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Nephrolepidina morgani (Lemoine and R. Douvillé, 1908) from the Oligo-Miocene of Decontra section (Majella, Central Apennines)

Francesco Schiavinotto

Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, P.le Aldo Moro 5, I-00185 Roma, Italy
francesco.schiavinotto@tin.it

ABSTRACT - A *Nephrolepidina* population, coming from the Oligo-Miocene outcrop of the Bolognano formation near Decontra (Majella Mt., Central Apennines), is investigated applying the biometric analysis of the embryo-nepionic chambers and of the fifth stage of the neanic equatorial chamberlets, supplying additional data about parameters and factors that had already demonstrated to have taxonomic-biostratigraphic significance. "Embryonic -Nepionic Acceleration" is detected. The population can be referred to the evolutionary stage of *N. morgani* (Lemoine and Douvillé).

The data evidence that the "Degree of stolonic distalization" (Factor FD5) and the "Shape Index" (Factor SI5), at the 5th neanic stage of the population have a very good fitting with the previously evidenced overall trend to modify the shape of the equatorial chambers, connected with a gradually more distal position of the radial stolons ("Neanic Acceleration").

The previous Chattian age of the upper part of the *Lepidocyclina* Limestone of the Bolognano formation can be better specified on the basis of the biometric data obtained here, with a correlation with the larger Foraminifera SBZ23 Biozone. The specific, phylogenetic and biostratigraphic definitions could be improved by means of further integration of the embryonic-nepionic-neanic data.

Keywords: Biometry; Larger foraminifera; Lepidocyclinidae; Taxonomy; Biostratigraphy; Oligocene.

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1. INTRODUCTION

The Oligocene larger foraminifers of the Majella carbonate platform (Central Apennines) were investigated biometrically only recently (Benedetti et al., 2010), although the occurrence of Oligocene shallow-water deposits on the slope of the Majella carbonate platform was recorded by several authors since more than six decades (Bonarelli, 1951; Di Napoli et al., 1958; Crescenti, 1969; Crescenti et al., 1969; Catenacci, 1974; Accarie, 1988; Vecsei, 1991; Pignatti, 1995; Rusciadelli and Di Simone, 2007). Benedetti et al. (2010) described *Nephrolepidina* populations at the primitive evolutionary stage of *N. praemarginata* from the S. Spirito Formation and proposed a biostratigraphic and paleoenvironmental interpretation based on the biometrical comparison with coeval populations from the Tethys.

The aim of this research is to define biometrically at least a part of the successive evolutionary stage of *Nephrolepidina* in the Majella area, using the methodology introduced by Van der Vlerk (1959; 1963), focusing on the megalospheric embryonic and nepionic apparatuses. On the other hand, new data are added, with the aim to refine the application of a quantitative methodology introduced by Schiavinotto (1992; 1993; 1994; 2010), extended to the neanic stage of these larger foraminifers, until now continued only by Benedetti and Pignatti (2012), under the name of neanic acceleration. Moreover, this study contributes to add concrete basis to the biostratigraphic definition of the Chattian interval of the Bolognano Formation, cropping out at the Decontra section, in the northern sector of Majella Mountain. This section was in fact recently object of multidisciplinary researches (Reuter et al., 2013; Auer et al., 2015) and the constraints in the age-assignments require accurate evidencies.

2. GEOLOGICAL AND STRATIGRAPHICAL SETTING

The Majella Mountain (Central Apennines) is part of the Apulian carbonate platform, as the edge of an isolated Bahama-type platform at the southern margin of the Mesozoic Tethys ocean (Accarie, 1988; Vecsei, 1991; Bernoulli et al., 1992; Eberli et al., 1993; Sanders, 1994; Anselmetti et al., 1997).

The evolution of the carbonate platform was characterised by: 1) a steep, non depositional escarpment that separated shallow-water platform carbonates from onlapping slope sediments (Jurassic-Cretaceous); 2) transformation of this steep relief between platform and adjacent slope into a more gradual ramp-like margin caused by progradation of carbonates (Late Cretaceous); 3) emersion (latest

Maastrichtian-earliest Paleocene), and subsequent deepening with backstepping submarine erosion and redeposition in an upper slope regime that was established along the platform margin; 4) prograding of skeletal sands and reefal units over the former slope sediments and again shifting of the platform margin basinward (late Paleocene - early Oligocene), with the development of algal and coral patch reef, delineated as S. Spirito Formation (Vecsei et al., 1997); 5) wide, "gently inclined shelf" (Vecsei et al.,1999) or "low angle ramp" (Mutti et al., 1997), dominated by bioclastic sedimentation, characterising the whole system. The result is the Bolognano Formation (Chattiano-Messinian) (Crescenti et al., 1969; Mutti et al.,1997; Vecsei and Sanders, 1999); 6) uplifting of the whole platform-basin system during the Apennine orogeny.

2.1. The Bolognano formation

According to Vecsei et al. (1998), the "Bolognano Formation" is the more recent of six supersequences (SS6, Chattian-Messinian). This supersequence is subdivided in three depositional sequences, with either shallow or deep water sediments (Mutti et al.,1997):

1. Lower Bryozoan Limestone*:* shallow water, grainstone, rudstone with bryozoa, red algae, molluscs and benthic larger foraminifera. Lepidocyclinids dominate the deposits assigned to this unit, under the name of "*Lepidocyclina* Limestone" (e.g. Brandano et al., 2012).
2. Upper Bryozoan Limestone: cross-bedded grainstone,with plankonic foraminifers-benthic microforaminifers, rare larger foraminifers, bryozoa, molluscs, fragmented echinidis. *Orbulina* Marls characterise the upper part of this unit.
3. *Lithothamnion* Limestone*:* red algae (*Lithothamnion*), bryozoa, echinids and bivalves are the main components; the terrigenous content increases in the upper part of the unit.

2.1.1. Decontra Section

The investigated *Nephrolepidina* population (labeled DE208) comes from calcareous layers of the Bolognano Formation (Crescenti, 1969; Crescenti et al., 1969) at the northwestern flank of the Majella Mts. The outcrop is located near the town of Caramanico Terme (Pescara), 1km southeast of the village Decontra, along a trail at the northern slope of the Orfento river valley (N 42°09'43, E 014°02'21; Fig. 1). The 120 m-thick Decontra section was recently investigated as a key section for correlating Mediterranean shallow-water successions and measured bed-for-bed (Reuter et al., 2013).

The measured section (Fig. 2), from the bottom to the top, results as follows:

Lepidocyclina Limestone (32-m-thick): depositional unit of bioclastic packstones, grainstones and rudstones dominated by lepidocyclinids and other larger benthic foraminifers (*Amphistegina*, nummulitids); it unconformably overlies Eocene limestones. Small benthic foraminifers, abraded bryozoan, echinoderm, mollusks and corallinacean fragments are associated. The lower part of the *Lepidocyclina* Limestone (0-21 m in the section) is characterised by a moderate angle cross-bedding and the occurrence of *Nephrolepidina praemarginata*. Its upper part shows low-angle planar cross-stratification and an increasing amount of planktonic foraminifers. The therein investigated sample DE208 comes from a level 24 m above the base of the section (Fig. 2), where *Nephrolepidina morgani* was signaled only on the preliminary basis of not measured morphological features (Reuter et al., 2013).

Cerratina cherty Limestone (35 m): succession of horizontally bedded, bioturbated, fine bioclastic planktonic foraminiferal limestones, with subordinate echinoderms, bryozoan, radiolarians and siliceous sponge spicules.The first occurrence of *Praeorbulina* in Decontra section is in the uppermost part of the Cerratina cherty Limestone.

Bryozoan Limestone: 32m-thick succession of low angle planar cross-bedded bioclastic grainstones and packstones, dominated by bryozoans, echinoderms (i.e. ophiurids) and planktonic and benthic foraminifers in variable portions.

Orbulina Limestone: A third 3 m-thick interval of planktonic foraminiferal packstones and grainstones, with abundant *Orbulina*.

Lithothamnion Limestone (20 m): characterised by a 1.5 m-thick bioclastic *Heterostegina* grainstone with phosphatic grains at the base of this succession. It is followed by thick bedded corallinacean packstones, rudstones and floatstones. Corallinales algae are represented by branches and rhodoliths. Larger (mostly amphisteginids, some operculinids and heterosteginids) and smaller benthic foraminifers (*Elphidium*, rotalids), molluscs, bryozoans, echinoids, serpulids (*Ditrupa*) and brachiopods are associated.

3. STUDY METHODS

Nephrolepidina Douvillé, 1911 is a lepidocyclinid genus, characterised by a biconvex, lenticular calcareous hyaline test composed by chambers arranged in an equatorial layer between two distinct packs of lateral chamberlets. The megalospheric test consists of a bilocular nucleoconch with the protoconch partially enclosed by the subcircular to reniform deuteroconch, slightly larger than the protoconch (Fig. 3). The equatorial chambers are arcuate, ogival, rhombic or hexagonal and were considered as arranged in cyclic annuli. Recently, Benedetti (2014) evidenced the spiral growth of the neanic stage of *Nephrolepidina*. Consequently, the "annuli" are considered as "pseudo-annuli" in the present research.

3.1. Biometric study

The "Degree of enclosure" of the protoconch by the deuteroconch (Factor Ai of Van der Vlerk, 1959 a,b; 1963; 1964), the number of adauxiliary chambers AACII (Parameter C of Drooger and Freudenthal, 1964) and the diameters of the protoconch (DI) and the deuteroconch (DII), were measured on equatorial sections of the megalospheric specimens (Fig. 3). For a description of the biometric method and the techniques used to obtain the various measurements, reference is made to the above-mentioned papers and to De Mulder (1975). The

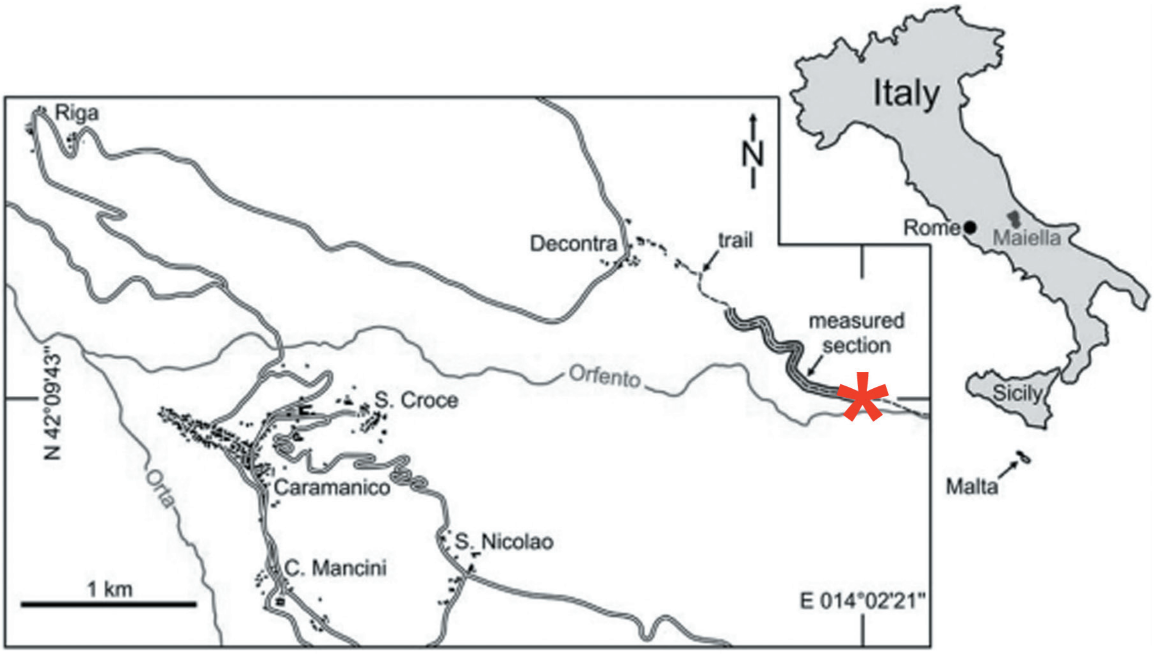

Fig. 1 - Location map of the outcrop (modified after Reuter et al., 2013).

diameters were measured including half thickness of the wall, to increase the number of comparisons with data in the literature. On the contrary, recently, Benedetti et al. (2010), and Benedetti and Pignatti (2012), measured DI and DII both considering and excluding the thickness of the wall, because there are evidences of environmental control on this feature (e.g., Beavington et al., 2004).

The neanic equatorial chambers in *Nephrolepidina* are commonly considered as arranged in concentric annuli, connected through annular, oblique and lateral stolons, without a canal system. Chaproniere (1980) and Schiavinotto (1992; 1994 a,b; 2010) investigated biometrically the arrangement of the neanic apparatus, i.e., the disposition of the chamberlets from the nepionic spirals to the periphery of the test. Chaproniere (1980) proposed a qualitative index, the "form number", to describe three main different types of growth.

Schiavinotto (1992), starting from some observations reported by Eames et al. (1962), evidenced the connection between the sequence of morphologies of the neanic equatorial chambers and the type of stolons as visible in the median plane of *Nephrolepidina*. The chamberlet shape varies from simple arcuate (not in lateral contact) and simple arcuate in lateral contact, to rhombic-ogival-exagonal. Subsequently, Adams (1987) confirmed the observations of Eames et al. (1962). The arrangement of the chambers is closely linked to the length of the common walls between contiguous chamberlets of the same cycle (or "annulus").

A greater extent of these walls is connected with a more distal position of the intercyclic stolons. Similar observations

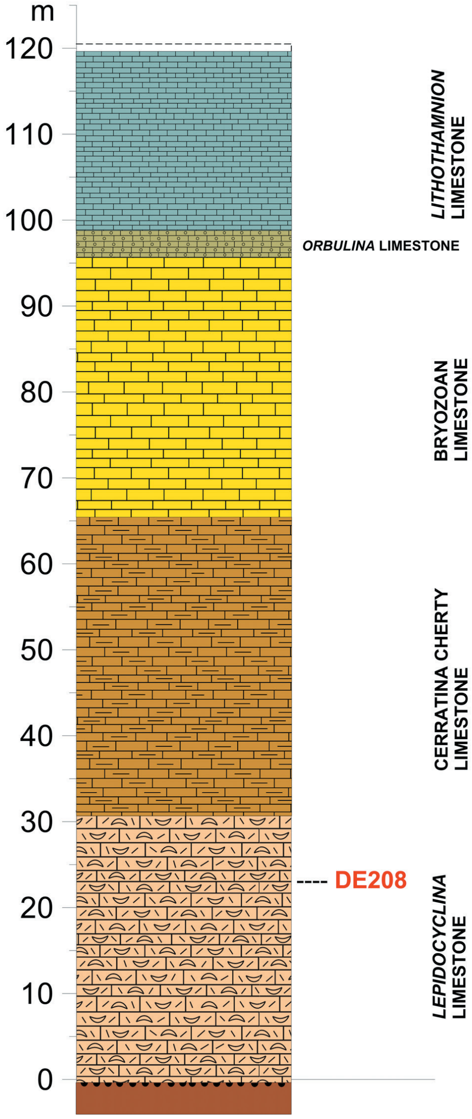

Fig. 2 - Simplified lithostratigraphic column of the sampled Decontra section. The position of the studied sample is indicated.

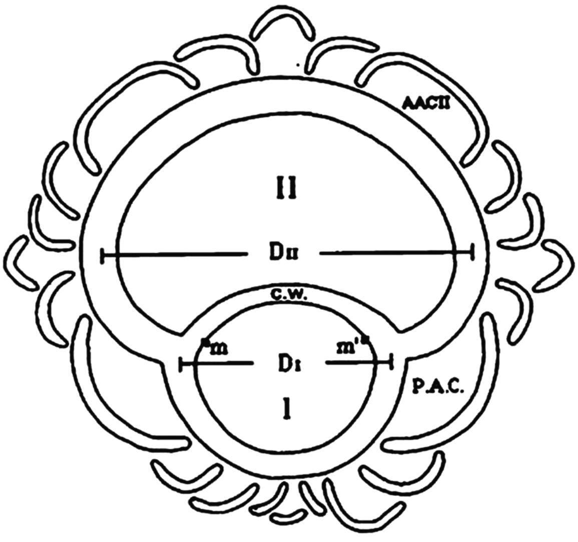

Fig. 3 - Schematic drawing of the internal features counted and measured on the horizontally sectioned embryonic-nepionic stage of megalospheric *Nephrolepidina*. I = protoconch; II = deuteroconch; PAC = principal auxiliary chamber; AACII = adauxiliary chamber.

were done on Cretaceous Orbitoidids (Van Gorsel, 1975; 1978). Consequently, Schiavinotto (1992), starting from the observations reported by Eames et al. (1962), introduced indexes of "stolonic distalization", measuring the tendency through time of the chambers to become more elongated, suggesting the statistical usefulness of the number of chamberlets in the fifth annulus, in each specimen. On the contrary, after the fifth annulus the growth becomes more irregular, possibly due to environmental factors (Schiavinotto, 2010).

Schiavinotto (1993; 1994) defined a "neanic acceleration" as the tendency to increase in time of the connections between the contiguous chambers (stolon system).

Recently, Benedetti (2014), suggested the concept of "Golden Selection", evidencing the spiral growth of the neanic chambers of *Nephrolepidina,* rather than annular-concentric and rephrased the neanic acceleration as the tendency through time of the equatorial chamberlets to achieve more efficient packing. This approach depicts a new fascinating path, but it is very difficult to follow proceeding on material coming only from thin sections of hard rocks; therefore, in this study the following measurements introduced by Schiavinotto (1992; 1993; 1994) are used (Fig. 4), related to the chamberlets belonging to the "pseudo-annuli":

c= "lateral length" of the common wall between contiguous chamberlets; since each chamberlet generally has unequal length of the two common walls with adjacent chamberlets, a mean value between the two measurements is calculated.

d= "protruding length" of the chamberlets, starting from the line joining the bases of the lateral walls; the front wall of the chamberlets is included.

h= "front height" of the chamberlets.

w= "front width" of the chamberlets, taken along the line connecting the distal ends of the common walls;

FD5= c/d x 100 = "Degree of Stolonic Distalization"; this factor is a quantitative expression of the "degree of crowding" of the chamberlets of a single cycle, according to the shape-growth relations described in Eames et al. (1962);

Re5= h/w x 100 = "curvature index of the front wall.

SI5= FD5/Re5 x 100 = "Shape Index" of the chamberlets.

n = number of annuli within 1mm distance measured from the deuteroconch along the axis of the embryo (introduced by Özcan et al., 2009 a,b; 2010). This counting may be considered a simplified method to express a neanic acceleration process and can be performed directly at the microscope.

Benedetti and Pignatti (2012), considering the difficulty to obtain specimens with a complete equatorial plane up to 1mm, adopted the new parameter N05 (number of annuli in a radius of 0.5 mm): it defines the number of annuli within 0.5 mm distance measured from the deuteroconch along the axis of the embryo.The authors, in addition, introduced parameter r5 (total height of the first five annuli) in defining the distance from the distal wall of the AACs on the deuteroconch and the fifth annulus along the axis of the embryo, connecting the centre of the protoconch and the centre of the deuteroconch.

The population DE208 was obtained from thin sections of hard rocks. In such a condition, the specimens show frequently an incomplete equatorial plane Consequently, to investigate the equatorial plane, a subdivision in 120° sectors may be suitable in few cases. Therefore, when it was unavoidable, the measurements were taken on the segments of the 5th annulus in a random well preserved area of the equatorial plane.

Also, in thin sections of hard rocks, incomplete annuli as described in Schiavinotto (2010) are difficult to be detected; in these cases, only a full, regular development of the visible chambers is a guarantee of reliable measurements, although Benedetti (2014) suggested that incomplete annuli are not growth anomalies, but they are due to the natural spiral pattern of growth of the equatorial plane of *Nephrolepidina,* reflecting the packing of the equatorial chamberlets.

Considering the time consuming peculiarity of the above described methodology, and the difficulty in obtaining complete "annuli" from thin sections of rocks, Benedetti et al. (2010), have taken these measures only for a single well-preserved chamberlet of the fifth "annulus", similarly to what is routinely used for Discocyclinids by Less (1987), that is in only one equatorial chamberlets at 0.5 mm from the embryonic chambers.

Picking only one representative chamberlet may be difficult and subjective, because the frequent irregular/asymmetric growth of the neanic equatorial chamberlets in *Nephrolepidina,* maybe related also to the pseudo-annular arrangement.

This simplified data collection was tested by Schiavinotto (2010), giving evidence that more reliable results are obtained measuring at least three chamberlets per pseudo-annulus, but also in the present case, only one-two chamberlets for some specimens were measured, because of the incomplete

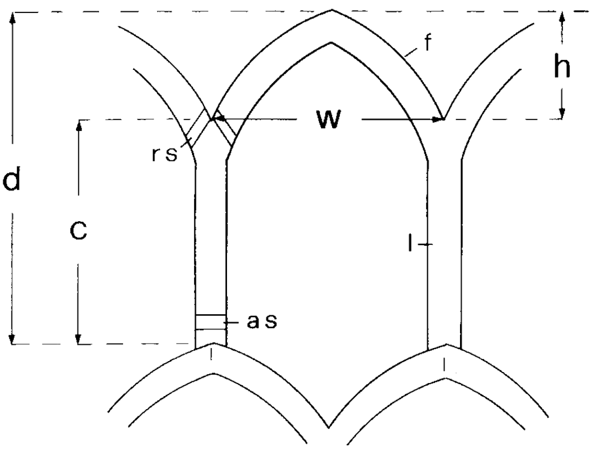

Fig. 4 - Schematic drawing of the internal features measured on the horizontally sectioned neanic equatorial chambers of *Nephrolepidina*. f = frontal wall; l = lateral (common) wall; rs = radial (intercyclic) stolons; as = annular (concyclic) stolons; c = lateral length; d = protruding length; h = front height; w = front width.

preservation of the neanic apparatuses.

The measurements were done on microphotographs, with the software Autocad, at an enlargement x 460.

The statistical comparison between the means of the variables obtained in the population DE208 and the data from the previous studies, was done by means of the Student's t-test. The normality of the distributions was checked by means of the Kolmogorov-Smirnov test (K-S), at a probability level P= 95%.

4. RESULTS

Results of counts and measurements are summarized in Table 1.

The data have quite normal distributions, considering the experimental values of the K-S test, all under the critical values. The "nephrolepidina-type" specimens (Ai between 40 and 45%) predominate in the populations(Pl. 1, Figs. 3, 4). The specimens with Ai below 40% are definitely subordinate, (Pl. 1, Figs. 1, 2). Large nucleoconchs tending towards the "trybliolepidina-type", with Ai above 50% (Pl. 1, Figs. 5, 6) are subordinate.

The specimens with a "degree of distalization" (FD5) around 50% (Fig. 5) are predominant. Specimens with rather primitive equatorial chambers (FD5 between 15 and 25%) are very rare. Specimens with FD5 around 60% have a good frequency, although they are subordinate.

5. DISCUSSION

5.1. Taxonomy

According to the phylogenetic classification of Lepidocyclinidae proposed by Sirotti (1982a, b), the investigated specimens belong to the genus *Nephrolepidina*. As yet, the Mediterranean *Nephrolepidina* species have been defined on the basis of the average values of the Factor Ai and the parameter C. According to De Mulder (1975) and Van Heck and Drooger (1984), the boundaries between the species are:

Nephrolepidina praemarginata
$35 < \bar{A}i \le 40\%$ and $1 < \bar{C} \le 3$
Nephrolepidina morgani
$40 < \bar{A}i \le 45$ and $3 < \bar{C} \le 5.25$
Nephrolepidina tournoueri
$45 < \bar{A}i$ and $\bar{C} > 5.25$

The population DE208, plotted in the $\bar{A}i$ - $\bar{C}$ scatter diagram of Fig. 6, based on Drooger and Rohling (1988) and including also additional data from Turkish populations (Özcan et al., 2009), fit well in the *N. morgani* field.

Following the chronospecies criteria of De Mulder (1975), the mean values of Ai and C are sufficient to refer the population DE208 to *N. morgani* (Lemoine *and* R. Douvillé, 1908), confirming the previous reports.

DE208 is far from *N. praemarginata* detected by Benedetti et al. (2010) in the S.Spirito formation, that are one of the most primitive *Nephrolepidina* populations found in Italy.

Population DE208	N	nc	CV	M	S	Sm	K-S	K-Sc
Factor Ai	32	-	31.82 - 56.89	43.28	5.90	1.04	0.111	0.284
Parameter C	28	-	2 - 8	4.10	1.50	0.28	0.228	0.250
DI	35	-	170 - 403	298.50	56.21	9.50	0.099	0.224
DII	35	-	244 - 713	432.50	105.00	17.75	0.089	0.224
Factor FD5	22	112	25.62 - 56.51	43.01	8.49	1.81	0.091	0.281
Factor Re5	22	112	30.69 - 65.66	42.32	8.27	1.76	0.130	0.281
Factor SI5	22	112	53.34 -166.40	111.53	34.24	7.30	0.097	0.281
Parameter n	12	-	15 - 20	17.25	1.66	0.47	0.191	0.375

Tab. 1 - Results of measurements on embryo-nepionic chambers and neanic equatorial chamberlets (5^{th} pseudo-annulus) in *Nephrolepidina* from Decontra. N= number of measured specimens; nc= total number of measured chamberlets; CV= range of the individual mean values; M= Mean value; S= Standard deviation; Sm= Standard error of the mean; K-S= Kolmogorov-Smirnov test; K-Sc= Kolmogorov-Smirnov critical value (95%).

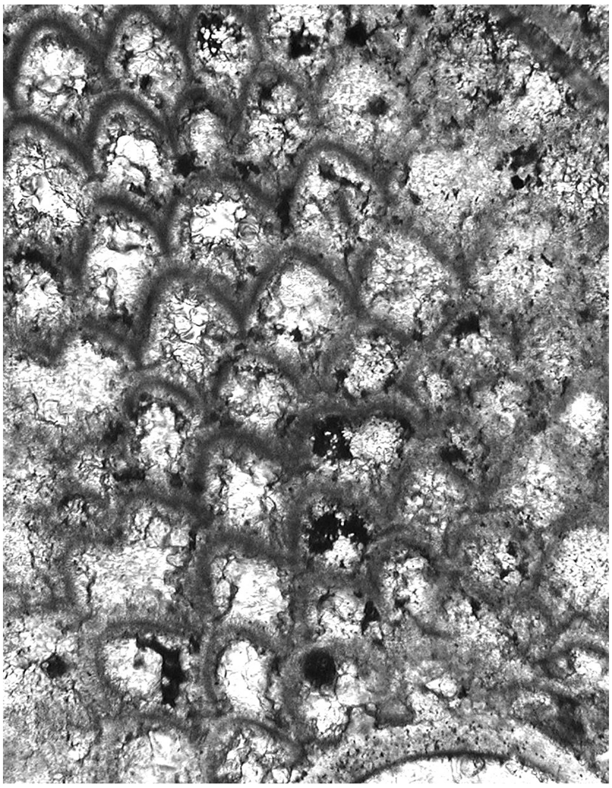

Fig. 5 - Ogival chambers with FD5 around 50%. Specimen DE208-29; x 200.

An extensive comparison with most of the data concerning the populations of *Nephrolepidina* in the literature was performed by inserting the data of DE208 in the Āi - C̄ scatter diagram in Fig. 6. The investigated population falls in the field of *N. morgani* at an intermediate stage of the embryo-nepionic evolutionary development, according to the principle of the "embryonic acceleration "(Drooger and Freudenthal, 1964) and of the "nepionic acceleration" (Tan Sin Hok, 1936 a,b; 1937 a,b).

In this field, many statistic comparisons with the populations already studied in the literature are possible without significant differences.

However, the evolutionary stage of DE208 is quite high both for Āi and C̄, enough to result without significant differences when compared with some popolations from Turkey, as KIR, HAC2-4, HAC6-8, referred to *N.* ex.interc. *morgani-tournoueri* and *N. tournoueri-morgani* (Özcan et al., 2009). Populations in Özcan et al. (2010), referred to the new species *N. musensis*, are significantly more primitive only for C.

N. praemarginata populations from Majella (S. Spirito Formation) studied by Benedetti et al. (2010) and from Sicily (Benedetti and Pignatti, 2012), are at a very low evolutionary stage and very significant differences result from comparisons with DE208 population.

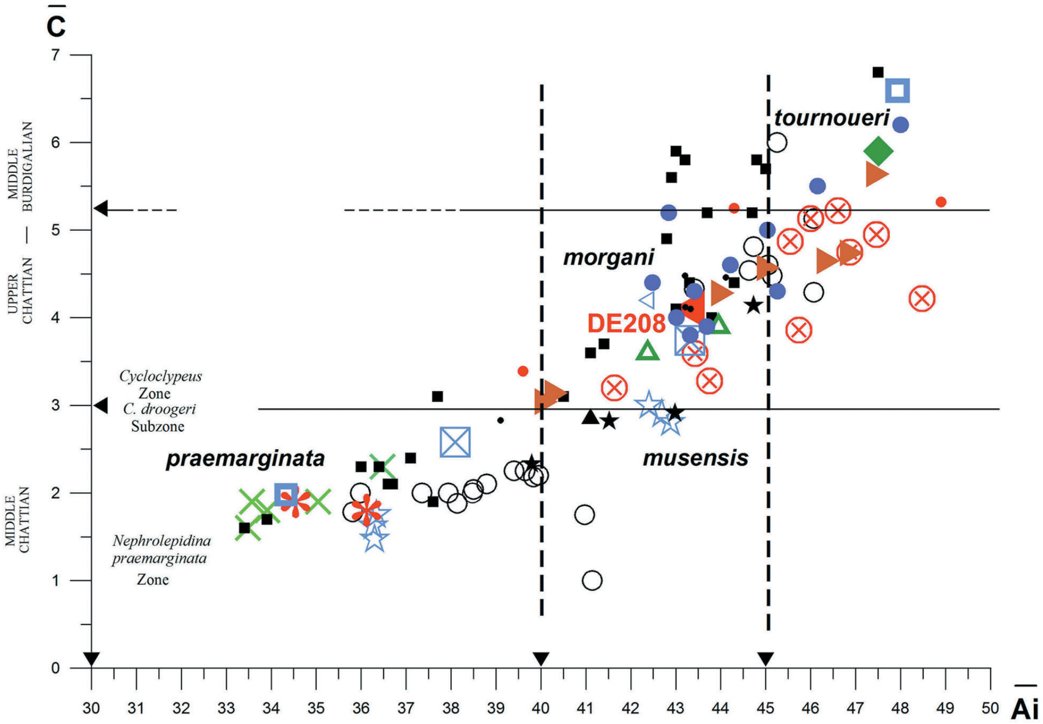

Fig. 6 - Āi - C̄ scatter diagram for a significant part of the available data on the Mediterranean *Nephrolepidina* populations: ■= Greece,De Mulder, 1975; ▲= Piedmont, Meulenkamp and Amato, 1972; □= northern Italy CVM76 - Monte La Serra TLS76, Schiavinotto, 1978, 1979; = Monte La Rocca TRMn-T1, Matteucci and Schiavinotto, 1977; ◆= Sardinia AC5, Giovagnoli and Schiavinotto, 1990; ★) northern Italy, Matsumaru, 1971; ◁= northern Italy, Serpagli and Sirotti, 1966; ●= Sicily, Wildenborg, 1991; ●= Gran Sasso, Schiavinotto and Verrubbi, 1994a; ▶= Monte Torretta PMT, Giovagnoli and Schiavinotto, 1995; ●= Monte Torretta PMT, Giannini et al., 2007; ○= western Taurids, Ozcan et al., 2009a; ⊗= Sivas basin-central Turkey, Ozcan et al., 2009b; ☆= eastern Turkey, Ozcan et al., 2010; ×= Sicily, Benedetti and Pignatti, 2012; ✻= Majella, Benedetti et al., 2010; △= northern Italy LND, Schiavinotto, 2010; ◀= Majella DE208, present work.

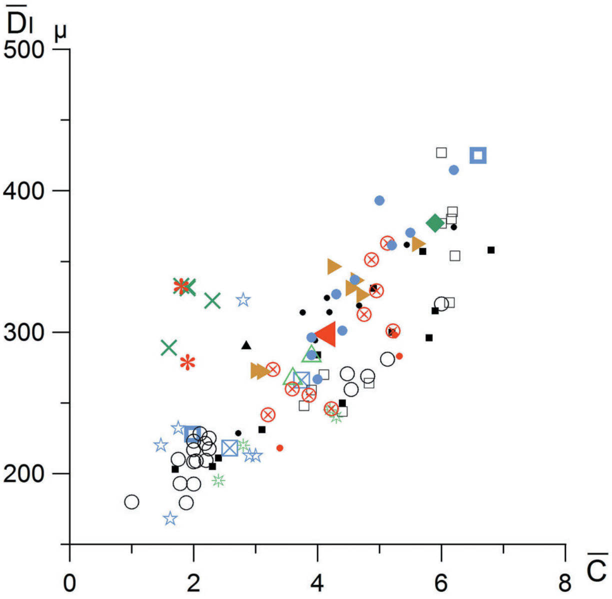

Fig. 7 - $\bar{C}$ - $\overline{DI}$ scatter diagram. DE208 population is plotted into the field of mean values obtained from the previous literature. □=Drooger and Freudenthal, 1964; ✻= Piedmont, Vervloet, 1966; other symbols as in figure 6.

5.1.1. Embryo-size

The insertion of the data of Decontra in the $\bar{C}$ - $\overline{DI}$ and $\overline{DI}$ - $\overline{DII}$ scatter diagrams (Fig. 7 and Fig. 8) (see also De Mulder, 1975; Van Heck and Drooger, 1984; Schiavinotto, 2010) gives an immediate comparison with the embryo sizes of a great part of the Mediterranean material.

The mean values of the absolute dimensions of the embryonic apparatus in DE208 are among the mean values of those related to the same embryo-nepionic evolutionary degree.

5.1.1.1. Neanic acceleration

The scatter diagram $\overline{FD5}$ - $\overline{SI5}$ in Fig. 9 might be a significant representation of the trend that is defined as "Neanic Acceleration". The value of DE208 is plotted keeping the high correlation between the mean values of the two variables.

It is also of particular interest that the mean values of FD5 and SI5 of DE208 are closer to the mean values regarding the T1 population, still showing a wide gap of values between the DE208 population and the TLS76, AC5 populations. These results evidence that the herein investigated *Nephrolepidina* can be differentiated from the more primitive and from the more evoluted stages of *Nephrolepidina*, at the level of the studied ontogenetic stage (5th pseudo-annulus), on the basis of the "Degree of Stolonic Distalization" and of the "Shape Index". This discrimination is much more marked than those obtained between populations of *N. tournoueri* (Schiavinotto, 1992), and between populations of *N. praemarginata* (Schiavinotto, 1994).

Therefore, the variations of the parameters/factors, as a whole, evidence the following tendencies in the changes of the morphology of neanic equatorial chamberlets in *Nephrolepidina*:

- increase of the degree of elongation;
- increase of the lateral length "c" of the common wall between contiguous chambers;
- consequent increase of the "Degree of Stolonic Distalization";
- increase of the "Shape Index", tending to more elongated chambers with smaller degree of curvature of the frontal wall.

So, the data obtained on the "Degree of Stolonic Distalization" in *Nephrolepidina* from Decontra provide another quantitative definition of the ontogenetic development already described qualitatively by Grimsdale (1959), Eames et al. (1962), Sirotti (1982 a,b) and Adams (1987) for *Nephrolepidina*, and by Van Gorsel (1975; 1978) for *Orbitoides* and *Lepidorbitoides*. In fact, the distal end of the common wall between contiguous chamberlets fits with the position of the radial (intercyclic) stolons; the more this wall is developed, the greater also is the distance of the annular (concyclic) stolons from the proximal end of the common walls (Eames et al., 1962; Adams, 1987). The Factor SI5 confirms the progressive weakening of the initially pointed-arcuated characteristic of the front wall, which can be connected with a more distal position and a less radial trend of the intercyclic radial stolons; consequently, the morphological differences between chamberlets of successive psedo-annuli are emphasized.

The $\bar{A}i$ - $\overline{FD5}$ and $\bar{C}$ - $\overline{FD5}$ scatter diagrams (Fig. 10 and Fig. 11) show that DE208 population are arranged in agree with the previously detected trends towards higher values.

5.1.1.1.1. Biostratigraphic remarks. The lower part of the *Lepidocyclina* Limestone was ascribed by Reuter et al. (2013) and Auer et al. (2015) to the late Rupelian to Chattian age (SBZ22–lowermost SBZ23 of Cahuzac and Poignant, 1997) on the basis of the occurrence of *Nephrolepidina*

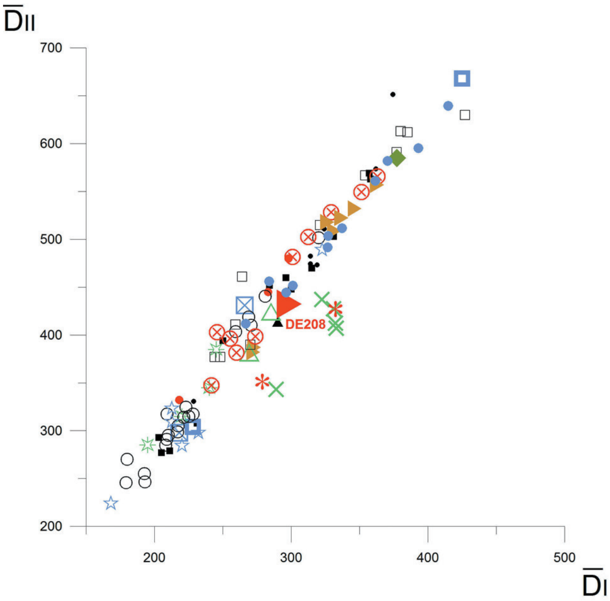

Fig. 8 - $\overline{DI}$ - $\overline{DII}$ scatter diagram. DE208 is plotted with mean values from the literature. Symbols as in Fig. 6 and 7.

praemarginata, following Benedetti et al. (2010), which suggest a late Rupelian age (SBZ22A of Cahuzac and Poignant, 1997) for two samples coming from about 15 m and 17 m of the Santo Spirito Formation (Santa Croce section, Caramanico), according to the biometric analysis of *Nephrolepidina*. However, caution is needed for the above mentioned age assignment to the lower part of the *Lepidocyclina* Limestone in Decontra section, because it is still without a biometrical support.

A Chattian to early Burdigalian age (SBZ22B-lower SBZ25) was assigned to the top of the *Lepidocyclina* Limestone by *Nephrolepidina morgani*, according to the preliminary morphological studies (Reuter et al., 2013). This constrained the age for the upper part of the *Lepidocyclina* Limestone to late Chattian-early Miocene (upper SBZ23-lower SBZ25).

The previous Chattian age of this part of the Bolognano formation can be better specified on the basis of the biometric data obtained here.

The high statistical similarity of $\bar{A}i$ and $\bar{C}$ in DE208 with other known populations such as T1 from Mt. La Rocca (Matteucci and Schiavinotto, 1977; 1985) and LND88, LND77 from Lonedo (Schiavinotto, 2010), is reasonably valuable to assign DE208 to the same biostratigraphical indications reported in Schiavinotto (2010), concluding with a correlation with the SBZ23 Biozone of Chauzac and Poignant (1997) and to the *Miogypsinoides complanatus* Subzone, with a possible correlation with the middle part of

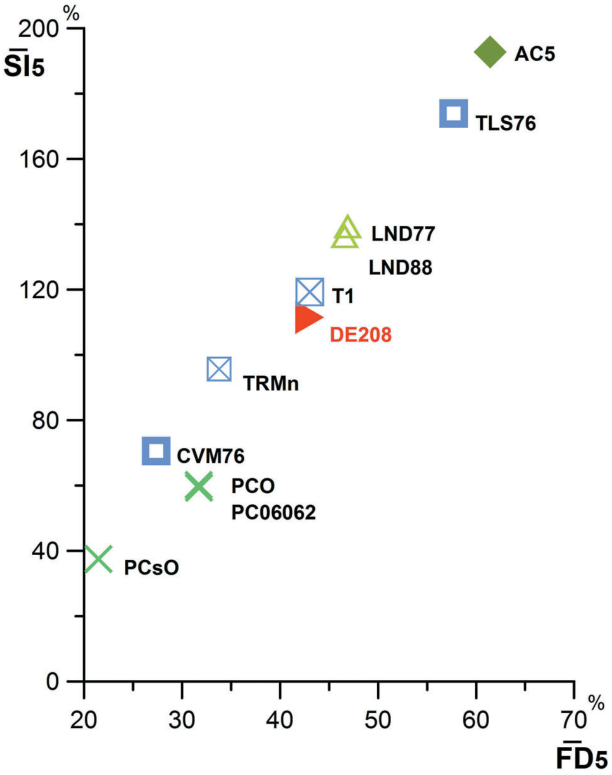

Fig. 9 - $\overline{FD}5$ - $\overline{SI}5$ scatter diagram for the *Nephrolepidina* populations studied to date. Mean values after Schiavinotto (1992; 1993; 1994; 2010), Benedetti and Pignatti (2012) and Benedetti (pers. com.).

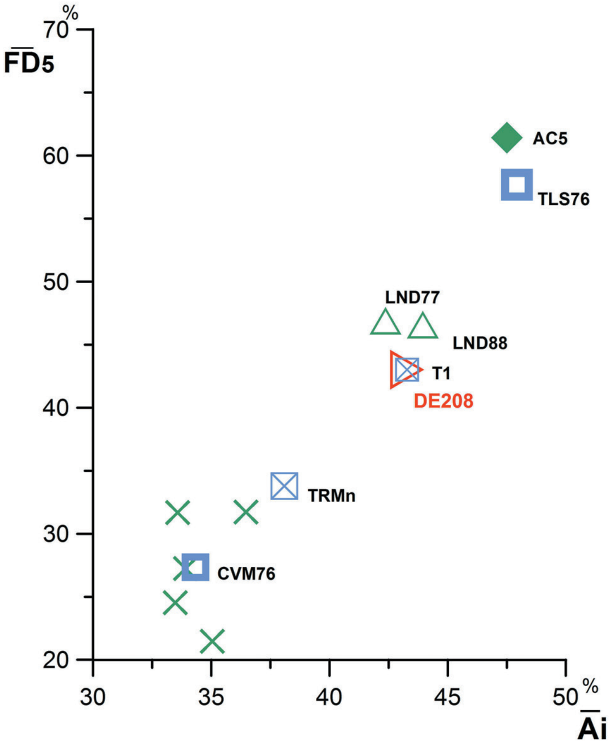

Fig. 10 - $\bar{A}i$ - $\overline{FD}5$ scatter diagram for the *Nephrolepidina* populations studied to date. Mean values after Schiavinotto (1992; 1993; 1994; 2010), Benedetti and Pignatti (2012).

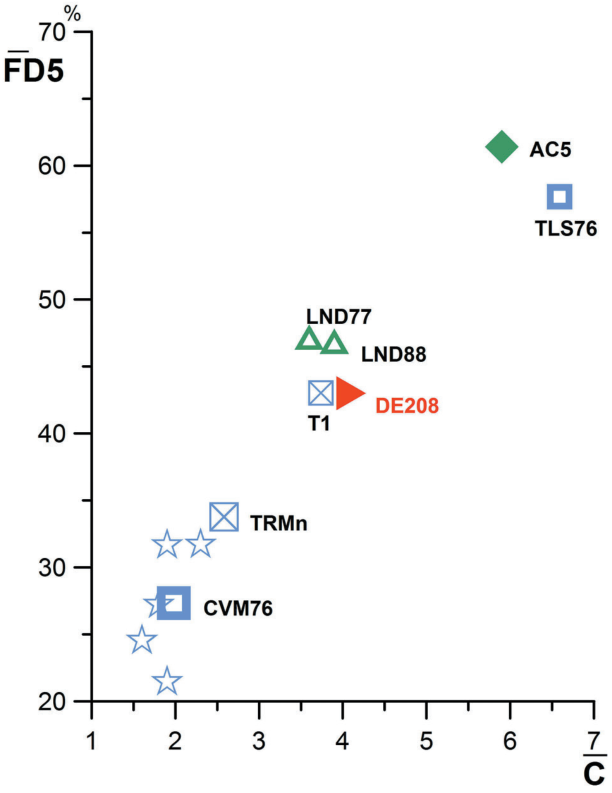

Fig. 11 - $\bar{C}$ - $\overline{FD}5$ scatter diagram for the *Nephrolepidina* populations studied to date. Mean values after Schiavinotto (1992; 1993; 1994; 2010), Benedetti and Pignatti (2012).

the *G. ciperoensis* Zone (P22/N3) (middle-upper Chattian), according to the biostratigraphic scheme of Drooger and Laagland (1986) revised by Laagland (1990).

Nephrolepidina morgani from Turkey, quite ex.interc. with *N. tournoueri* have a wide age reference: according to Özcan et al. (2009; 2010), *N. morgani* has a long stratigraphic range from the late Chattian to the early Burdigalian (SBZ 23 to the early part of SBZ 25) while *N. tournoueri* spans from the latest Aquitanian to the whole Burdigalian (late SBZ 24 and SBZ 25).

Also, Özcan et al. (2009), about difficulties in discriminating *N. morgani* from *N. tournoueri*, evidence "a clear contradiction to de Mulder's suggestion of adopting the morphometric limits of both parameters to differentiate the two taxa". This is a long-time taxonomic problem, affecting also the biostratigraphic field. Perhaps, it might be solved with modifications near to what is suggested in Schiavinotto (1996b).

The population DE208 from Decontra has not associated Miogypsinids. This, if not related to environmental factors, can reinforce its assignment to late Chattian. Consequently, according to all the collected data, it seems useful to focus the attention on the neanic features, in order to be able to identify a new basis for a possible implementation of the biostratigraphic resolution of *Nephrolepidina*.

The new biometric measurements of the neanic chambers on the equatorial layer of the *Nephrolepidina* test gave rather encouraging first results and allowed to hypothesize an evolutionary process based on a "Neanic Acceleration", with a progression of the mean values of the parameters and factors at any rate in agreement with their stratigraphic sequence.

6. CONCLUSIONS

This investigation of embryo-nepionic features of the lepidocyclinid genus *Nephrolepidina* confirms an evolutionary trend according to the embryonic and nepionic acceleration, allowing to refer the DE208 population from Decontra to the species *N. morgani*, at an evolutionary stage very near to the *N. morgani* - *N. tournoueri* transition.

The previous Chattian age of the upper part of the *Lepidocyclina* Limestone of the Bolognano formation is better specified on the basis of the biometric data herein obtained, assigning the sample to SBZ23 Biozone of Cahuzac and Poignant (1997).

The neanic data obtained provide a new confirm to the "Neanic acceleration". However, the spiral growth of the equatorial chambers, recently evidenced by Benedetti (2014), suggests at the moment some changes in the terminology and the need of further developments in the biometrical approach.

On the basis of the data obtained here, the "Degree of Stolonic Distalization" (FD5) is confirmed to be the most significant factor.

The mean values of the Factor FD5, integrated with the Factor SI5 ("Shape Index") appear useful for taxonomic purposes: the data obtained here confirm what is suggested by Schiavinotto (2010), i.e.: in the *Nephrolepidina* populations, classified on the basis of the mean values of embryo-nepionic features, a further distinction can be made on the basis of the mean values of neanic features, mainly at the level of the intermediate species *N. morgani*. Consequently, it seems that the present specific/biostratigraphic definition of the Mediterranean *Nephrolepidina* lineage could be improved by supplementing the embryonic and nepionic data with the neanic morphometric data, in order to be able to detect especially the Oligocene/Miocene boundary. Further researches on the "Neanic Acceleration" process in the evolution of *Nephrolepidina* are encouraged.

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PLATE

Variability of the embryonic-nepionic chambers in equatorial sections of *Nephrolepidina* from Decontra, Sample DE208.

1 - Low values of Ai and C. Specimen DE208-8, x 120.

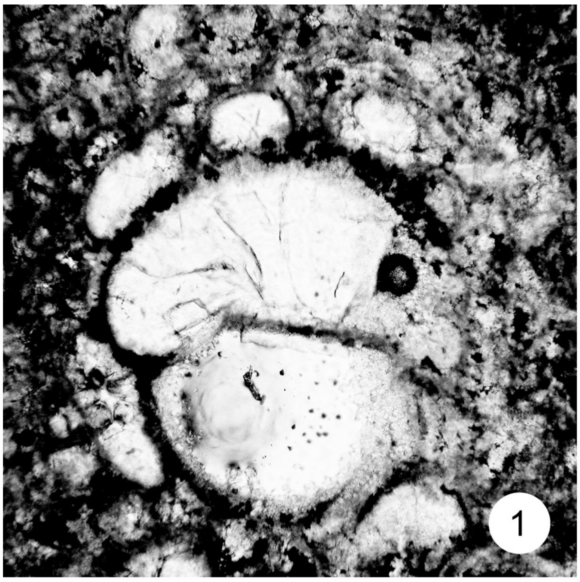
2 - Low values of Ai and C. Specimen DE208-21, x 120.

3 - Intermediate values of Ai and C. Specimen DE208-35, x 80.

4 - Intermediate values of Ai and C. Specimen DE208-10, x 90.

5 - High values of Ai and C. Specimen DE208-27, x 90.

6 - High values of Ai and C. Specimen DE208 -12, x 90.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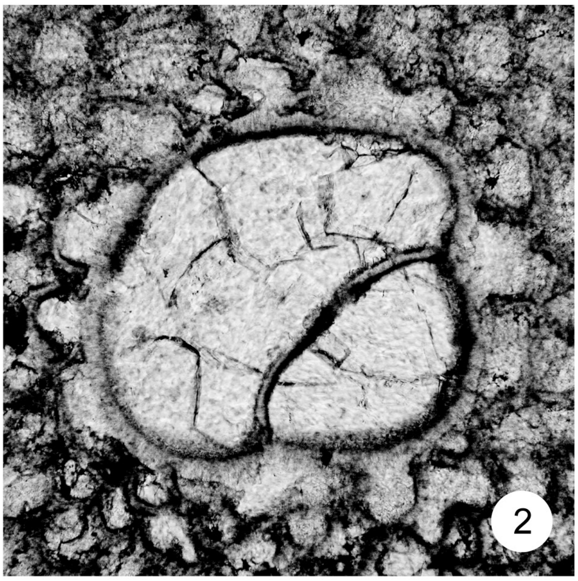
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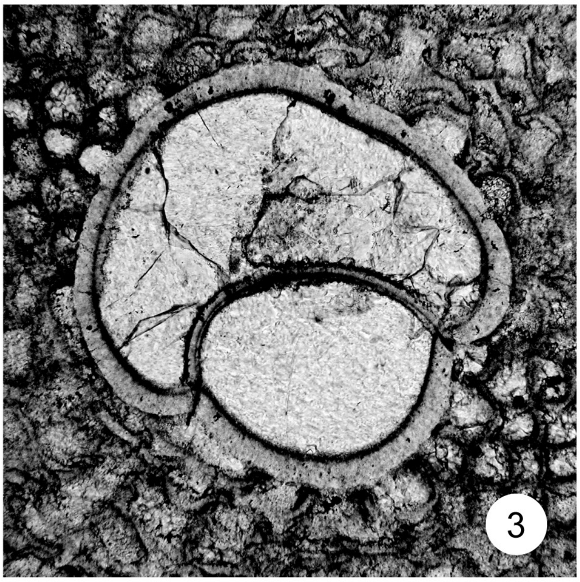
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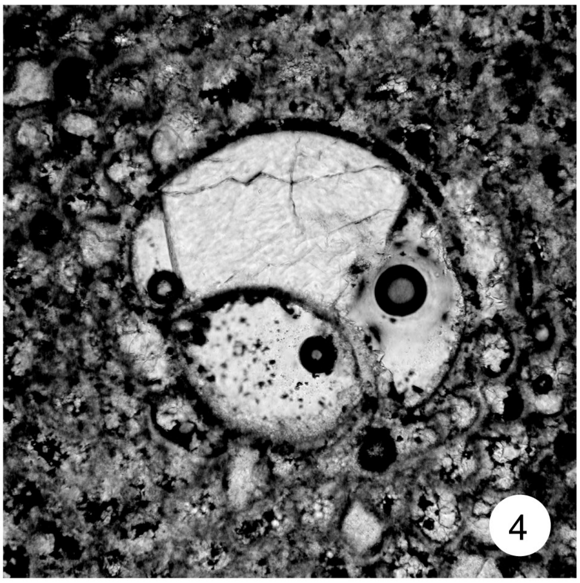
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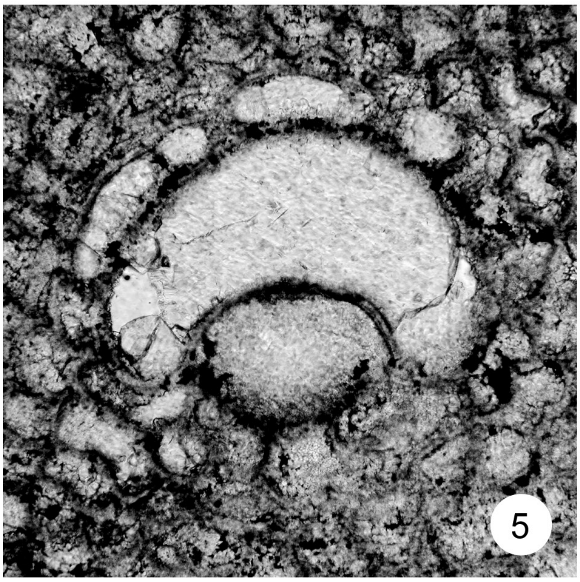
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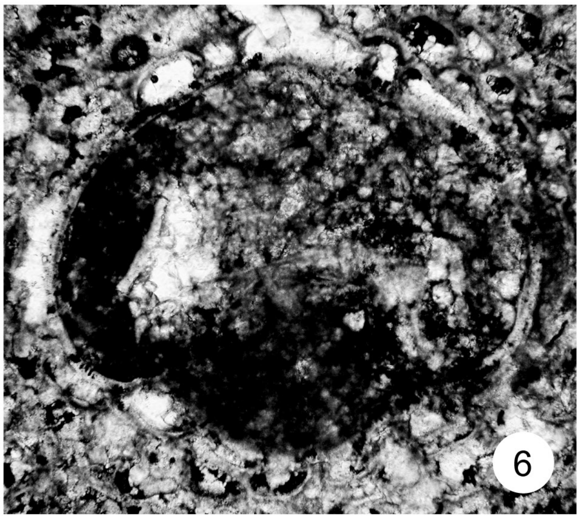
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