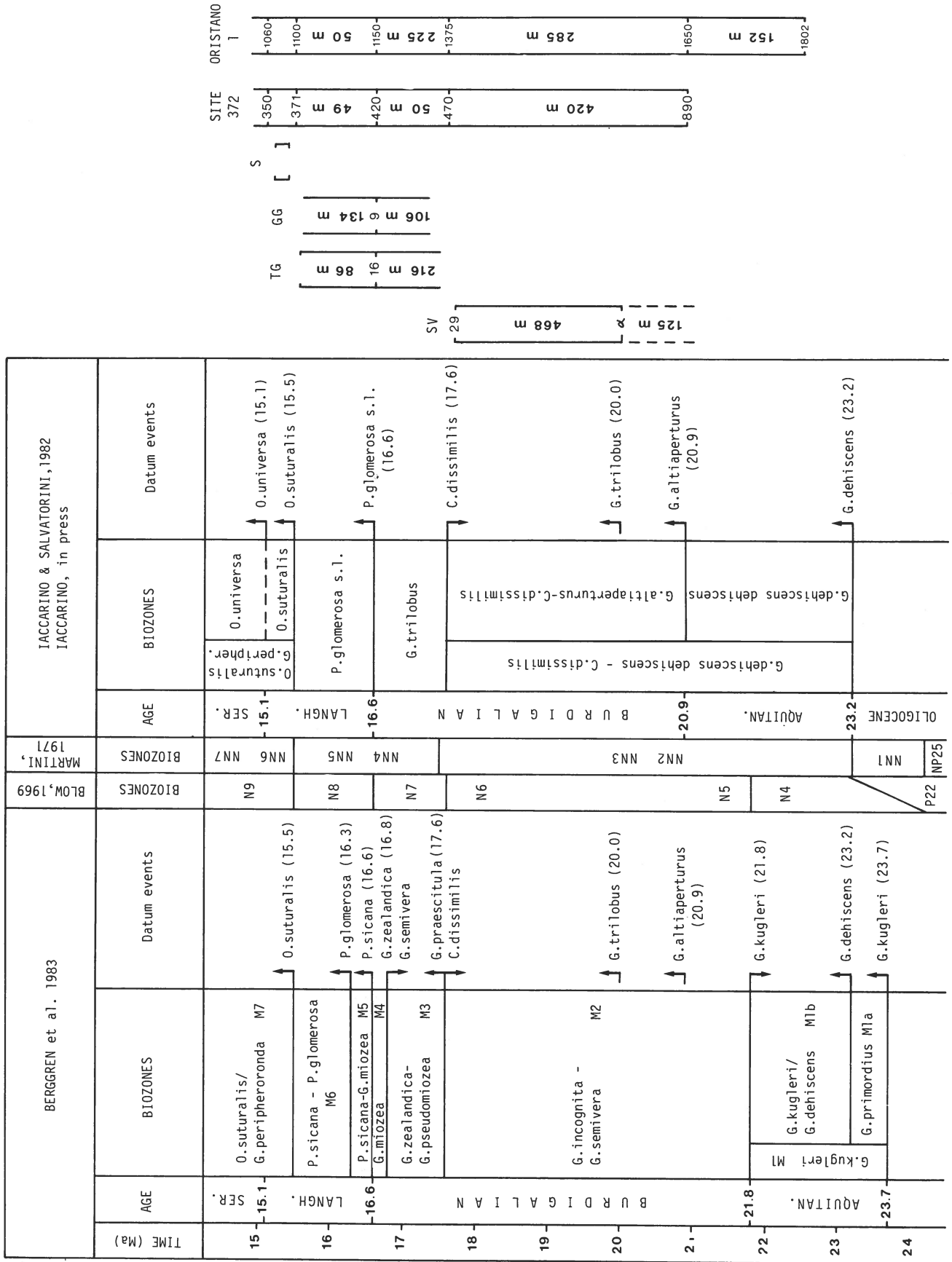
SARDARA - VILLANOVAFORRU SECTION (SV)

The foraminiferal assemblages yielded in this section are not well diversified but generally rather common and poorly preserved. The foraminifera are mostly recrystallized (sparry calcite) and deformed. In particular the original perforation is no longer visible.

Along the entire section, even if not in all samples, *Globigerinoides* is well represented qualitatively and

Text-fig. 3 - Left side: calibration of Blow (1969), Martini (1971) and Iaccarino & Salvatorini (1982) zonations to the geochronological time scale of Berggren *et al.* (1983).

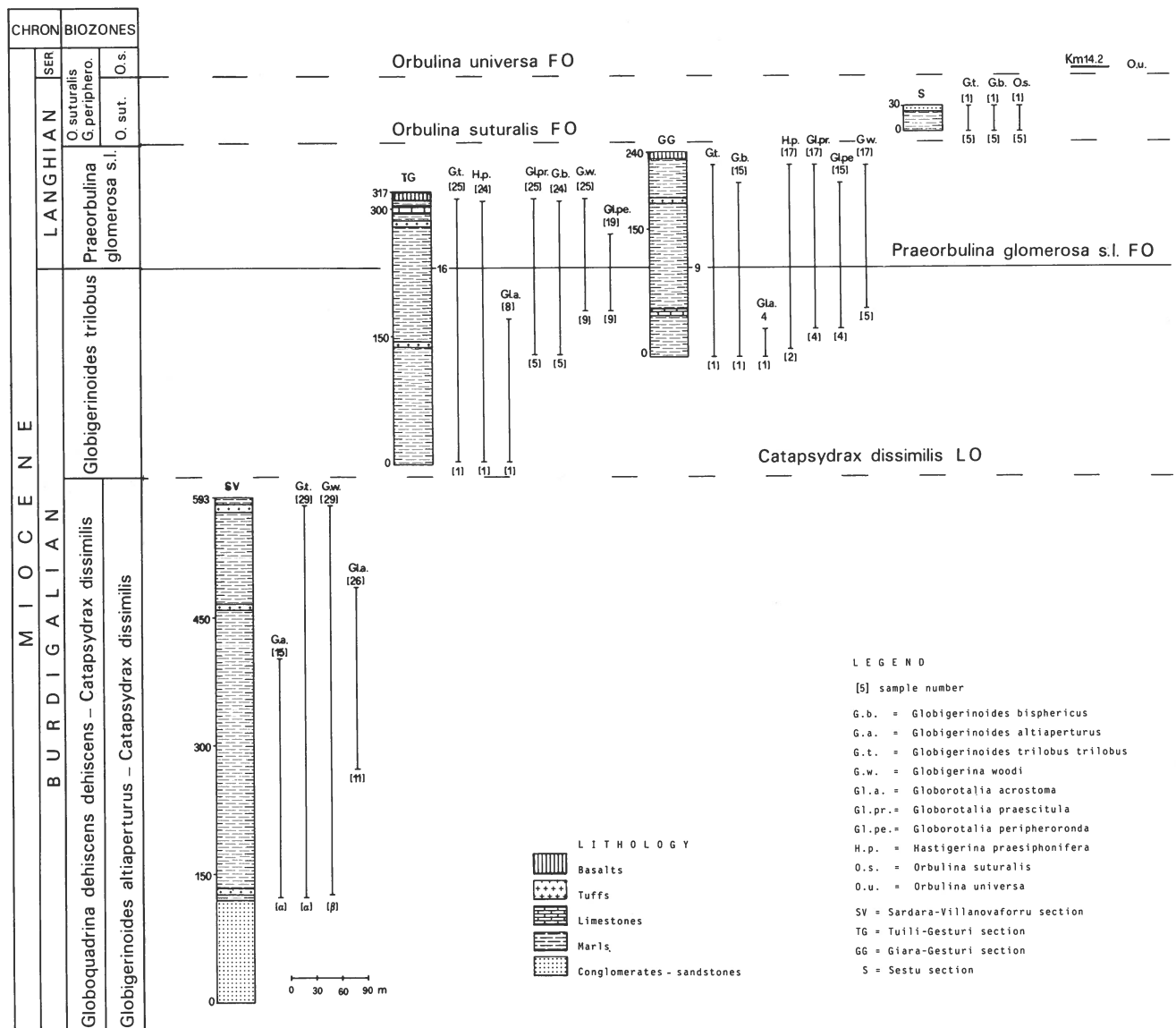
Right side: sediment thicknesses of the various identified biozones from the investigated sections SV, TG, GG, S, from Site 372 (Hsü *et al.*, 1978) and Pozzo Oristano 1 (Pomesano Cherchi, 1971).



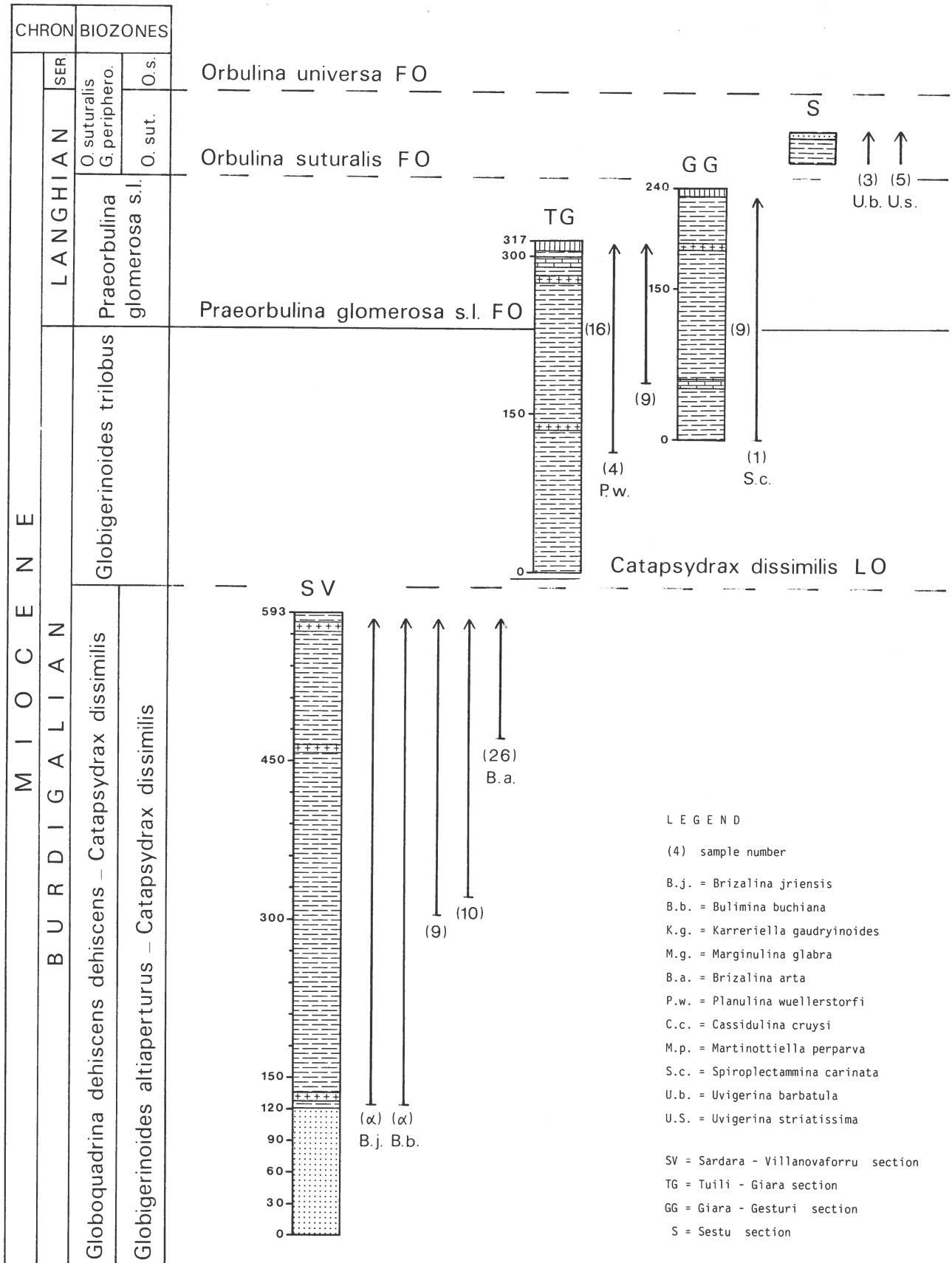
quantitatively. *G. altiapertura* occurs from the lowermost sample up to sample SV-15. *G. trilobus* is represented by typical specimens from the base of the section, in association with *G. altiapertura*, and by more primitive forms (like *G. immaturus*, *G. irregularis*, *G. bullatus*).

The genus *Catapsydrax* with the species *dissimilis* and *unicavus* is very rare and represented by atypical specimens. Its scarcity does seem to be controlled by the environmental conditions. This genus is well known to be resistant to dissolution (Cita, 1971) and to be typical of deep water. According to Biolzi (1984), *C. dissimilis* is a taxon which lived beneath

the thermocline at a depth greater than 600m, as proved by its isotopic composition which reflects stable hydrographic conditions typical of deep and bottom water. Therefore, it is inferred that the investigated area, located on the edge of the sedimentary basin, was not in suitable environment for the development of the genus *Catapsydrax*. *C. dissimilis* is well documented in Pozzo Oristano 1 (Pomesano Cherchi, 1971), but also rare in the Marmilla Formation and in the Ales marls (Cherchi, 1971). The Pozzo Oristano 1 is located in the central part of the rift, therefore the basin is expected to be filled by water masses enough deep for hosting the eco-



Text-fig. 4 - Distribution of selected planktonic foraminifera in the investigated sections and correlation with the adopted zonal scheme.



Text-fig. 5 - Distribution of selected benthic foraminifera in the investigated sections and correlation with the adopted zonal scheme.

logical niche suitable for the *Catapsydrax* to live in. The Marmilla and Ales areas, being located on the flank of the basin as the studied sections, show the same sporadic distribution of *Catapsydrax*.

By contrast *Globigerina venezuelana*, whose habitat seems to be typical of intermediate waters (200m to 600m) is common throughout the section. Among the other species of *Globigerina*, *G. woodi* and *G. praebulloides* are the most common.

The genus *Globoquadrina* is consistently rare throughout the section: rare specimens of atypical *G. debiscens debiscens* occur in two samples. (Pl. 1, fig. 5).

The genus *Globorotalia* is also rare and it is represented by the species *G. siakensis* and *G. acrostoma*.

Because of the occurrence of *G. altiapturus* from the base, the section belongs to the *G. altiapturus*-*C. dissimilis* Subzone (Burdigalian). More precisely, since *G. altiapturus* is already associated with *G. trilobus trilobus*, it is suggested that the base of the subzone is not represented. Because of the absence of *C. dissimilis*, it is impossible to establish if the top of the section is still referable to the same subzone or falls in the next *G. trilobus* Zone. The absence of other taxa like *Globorotalia praescitula*, *H. praesiphonifera* seems to be in favour of the *G. altiapturus*-*C. dissimilis* Subzone. In fact, according to Berggren *et al.* (1983) *G. praescitula* appears in correspondence of the extinction level of *G. dissimilis*, and at Site 372, located in the Balearic basin the FAD of *G. praescitula* closely follows the LAD of *C. dissimilis*.

TUILLI - GESTURI SECTION (TG)

The planktonic foraminiferal assemblage is abundant and generally well preserved throughout the section.

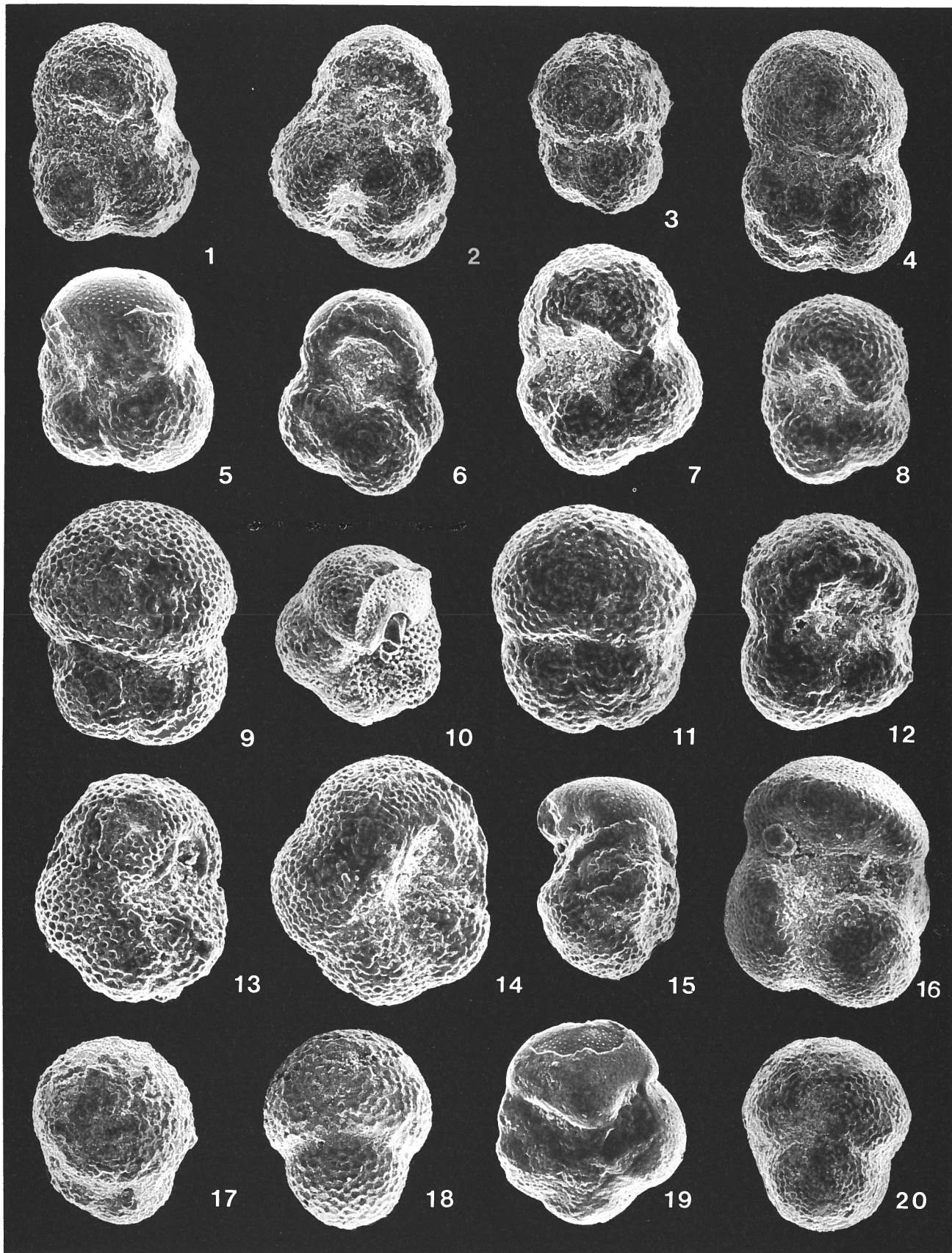
Globigerinoides trilobus trilobus (at time dominant) is one of the most common taxa; the other *Globigerinoides* such as *G. quadrilobatus*, *G. sacculifer*, *G. subquadratus* are less frequent. Through the section, several species enter successively: they are *Globigerinoides bisphericus*, *Globorotalia praescitula*, *G. peripheroronda* and *Praeorbulina glomerosa*, respectively. *G. acrostoma* disappears. Typical specimens of *G. debiscens debiscens* occur and in some levels the taxon is common. Associated with *G. debiscens debiscens*, *G. langhiana*, and *G. baroemoenensis* have been observed. The specimens of *G. baroemoenensis* do not show the morphologic features of the typical form (large umbilical area) but are umbilically closer.

Hastigerina praesiphonifera occurs from the base of the section. In sample TG-16 the first evolutionary appearance of *Praeorbulina* has been observed; the subspecies *P. sicana* and *P. glomerosa* have been recognized while *P. circularis* is absent. Unfortunately the topmost two samples (TG-24 and TG-25) delivered a poor and badly preserved assemblage and then not suitable for a good taxonomical resolution.

In terms of biostratigraphy, the *G. trilobus* Zone is surely recognizable from sample TG-5, whereas the lowermost part of the section could still belong to the *G. altiapturus*-*C. dissimilis* Subzone. However, although *G. praescitula* whose first occurrence closely

EXPLANATION OF PLATE 1

- Figs. 1-2 - *Globigerinoides altiapturus* Bolli (x 60); SV- α . *Globigerinoides altiapturus* - *Catapsydrax dissimilis* Subzone.
 Fig. 3 - *Globigerinoides trilobus trilobus* (Reuss) (x 60); SV- α . *Globigerinoides altiapturus* - *Catapsydrax dissimilis* Subzone.
 Fig. 4 - *Globigerinoides trilobus* s.l. (Reuss) (x 60); SV- α . *Globigerinoides altiapturus* - *Catapsydrax dissimilis* Subzone.
 Fig. 5 - *Globoquadrina debiscens debiscens* Chapman, Parr & Collins (x80); SV-5. *Globigerinoides altiapturus* - *Catapsydrax dissimilis* Subzone. The specimen does not show the typic features of the species.
 Fig. 6 - *Globigerina woodi* Jenkins (x 80); SV-6. *Globigerinoides altiapturus* - *Catapsydrax dissimilis* Subzone.
 Figs. 7-8 - *Globigerina woodi* Jenkins (x 80); SV-25. *Globigerinoides altiapturus* - *Catapsydrax dissimilis* Subzone.
 Fig. 9 - *Globigerinoides trilobus trilobus* (Reuss) (x 80); TG-3. *Globigerinoides trilobus* Zone.
 Fig. 10 - *Globorotalia acrostoma* Wezel (x 80); TG-1. *Globigerinoides trilobus* Zone.
 Fig. 11 - *Globigerinoides trilobus trilobus* (Reuss) (x 80); TG-1. *Globigerinoides trilobus* Zone.
 Fig. 12 - *Globigerinoides subquadratus* Bronnimann (x 80); TG-1. *Globigerinoides trilobus* Zone.
 Fig. 13 - *Globigerinoides trilobus trilobus* (Reuss) (x 100); TG-3. *Globigerinoides trilobus* Zone.
 Fig. 14 - *Globigerinoides trilobus trilobus* (Reuss) (x 100); TG-7. *Globigerinoides trilobus* Zone.
 Fig. 15 - *Globoquadrina debiscens debiscens* Chapman, Parr & Collins (x 80); TG-3. *Globigerinoides trilobus* Zone.
 Fig. 16 - *Globoquadrina baroemoenensis* (Le Roy) (x 60); TG-11. *Globigerinoides trilobus* Zone.
 Figs. 17,20 - *Globigerinoides bisphericus* Todd (x 60); TG-9. *Globigerinoides trilobus* Zone.
 Fig. 18 - *Globigerinoides bisphericus* Todd (x 80); GG-1. *Globigerinoides trilobus* Zone.
 Fig. 19 - *Globorotalia praescitula* Blow (x 100); TG-4. *Globigerinoides trilobus* Zone.



follows the extinction of *C. dissimilis* is still absent, the occurrence of *H. praesiphonifera* from the base and the abundance of advanced forms of *Globigerinoides* speak in favour of an attribution to the *G. trilobus* Zone also of the lowermost part of the section. Therefore, the sediments belong partly to the Burdigalian and partly to the Langhian.

GIARA - GESTURI SECTION (GG)

This section delivered a planktonic foraminiferal assemblage having the same characteristics of those observed in the Tuili-Gesturi section.

G. bisphericus occurs from the base up to the top of the section. The absence of *G. praescitula* in the lowermost part of the section is probably due to a sampling gap. In fact the first *G. peripheroronda* occurs in sample GG14 together with the first specimens of *G. praescitula*, while it is known, that the FAD of *G. peripheroronda* follows the FAD of *G. praescitula*. *G. peripheroronda* is never common. *Praeorbulina glomerosa* first appears in sample GG-9 and the subspecies *P. sicana*, *P. glomerosa* and *P. circularis* have been observed.

Therefore the *G. trilobus* Zone and the *Praeorbulina glomerosa* s.l. Zone are recognizable in the lower and in the upper part of the section, respectively (top Burdigalian and early Langhian).

The Giara-Gesturi section encompasses a time interval which overlaps for the most part with the Tuili-Gesturi section.

SESTU SECTION (S)

This section which outcrops in a quarry, is about 30m thick. It is characterized by a very rich foraminiferal assemblage known in the literature as the fauna of Fangario (Fornasini, 1887).

The planktonic foraminifera are very common. *Praeorbulina glomerosa* with the subspecies *P. glomerosa* and *P. circularis* are well represented together with *Orbulina suturalis* all the way through. Typical

forms referable to *Orbulina universa* were not observed.

Therefore the entire section belongs to the *Orbulina suturalis* Subzone (late Langhian). However, the early Serravallian is exposed nearly the Sestu quarry in correspondence to Km 14.2 along the road, stratigraphically a few meters above.

ALES SECTION (AC)

This section outcrops along the flanks of the M. Arci. The planktonic foraminifera are rather rare, badly preserved and poorly diversified. Eocene reworked forms have been observed. Various species of *Globigerina* have been recognized, whereas the genera *Globigerinoides*, *Globorotalia* and *Globoquadrina* are generally rare. Only in sample AC-4 *Globigerinoides* is more common and represented by *Globigerinoides trilobus trilobus*, *G. t. immaturus*, *G. t. irregularis* and *G. sacculifer*. Among the most significant forms, *Globigerinoides altiapertura* and *Globigerina woodi* occur in sample AC-7 and AC-4 ter. *Hastigerina* cf. *praesiphonifera* occurs in samples AC-1 and AC-6. In terms of stratigraphic position the planktonic foraminifera are indicative of the highest part of the *Globigerinoides altiapertura-Catapsydrax dissimilis* Subzone (early Burdigalian).

COMMENTS ON THE RANGE OF SOME SIGNIFICANT TAXA

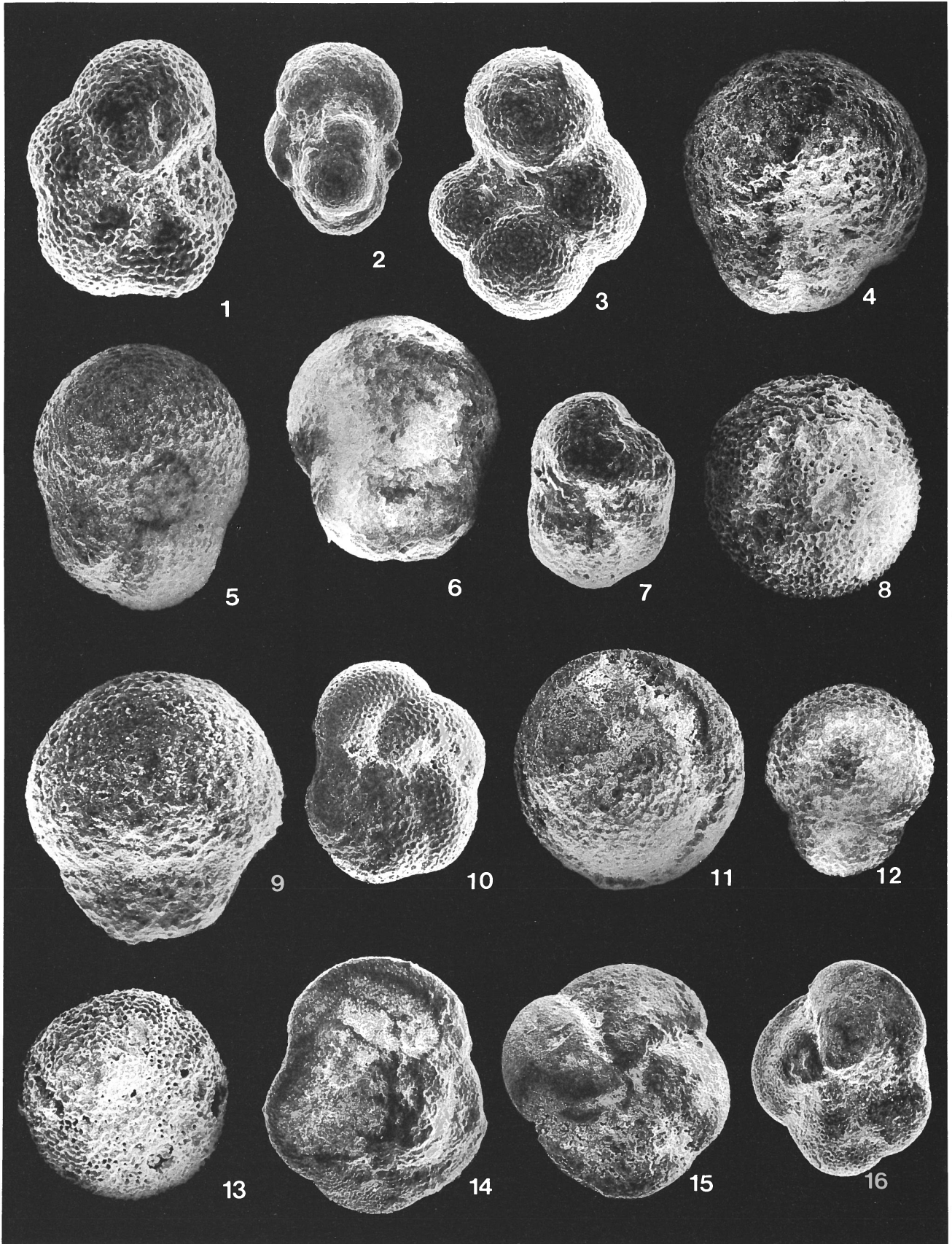
In the study of the Sardinia Miocene sections particular attention has been given to the range of the following taxa:

Globigerina woodi Jenkins (Pl. 1, figs. 6-8)

This taxon, originally described from New Zealand (Jenkins, 1960) is well represented in the investigated sections with typical specimens. The FAD of this species, as given by most of the authors, occurs within the *G. kugleri* Zone, between the FAD of *G. debiscens debiscens* and the FAD of *G. altiapertura*

EXPLANATION OF PLATE 2

- Fig. 1 - *Globorotalia siakensis* Le Roy (x 100); TG-7. *Globigerinoides trilobus* Zone.
 Fig. 2 - *Hastigerina praesiphonifera* Blow (x 60); TG-9. *Globigerinoides trilobus* Zone.
 Fig. 3 - *Hastigerina praesiphonifera* Blow (x 60); TG-4. *Globigerinoides trilobus* Zone.
 Figs. 4, 9 - *Praeorbulina glomerosa sicana* (De Stefani) (x 80); TG-18. *Praeorbulina glomerosa* s.l. Zone.
 Figs. 5, 12 - *Praeorbulina glomerosa sicana* (De Stefani) (x 80); TG-16. *Praeorbulina glomerosa* s.l. Zone.
 Fig. 6 - *Globigerinoides bisphericus* Todd (x 80); TG-18; *Praeorbulina glomerosa* s.l. Zone.
 Figs. 7, 10 - *Globorotalia peripheroronda* Blow & Banner (x 80); GG-9. *Praeorbulina glomerosa* s.l. Zone.
 Fig. 8 - *Orbulina suturalis* Bronnimann (x 80); S-1. *Orbulina suturalis* Subzone.
 Figs. 11,13 - *Praeorbulina glomerosa circularis* (Blow) (x 80); TG-18. *Praeorbulina glomerosa* s.l. Zone.
 Figs. 14,15 - *Globorotalia praescitula* Blow (x 80); TG-18. *Praeorbulina glomerosa* s.l. Zone.
 Fig. 16 - *Globorotalia praescitula* Blow (x 80); TG-12. *Globigerinoides trilobus* Zone.



(Jenkins 1981, Biolzi *et al.*, 1981). According to Molina (1979), the first appearance of *G. woodi* occurs at the same level of *G. debiscens debiscens*. Therefore, there is a good agreement about the position of the first occurrence of this species in the lowermost Miocene (Aquitanian). It is worth mentioning that Keller (1984) documented that in deep-sea sediments from the equatorial Pacific, *G. woodi* appears earlier than *G. debiscens*, then in the Upper Oligocene, whereas Bizon & Müller (1981), studying the deep-sea sediments from the same areas found just the opposite.

Globigerinoides altiapertura Bolli (Pl. 1, figs. 1, 2)

This taxon originally described by Bolli (1957) is well recognizable not only for the large primary and secondary apertures but also for the structure of the ultimate chamber which shows the same features of *G. woodi* from which it seems to evolve (Bizon, 1979, 1984).

It is largely accepted that *G. altiapertura* FAD precedes that of *G. trilobus trilobus* and marks the Aquitanian/Burdigalian boundary (see above).

Globigerinoides trilobus trilobus (Reuss) (Pl. 1, figs. 3, 9, 11, 13, 14)

Globigerinoides trilobus s.l. which includes different forms (such as *immaturus*, *irregularis*, *bullatus*) is recorded from the lowermost Miocene (Aquitanian) by most authors, but there is not unanimous agreement on the stratigraphic position of the FAD of *G. trilobus trilobus*.

According to some authors (Bolli & Saunders, in press; Molina, 1979; Biolzi, 1984) *G. trilobus trilobus* appears before *G. altiapertura* whereas according to Blow (1969), Demarcq *et al.* (1974), Borsetti *et al.* (1979), Biolzi *et al.* (1981), Bizon & Müller (1981), Iaccarino (in press) it appears after the FAD of *G. altiapertura*. In the stratotype of the Burdigalian *G. trilobus* occurs at the same level as *G. altiapertura*.

According to Keller (1984) the *G. trilobus* datum precedes not only that of *G. altiapertura* but also that of *G. debiscens debiscens*.

In the investigated sections the lowest finding of *G. trilobus trilobus* is generally associated with *G. altiapertura* (SV- α ; AC-7). In our opinion the co-occurrence of the two taxa is indicative of non-basal levels of the *G. altiapertura*-*C. dissimilis* Subzone.

Hastigerina praesiphonifera Blow (Pl. 2, figs. 2, 3)

The first findings of this taxon are documented by Blow (1969) from the middle part of Zone N7 which is correlated with the *G. trilobus* Zone.

In the investigated section it occurs in TG and GG sections from the base and throughout AC section. On the basis of the general aspect of the foraminiferal assemblages it is possible that the *H. praesiphonifera* first appears in the early N7 or in the latest N6.

Globorotalia praescitula Blow (Pl. 1, fig. 19; Pl. 2, figs. 14-16)

This species, originally described by Blow (1959), first appears according to the author within Zone N5, whereas according to Berggren *et al.* (1983) it immediately follows the extinction of *C. dissimilis* (= top N6). In the Mediterranean area the range of this taxon agrees with that given by Berggren *et al.* (Bizon & Bizon, 1972; Iaccarino, in press; Cita, 1976), and in that sense it has been used in this paper.

REMARKS ON THE BENTHIC FORAMINIFERA

The benthic foraminifera yielded in the investigated sections are generally scarcely represented as testified by the P/B ratio which is always largely > 1.

The preservation is rather poor in the Sardara-Villanovaforru and Ales sections while it is fairly good in the Tuili and Giara di Gesturi sections.

The assemblages are in general indicative of a lower epibathyal depositional environment (*sensu* Masciotta, Cita & Mancuso, 1976 and Wright 1978b) as supported also by the absence of Miliolids and other shallow-water forms. Biostratigraphically the benthic foraminifera do not allow any reliable resolution. However, as shown in Text-fig. 5, there are some species which appear to display a range restricted to a particular stratigraphic interval (*Uvigerina barbatula* and *U. striatissima* are firstly represented in the *O. suturalis* Subzone).

The range chart of the benthic foraminifera of the investigated sections is reported in Cherchi (1985).

The main characteristics of the benthic assemblages observed in the four sections are as follows.

SARDARA - VILLANOVAFORRU SECTION (SV)

58 species have been recognized in the 24 investigated samples but in each sample the assemblage is generally poorly diversified and at times has oligo-specific characters. In the lowest part of the section *Florilus* spp. is very common and may be associated with Nodosarids (*Lenticulina* spp., *Marginulina* spp., *Dentalina* spp.). In the overlying samples (SV-2; SV-2bis) *Lenticulina* becomes dominant. Upwards (SV-11; SV-15; SV-17) the major components of the assemblages are representatives of *Uvigerina* (*U. gal-*

lowayi and *U. schwageri*) at levels associated with *Heterolepa dutemplei*, whereas *Lenticulina* is decreasing in abundance.

The P/B ratio is characterized mostly by rather constant values ranging from 1 to 25. Only in sample SV-4 the ratio reaches an abnormally high peak (P/B = 105.3).

The benthic foraminifera from SV section indicating an epibathyal environment are: *Karreriella bradyi* which, at present, occurs in deep waters of the Mediterranean (Tood, 1958), *K. gaudryinoides*, *Haplophragmoides* and *Cyclammina*; *Pullenia bulloides* which is recorded below 200 m (Blanc-Vernet, 1969; Wright, 1978b) and is living below 400m (Phleger, 1951), *P. quinqueloba* found in bathyal clays (Blanc-Vernet, 1969) and abundant below 500 m (Phleger & Parker, 1951; Caralp, Lamy & Pujos, 1970; Frerichs 1970); common Lagenids and very rare specimens of *Planulina wuellerstorfi* which according to Wright (1978b) occurs in the Mediterranean below 1000m.

TUILI - GESTURI SECTION (TG)

The benthic foraminifera are always in suborder to the planktonic ones. In fact the P/B ratio is mostly > 10.

67 species have been recognized and among them the porcellanaceous and the shallow-water forms are absent.

From the base up to sample TG-5 the assemblage is characterized by few species and specimens. Above, the benthic fauna is better diversified and richer: the most common forms are *Lenticulina* spp., *Heterolepa dutemplei*, *Cibicidoides* spp. and, in some layers, great-sized agglutinated foraminifera such as *Cylindroclavulina rudis*, *Cyclammina* spp., *Haplophragmoides obliquecameratus*, *Reophax* sp., *Uvigerina* and *Bulimina* occur sporadically. In the highest part of the section the agglutinated forms decrease and are substituted by *Melonis pompilioides* and *M. soldanii*.

The epibathyal environment is suggested by common Lagenids, « costate » *Bulimina* as *B. buchiana* which is considered an epibathyal species (Pujos-Lamy, 1973), and *Planulina ariminensis*. Other species which indicate a depth below 200m are, even rare: *Oridorsalis umbonatus* which has been found in deep waters in the Gulf of Gascogne (Pujos-Lamy, 1973), *Pleurostomella alternans* (Cushman, 1921; Frerichs, 1970), *Cibicidoides kullenbergi* which in the Atlantic and in the Gulf of Gascogne occurs at depth below 580m, whereas in the Mediterranean it occurs in mesobathyal assemblages (Wright, 1978) and in bathyal clays (Blanc-Vernet, 1969). *Gyroidina soldanii* which is abundant below 600m, is rare in this section.

GIARA - GESTURI SECTION (GG)

The best preserved benthic foraminifera occur in this section. The P/B ratio does not show remarkable fluctuations; it is fairly constantly > 10. The assemblage is mostly characterized by the same forms throughout the section. 54 species have been classified: the most common are *Lenticulina* spp., *Vaginulina legumen*, *Marginulina hirsuta*, followed in abundance by *Heterolepa dutemplei* and *Praeglobobulimina pupoides*. The agglutinated foraminifera, *Cylindroclavulina rudis*, *Karreriella gaudryinoides* and *Spiroplectammina carinata*, are also well represented. The rare shallow-water species observed in sample GG-14 have been considered reworked.

The paleobathymetric indications suggested by the benthic foraminifera of GG section are similar to those reported for TG section. We can mention the absence of Miliolids and shallow-water forms, the occurrence of *Karreriella bradyi*, *Siphotextularia affinis*, common Lagenids, *Gyroidina soldanii*, *Planulina wuellerstorfi*, *Cibicidoides kullenbergi*, « costate » *Bulimina*, and *Trifarina bradyi*, whose habitat is deeper than 150m.

SESTU SECTION (S)

This section contains the best diversified assemblages: 39 species have been recognized. There are no dominant species and the assemblages do not show substantially any qualitative variations from the base to the top. The most common forms are *Lenticulina* spp., *Praeglobobulimina pupoides*, *Heterolepa dutemplei*, followed by *Uvigerina barbatula*, *Hanzawaia boueana*, *Uvigerina longistriata*, *Bulimina buchiana*, *Brizalina arta*, *Uvigerina schwageri*, *Planulina wuellerstorfi*, *Marginulina hirsuta*, which all are represented by very few specimens. The agglutinated foraminifera are represented by *Spiroplectammina carinata*, *Martinottiella communis*, *M. perparva*, and *Karreriella gaudryinoides*.

Among the species highly indicative of lower epibathyal environment there are: *Cyclammina cancellata* indicated by Pflum, Frerichs & Sliter (1976) as an isobathyal species, here recorded frequently at times, and *Gyroidinoides altiformis* which in the Mediterranean occurs from 200m downwards and becomes abundant below 600m, and very abundant below 800m (Wright, 1978b).

ALES SECTION (AC)

The benthic assemblages observed in this section show great similarities with that of Sardara-Villanova-forru with many species in common, (i.e. *Bulimina buchiana*, *Uvigerina gallowayi*, *U. schwageri*).

CORRELATIONS WITH SITE 372
AND POZZO ORISTANO 1

The biostratigraphic results obtained from this study are compared with those from the same interval of Site 372 (Hsü *et al.*, 1978) and of Pozzo Oristano 1 (Pomesano Cherchi, 1971) (Text-fig. 3).

In Site 372, located on the western flank of the Western Mediterranean basin (Text-fig. 6), Bizon and Cita (in Hsü *et al.*, 1978) recognized separately, at the very base of the hole, the *Catapsydrax dissimilis* - *Globigerinoides altiapturus* Zone (N5/N6) (Burdigalian) whereas according to the calcareous nannofossils (Müller, in Hsü *et al.*, 1978), the bottom of the hole belongs to the *T. carinatus* Zone (NN1) (Aquitanian).

The same difference in the age assignment has been documented in the Sardara-Villanovaforru section where on the base of the planktonic foraminifera the first marine sediments are Burdigalian in age (*G. altiapturus*-*C. dissimilis* Subzone) whereas on the base of the calcareous nannofossils are Aquitanian (NN1) (Cherchi, 1985).

From the bottom of the Site 372 upwards the following succession of bioevents have been observed: *G. altiapturus*, *G. trilobus trilobus*, *G. subquadratus* and *Globorotalia praescitula*. As in the SV section, the *G. altiapturus*-*C. dissimilis* Zone has a great thickness (about 420m) made up of mudstones to nannofossil marlstones. The sedimentation rate estimated for this interval is 12cm/1000 years if the bottom sediments of the site are dated as earliest Burdigalian. This value calculated from the geochronologic time scale of Berggren *et al.* (1983) is very close to that evaluated for the same interval in the Sardara-Villano-

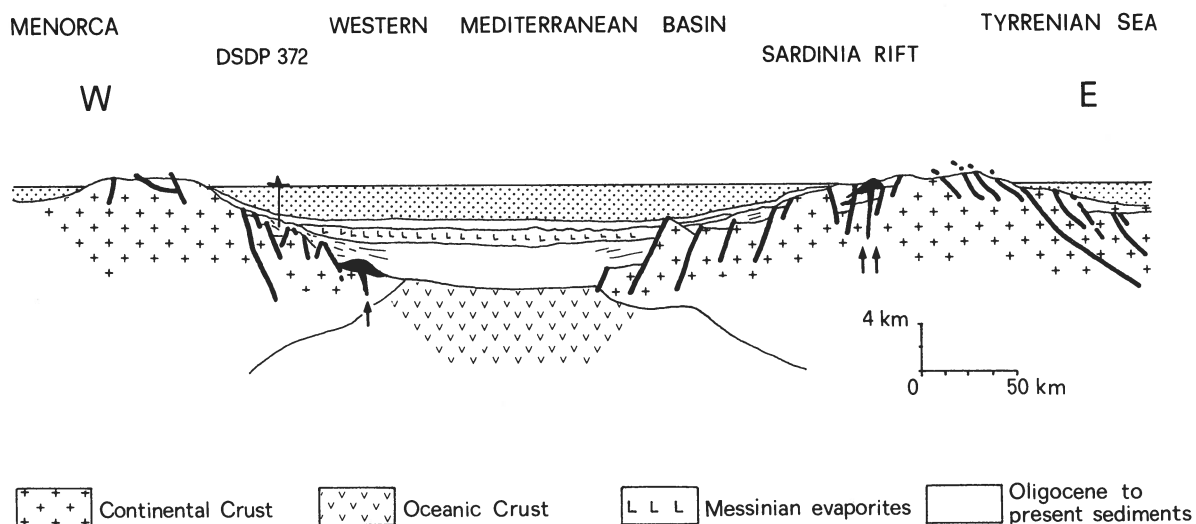
vaforru section (14cm/1000 years), taking into account that in the latter sequence intercalations of tuffitic layers are common, and that the base of the section does not represent the base of the Burdigalian.

The sedimentation rate for the entire Burdigalian sequence which at Site 372 has been estimated 10.3 cm/1000 years cannot be evaluated for the sections from the Marmilla because the *G. trilobus* Zone is not documented in its complete thickness.

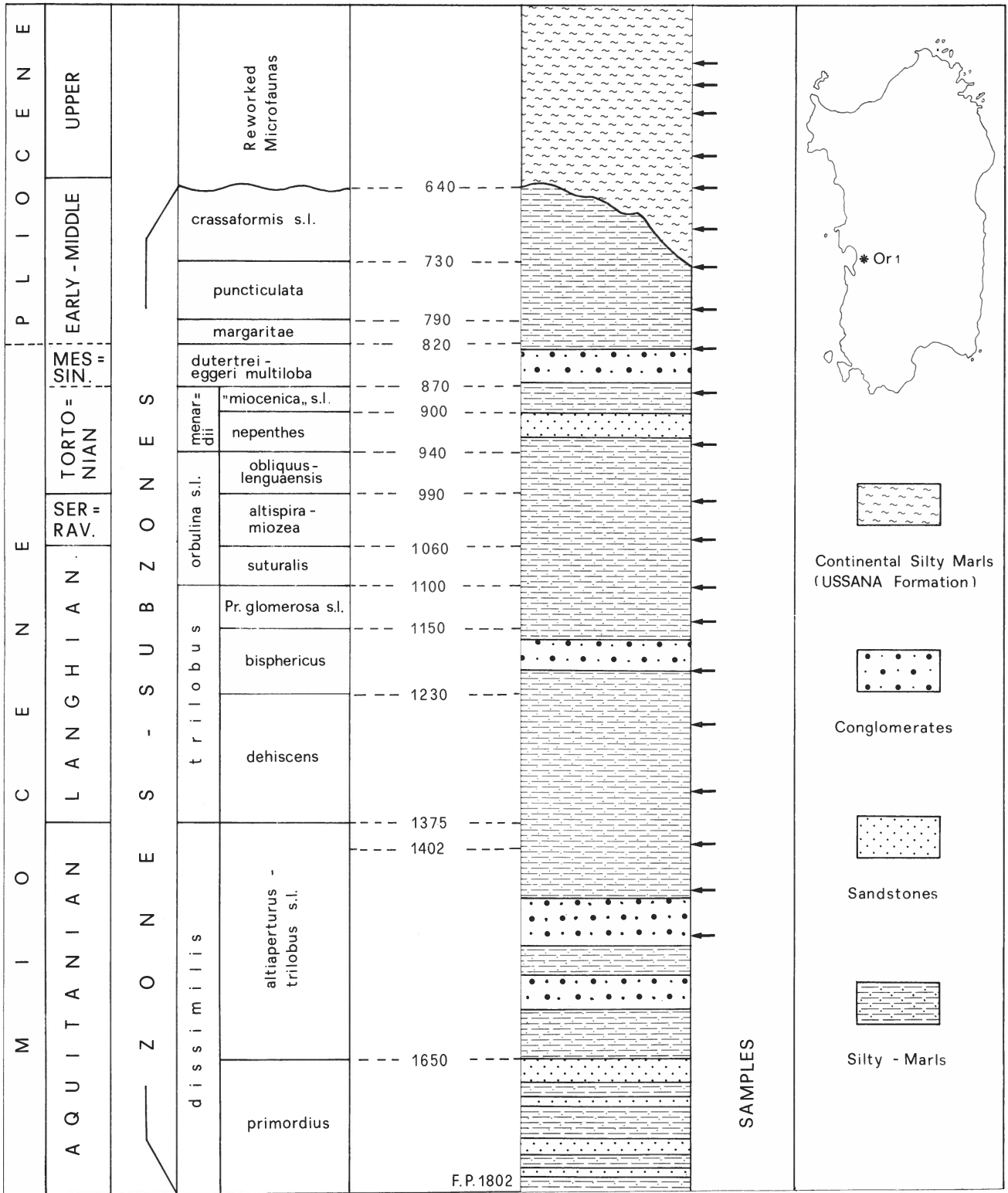
The Aquitanian has been recognized in Pozzo Oristano 1 located in the axial part of the graben. There, from the bottom of the hole (—1802m) to —1650m (Text-fig. 7), Pomesano Cherchi (1971) identified the *G. primordius* Subzone, within which *G. trilobus* has been recorded. The *G. altiapturus*-*G. trilobus* s.l. Subzone (of Cati *et al.*, 1968), which correlates with the *G. altiapturus*-*C. dissimilis* Subzone of Iaccarino & Salvatorini (1982), is represented only by 285m of sediments (—1650m to —1375m) which in terms of sedimentation rate would have been deposited at a rate of 0.6cm/1000 years. Taking into account that tuffitic intercalations are present within this interval the estimated value seems to indicate a sedimentation rate slower in the axial part of the basin than on the edges.

CONCLUDING REMARKS

In the Marmilla area the first marine sediments resting on the basement, belong to the *G. altiapturus*-*C. dissimilis* Subzone as documented in the Sardara-Villanovaforru section. Therefore, along the eastern edge of the Oligo-Miocene Sardinian rift the continental sedimentation of the Ussana formation continued up to the Aquitanian and locally to the earliest Bur-



Text-fig. 6 - Schematic geological cross-section from Menorca to Sardinia, and location of Site 372 (After Cherchi & Montadert, 1982).



Text-fig. 7 - Stratigraphic Log of the Pozzo Oristano 1 (After Pomesano Cherchi, 1971).

digalian. It is worth emphasizing that there is no agreement in the age assignment between planktonic foraminifera and calcareous nannofossils, at least, as far as the lowermost Miocene it concerns. In fact the very base of the SV section is attributed to the NN1 of Martini (1971) of Aquitanian age (Cherchi, 1985).

The great thickness of the early Miocene *G. altiaperturaus-C. dissimilis* Subzone recorded in the SV section cannot be explained only by the numerous tuffitic intercalations which characterize this section, but probably the high sedimentation rate evaluated for this interval (14cm/1000 years) has some relationships with the tectonic activity very high during this time in the western Mediterranean. In fact, also at Site 372 where the tuffitic layers have not been observed, the same interval has been estimated to have deposited at 12cm/1000 years and the entire Burdigalian sequence at 10.3cm/1000 years (Hsü *et al.*, 1978). Slightly lower values have been estimated for the Pozzo Oristano 1 located in the axial part of the rift, suggesting that large amount of sediments were trapped on the edges of the basin.

The Langhian deposits are represented in the TG, GG, S sections: the Burdigalian/Langhian boundary has been observed both in TG and GG sections where the top of *Praeorbulina glomerosa* Zone, however, was not observed. The S section belongs to the *O. suturalis* Subzone, but the first appearance of *Orbulina universa* which marks the Langhian/Serravallian boundary was not found. This taxon occurs in an isolated sample collected along the national road at km 14,2.

The complete thickness of the Langhian deposits is not detectable, therefore the sedimentation rate can not be estimated. Considering that for the outcropping Langhian deposits the evaluated sedimentation rate is 0.8cm/1000 years and that of Site 372 is 10.5cm/1000 years it is reasonable to suggest that the geodynamic conditions in the two basins during the Langhian were quite similar.

The benthic foraminifera yielded in all the sections provided good information about the bathymetry of the depositional environment indicating a lower epibathyal environment between 500 and 1300 meters (*sensu* Wright, 1978b). Their distribution is not particularly significant from a biostratigraphic point of view. However, it is evident that some of them have a distribution confined to a given stratigraphic interval.

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(*manuscript received April 5, 1985*
accepted May 2, 1985)

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