INTRODUCTION

In the last years, biometric studies of Miogypsinidae populations are finalized to improve the correlation between their evolutionary stage and the stratigraphic scale. Previous studies on the Miocene transgression in the Cassino Plain, were made by using a preliminary attribution of miogypsinid specimens to *M. cf. globulina* (Michelotti) without any biometric analyses (Pignatti, pers. comm.; Brandano, 2001). As a consequence a complete biometric analysis is necessary to refine the taxonomic determination, to verify the proposed age for the Miocene transgression in the Cassino Plain and to compare with Miogypsinidae populations of equivalent Miocene limestones from published examples of western Mediterranean area (Schüttenhelm, 1976; Schiavinotto, 1985; Wildenborg, 1985).

GEOLOGICAL SETTING

The investigated horizon outcrops in the southwestern sector of the M.te Cairo structure. This structure represents the north-western limit of the Cassino plain (Fig. 1). The investigated area is placed in the Apennine sector belonging to the wide neritic area known as Latium-Abruzzi carbonate platform.

The Latium-Abruzzi platform consists of a thick, discontinuous succession of about 5000 m of limestones and, subordinately, dolostones of late Triassic to late Miocene age. A hiatus covering the late Cretaceous to Paleogene, is physically expressed by a paraconformity recognizable in almost the entire Latium-Abruzzi platform. Above this stratigraphic discontinuity, lower and/or middle Miocene carbonates directly overlie Cretaceous limestones. The Miocene carbonate deposition was terminated by plate flexure-related drowning and coeval input of terrigenous sediments represented in the first stage by the "Orbulina Marls" and, successively, by the siliciclastic turbidites. The Miocene carbonates were shortened and thrust onto clastic sediments of the active margin. The period of thrusting and foredeep development in the Latium-Abruzzi platform is dated Middle to Latest Miocene (e.g., Patacca et al., 1991; Cipollari & Cosentino, 1995). The Miocene carbonate succession in the Latium-Abruzzi domain is represented by the "Calcari a Briozoi e Litotamni" Formation (CBL) consisting of rhodalgal/bryomol limestones that unconformably
overlie Cretaceous limestones (Accordi et al., 1967; Bergomi & Damiani, 1976; Damiani et al., 1991). Strontium isotope stratigraphy and biostratigraphy indicate a Late Aquitanian-Early Tortonian age for the CBL (Brandano, 2001; Brandano et al., 2001). The lower boundary of the CBL is marked by a sharp surface, locally stylolitic. A hardground a few cm thick, strongly glauconitized and bioeroded, occurs on top (Bergomi & Damiani, 1976). On the basis of sediment textures and biotic associations, integrated with taxonomic and paleoecological analyses, five lithofacies associations were identified by Brandano (2001) and Civitelli & Brandano (2005) (Tab. 1 in Civitelli & Brandano, 2005). They are: Benthonic Foraminifer-Echinoid Limestones (UL1), Bryozoan-Echinoid Limestones (UL2), Rhodolithic-Coral Limestones (UL3C), Rhodolithic Limestones (UL3R); Planktonic Foraminifer-Echinoid Limestones (UL4).

The depositional profile obtained by using the relative position of facies belts and the dependence of some skeletal components upon light penetration, is a homoclinal ramp (Brandano, 2001; Civitelli & Brandano, 2005). The profile results from both the inherited substratum (the Cretaceous carbonate platform) and the locus of carbonate production and accumulation. The ramp can be divided into three depositional environments: inner ramp, middle ramp and outer ramp. The inner ramp is characterized by a high-energy environment immediately below the littoral zone, with sea grasses meadows and associated Maërl facies and coral carpets (UL3C). Local and limited emersions are testified by Microcodium. The biota associations and the ichnogenera assemblages indicate that the inner ramp carbonate production took place in the euphotic zone (sensu Pomar, 2001a) at water-depth of a few tens of meters (Brandano, 2003). The middle ramp lithofacies are characterized by Larger Foraminifera (Heterostegina, Operculina, Amphistegina, Miogypsina) and red algae and subordinately echinoids, bryozoans and bivalves (UL3R). Based on biota associations, the middle ramp should be located in the oligophotic zone (sensu Pomar, 2001). The outer ramp can be sub-divided into a proximal, an intermediate and a distal outer ramp.

In the proximal outer ramp the main sediment-producing biota are represented by bryozoan colonies, bivalves (pectinids and oysters) and echinoids; benthonic foraminifera are common (UL2). The scattered rhodolith levels and the absence of larger foraminifera suggest a depositional environment placed at the passage from the oligophotic to the aphytic zone. The intermediate outer ramp lithofacies are dominated by benthonic and planktonic foraminifera, echinoids and bivalve fragments. In the distal outer ramp the biota assemblage is mainly characterised by planktonic foraminifera, silica sponge spicules and, subordinately, by bryozoans and echinoids fragments (UL1, UL4). Based on sedimentological features and biota assemblages the outer ramp, from the intermediate to the distal zone, is placed in the aphytic zone.

THE VILLA S. LUCIA SECTION

The investigated section was measured along the local road that connects Villa S. Lucia village with the national road SS6 Casilina (Fig. 1). The outcrop is characterized by crudely stratified limestone of the UL3R unit of Civitelli & Brandano (2005).

The section is crudely stratified with 0.5-2 m thick beds bound by subhorizontal surfaces and is composed by:

- 70 cm thick bed made up in the lower part by white, medium grained bioclastic packstone. This deposit lies paraconformally on the Cretaceous carbonate limestone.
- 40 cm are characterised by light-brown coarse packstone consisting of echinoids fragments, by Heterostegina, Operculina, Miogypsina and red algae fragments.
- 20 cm of light-brown floatstone constituted by bivalve remains, echinoids, larger foraminifera, echinoids remains are present; other components are red algae crusts and rhodoliths.
- 80 cm layer thick made up of fine-grained, light brown packstone is present. The main components are larger foraminifera (Heterostegina, Operculina), pectinids and large echinoids (Clypeaster).
- a rhodolith floatstone bed, 30 cm thick.
- 1 m characterized by brown fine grained packstone constituted by fragments of echinoids, coralline algae, larger foraminifera and small bryozoan colonies.
- 1 m thick bed characterized by 20 cm of coarse-grained, bioclastic packstone.
- 1.4 m of light-brown packstone made up of bioclastic sediments. The recognizable portion is represented by echinoid fragments, larger foraminifera (Heterostegina, Operculina, Amphistegina) and red algae.
- 30 cm of rhodolith floatstone. The next interval of the section is 3.2 m thick and it is characterized by light-brown coarse grained packstone dominated again by echinoid fragments, larger foraminifera and red algae fragments.
- 4 m of white rudstone made up of large bivalve (pectinids and oysters) and rhodoliths.

Recently, a study on the red algal associations has been carried out in the rhodoliths of this section by Brandano et al. (2007). This analysis evidences a dominance of thalli belonging to melobesoids subfamily (93.52%) represented by the genera Mesophyllum spp., Lithothamnion sp. and Lithothamnion/Phymatolithon. Thalli of family sporolithaceae are accessory (6.48%) and are represented only by the species Sporolithon intermedium.

The rhodoliths generally show a subospheroidal shape with diameter ranging between 2 cm and 4 cm, whereas the ellipsoidal rhodoliths are subordinate and show minor axis ranging between 1 cm and 3 cm and major axis between 2 cm and 4 cm. Bryozoans or balanids generally constitute the nucleus.

Rhodolith structure may be only laminar, or with the internal portion columnar or branching (II and III group).
passing outward to laminar. The columnar rhodolith are subordinate. Isolated warty to encrusting thalli are present.

**PALEOECOLOGICAL REMARKS**

According to Geel (2000), Miogypsinids lived in shallow water (less than 50 m deep) with normal salinity. Frost et al. (1985) reported the occurrence of *Miogypsinia* from backreef shoals with coral thickets or seagrass banks and *Miogyspinoides* from sandy skeletal sands co-occurring with Miliolids and Lepidocyclinids.

Mateu-Vicens et al. (2005), on the basis of a model for paleodepth reconstruction by using *Amphistegina* test morphology (T/D ratios), suggest for individuals of *Amphistegina* collected in the Villa S. Lucia a growth at water-depth < 30 m.

Brandano et al. (2007), by using the classical paleobathymetric and palaeoclimatic schemes of Adey (1979), Bosence (1983; 1991) and Aguirre et al. (2000), suggest for the red algal assemblages of Villa S. Lucia section a growth in the oligophotic zone (sensu Pomar, 2001) in a middle ramp environment in a water-depth < 30 m.

The shape and structure of rhodoliths in the Villa S. Lucia section suggest frequent rhodoliths displacement in the deeper environments, possibly due to bottom-dwelling organisms moving the rhodoliths (Steneck, 1986; Prager & Ginsburg, 1989; Marrack, 1999; Gischler & Pisera, 1999).

**MATERIAL**

The examined sample (VSL) was taken just above the stylolitic surface separating the Miocene from the Cretaceous carbonates, (Fig. 2). The location of the outcrop, as reported in Fig. 1, is near Villa Santa Lucia village (F° 160, Tav I S.O. Terelle), in coordinates UTM ED50 33 T 4596064 N 397576 E.

The VLS sample is characterised by many Miogypsinidae specimens with isolated and chaotic biofabric, as a consequence it was very difficult to obtain many specimens showing a correct section of embryonic and nepionic chambers. In order to obtain a sufficient number of specimens to get a significant statistic result on the mean values of the biometric indexes, 80 thin sections have been prepared.

**STUDY METHOD**

Counts and measurements, schematized in Fig. 3, are made on embryonic-nepionic chambers (equatorial sections).

X = number of the chambers of the principal spiral, excluding protoconch (I) and deuteroconch (II).

In the presence of the second principal chamber (PAC) with its spiral, the number of chambers of the longest spiral around the protoconch will be counted. In this case, the “symmetrical (or closing) chamber”, placed at

Fig. 2 - View of the Villa Santa Lucia outcrop. The white line indicates the contact between Cretaceous (K) and Miocene (M) limestones.

Fig. 3 - Schematic drawing showing the methods of counting and measuring the internal features in horizontally sectioned embryonic-nepionic stage of primitive (a) and more developed (b) *Miogypsinia*. Meaning of the symbols: I= protoconch; II= deuteroconch; PAC = primary auxiliary chambers; c = closing chambers; AF = apical-frontal line; ME = medio-embryonic line; $\gamma$ = angle between ME and AF lines; $\alpha$ = angle made by the shortest spiral around the protoconch; $\beta$ = angle made by both spirals around the protoconch; DI = diameter of the protoconch; DII = diameter of the deuteroconch (after Schiavinotto, 1985).
the meeting point of the two nepionic spirals from opposite directions, will be considered as 1/2 (XI) (De Mulder, 1975) or as a whole chamber (XII) (Drooger, 1952, 1963; Raju, 1974; Schüttenhelm, 1976).

- γ = Angle between the apical-frontal line of the test (AF) and the medio-embryonic line (ME) (Drooger, 1952).

The apical-frontal line passes through the centre of the protoconch between the apex and the middle of the frontal edge. It divides the test into two approximately equal parts. The medio-embryonic line passes through the centres of the protoconch and the deuteroconch. The value of the angle γ depends on the length of the nepionic spiral; it may be either positive or negative (Amato & Drooger, 1969; Raju, 1974; De Mulder, 1975): 

- γ is negative when the length of the principal spiral exceeds one whorl; in the case of shorter spiral or of two spirals round the protoconch, γ is negative if the third chamber or the larger the two PAC is turned towards the apex of the test.

- γ = 0 when the apical-frontal line and the medio-embryonic line coincide.

- γ is positive when the length of the principal spiral is less than one whorl and the third chamber, or the larger of the two PAC, is turned towards the frontal edge of the test.

V = Degree of symmetry of the spirals round the protoconch in specimens with two PAC. V is calculated by means of the formula \( V = \frac{\alpha \beta}{200} \). In this equation the angle \( \beta \) represents the length of the arc relating to both the spirals round the protoconch, delimited by the half-lines with origin in the centre of the protoconch and passing through the points of contact between the walls of the two embryonic chambers, while the angle \( \beta \) represents the length of the arc relating to the shortest spiral.

DI and DII = Diameters of the protoconch and of the deuteroconch, measured at right angles to the line joining the centers of the first two chambers (ME line). In these measurements, half of the thickness of the walls is included.

### EXTERNAL CHARACTERISTICS

In crossed section, the tests are very bulging on the embryonic areas, that are peripheric (Pl. 1, Figs. c, d, e). A lot of tests are characterized by the presence of pillars (Pl. 1, Fig. b) with thickness variable between 30 and 90 µm. In equatorial section, the test outline is always sub-triangular (Pl. 1, Figs. c, d).

### INTERNAL CHARACTERISTICS

The embryonic chambers are always in a peripheral-apical position.

A second principal auxiliary chamber (Pl. 1, Fig. f) is present in all specimens. At the meeting point of the two nepionic spirals, a symmetrical or closing chamber can be seen not in all specimens, because slight obliquity of the thin sections.

Specimens without lateral chambers (typical for *Miogypsinoidea*) are absent. An intraseptal canal-system (typical for *Miogypsinoidea*) has not been detected. The larger PAC is always turned toward the test’s frontal margin.

The results of counts and measurements are summarized in Tab. 1.

<table>
<thead>
<tr>
<th>VSL</th>
<th>N</th>
<th>Range</th>
<th>M</th>
<th>S</th>
<th>Sm</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>28</td>
<td>29.5 - 61.4</td>
<td>43.01</td>
<td>9.14</td>
<td>1.73</td>
</tr>
<tr>
<td>XI</td>
<td>28</td>
<td>5 - 8</td>
<td>6.1</td>
<td>0.81</td>
<td>0.15</td>
</tr>
<tr>
<td>D</td>
<td>28</td>
<td>105-205</td>
<td>145</td>
<td>35.24</td>
<td>6.66</td>
</tr>
</tbody>
</table>

Tab. 1 - Results of count and measurements on internal characteristics of *Miogypsinoides globulina* (Michelotti) population from sample VSL.

### DIAGNOSIS

The characters of VSL population from Villa Santa Lucia fall within the limits of *Miogypsinoides (Miogypsinoides) globulina* (Michelotti). For that species, values of \( X_1 \) less than 7, values of \( V \) between 0 and 45 %, and a positive \( \gamma \) are defined (Drooger, 1952; Schüttenhelm, 1976). More than 50 % of the specimens must have a second principal auxiliary chamber (Drooger, 1952).

Drooger introduced these limits for the species *Miogypsina irregularis* established by Michelotti (1841); later on, the substitution of the name *Miogypsinoides globulina* for *Miogypsinoides irregularis* has been confirmed definitively by Drooger & Socin (1959).

The histograms in Fig. 4 demonstrate the homogeneity of the population. Overall unimodal distributions are evidenced, close to the normal trend for all the parameters/factors.

### EVOLUTIONARY STAGE

The mean value of \( V \) for the VSL population has been compared with the mean value of selected populations previously studied (Tab. 2). The VSL value is very similar to value of some populations from Piedmont sedimentary basin (Schüttenhelm, 1976), CC43 population from from Capaccio (Southern Apennines), JT5124 and JT5063 populations from Sicily (Wildenborg, 1985).

By the comparison between the mean value of \( X_1 \) in Tab. 2, it is clear that the first one is very similar to the populations 24 and 43 from Aquitaine (Drooger et al. 1955), to the population DM 116 from Greece (De Mulder, 1975), to the populations SM 87, SM 166, SM
PLATE 1
Fig. 1 - Calcarenite with larger foraminifera. The larger foraminifera are not orientated. They belong mainly to the *Operculina*, *Amphistegina* and *Miogypsina* genera. Sample VSL, section 10.
Fig. 2 - Axial section evidencing the pillars. Specimen VSL 45.
Fig. 3 - Equatorial section evidencing the sub-triangular outline of the test, the embryonic chambers in a peripheral position. The $\gamma$ angle with a clearly positive value. Specimen VSL 45.
Fig. 4 - Equatorial section evidencing the sub-triangular outline of the test, the embryonic chambers in a peripheral position, the $\gamma$ angle with a clearly positive value. Specimen VSL66.
Fig. 5 - Axial section showing a bulging on the embryonic area. Specimen VSL29.
Fig. 6 - Detail of the embryonic and nepionic chambers in specimen VSL27.
248, from Piedmont sedimentary basin (Schüttenhelm, 1976), to the population KR 36(b) from India (Raju, 1974) and to the population CC41 from Capaccio (Southern Apennines).

Mean values of V and DI of VSL population are displayed in the scatter diagram (Fig. 5), in order to test the relationship of the VSL population with other Miogypsinids studied in Europe and in Africa. VSL population fall in the diagram sector corresponding to other populations of *M. globulina*. Fig. 6 emphasizes the evolutionary stage of VSL population with respect to *M. globulina* described in literature. VSL mean value of the degree of spirals simmetry shows a very high evolutionary stage with respect to other populations. On the contrary, the mean values of the main nepionic spiral and of the diameter of the protoconch show an intermediate value.

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Fig. 4 - Histograms showing the distribution of counts and measurements on internal characteristics of the *Miogypsinida globulina* (Michelotti) population from sample VSL.

Fig. 5 - Scatter diagram showing the relationship between the mean diameter of protoconch DI and the X - V scale values in *Miogypsinidae assemblages* studied in the World with the position of the *Miogypsinidae* population from Villa Santa Lucia (VSL). (After Drooger and Raju, 1973).

Fig. 6 - Scatter diagrams showing the relationship between mean value of V and the values of DI, and XI in *Miogypsinida globulina* (Michelotti) from sample VSL and in co-specific populations from literature.
BIOSTRATIGRAPHY

*M. globulina* marks the Lower Burdigalian in the Mediterranean realm (Drooger, 1993; De Mulder, 1975; Schüttenhelm, 1976; Cahuzac & Poignant, 1997, 2002, 2004, 2005; Ferrandini et al., 2003; Verrubbi & Schiavinotto, 2005), nevertheless according to Ferrero et al. (1994), *M. globulina* is referred to Upper Burdigalian in the Pietra da Cantoni Group in Eastern Monferrato, according to the biostratigraphic scheme proposed by Mancin et al., 2003 and Bicchi et al., 2006.

In the Mediterranean area, the phylogeny of the main lineage of the Miocene Miogypsinidae develops from *M. gunteri* to *M. tani* in the Aquitanian, while the sequence *M. globulina, M. intermedia, M. cushmani* and *M. mediterranea* would be in the Burdigalian.

In the population from Villa Santa Lucia, the measure
of the angle $\gamma$ resulted to be very difficult and the index was determined in only 5 specimens. The value is positive and ranges between 11 and 46 degrees; it is interesting to note that the angle $\gamma$ becomes positive at the Aquitanian-Burdigalian boundary (Cahuzac & Poignant, 2005).

CONCLUSIONS

The values of biometric indexes obtained for Miogypsinids of VSL Sample are included in the boundaries established by Drooger (1952) for *Miogypsinia globulina* (Michelotti).

The comparison with other populations of the Mediterranean area of *M. globulina*, evidences an intermediate to high evolutionary stage of the specimens.

The evolutionary stage of the Miogypsinsids from the studied sample, suggests that the basal Miocene limestone of the M.te Cairo structure may be assigned to the middle part of Lower Burdigalian.

The age obtained from this study is in agreement with the results of previous works by Brandano (2001) and Civitelli & Brandano (2005) on the stratigraphy of Miocene limestone of the Latium-Abruzzi carbonate platform domain and in particular in the M.te Cairo structure.

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