

***Nephrolepidina* and unispiralled *Miogypsina* from the Oligo-Miocene toe-of-slope succession of Gran Sasso (L'Aquila, Central Apennines - Italy): biometric and evolutionary remarks**

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ABSTRACT: A biometric analysis was performed on twelve *Nephrolepidina* and ten *Miogypsina* and *Miogypsinoidea* populations, coming from the Tre Valloni section, an Oligo-Miocene calcarenitic toe-of-slope succession outcropping in the southern sector of Gran Sasso (L'Aquila, Central Apennines - Italy). *Miogypsina* populations are investigated applying two essential parameters, i.e., the number of the nepionic chambers and the protoconch diameter. Previously detected evidences of reworking in the same material suggested to use some cautions to avoid misleading results. A mixed typological-statistical methodology is used, leading from starting "disordered" assemblages to final "virtual but reliable" populations, cleaned up from reworked specimens, in order to implement the accuracy of the biostratigraphic results. This goal is reached for the lower part of the succession only. According to the biometric limits proposed for the various chronospecies in the recent literature, the resulting populations are referred to *Miogypsinoidea* ex. interc. *complanatus-formosensis* up to *Md. bantamensis*, and to *Miogypsina basraensis* up to *M. ex. interc. gunteri-tani*. This sequence of taxa, in general, is in agreement with the principle of nepionic acceleration, with a progressive reduction in the average number of nepionic chambers (X), arranged in a single spiral, just peculiar in the more primitive populations. *Miogypsinoidea bantamensis* and *Miogypsina basraensis* are recognized biometrically for the first time in the Central Apennines.

Nephrolepidina populations are investigated applying the recently introduced biometry 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. The biometric analysis of the embryo-nepionic stages was performed as an integration of the data obtained in a previous study, excluding the uppermost samples in which *Nephrolepidina* is clearly reworked, being characterized by primitive morphology, i.e., almost isolepidine embryo, few adauxiliary chamberlets, and ogival equatorial chamberlets.

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

Unispiralled *Miogypsina*, associated with *Nephrolepidina* at an advanced evolutionary stage, suggest a continuous reworking of primitive miogypsinids, without an involvement of more evolute bispiralled forms.

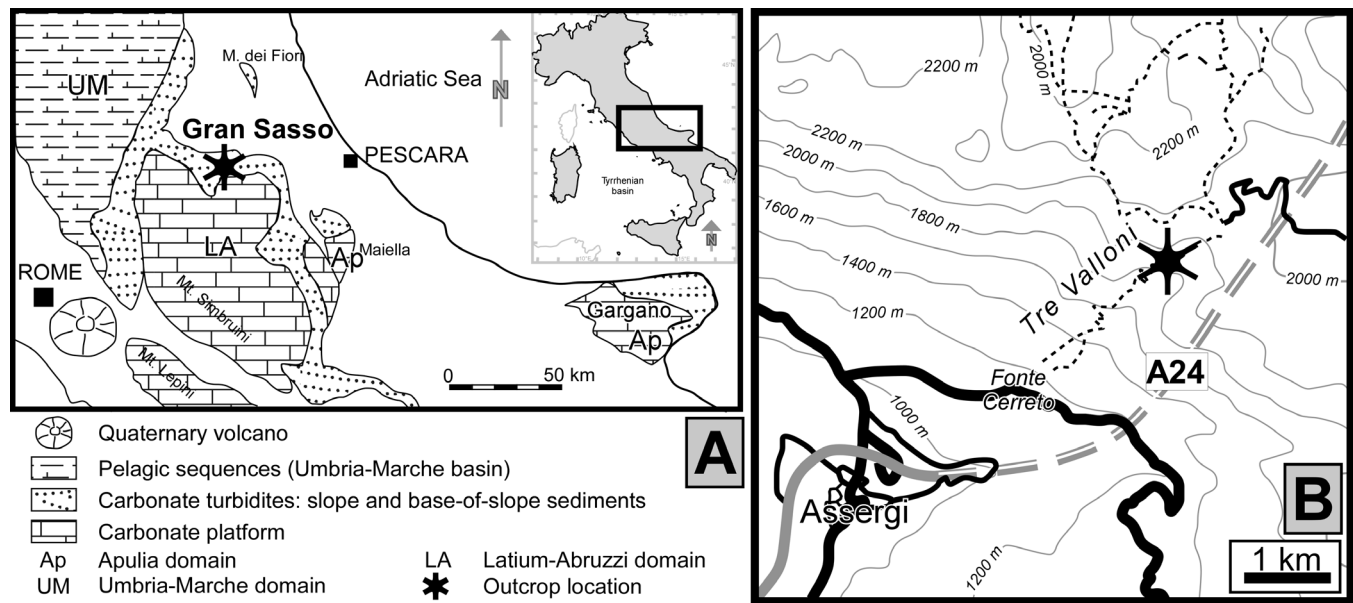
The biostratigraphic assessment of the Venacquaro and Glauconitic Calcarenite formations is improved, assigning the Venacquaro Formation to the Chattian-lowermost Aquitanian (SBZ22B-basal SBZ24) and the base of the Glauconitic Calcatenite to the Aquitanian (SBZ24 p. p.). The investigated sedimentary succession was deposited along a slope to toe of slope characterized by a mixture of taxa displaced from shallow-water environments and reworked primitive specimens eroded along channels.

Key words: *Nephrolepidina*, *Miogypsina*, biometry, Oligocene, Miocene, Gran Sasso

INTRODUCTION

Larger benthic foraminifera (LBF) are generally abundant in neritic facies (e.g., Hottinger 1997) and have high biostratigraphic potential (Cahuzac and Poignant 1997; Serra-Kiel et al. 1998). Their study is particularly pivotal to date Paleogene to lower Neogene carbonate successions, although their application is usually hampered by the necessity to investigate oriented sections of a statistical number of individuals (e.g., Drooger 1993). Oligocene to lower Miocene sedimentary successions, outcropping in the areas near the margins of the Mesozoic carbonate shelf in Latium and Abruzzo (Central Apennines) are characterized by the occurrence of Lepidocyclinidae and Miogypsinidae (Renz 1951; Matteucci and

Schiavinotto 1978; Schiavinotto 1979) that, due to their evolutionary trends through time, lead to biostratigraphic definition of stratigraphic biozones (or sub-biozones) within the scheme of Cahuzac and Poignant (1997). Anyway, continuous Oligocene-Lower Miocene sequences are very rare in these areas that acts as transitional zones between Latium-Abruzzi and Umbria-Marche tectonostratigraphic domains (Parotto and Pratlun 1975; Centamore et al. 2002). Miogypsinids and Lepidocyclinids are however generally well-documented from Oligocene-Lower Miocene sedimentary successions of Central Italy (Delicati and Schiavinotto 1985; Giovagnoli and Schiavinotto 1995; Benedetti et al. 2010; Schiavinotto 2015; 2016), that can reach thicknesses of hundred meters.



TEXT-FIGURE 1

Schematic geological map of the main carbonate platforms and pelagic domains of Central Italy (after van Konijnenburg et al. 1999), and location of the investigated section at Tre Valloni, Gran Sasso.

In the last few years, biometric studies of statistical populations of these LBF have been lead off, with the aim to increase our knowledge about their evolutionary trends and their biostratigraphic potential. A large amount of data exists about the biometry of *Miogypsinids* from the whole Mediterranean area, including both Northern and Southern Italy (Drooger and Freudenthal 1964; Serpagli and Sirotti 1966; Schüttenhelm 1976; Wildenborg 1991; Ferrandini et al. 2010), but very few works have been carried out on the *Miogypsinidae* from Central Italy (Pieroni 1965; Schiavinotto 1979; Delicati and Schiavinotto 1985; Brandano et al. 2007). Therefore, in this area, only a part of the phylogenetic development achieved by this group in the Mediterranean Tethys has been identified, with still no information on whether some forms belonging to the phyletic line of *Miogypsinoides* and the more primitive forms belonging to *Miogypsina*, were present or not.

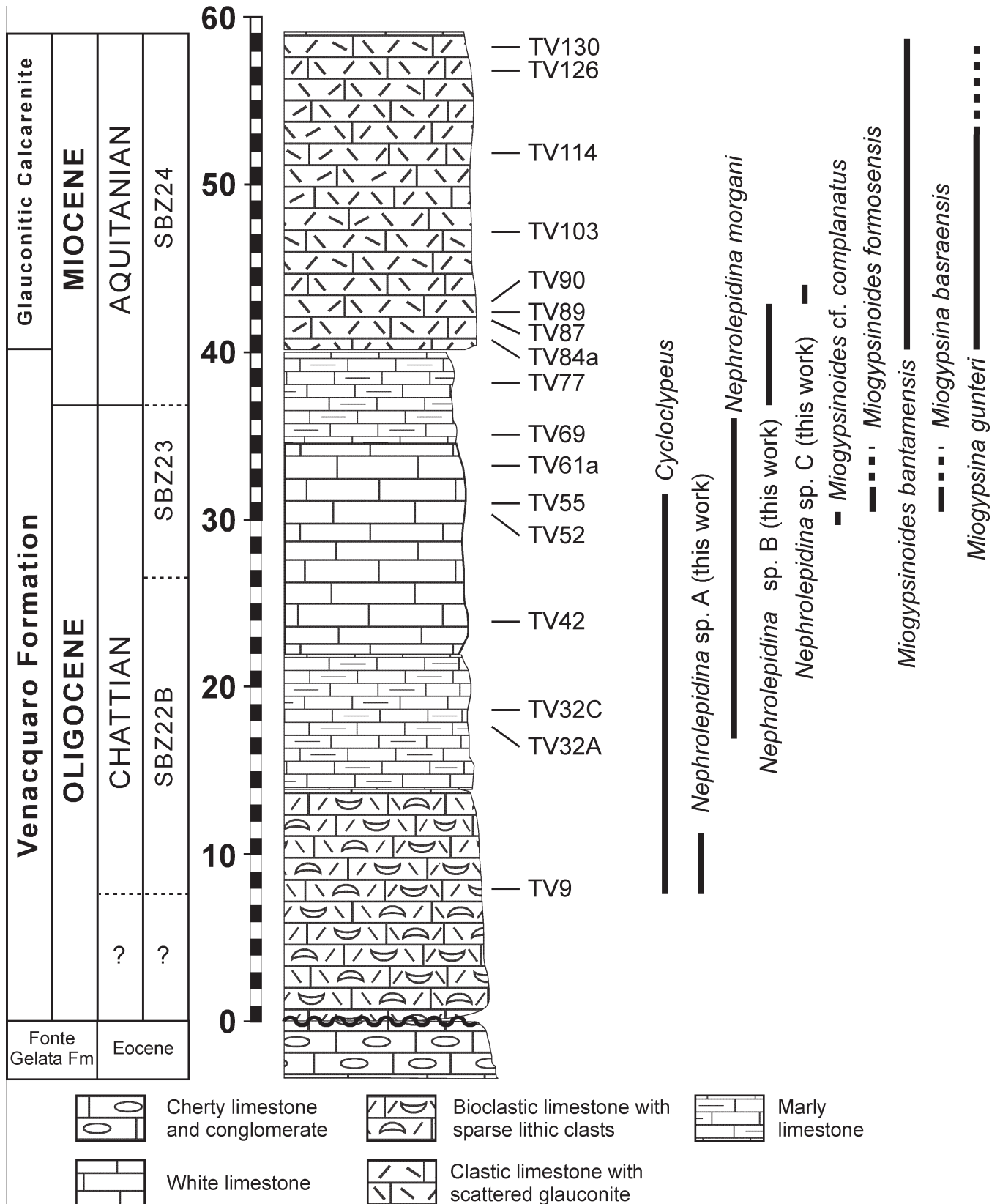
As above mentioned, the low number of biometric analysis of *Miogypsinids* and *Lepidocyclinids* in Central Italy is mainly due to their occurrence mostly in hard rocks, that is an unfavorable and time-consuming condition to obtain well-oriented thin sections to carry out biometric analyses for populations composed by a statistically consistent number of individuals. In addition, in the investigated area, LBF, belonging to Oligocene-Miocene sedimentary successions, were frequently displaced by turbiditic flows into a base-of-slope environment, variably far from the shallow-water source of the populations, that could be altered by reworking. Consequently, the researchers are discouraged to face investigations that appear a priori both time-consuming and with uncertain results.

Previous biometric studies on *Nephrolepidina* populations from the Gran Sasso belt (Schiavinotto and Verrubbi 1994a; 1994b; 2000) were performed still with the uncertainty about the sig-

nificance of the reworking, nevertheless providing results that currently, albeit at a distance of more than twenty years, are not as yet outdated and, on the contrary, have brought forward (even though not cited) some conclusions that were refined and reported in papers published years later (van Konijnenburg et al. 1998; 1999; Cardello and Doglioni 2015).

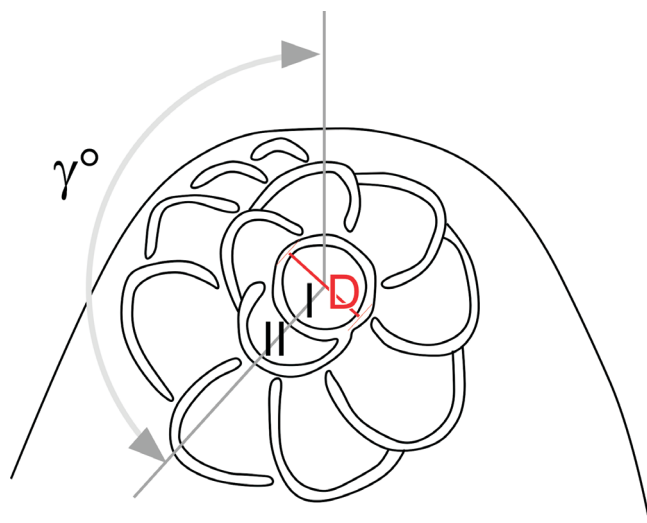
The biostratigraphic definition of the Oligocene-Miocene formations from Gran Sasso suffers the lacking of detailed micropaleontological study. Consequently, the main goal of this paper is to add some contributions to refine this knowledge. Therefore, a more refined biometric analysis of ten *Miogypsina* and twelve *Nephrolepidina* populations, coming from the same samples studied by Schiavinotto and Verrubbi (1994b), is carried out in the present work, with the following aims:

- a) to overcome the reworking, obtaining reliable populations from rough, non homogeneous assemblages, and to provide new biostratigraphic constraints for the investigated succession by means of LBF;
- b) to investigate the possible presence in the Central Apennines of *miogypsinids* with a low evolutionary degree which, to date, have as yet never been identified on a biometric basis;
- c) to obtain additional data about the evolutionary trend and biostratigraphic meaning of the neanic chamberlets in *Nephrolepidina*, previously investigated by Schiavinotto and Verrubbi (1994a; 1994b; 2000) on the base of embryo-nepionic acceleration;
- d) to increase the biostratigraphic potential of Mediterranean *Nephrolepidina* integrating embryonic data with statistical in-



TEXT-FIGURE 2

a) Measured stratigraphic section of Tre Valloni outcrop and location of investigated samples; b) vertical distribution of larger foraminifera as discussed in the text.



TEXT-FIGURE 3

Schematic drawing of the embryonic and nepionic chambers of *Miogypsinidae* in equatorial section showing a single spiral consisting of 11 chambers (parameter X, excluding the two embryonic chambers). I=protoconch, II=deutoconch. γ° =angle formed by the line conjoining the centres of the two embryonic chambers and the line passing to the centre of protoconch and the apical front of the test.

vestigation of the shape of the equatorial chamberlets (i.e., neanic acceleration);

e) to provide a possible depositional scenario for the as yet poorly known Venacquaro and Glauconitic Calcarene Formations.

REGIONAL GEOLOGICAL AND STRATIGRAPHICAL SETTING

As summarized by Cardello and Doglioni (2015), the Gran Sasso belt (Central Apennines) is an area characterized by the geodynamic evolution of a Triassic carbonatic platform extending along the passive edge of the expanding Tethys. The different evolutionary stages of the primitive Triassic platform were determined mostly by tectonics, the variation of the growth potential of the carbonatic platform and its edges, and the sea-level changes on a global scale (Vail et al. 1977; Vail and Hardenbol 1979; Haq et al. 1988).

The Cenozoic orogenic crisis, connected to the closing of the Tethys, leads to the emersion and a gradual disarticulation of the whole carbonatic units, with folds and overthrusts with E and NE vergence (Accordi 1963; 1966; Parotto and Pratlurion 1975). An open neritic platform developed with organogenous formations that are transgressive on a large part of the Cretaceous platform. These sedimentary complexes can be subdivided in platform, edge, slope, basin, characterized by associations of recurrent lithotypes, which alternate and are repeated in various patterns in relation to the evolution of the area (Accordi et al. 1988).

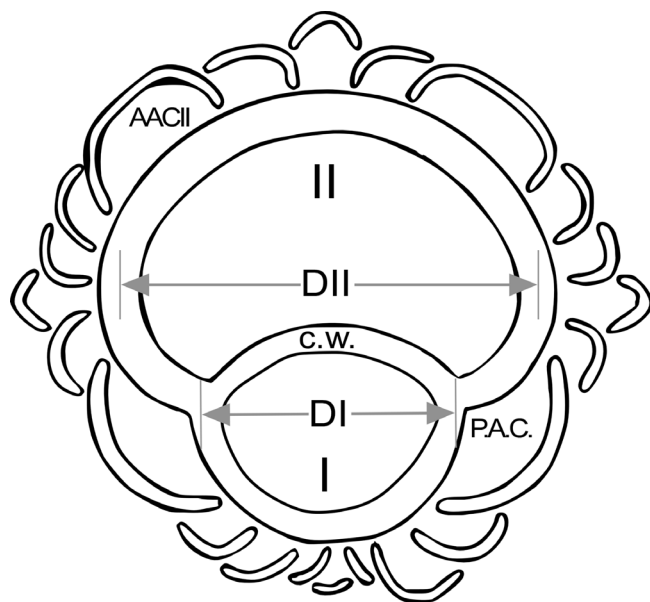
The Tertiary rocks at the edges of the L'Aquila plain, up to the Gran Sasso belt, show numerous local variations. The contacts

between Cenozoic sequences and the underlying Mesozoic rocks are lacunose and transgressive. Consequently, it is quite difficult to reconstruct the sedimentary events which anticipated the more general transgression that occurred during the Middle Miocene. The overlying basinal succession (upper Liassic-Middle Miocene) is constituted by prevailing carbonate and marly deposits. The mass-flow input of reworked shallow-water sediments documents marked progradation of the slope during Middle-Late Jurassic, Cenomanian, and late Paleocene-Middle Eocene (e.g., van Konijnenburg et al. 1999; Adamoli et al. 2012).

According to van Konijnenburg (1997), in the Gran Sasso area, Cretaceous to lower Cenozoic pelagic and displaced neritic carbonate sediments were deposited along the base-of-slope separating the Latium-Abruzzi carbonate platform (to the southwest) and the Maiella platform margin (to the south) from the Umbria-Marche basin to the north. Three major facies types were distinguished: (1) breccias and megabreccias, containing a large variety of platform- and slope-derived lithoclasts and minor skeletal fragments, originating from the collapse of platform margin areas; (2) turbidite beds, with mainly skeletal fragments and minor amounts of smaller lithoclasts shed from the nearby platforms; and (3) pelagic foraminiferal lime mud- and wackestones. Changes in facies associations were related to different sedimentary processes (down-slope and/or along depositional strike). Reworking of slope deposits occurs, but additional evidence for platform evolution can be provided by the whole redeposited material, that derives from the adjacent platforms. Van Konijnenburg (1997) and van Konijnenburg et al. (1999) subdivided the Cretaceous-lower Cenozoic succession into six mappable formations, by means of the unconformities and rapid vertical changes in facies associations; each of these formations was dated by planktonic organisms occurring in pelagic interbeds.

Recently, for the lithostratigraphy characterization of the Gran Sasso belt, Cardello and Doglioni (2015) adopted a combination of traditional and more recent names, formally defined units, for the Jurassic (e.g., Passeri et al., 2008); they accepted the subdivisions of van Konijnenburg et al. (1998; 1999) for Cretaceous and Paleogene sedimentary successions, while for the Neogene units they referenced to the Sheet "Gran Sasso d'Italia" of the Geological Map of Italy, 1:50,000 (Adamoli et al. 2012). Following Cardello and Doglioni (2015), the samples investigated in this work belong to the Venacquaro and the Glauconitic Calcarene Formations referred to Oligocene to Lower Miocene.

The Venacquaro Formation was introduced by van Konijnenburg et al. (1999) for the Oligocene (upper Rupelian – upper Chattian) sedimentary rocks in the Gran Sasso area, just in order to avoid confusion with variable sedimentary features labeled previously as Scaglia bianca, rossa, cinerea, cinerea with turbidites (Dela Pierre et al. 1992; Dela Pierre and Clari 1994). The Venacquaro Formation paraconformably overlies the Fonte Gelata Formation (Thanetian-late Eocene), with a depositional hiatus ranging from latest Bartonian or latest Priabonian, locally up to the late Rupelian. It is characterized by 45–65 m-thick greenish or reddish marly hemipelagic wackestones with planktonic foraminifera and commonly intercalated bioclastic packstones to grainstones dominated by displaced tests of *Nephrolepidina* and *Amphistegina* (Schiavinotto and Verrubbi 1994a), bryozoans, red algae and sponge spicules.



TEXT-FIGURE 4

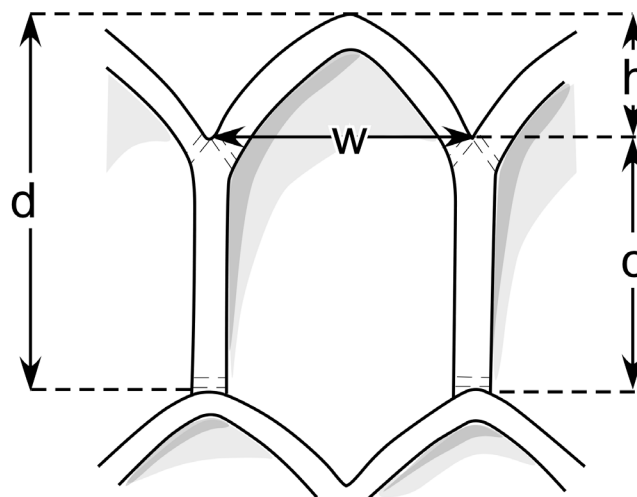
Schematic drawing of the embryonic and nepionic chambers and chamberlets of *Nephrolepidina* in equatorial section. I= protoconch, II=deutoconch; AACII: adauxiliary chamberlets on the deutoconch, in this example 2 (parameter C); P.A.C.: principal auxiliary chamber; D_I: diameter of the protoconch; D_{II}: diameter of the deutoconch; c.w., common wall between protoconch and deutoconch.

The hemipelagic levels of Venacquaro Formation contain minor amounts of very fine siliciclastic debris, quartz, feldspar and chlorite and show burrows such as *Thalassinoides*, *Zoophycos* and *Chondrites* (e.g., Schiavinotto and Verrubbi 1994a; 1994b). The thickness of the sampled strata varies from 10 to 50 cm, although some levels are up to 150 cm-thick.

Because of the occurrence of slump features, displaced shallow water biota and the faint grading, van Konijnenburg et al. (1999) interpreted the sediments of the Venacquaro Formation as deposited by turbidity currents. The absence of significant differences in the thickness of the turbidite beds seems to indicate that they were deposited as distal turbidites.

The upper boundary is defined by a marked change to coarse grained white redeposited skeletal packstones bearing glauconite, and no hemipelagic marly limestones are found. This boundary coincides approximately with the Oligo-Miocene boundary.

The Glauconitic Calcarene Formation (Aquitania p. p.-Burdigalian p. p.), introduced by Adamoli (1992), has a thickness ranging from about 45 m to 80 m although, locally, it may reach 110 m; the lower boundary is characterized by a sharp contact, marked by an evident morphological contrast in respect to the marly Venacquaro Formation. It consists mostly of resedimented limestone derived from the Miocenic carbonate ramp of the Latium-Abruzzi platform, rich in displaced larger foraminiferal tests such as *Miogypsinoidea* and *Heterostegina* (e.g., Ghisetti and Vezzani 1990).



TEXT-FIGURE 5

Schematic drawing of neanic equatorial chamberlets of *Nephrolepidina* showing the internal features (redrawn after Schiavinotto 1992).

Glauconite, present in the whole formation, increases in the last 10 meters and the upper portion was probably wrongly referred by Ghisetti and Vezzani (1990) to the Bisciario Formation.

MATERIAL AND METHODS

The sampled section

The sampled succession is located in an area named Tre Valloni (42°27'N-13°33'E), on the western flank of the Gran Sasso (text-fig. 1, Sheet 349, Gran Sasso d'Italia). The investigated stratigraphic section spans from 1850 m to 1870 m height on sea-level and it is about 60 m-thick (text-fig. 2). The sampled strata have a NW-SE direction and dip with an angle of 40° NE, and overlie the Eocene conglomerates of the Fonte Gelata Formation. The lithological and faunal content, as previously reported by Schiavinotto and Verrubbi (1994a; 1994b; 2000), are comparable with those described by Renz (1936, 1951) in the Oligo-Miocene section outcropping along the old funicular railway (profile XXIV in Renz 1936). Schiavinotto and Verrubbi (1994a) subdivided the succession into two informal units that fully correspond to the formal subdivision provided above according to Cardello and Doglioni (2015).

A total number of 10 populations of *Miogypsinoidea*, 10 populations of *Miogypsina* and 12 populations of *Nephrolepidina* have been isolated along the Tre Valloni stratigraphic section.

Miogypsinoidea appear in Sample TV52, with few specimens of *Miogypsinoidea* cf. *complanatus* (Pl. 1, fig. 1, not biometrically investigated in this work). From TV55 to the uppermost part of the section, *Miogypsinoidea* become predominant over the lepidocyclinids. Sometimes the tests are iso-oriented, allowing a biometric study at population level in the same samples containing the studied *Nephrolepidina* populations. No free-matrix specimens were obtained due to the absence of marly layers with LBF in the outcrop.

The studied material is almost the same sampled by Schiavinotto and Verrubbi (1994a; 1994b), but the number of data has been here increased as much as possible for each popu-

lation, in order to obtain a statistical valid number of individuals ($N=25$ as an optimal standard minimum) and, consequently, offsetting partially the effect of reworking on variation in the evolutionary embryo-nepionic-neanic characteristics of the taxon. It is worth of notice that, working with a hard-rock sample, the number of specimens cut along a reliable equatorial section can be increased using seriate thin sections, parallel to preferential directions through “clouds” of iso-oriented specimens; the latter can be easily detected on a wet surface of the sample, using a 10x lens.

As concerns *Nephrolepidina* the four uppermost populations in Schiavinotto and Verrubbi (1994a) were excluded from this work because they result unambiguously reworked, whereas two populations (TV32A and TV42) were added in the lower part of the section.

For each parameter and index of the investigated populations, descriptive statistics were calculated by standard methods using PAST 3.20 - SPSS 23 - ProUCL 5.1.002.

Biometry in *Miogypsina*

According to Drooger (1993), the Oligo-Miocene Mediterranean miogypsinids are represented by the genus *Miogypsina*, subdivided with the subgenera *Miogypsinoides* (unispiralled nepiont, with thick, lamellar side walls and intraseptal canal system, without lateral chambers), *Miogypsina* s.s. (unispiralled-bispiralled nepiont, with lateral chambers), and *Miolepidocyclina* (bispiralled, with centripetal trend of embryonic apparatus and with lateral chambers). In thin sections of hard rocks, the occurrence of lateral chambers cannot be detected in equatorially sectioned specimens, consequently, the discrimination between *Miogypsinoides* and *Miogypsina* require the detection of the intraseptal canal system, present only in *Miogypsinoides* (De Bock 1976).

More recently other genera has been erected, such as *Marasella* (Sirel and Işik 2011), *Postmiogypsinella* (Sirel and Gedik 2011) and *Miogypsinoidella* (Ferrandini et al. 2010) from the Oligo-Miocene of Mediterranean area, without an accurate biometric comparison of megalospheric forms. The relationships among these new miogypsinids and the possible ancestor *Risananeiza*, in having canals open in both ventral and dorsal sides and lower trochospiral arrangement (e.g., Sirel and Işik 2011; Benedetti and Briguglio 2012), has been only speculatively debated (Ferrández-Cañadell and Bover-Arnal 2017; Gedik 2020). The biometric method is mandatory in recognizing several groups of LBF in which internal characters in megalospheric specimens vary along a lineage presumably according to a linear regression, but only considering a statistical valid number of oriented sectioned individuals from each population (e.g., Drooger 1993). Each taxon represents a definite chronospecies constrained within a certain range (e.g., Less 1987; Less et al. 2008). When the mean value of a population falls close to the morphometrical limit between two chronospecies within less than one standard error (SE), according to Drooger (1993) we use the notation “exemplum intercentrale” (ex. interc.) followed by the names of the two nominal neighboring species.

Counts and measurements on megalospheric specimens, sectioned along the equatorial plane of the test in thin sections of hard rocks, were performed following the criteria introduced by Tan Sin Hok (1936), and according to the methodology intro-

duced by Drooger (1953) and summarized in Drooger (1993). In the present study, two parameters are considered:

X = number of the chambers of the principal nepionic spiral around the protoconch (I) and the deuteroconch (II); the two embryonic chambers are excluded from the count ($X=11$, in text-fig. 3);

DI = the diameter of the protoconch, measured perpendicularly to the line joining the centers of the first two chambers (line ME in text-fig. 3). In these measurements, half of the thickness of the walls is included to allow a more accurate comparison with a large part of the data in the previous literature. However, this procedure will be further modified, considering the recent evidences on depth-dependence wall-thickness in *Nephrolepidina* (Benedetti and Pignatti 2013).

The counting of the chambers (X) and the measurements of DI have been done under the microscope with an eyepiece equipped with a micrometer, and were subsequently checked on photographic enlargements.

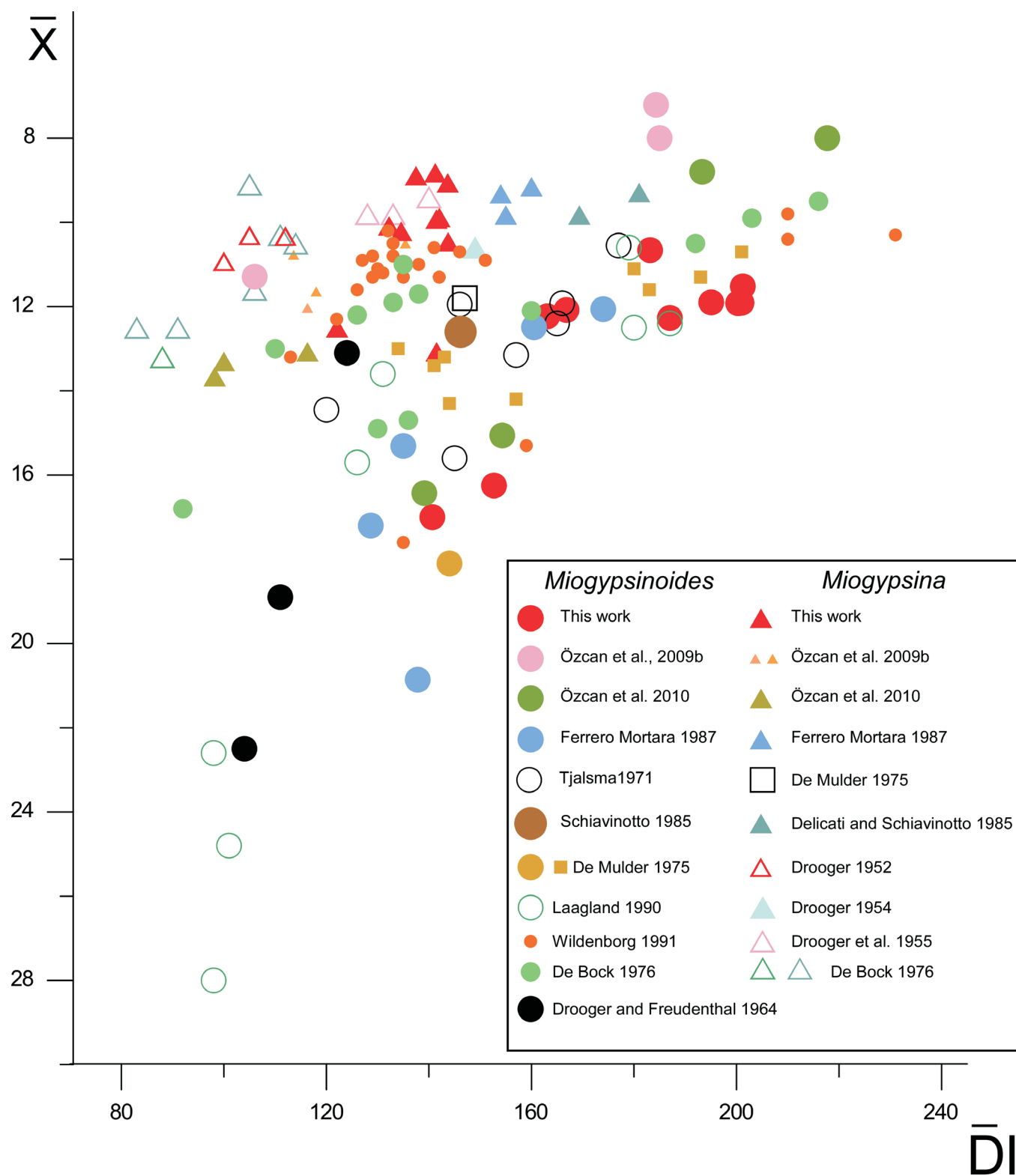
Routinely other biometric parameters are adopted in the study of Miogypsinidae, i.e., the measure of angle γ° (as reported in text-fig. 3) and the degree of symmetry V . The angle γ° was measured in very few specimens because of the high frequency of not clearly delimited frontal margins of the test; consequently, N was always without statistical significance. However, the measured γ° values are always negative. The degree of symmetry $V = \alpha/\beta \times 200$ was not measured because of the lack of bispiralled specimens.

Biometry in *Nephrolepidina*

Nephrolepidina Douvillé, 1911 is a lepidocyclinid genus characterized 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 a subcircular to reniform deuteroconch, larger than the protoconch (text-fig. 4). The equatorial chambers are arcuate, ogival, rhombic or hexagonal and were considered as arranged in cyclic annuli (Eames et al. 1962). Benedetti (2014) evidenced the spiral growth of the neanic stage of *Nephrolepidina*. Consequently, annuli are considered as pseudo-annuli in the present research.

The “Degree of enclosure” of the protoconch by the deuteroconch (Factor Ai of Van der Vlerk 1959a; 1959b; 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), with the ratio DII/DI, were measured on equatorial sections of the megalospheric specimens (text-fig. 4).

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 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 (2013), 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-Penney and Racey 2004).



TEXT-FIGURE 6
DI vs X scatter diagram of Mediterranean *Miogypsinoides* and *Miogypsina*.

TABLE 1

Results of counts and measurements on miogypsinid populations from Tre Valloni section. N: number of observations; range: minimum and maximum values recorded; mean: sample mean; S: standard deviation; Se: standard error; cv: coefficient of variation; KS: Kolmogorov–Smirnov test for normal distribution; W: Shapiro-Wilk test for normality. Boldface values are significant at the 95% confidence level.

				X								D1							
Taxon			Population	N	range	mean	S	Se	cv	KS	W	N	range	mean	S	Se	cv	KS	W
Mioegypsinoides		formosensis	TV130	124	9 - 23	13.50	3.78	0.34	0.28	0.186	0.898	124	85 - 324	179.89	54.26	4.87	0.30	0.086	0.972
		formosensis	TV126	46	9 - 25	13.84	4.39	0.64	0.31	0.207	0.870	46	74 - 307	182.97	51.01	7.52	0.27	0.110	0.971
		formosensis	TV114	132	9 - 28	13.38	4.20	0.36	0.31	0.167	0.878	132	85 - 352	186.90	58.40	5.08	0.31	0.072	0.979
	ex.interc.	formosensis-bantamensis	TV103	160	9 - 22	13.23	3.66	0.28	0.27	0.182	0.899	160	80 - 341	185.11	54.75	4.32	0.29	0.096	0.973
		formosensis	TV90	69	9 - 23	13.55	3.65	0.43	0.26	0.215	0.894	69	85 - 284	176.95	49.26	5.93	0.27	0.138	0.948
		formosensis	TV89	46	9 - 22	13.95	3.86	0.57	0.27	0.151	0.901	46	85 - 261	154.28	44.17	6.51	0.28	0.122	0.927
		bantamensis	TV87	31	9 - 21	11.74	3.32	0.59	0.28	0.205	0.795	31	102 - 278	174.54	46.76	8.40	0.26	0.118	0.952
	ex.interc.	formosensis-bantamensis	TV84a	29	9 - 21	13.34	3.57	0.66	0.26	0.158	0.909	29	97 - 256	162.37	36.39	6.75	0.22	0.125	0.956
		complanatus	TV61a	87	10 - 29	17.85	3.80	0.40	0.21	0.105	0.976	87	74 - 233	138.20	31.26	3.35	0.22	0.091	0.981
		formosensis	TV55	56	9 - 24	16.25	3.90	0.52	0.24	0.097	0.973	56	85 - 239	152.69	37.59	5.02	0.24	0.086	0.975
Mioegypsina		gunteri	TV130	54	7 - 14	10.22	2.16	0.29	0.21	0.162	0.925	54	97 - 187	135.48	24.01	3.26	0.17	0.097	0.956
	ex.int.	gunteri-tani	TV126	23	7 - 14	9.30	1.89	0.39	0.20	0.303	0.861	23	74 - 216	141.30	30.98	6.46	0.21	0.118	0.977
		gunteri	TV114	48	8 - 16	10.75	2.15	0.31	0.20	0.157	0.912	48	80 - 182	136.64	24.39	3.52	0.17	0.094	0.958
	ex. interc.	gunteri-basraensis	TV103	72	7 - 16	12.30	2.18	0.25	0.17	0.139	0.948	72	97 - 210	136.56	24.16	2.84	0.17	0.184	0.914
		gunteri	TV90	36	8 - 16	11.22	2.30	0.38	0.20	0.147	0.925	36	74 - 182	136.08	25.68	4.28	0.18	0.162	0.930
		gunteri	TV89	24	8 - 16	11.45	2.26	0.46	0.19	0.122	0.955	24	97 - 170	133.20	19.79	4.04	0.14	0.111	0.970
		gunteri	TV87	25	7 - 16	10.00	2.46	0.49	0.24	0.180	0.888	25	97 - 193	139.12	29.22	5.84	0.21	0.182	0.932
		gunteri	TV84a	22	8 - 18	11.31	2.96	0.63	0.26	0.227	0.864	22	85 - 182	130.68	23.50	5.01	0.17	0.092	0.980
	ex.interc.	basraensis-gunteri	TV61a	12	9 - 16	12.58	2.53	0.73	0.20	0.174	0.897	12	91 - 159	122.08	20.03	5.78	0.16	0.173	0.963
		basraensis	TV55	20	9 - 16	13.15	2.20	0.49	0.16	0.200	0.920	20	85 - 199	141.50	28.71	6.42	0.20	0.176	0.955

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; 1994a; 1994b; 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) and successively by Adams (1987), 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. The arrangement of the chambers is closely linked to the length of the common walls between contiguous chamberlets of the same cycle (or pseudo-annulus).

A greater extent of these walls is related to a more distal position of the intercycle stolons. Similar observations were done on Cretaceous Orbitoididae (Van Gorsel 1975, 1978). Consequently, Schiavinotto (1992) 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 (1994a; 1994b) defined a “neanic acceleration” as the tendency to increase in time of the connections between the contiguous chambers (stolon system). More 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, in order to reach faster the mature stage. 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; 1994a; 1994b) are used (text-fig. 5), related to the equatorial 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 chambers 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 wall;

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

Re5= $h/w \times 100$ = “curvature index” of the front wall.

SI5= $FD5/Re5 \times 100$ = “Shape Index” of the chambers.

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

TABLE 2

Values of miogypsinid outliers identified by statistical tests, boxplot, Q-Q plot and morphotypic determination for all the investigated samples.

Sample	<i>Miogypsinoides</i>				<i>Miogypsina</i>			
	Rosner or Dixon (at 5%)	Box-Plot	Q-Q	Morphotypic discrimination	Rosner or Dixon (at 5%)	Box-Plot	Q-Q	Morphotypic discrimination
TV130	-	-	-	17-23	-	-	11-14	12-14
TV126	20-25	-	22-25	18-25	-	14	11-14	13-14
TV114	28	28	25-28	18-28	-	-	13-16	13-16
TV103	-	-	22	17-22	-	-	11-16	13-16
TV90	-	-	20-23	17-23	-	-	13-16	13-16
TV89	-	-	-	18-22	-	-	13-16	13-16
TV87	17-21	20-21	18-21	15-21	-	-	-	13-16
TV84a	-	-	18-21	17-21	-	18	16-18	13-18
TV61a	-	28-29	25-29	24-29	-	-	-	-
TV55	-	-	-	-	-	-	13	-

Benedetti and Pignatti (2013), considering the difficulty to obtain specimens with a complete equatorial plane up to 1 mm, 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 center of the protoconch and the center of the deuteroconch.

The populations TV were 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 (as established by Schiavinotto 1992) may be suitable only 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 chamberlets 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 pseudo-annuli from thin sections of rocks, Benedetti and Pignatti (2013) took these measures only for a single well-preserved chamberlet of the fifth “annulus”, similarly to what is routinely used for Discocyclinidae by Less (1987), that is in only one equatorial chamber at 0.5 mm from the embryonic chambers. Picking only one representative chamberlet may be difficult and subjective, because of 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 chambers per pseudo-annulus, but also in the present case, only one-two chamberlets for

some specimens were measured, because of the incomplete preservation of the neanic apparatuses. However, when possible we took into account as more equatorial chamberlets as possible.

The measurements were done on microphotographs, with the software Autocad, at an enlargement x 460. The normality of the distributions was checked by means of the Kolmogorov-Smirnov (K-S), at a probability level P= 95%, and of the Shapiro-Wilk (W) tests.

Recognizing the reworked material

Most of the investigated population, although not autochthonous, can be considered as simply displaced from shallow water into deeper environments (e.g., Benedetti and Pignatti 2013), but the oscillating vertical trend of mean values of main biometrical indexes, as reported by Schiavinotto and Verrubbi (1994a; 1994b; 2000) from Tre Valloni succession, calls for a possible reworking in the uppermost levels. Isolated Eocene taxa, such as orthophragminids and alveolinids, occur scattered in some samples and, unispiralled, primitive *Miogypsina* is also documented in the upper part of the succession, associated with stratigraphically younger nephrolepidines. Consequently, the first aim is to obtain *Miogypsina* populations “cleaned up” from outliers, who could compromise their homogeneity.

The selection/exclusion of reworked *Miogypsina* specimens was performed using different statistical tools:

- i) the Shapiro-Wilk’s Test (Shapiro and Wilk 1965), in order to recognize the assemblages with not normal distribution of the data.
- ii) The generalized (extreme Studentized deviate) ESD Rosner’s test (Rosner 1983), the Dixon’s test (Dean and Dixon 1951), to detect one or more outliers in an univariate data set that follows an approximately normal distribution.
- iii) Box-plots and Q-Q plots as graphical procedure to detect the outliers.

In addition to the statistical objective approach, a second more subjective morphotypic approach has been attempted, consisting

TABLE 3

Results of counts and measurements on miogypsinid populations from Tre Valloni section without outlier values resulted from statistical analysis. N: number of observations; range: minimum and maximum values recorded; mean: sample mean; S: standard deviation; Se: standard error; cv: coefficient of variation; Sk: sample skewness; Ku: sample kurtosis; KS: Kolmogorov–Smirnov test for normal distribution; W: Shapiro-Wilk test for normality. Boldface values are significant at the 95% confidence level.

			X										D1									
Taxon		Population	N	range	mean	S	Se	cv	Sk	Ku	KS	W	N	range	mean	S	Se	cv	Sk	Ku	KS	W
Miogypsinoides	<i>formosensis</i>	TV130	124	9 - 23	13.50	3.78	0.34	0.28	0.76	-0.51	0.186	0.898	124	85-324	179.89	54.26	4.87	0.30	0.21	-0.75	0.086	0.972
	ex. interc. <i>bantamensis-formosensis</i>	TV126	40	9 - 19	12.57	3.00	0.47	0.23	0.76	-0.58	0.201	0.8798	40	85-307	193.65	45.05	7.12	0.23	-0.06	-0.01	0.120	0.976
	ex. interc. <i>bantamensis-formosensis</i>	TV114	128	9 - 21	12.97	3.54	0.31	0.27	0.67	-0.72	0.163	0.8958	128	85-352	190.00	56.57	5.00	0.29	0.17	-0.61	0.072	0.981
	ex. interc. <i>bantamensis-formosensis</i>	TV103	156	9 - 21	13.00	3.42	0.27	0.26	0.72	-0.58	0.180	0.9008	156	80-341	187.01	54.11	4.33	0.28	0.15	-0.72	0.090	0.977
	ex. interc. <i>bantamensis-formosensis</i>	TV90	63	9 - 19	12.77	2.73	0.34	0.21	0.66	-0.43	0.215	0.9178	63	85-284	180.82	49.25	6.20	0.27	-0.16	-1.18	0.121	0.943
	<i>formosensis</i>	TV89	46	9 - 22	13.95	3.86	0.57	0.27	0.08	-1.27	0.151	0.901	46	85-261	154.28	44.17	6.51	0.28	0.77	-0.11	0.122	0.927
	<i>bantamensis</i>	TV87	27	9 - 14	10.66	1.75	0.33	0.16	0.55	-1.14	0.236	0.832	27	114-278	183.14	43.75	8.42	0.23	0.18	-0.79	0.088	0.966
	<i>bantamensis</i>	TV84a	24	9 - 16	12.08	2.39	0.48	0.19	0.30	-1.41	0.183	0.894	24	108-256	166.83	34.51	7.04	0.20	0.70	0.43	0.114	0.958
	<i>complanatus</i>	TV61a	83	10 - 23	17.40	3.28	0.36	0.18	-0.08	-0.47	0.113	0.968	83	85-233	139.86	30.02	3.29	0.21	0.58	0.18	0.105	0.971
	<i>formosensis</i>	TV55	56	9 - 24	16.25	3.90	0.52	0.24	0.10	-0.75	0.097	0.973	56	85-239	152.69	37.59	5.02	0.24	0.16	-0.75	0.086	0.973
Miogypsina	<i>tani</i>	TV130	28	7 - 10	8.39	0.99	0.18	0.11	0.32	-0.84	0.261	0.863	28	97-187	138.75	26.38	4.98	0.19	0.12	-0.708	0.097	0.954
	<i>tani</i>	TV126	19	7 - 11	8.57	1.01	0.23	0.11	0.29	0.623	0.240	0.883	19	74 - 216	140.26	32.53	7.46	0.23	0.07	0.910	0.153	0.966
	<i>gunteri</i>	TV114	41	8 - 13	10.07	1.47	0.23	0.14	0.06	-1.104	0.133	0.905	41	80 - 182	141.48	22.06	3.44	0.15	-0.152	0.051	0.101	0.955
	ex. interc. <i>gunteri-basraensis</i>	TV103	72	7 - 16	12.30	2.18	0.25	0.17	-0.570	0.113	0.139	0.948	72	97 - 210	136.56	24.16	2.84	0.17	1.887000	1.29338	0.184	0.914
	<i>gunteri</i>	TV90	30	8 - 13	10.46	1.65	0.30	0.15	0.209	-1.209	0.179	0.902	30	97 - 182	140.16	24.48	4.46	0.17	0.168	-1.39	0.178	0.893
	<i>gunteri</i>	TV89	19	8 - 13	10.57	1.57	0.36	0.14	-0.162	-1.065	0.184	0.928	19	102 - 159	132.36	15.99	3.66	0.12	-0.262	-0.287	0.112	0.956
	ex. interc. <i>gunteri-tani</i>	TV87	21	7 - 12	9.14	1.49	0.32	0.16	0.52	-0.607	0.207	0.914	21	97 - 193	143.66	28.67	6.25	0.19	0.424	-0.930	0.177	0.935
	<i>gunteri</i>	TV84a	19	8 - 14	10.36	1.77	0.40	0.17	0.24	-0.977	0.201	0.900	19	85 - 182	130.94	24.48	5.61	0.18	0.349	-0.055	0.115	0.979
	ex. interc. <i>basraensis-gunteri</i>	TV61a	12	9 - 16	12.58	2.53	0.73	0.20	0.08	-1.047	0.174	0.897	12	91 - 159	122.08	20.03	5.78	0.16	1.19402	0.57392	0.173	0.963
	<i>basraensis</i>	TV55	20	9 - 16	13.15	2.20	0.49	0.16	-0.536973	0.62942	0.200	0.920	20	85 - 199	141.50	28.71	6.42	0.20	1.33983	0.21981	0.176	0.955

in recognize possible outliers that show a nepionic spiral as longer as the the maximum value of X recorded in literature for the species.

RESULTS

Miogypsinoides

Results of counts and measurements for miogypsinid populations are summarized in Table 1.

For *Miogypsinoides*, the Kolmogorov–Smirnov test indicates a normality of X from TV55 up to TV89, but the Shapiro–Wilk test appears to be more severe, with only two assemblages (TV55 and TV61a), from the lower part of the succession, showing a normal distribution of the data related to the nepionic spiral. For D1, the KS test indicates a normal distribution for all the assemblages, while three populations (TV90, TV103 and TV130) are not normally distributed according to the Shapiro–Wilk test.

For *Miogypsina*, again the Shapiro–Wilk test appears to be more severe than KS, evidencing a normal distribution of X only in TV55, TV61a and TV89 populations, whereas D1 shows a distribution close to normal in most populations (Tab. 1). Indeed, the Kolmogorov–Smirnov test is based on class frequencies and its operability failed in samples with small individual numbers for each class, whereas Shapiro–Wilk test is reliable for both small and high number of counts.

To discriminate statistical outliers, resulting possibly from reworking, the Rosner test has been adopted for the populations composed by more than 25 individuals, whereas the Dixon test was performed for the others. The results of possible outliers identified by statistical test, boxplot and Q-Q plot are reported in Table 2.

The polished data, without the statistical outliers, are listed in Table 3. The refinement of the statistical data gives a different scenario as concern the systematic attribution of each chronospecies. The variation of both X and D1 along the stratigraphic section evidences an almost linear trend of embryo–nepionic acceleration with some oscillation. The values for outliers derived from morphotipic analysis are listed in Tab. 2 and results of counts and measurements are reported in Tab. 4. This latter analysis allows us to obtain more normal distribution of data and to remove from the statistical population the individual definitely reworked in having very primitive biometric values.

Nephrolepidina

Results of measurements and counts of the embryo–nepionic apparatus are given in Tab. 5. These data integrate those in Schiavinotto and Verrubbi (1994a; 1994b; 2000). 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. The specimens with Ai below 40% are definitely subordinate. Large nucleococonchs tending towards the tryblielepidina-type, with Ai above 50% are subordinate. The number of adauxiliary chamberlets on the deuteroconch C, due to its lower variability and to the grade of subjectivity in measuring this parameter, shows distribution far from normal in eight populations.

For the neanic chamberlets results of measurements are summarized in Tab. 6. The specimens with a “degree of distalization” (FD5) around 50% (text-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. The normality of most biometrical data, for embryonic, nepionic and neanic

chambers, allows to consider the specimens of *Nephrolepidina* from a sample as belonging to a single species.

DISCUSSION

Miogypsinids

As above stated, according to Drooger (1963; 1993), the Mediterranean Miogypsinidae consists of three genera: *Miogypsinoides*, *Miogypsina* and *Miolepidocyclina*. The main *Miogypsinoides* lineage includes a sequence of successive species, arranged in accordance with the general principle of nepionic acceleration, discussed in detail by Drooger (1993). In circum-Mediterranean region, the proposed succession of species and the numerical values of the biometric limits are: *Miogypsinoides butterlinus* (Xmean: > 23) – *complanatus* (Xmean: 23–17) – *formosensis* (Xmean: 17–13) – *bantamensis* (Xmean: 13–10). The taxa cover the stratigraphic interval from upper Chattian to lower Aquitanian. Despite the occurrence of *Miogypsinoides* in upper Aquitanian and Burdigalian deposits has been signalled (De Bock 1976), no biometric data have been documented yet. According to Drooger (1993) *Miogypsinoides* did not evolve beyond the biometric level of *Miogypsinoides bantamensis* in the western Tethys. The *Miogypsinoides/Miogypsina* transition was proposed to occur at different levels of the X scale, corresponding to the *formosensis* level (upper Chattian) in Europe and to *bantamensis* (lower Aquitanian) in India and in the Far East (Raju 1974; Adams 1984; Drooger 1993).

According to Drooger (1993), two species of *Miogypsina*, *M. septentrionalis* (Xmean: >15) and *M. basraensis* (Xmean: between 12.5 and 15), occur in the uppermost Chattian of circum-Mediterranean region. The Aquitanian interval is characterized by the evolution of *M. gunteri* and *M. tani*, whereas *M. globulina*, *M. intermedia*, *M. cushmani* and *M. mediterranea* cover the Burdigalian (Drooger 1993).

Özcan et al. (2009a) described the new species *Miogypsinoides sivasensis* from the upper Chattian-lower Aquitanian of Turkey in having very short spiral, large embryo and low negative value of γ . More recently Gedik and Sirel (2011) erected *Md. akcadagensis* from the upper Chattian of Turkey characterized by few spiral chambers (Xmean: 8–10), but its relationship with the well-known lineage is not yet accurately investigated (e.g., Gedik 2020). The relationship and possibly synonymy of these two species will require detailed morphometric investigation.

The TV populations are plotted in the X-DI scatter diagram of text-figure 6 to compare them with those available in literature, selecting only the Mediterranean unispiralled forms (Drooger and Raju 1973), and including also additional data about populations from central Apennines, Sardinia and Turkey (Schiavinotto 1979; 1984; 1985; Delicati and Schiavinotto 1985; Özcan and Les 2009; Özcan et al. 2009a; 2009b; 2010). In the X–DI scatter diagram (text-fig. 6), the lowermost populations of *Miogypsinoides* from Tre Valloni are linearly distributed and show affinities with primitive *Md. complanatus* and *formosensis* in Wildemborg (1991), Tjalsma (1971), Özcan et al. (2009a) and De Bock (1976), and with *M. ex.interc. complanatus-formosensis* in De Mulder (1975). The more primitive TV population is closest to *Md. complanatus* of Drooger and Freudental (1964), according to the parameter X, despite its larger embryo. The more advanced populations TV fit well with *Md. bantamensis* of Schiavinotto (1985), Tjalsma (1971) and

TABLE 4

Results of counts and measurements on miogypsinid populations from Tre Valloni section without outlier values resulted from morphotopic analysis. N: number of observations; range: minimum and maximum values recorded; mean: sample mean; S: standard deviation; Se: standard error; cv: coefficient of variation; Sk: sample skewness; Ku: sample kurtosis; KS: Kolmogorov–Smirnov test for normal distribution; W: Shapiro–Wilk test for normality. Boldface values are significant at the 95% confidence level.

Taxon	X											DI										
	Populatio	N	range	mean	S	Se	cv	Sk	Ku	KS	W	N	range	mean	S	Se	cv	Sk	Ku	KS	W	
<i>Miogypsinoides</i>	<i>bantamensis</i>	TV130	99	9–16	11.90	2.19	0.22	0.18	0.44888	-1.023286	0.176	0.908	99	91–324	195.07	49.21	4.94	0.25	0.0304221	-0.432598	0.047	0.988
	<i>bantamensis</i>	TV126	36	9–17	11.91	2.35	0.39	0.19	0.727658	-0.628468	0.180	0.884	36	125–307	200.97	40.30	6.71	0.20	0.134045	-0.0896400	0.130	0.963
	<i>bantamensis</i>	TV114	110	9–17	11.92	2.57	0.24	0.21	0.612137	-0.826425	0.164	0.891	110	85–352	200.32	53.27	5.07	0.26	0.0796330	-0.436250	0.074	0.988
	<i>bantamensis</i>	TV103	123	9–16	11.52	1.99	0.17	0.17	0.516173	-0.584879	0.149	0.923	123	97–341	201.23	50.23	4.52	0.24	-0.0442476	-0.489065	0.086	0.982
	<i>bantamensis</i>	TV90	58	9–16	12.27	2.21	0.29	0.18	0.410468	-0.992385	0.205	0.907	58	85–284	187.00	46.32	6.08	0.24	-0.289445	-0.949038	0.122	0.950
	<i>bantamensis</i>	TV89	34	9–17	12.23	2.87	0.49	0.23	0.1733	-1.617067	0.194	0.849	34	85–261	163.08	45.73	7.84	0.28	0.564500	-0.486076	0.131	0.944
	<i>bantamensis</i>	TV87	27	9–14	10.66	1.75	0.33	0.16	0.5541	-1.000512	0.236	0.832	27	114–278	183.14	43.75	8.42	0.23	0.185719	-0.791783	0.088	0.966
	<i>bantamensis</i>	TV84a	24	9–16	12.08	2.39	0.48	0.19	0.3077	-1.41251	0.183	0.894	24	108–256	166.83	34.51	7.04	0.20	0.709413	0.431518	0.114	0.958
	<i>ex. int. complanatus-formosensis</i>	TV61a	77	10–23	17.00	3.04	0.34	0.17	-0.123622	-0.231424	0.135	0.976	77	85–233	140.66	29.99	3.41	0.21	0.570104	0.285613	0.107	0.973
<i>Miogypsina</i>	<i>formosensis</i>	TV55	56	9–24	16.25	3.90	0.52	0.24	0.104392	-0.757113	0.097	0.973	56	85–239	152.69	37.59	5.02	0.24	0.164874	-0.668585	0.086	0.975
	<i>ex. int. gunteri-tani</i>	TV130	36	7–11	8.97	1.40	0.23	0.15	0.249	-1.291	0.228	0.863	36	97–187	137.47	25.07	4.17	0.18	0.292	-0.595	0.107	0.952
	<i>ex. int. gunteri-tani</i>	TV126	21	7–12	8.90	1.41	0.30	0.15	0.893	0.704	0.283	0.866	21	74–216	141.23	32.04	6.99	0.22	0.034	0.730	0.128	0.974
	<i>gunteri</i>	TV114	40	8–12	10.00	1.41	0.22	0.14	0.000	-1.227	0.135	0.880	40	80–182	141.47	22.34	3.53	0.15	-0.148	-0.026	0.106	0.953
	<i>gunteri</i>	TV103	35	7–12	10.54	1.61	0.27	0.15	-1.059	-0.015	0.297	0.800	35	97–210	143.74	27.81	4.70	0.19	0.463	-0.611	0.178	0.948
	<i>gunteri</i>	TV90	25	8–12	9.96	1.30	0.26	0.13	0.201	-1.096	0.209	0.900	25	114–182	142.04	24.24	4.84	0.17	0.224	-1.657	0.196	0.946
	<i>gunteri</i>	TV89	17	8–12	10.29	1.40	0.34	0.13	-0.288	-1.271	0.222	0.887	17	102–159	134.58	14.88	3.60	0.11	-0.272	-0.085	0.110	0.968
	<i>ex. int. gunteri-tani</i>	TV87	21	7–12	9.14	1.49	0.32	0.16	0.529	-0.607	0.207	0.914	21	97–193	143.66	28.67	6.25	0.19	0.424	-0.930	0.177	0.935
	<i>gunteri</i>	TV84a	18	8–12	10.16	1.58	0.37	0.15	-0.006	-1.68	0.214	0.843	18	85–182	132.22	24.53	5.78	0.18	0.248	0.002	0.123	0.983
<i>ex. int. basraensis-gunteri</i>	TV61a	12	9–16	12.58	2.53	0.73	0.20	0.083	-1.047	0.174	0.897	12	91–159	122.08	20.03	5.78	0.16	0.194	-0.573	0.173	0.963	
<i>basraensis</i>	TV55	20	9–16	13.15	2.20	0.49	0.16	-0.536	-0.629	0.200	0.920	20	85–199	141.50	28.71	6.42	0.20	0.339	-0.219	0.176	0.955	

TABLE 5

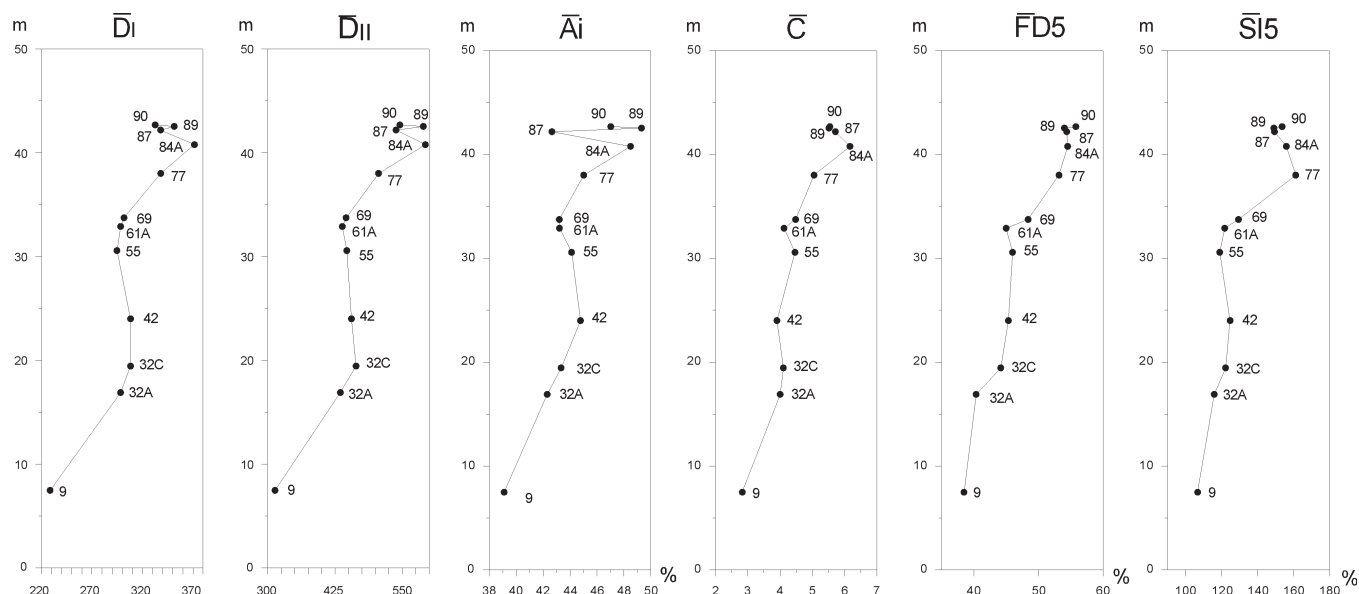
Results of embryonic and nepionic measurements in Nephrolepidina populations from Tre Valloni. N: number of observations; range: minimum and maximum values recorded; M: sample mean; S: standard deviation; Se: standard error; cv: KS: Kolmogorov-Smirnov test for normal distribution; W: Shapiro-Wilk test for normality. Boldface values are significant at the 95% confidence level.

Population	Ai				C				DI				DII				DIII				Taxon										
	N	Range	M	S	Se	K-S	W	N	Range	M	S	Se	K-S	N	Range	M	S	Se	K-S	N	Range	M	S	Se	K-S	N	Range	M	S	Se	K-S
TV90	59	36.57-60.23	47.02	5.70	0.74	0.070	0.976	66	2-11	5.54	1.79	0.22	0.165	77	170-592	332.57	101.21	11.53	0.112	78	230-545.49	184.11	20.84	0.114	76	1.10-3.43	1.62	0.33	0.03	0.130	tauroi
TV89	43	29.92-75.81	49.30	8.87	1.35	0.082	0.985	64	2-11	5.51	2.04	0.25	0.125	79	172-648	351.41	106.50	11.98	0.066	79	204-589.05	200.49	22.55	0.053	77	1.12-2.35	1.65	0.30	0.03	0.105	tauroi
TV87	35	31.43-60.72	42.65	6.54	1.10	0.100	0.937	46	3-10	5.71	1.66	0.24	0.150	48	182-740	337.89	104.66	15.10	0.179	52	153-538.32	180.84	25.07	0.145	48	1.12-2.34	1.58	0.25	0.03	0.111	tauroi
TV84A	43	33.92-76.44	48.49	7.56	1.15	0.091	0.941	50	3-9	6.16	1.90	0.27	0.133	53	187-676	371.45	109.08	14.98	0.112	56	164-592.87	205.38	27.44	0.079	53	1.10-2.44	1.58	0.28	0.03	0.103	tauroi
TV77	103	30.59-59.88	45.01	6.00	0.59	0.055	0.991	72	3-7	5.05	1.08	0.12	0.173	82	204-534	338.08	71.15	7.85	0.077	81	278-888	505.84	105.27	0.169	80	1.19-2.21	1.51	0.19	0.02	0.097	tauroi
TV69	43	30.90-58.85	43.20	6.05	0.92	0.126	0.940	54	3-7	4.48	1.12	0.15	0.239	54	193-420	301.70	51.81	7.05	0.088	55	301-620	445.56	82.19	0.118	54	1.19-1.82	1.46	0.15	0.02	0.068	tauroi
TV61A	45	20.75-61.47	43.21	6.73	1.00	0.139	0.961	98	2-9	4.12	1.20	0.12	0.254	121	182-528	298.31	62.85	5.71	0.110	122	267-935	438.68	112.59	0.126	118	1.15-2.15	1.45	0.18	0.01	0.058	tauroi
TV55	30	36.14-57.68	44.11	5.23	0.95	0.136	0.938	54	3-8	4.46	1.22	0.16	0.239	64	142-528	294.67	66.15	8.26	0.090	61	261-768	446.90	119.03	0.152	60	1.10-2.09	1.51	0.21	0.02	0.137	tauroi
TV42	45	33.39-61.73	44.77	5.97	0.89	0.068	0.980	41	2-7	3.90	1.20	0.19	0.254	51	204-449	308.20	60.95	8.53	0.068	51	284-675	455.60	97.52	0.136	51	1.07-1.92	1.48	0.21	0.03	0.068	tauroi
TV32C	94	29.09-61.68	43.33	5.23	0.53	0.049	0.984	130	2-7	4.10	1.19	0.10	0.197	139	170-568	308.18	65.56	5.56	0.083	140	250-731	464.10	105.59	0.098	139	1.05-2.35	1.51	0.21	0.01	0.067	tauroi
TV32A	90	32.48-51.98	42.30	4.45	0.46	0.050	0.988	124	2-7	4.00	1.00	0.09	0.216	153	193-540	298.30	62.95	5.08	0.109	156	250-750	435.00	96.73	0.106	153	1.12-2.06	1.45	0.17	0.01	0.079	tauroi
TV9	39	29.98-47.97	39.10	3.85	0.61	0.106	0.980	48	2-4	2.83	0.63	0.09	0.312	50	159-352	228.48	41.22	5.82	0.120	50	204-454	313.56	58.82	0.069	50	1.02-1.94	1.37	0.16	0.02	0.106	tauroi

TABLE 6

Results of neanic measurements in Nephrolepidina populations from Tre Valloni. N: number of observations; nc: number of measured neanic chamberlets; range: minimum and maximum values recorded; M: sample mean; S: standard deviation; Se: standard error; cv: KS: Kolmogorov-Smirnov test for normal distribution. Boldface values are significant at the 95% confidence level.

Taxon	Population	FD5						Re5						SI5						N1								
		N	nc	Range	M	S	Se	K-S	N	nc	Range	M	S	Se	K-S	N	nc	Range	M	S	Se	K-S	N	Range	M	S	Se	K-S
N. sp. C	TV90	23	130	41.92-70.23	55.77	7.48	1.56	0.107	23	130	28.01-54.08	39.97	7.15	1.49	0.128	23	130	83.26-266.92	153.67	48.31	10.07	0.105	11	10-17	14.18	2.27	0.68	0.152
N. sp. B	TV89	34	221	27.64-72.92	54.00	9.62	1.65	0.171	34	221	29.73-66.43	40.91	7.85	1.34	0.124	34	221	44.56-283.38	149.08	50.92	8.73	0.123	26	12-18	14.03	1.37	0.26	0.203
N. sp. B	TV87	16	75	39.39-65.92	54.36	6.43	1.60	0.160	16	75	32.37-53.20	40.27	6.37	1.59	0.175	16	75	83.39-216.00	149.46	40.80	10.20	0.128	19	12-20	14.57	2.17	0.49	0.188
N. sp. B	TV84A	26	218	38.57-63.98	54.50	6.60	1.29	0.142	26	218	27.37-48.46	37.44	5.10	1.00	0.088	26	218	92.97-219.11	156.04	34.36	6.73	0.081	19	12-20	15.21	2.30	0.52	0.220
N. sp. B	TV77	27	249	28.63-66.23	53.17	7.95	1.53	0.184	27	249	27.88-44.51	35.56	4.67	0.90	0.066	27	249	74.43-248.35	161.27	38.70	7.44	0.093	40	13-21	16.87	2.07	0.32	0.151
N. murgani	TV69	25	187	30.26-59.18	48.39	7.51	1.50	0.134	25	187	31.80-51.02	39.67	4.85	0.97	0.084	25	187	70.10-171.98	129.40	29.83	5.96	0.137	22	15-23	18.68	2.19	0.46	0.122
N. murgani	TV61A	15	59	19.31-62.20	44.99	12.29	3.17	0.174	15	59	32.44-51.41	40.36	5.74	1.48	0.169	15	59	51.72-198.69	121.71	37.81	9.76	0.104	11	13-23	17.72	3.00	0.90	0.232
N. murgani	TV55	14	91	30.46-63.34	45.98	9.02	2.41	0.124	14	91	29.71-53.58	40.57	5.17	1.38	0.240	14	91	73.64-216.34	118.95	36.59	9.78	0.149	12	14-21	17.16	2.59	0.74	0.174
N. murgani	TV42	37	224	13.10-66.03	45.34	9.11	1.49	0.136	37	224	28.85-81.74	38.88	8.44	1.38	0.224	37	224	38.09-240.67	124.74	34.11	5.60	0.096	27	14-22	17.62	2.15	0.41	0.173
N. murgani	TV32C	19	172	21.61-58.63	44.15	9.24	2.12	0.103	19	172	30.29-50.95	38.95	5.10	1.17	0.099	19	172	52.47-195.42	122.21	31.20	7.15	0.138	21	14-23	18.38	2.62	0.57	0.165
N. murgani	TV32A	30	230	17.13-65.27	40.34	10.34	1.88	0.119	30	230	29.08-51.83	39.11	5.85	1.06	0.120	30	230	38.42-206.69	115.90	39.87	7.28	0.108	23	15-24	19.30	2.53	0.52	0.130
N. sp. A	TV9	22	175	20.16-51.26	38.46	9.65	2.05	0.182	22	175	28.55-55.24	39.47	5.96	1.27	0.132	22	175	44.31-177.40	106.65	36.20	7.71	0.108	18	18-24	21.11	1.60	0.37	0.250



TEXT-FIGURE 7

Vertical distributions of the mean values of the parameters and indexes in *Nephrolepidina* from Tre Valloni.

some *bantamensis* in De Bock (1976). Others *Md. bantamensis* and *Md. sivasensis* in Özcan et al. (2009a) present clearly more advanced internal characters.

According to Drooger (1993) the lineage of Mediterranean *Miogypsina* is characterized by the following species: *Miogypsina septentrionalis* (Xmean: >15) – *M. basraensis* (Xmean: 15–12.5) – *M. gunteri* (Xmean between 9 and 12.5) – *M. tani* (Xmean below 9 and negative values of γ) up to bispiralled *M. globulina* (Xmean below 7 and positive values of γ) – *M. intermedia* – *M. cushmani* – *M. mediterranea*.

The mean values of the Gran Sasso populations fall mainly within the sequence of low-intermediate fields that characterize the Mediterranean *Miogypsina* lineage. The lowermost TV populations fit with *M. basraensis-gunteri* in Ozcan et al. (2009a), *M. gunteri* in Drooger et al. (1955) and Drooger (1954).

Nephrolepidina

The graph in text-figure 7 results from the vertical distribution of mean values of selected measured parameters and indexes in *Nephrolepidina*. The mean values of A_i , C, DI and DII tend to increase from the bottom to the top of the investigated section, overall, the trends are accordance with the principle of the “embryonic acceleration” (Drooger and Freudenthal 1964), but deviations from the expected trend occur above the population TV84. The drop of TV87 is particularly dramatic just for A_i , the most diagnostic index in lepidocyclinids.

The deviation from the expected trend could derive from ecological, environmental, bathymetrical factors (e.g., Benedetti and Pignatti 2013), reproductive strategies (e.g., Benedetti 2015), occurrence of competitors (e.g., Schiavinotto and Verrubbi 2000) or more simply reworking. For the Tre Valloni succession, the conclusion by Schiavinotto and Verrubbi (1994a; 1994b; 2000) must be partly revised on the base of the currently added data. First of all, the four uppermost popula-

tions in Schiavinotto and Verrubbi (1994a) are not investigated in this work as they are evidently reworked, since very primitive almost incomplete individuals occur in the assemblage, secondarily the neanic equatorial chamberlets show a more linear trend of increase in degree of stolon distalization as evidenced by the distribution of mean values of FD5 in text-figure 7.

The TV *Nephrolepidina* populations, plotted in the \bar{A}_i - C scatter diagram of text-figure 8, based on Drooger and Rohling (1988) and including also additional data from Turkish populations (Özcan et al. 2009a; 2009b; 2010), allow an extensive comparison with most of the data concerning the populations of *Nephrolepidina* in the literature, in tune with the principles of the embryonic acceleration (Drooger and Freudenthal 1964) and of the nepionic acceleration (e.g., Tan Sin Hok 1936). Only the population TV87 shows a significant deviation respect the expected fields of values in the Mediterranean lineage of *Nephrolepidina*.

The mean values of the proloculus size in TV populations are rather high with respect to the data reported in the literature on the Mediterranean forms (e.g., Özcan et al. 2009a; 2009b; 2010; Parente and Less 2019); this seems to be linked to bathymetric conditions close to the lower limit of survival for these LBF (e.g., Benedetti and Pignatti 2013).

As yet, the Mediterranean *Nephrolepidina* species have been defined on the basis of the average values of the Factor A_i and the parameter C. According to De Mulder (1975) and Van Heck and Drooger (1984), the boundaries between the species are:

Nephrolepidina praemarginata $35 < \bar{A}_i \leq 40\%$ and $1 \leq \text{mean} = 3$

Nephrolepidina morgani $40 < \bar{A}_i \leq 45$ and $3 < C_{\text{mean}} \leq 5.25$

Nephrolepidina tournoueri $45 < \bar{A}_i$ and $C_{\text{mean}} > 5.25$

Following the chronospecies criteria of De Mulder (1975), the mean values of \bar{A}_i are sufficient to refer the TV populations as in Tab. 5.

This classification has proved to be not sufficient for solving the problems imposed by some cases with marked deviations of the mean values, that appear to be not correlated with the stratigraphic sequence of the populations and might be produced by a dependence of the embryo-nepionic features regarding numerous interacting environmental and/or reworking factors (Schiavinotto and Verrubbi 1994a; 1994b; Giannini et al. 2007). Consequently, Schiavinotto (1996) suggested modified specific boundaries, as follows:

N. praemarginata $\bar{A}_i \leq 38.00$; $C_{mean} \leq 2.50$

N. morgani $38.00 < \bar{A}_i \leq 41.00$; $2.50 < C_{mean} \leq 3.45$

N. tournoueri $\bar{A}_i > 41.00$; $C_{mean} > 3.45$

This proposal has never been adopted by other researchers, but its use should be implemented. The data obtained in the present analysis are also suggesting a change of the mean value of \bar{A}_i , from 38 to 37, for the upper limit of *praemarginata*. These boundaries should allow to attenuate the deviations of \bar{A}_i and C_{mean} , including them all within the most advanced evolutionary stage of *Nephrolepidina*, and thus obtaining less confusion not only at the taxonomic, but also at the biostratigraphic level. Therefore, the modification proposed by Schiavinotto (1996) seems to be consistent in this case, although it awaits further confirmations, because the data about the total range of the oscillations caused by the environment, and also by possible resedimentation/reworking processes, are not exhaustive as yet.

Neanic acceleration

The scatter diagram FD5-SI5 in text-figure 9 might be a significant representation of the trend that is defined as neanic acceleration. The mean values of TV populations are plotted keeping the high correlation between the mean values of the two variables. These results evidence that the herein investigated *Nephrolepidina* populations can be differentiated from the more primitive and from the more evolved stages of *Nephrolepidina*, at the level of the studied ontogenetic stage of the 5th pseudo-annulus, on the basis of the “Degree of Stolonization” 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 1994b).

Therefore, as confirmed also by Schiavinotto (2016), 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 Stolonization”;
- 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 Stolonization” in *Nephrolepidina* from Tre Valloni provide another quantita-

tive definition of the ontogenetic development already described qualitatively by Grimsdale (1959), Eames et al. (1962), Sirotti (1982a; 1982b) and Adams (1987) for *Nephrolepidina*, and by Van Gorsel (1975; 1978) for *Orbitoides* and *Lepidorbitoides*.

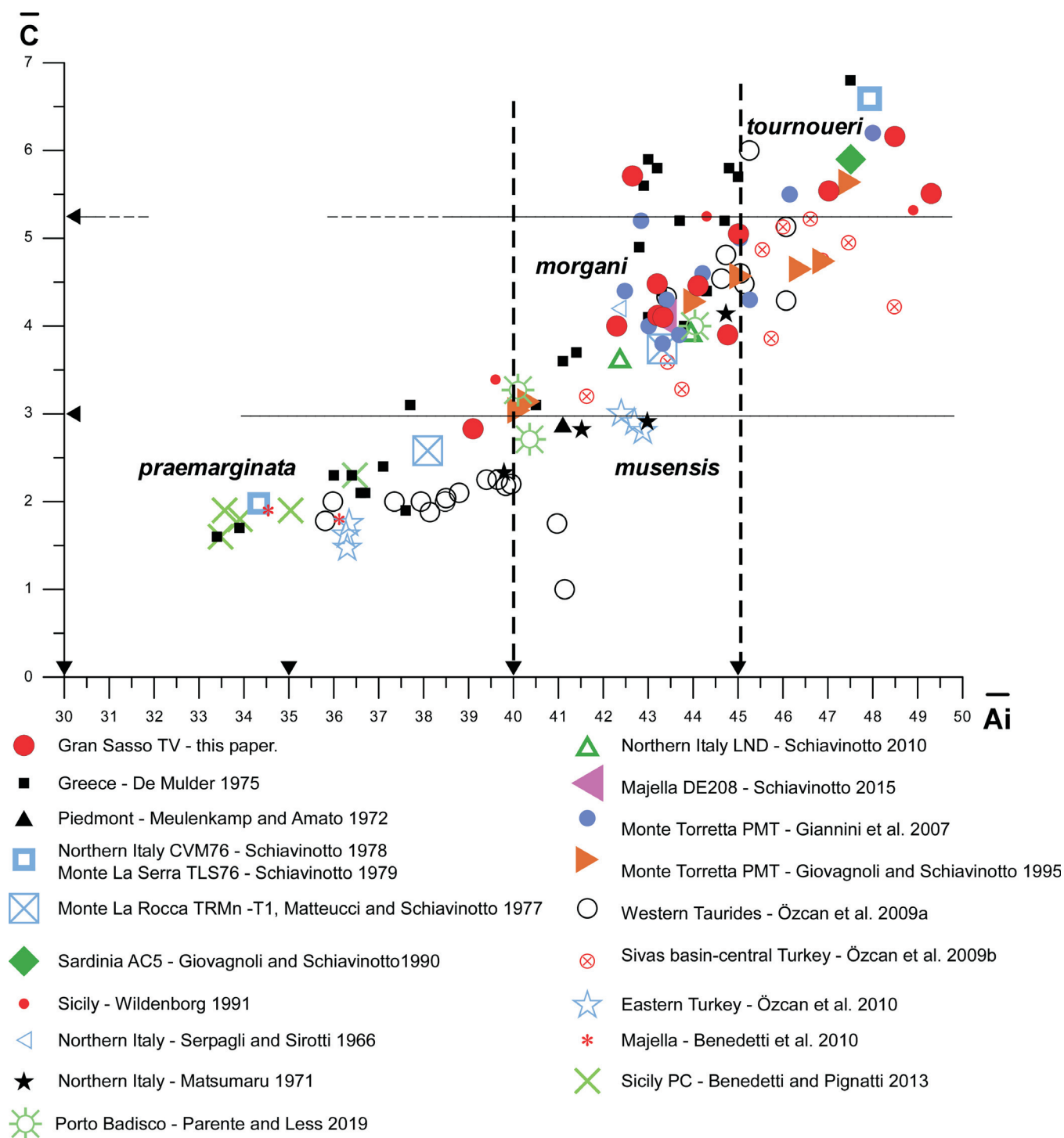
Neanic chamberlets are arranged in pseudo-annuli possibly resulted from a very tight logarithmic spiral (Benedetti 2014) involving in a tendency through time to achieve faster ontogenetical steps. Changes in the equatorial chambers during growth in lepidocyclinids have been more recently explained by the study of chamberlets’ shape (Hohenegger and Torres-Silva 2020) allowing the reconstruction of the entire equatorial plane to understand the spirals generating by the chamberlets arrangement. The modification through time of spirals in LBF has been recently related to the golden selection (Benedetti 2014; 2020), a trend of neanic acceleration with high potential in testing evolutionary variations in chronospecies.

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 (concylic) 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 pseudo-annuli are emphasized, although FD5 shows a more linear trend of increase through time (text-fig. 7).

The \bar{A}_i - FD5 and C - FD5 scatter diagrams (text-fig. 10a-b) evidence that population are arranged in agreement with the previously detected combined trends towards higher values. Both the shape of the chambers and the type and position of the stolons are considered a feature of taxonomic value, at the specific level (Eames et al. 1962, p. 298; Adams 1987). Consequently, the data obtained here confirm that 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, as hypothesized in Schiavinotto (1993).

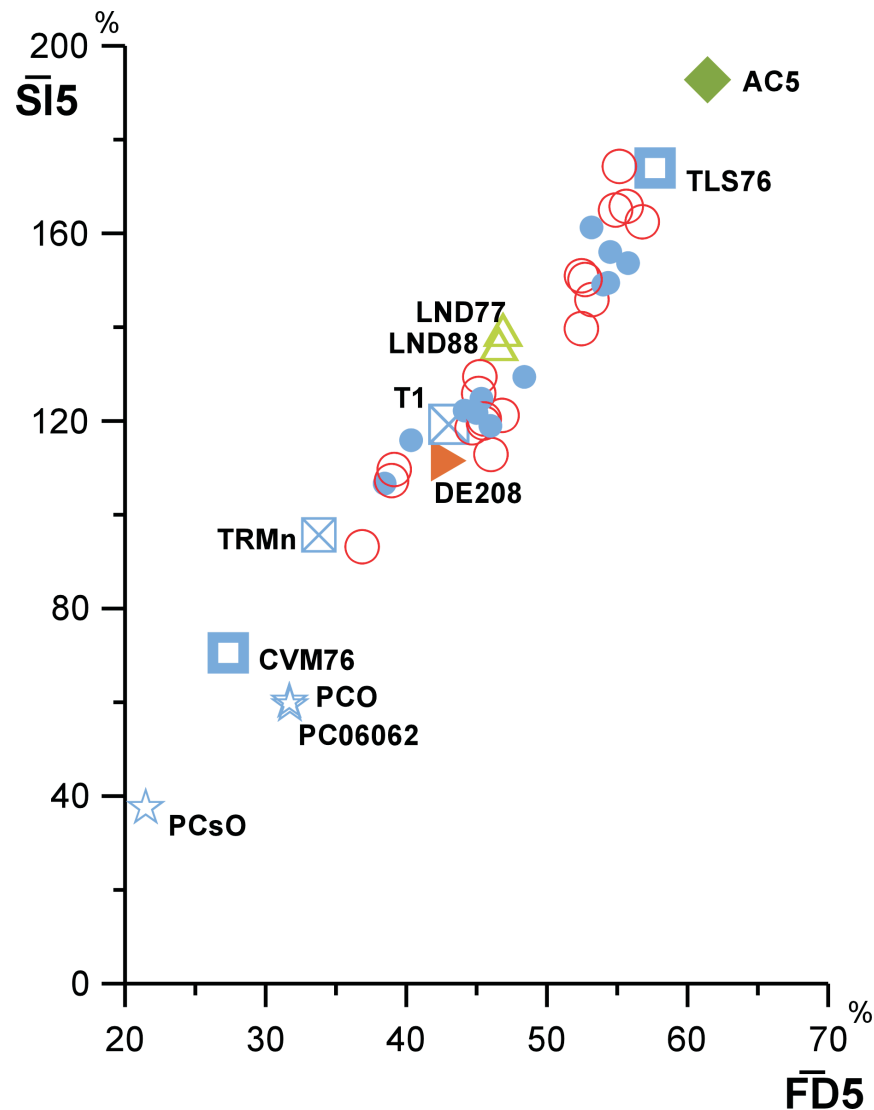
Text-figure 11 shows the relationship between the diameters of the two embryonal chamberlets and the indexes indicating neanic acceleration. Although the embryo size has an important evolutionary value in nummulitids (e.g., Less et al. 2008; Benedetti et al. 2018; Parente and Less 2019) and orthophragminids (Less 1987), and it is also considered of taxonomic relevance in *Nephrolepidina* (Özcan et al. 2009a; Boukhari et al. 2008), Benedetti et al. (2010) and Benedetti and Pignatti (2013) consider protoconch size in *Nephrolepidina praemarginata* as dependent from ecological, i.e., paleobathymetrical, factors. Thus, the relationship between embryonic chamberlets and neanic acceleration suffers from the depth dependence of embryo size itself.

Scatter diagrams of text-figure 12 suggest a strict direct correlation between the grade of enclosure of the protoconch by the deuteroconch and the shape of neanic chamberlets. Since the subjectivity to count the number of chamberlets around the deuteroconch (parameter C) and the difficulty to have perfect oriented embryonic apparatus to intercept all the adauxiliary chamberlets, the consideration of the neanic variables in the tax-



TEXT-FIGURE 8

Ai vs C scatter diagram for mean values most available data on the Mediterranean *Nephrolepidina* populations.



TEXT-FIGURE 9

FD5 vs SI5 scatter diagram with data from all populations for which the neanic chamberlets have been investigated (Schiavinotto 1992, 1994a, 1994b, 2010, 2015; Benedetti and Pignatti, 2013). White dots are data from Monte Torretta, L'Aquila (Schiavinotto 2016); blue full dots are from this work (section TV).

onomic identification of *Nephrolepidina* appears to be very promising.

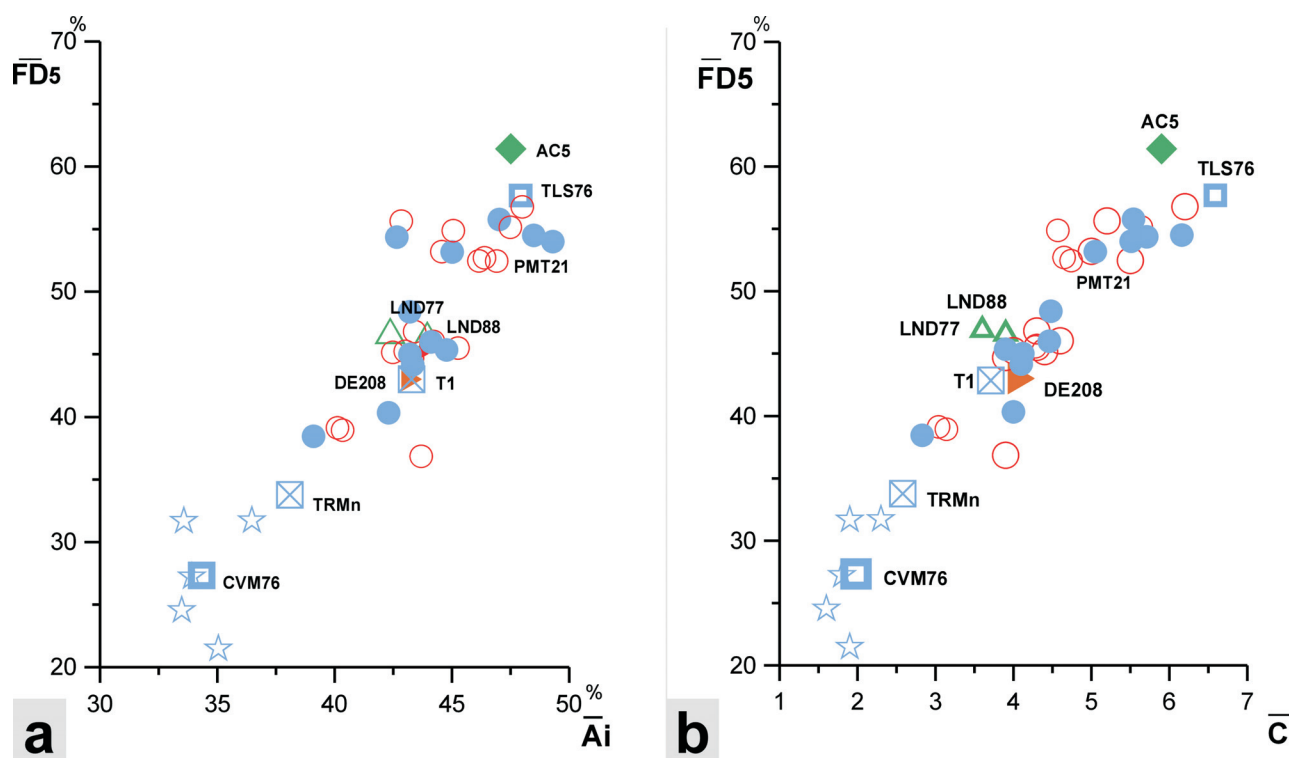
Some possible boundaries between chronospecies are indicated in text-figure 12. The populations might be separated in two main groups, placing a first boundary at FD5=50% and SI5=140%. These limits separate a low-intermediate evolutionary stage of *N. tournoueri* defined according to the Ai-C range proposed by Schiavinotto (1996).

Some new boundaries can be proposed between species according to methodology used by Van Vessel (1978) to distinguish the species belonging to the Indo-Pacific lineage, when no significant changes are evidenced by increasing mean Ai values. In these cases the subdivision must be based entirely on another character; this is effectual especially in cases of stasis of one of the two variables (Van Vessel 1978, p. 121; Drooger 1993).

Nephrolepidina praemarginata is restricted to the lower part of both scatter diagrams of text-figure 12 and it is characterized by mean values of Ai<37%, FD5<32% and SI5<80%. A second field is defined by Ai ranging from 37% to 40% and FD5 varying between 32% and 40%, or SI5 between 80% and 110%. The population TRMn, described by Matteucci and Schiavinotto (1978) and occurring in this sector, could be indicative of a new species, preliminarily designated as *Nephrolepidina* n.sp. A.

The field of *N. morgani* is defined by Ai between 40% and 45% (sensu De Mulder 1975) and FD5 ranging from 40% to 50% or SI5 from 110% to 140%.

Again, a boundary at FD5=50 and SI5=140% up to FD5=55% and SI5=160% can define a new species, described provisionally as *Nephrolepidina* n.sp. B.



TEXT-FIGURE 10

a) Ai-FD5 scatter diagram; b) C-FD5 scatter diagram. Stars are data from Sicily (PC populations of Benedetti and Pignatti 2013); white dots are data from Monte Torretta, L'Aquila (PMT populations of Schiavinotto 2016); blue full dots are from this work (populations TV).

Another upper boundary could be identified at FD5=60% and SI5=180%, in order to mark the significant differences found between the TLS76 and AC5 populations by Schiavinotto (1992). Taking into account the values measured from some photographs of the type and topotypic specimens found in literature (Drooger and Socin 1959; Vervloet 1966; De Mulder 1975; Ellis and Messina 1940 et seq.), a possible delineation of the TLS76 population as a new species could be also hypothesized (described as *Nephrolepidina* n. sp. C in the systematic part).

An exhaustive definition of the new species, can be obtained only with a biometrical analysis, at the neanic level, of typical/topotypic material of the numerous species that have been erected on the basis of typological approach

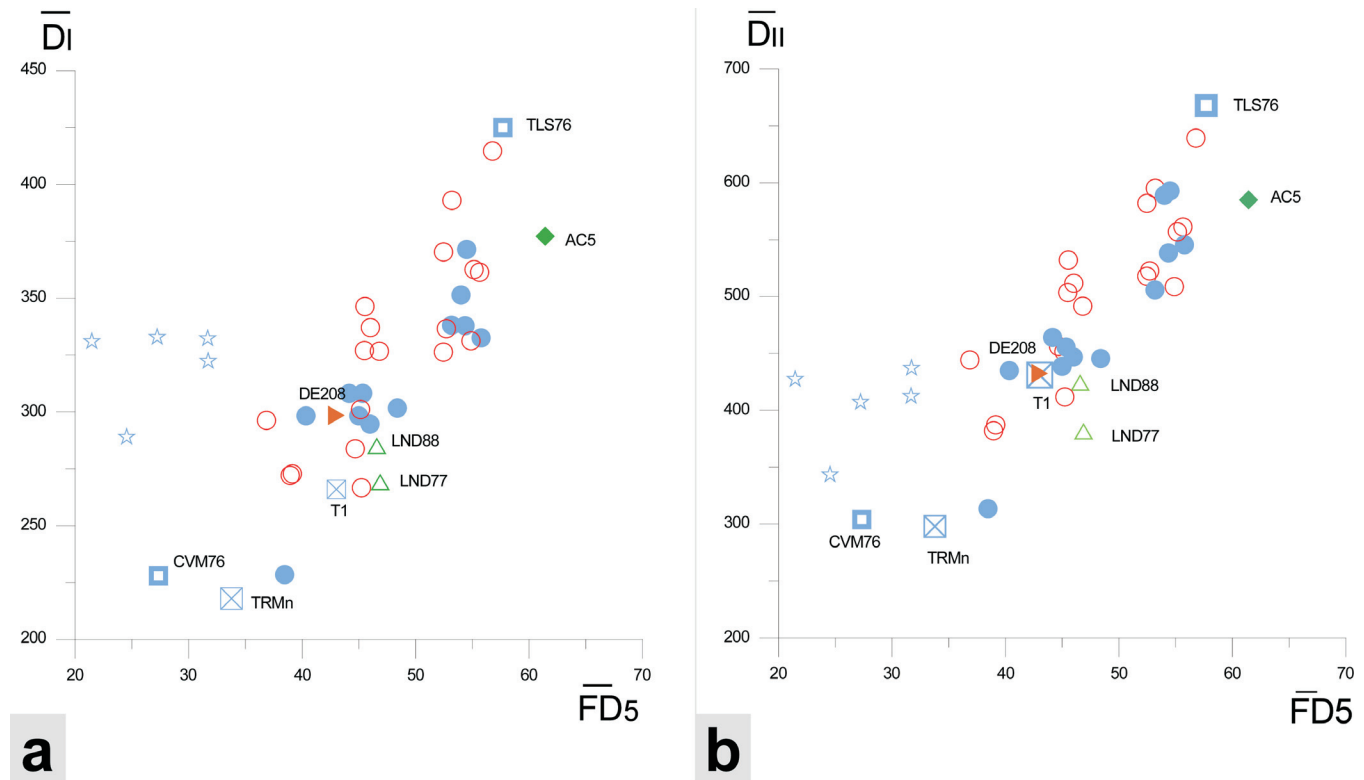
Depositional environment

Schiavinotto and Verrubbi (1994a) interpreted the herein investigated stratigraphic succession as derived from a deposition along a slope in which tectonic instability and eustatic variation caused frequent turbiditic episodes. In the Central Apennines Eocene-Oligocene LBF calcarenites were usually deposited along the margin of the former Cretaceous platform (e.g., Tomassetti and Benedetti 2020). Lepidocyclinids, such as *Nephrolepidina*, settled up to the limit of the photic zone in respect to miogypsinids that were possibly restricted to shallower environments (e.g., Hottinger 1997), thus the upsection variation in number of *Miogypsina* and decrease in *Nephrolepidina*, instead of competition causes, as suggested by Schiavinotto and

Verrubbi (2000), is more possibly linked to a shifting of the source area of the displaced material.

Van Konijnenburg (1997) suggested that the skeletal turbidite deposits of the Venacquaro Formation are coeval with patch reefs, which occur as isolated relics on the upper slope and record downward shift of facies during sea-level lowstand. The lowermost displaced LBF assemblages coincide almost with the sea-level fall at about 32 Ma (late Rupelian, Haq et al. 1988), when the carbonate factory was mostly characterized by abundant *Nephrolepidina*, which as above stated commonly settle deeper environments in respect to miogypsinids, with no significant reworking. The dramatic sea-fall at about 30 Ma (Haq et al. 1988) lead to the erosion of shallow-water deposits (van Konijnenburg et al. 1999), thus involving also the displacing of *Miogypsinoides* from shallower water. During Chattian epoch, the sea-level fluctuations favoured the deposition of both displaced and reworked material belonging to both lepidocyclinids and miogypsinids, up to the low-stand phase near the Oligocene-Miocene boundary. In the Tre Valloni section this stratigraphic interval corresponds to the transition between Venacquaro and Glauconitic Calcarenite Formations and it is characterized by the occurrence of *Nephrolepidina* without miogypsinids.

During the Aquitanian-Burdigalian interval, possibly due to sea-level rise linked to a transgressive phase, a mixing of miogypsinids and lepidocyclinids were transported downslope, but at the same time older miogypsinids were eroded and reworked possibly along submarine channels. Up section, the increase in *Miogypsina*, with the co-occurrence of *M. gunteri* and



TEXT-FIGURE 11

a) FD5-DI scatter diagram; b) FD5-DII scatter diagram. Stars are data from Sicily (PC populations of Benedetti and Pignatti 2013); white dots are data from Monte Torretta, L'Aquila (PMT populations of Schiavinotto 2016); blue full dots are from this work (populations TV).

reworked primitive morphotypes is noteworthy, since the uppermost samples of Tre Valloni section, investigated by Schiavinotto and Verrubbi (1994a; 1994b; 2000), recorded only reworked unispiralled miogypsinids, possibly transported also along submarine canyon and channels. The bispiralled forms, that should appear after the evolution of the *M. gunteri-tani* stage (e.g., Drooger 1993; Cahuzach and Poignant 1997) are here totally absent because they were confined in the inner ramp and they were not affected by reworking.

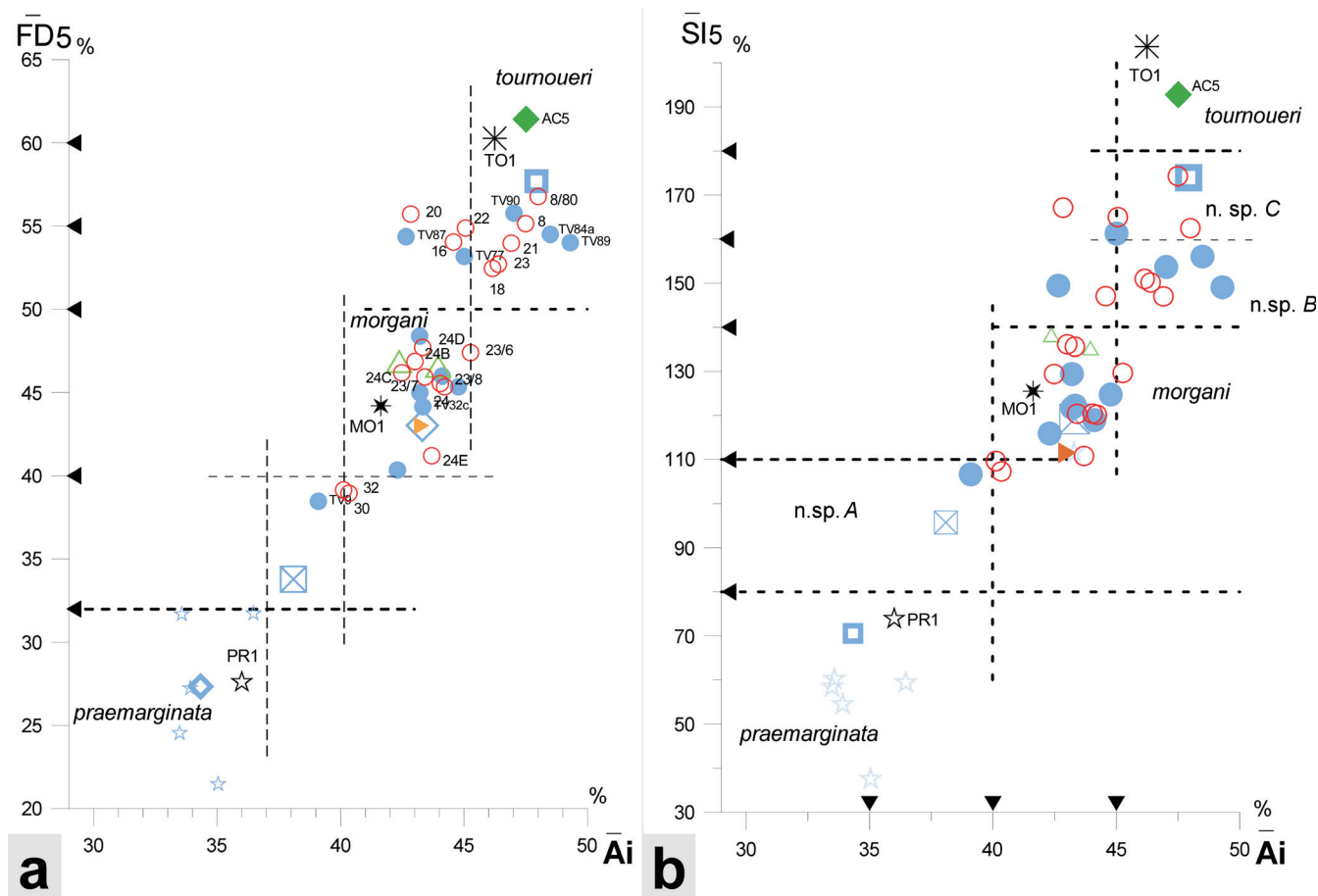
Primitive isolepidine morphotypes of *Nephrolepidina* and unispiralled miogypsinids (both with short and long spirals) are then widely reworked in the sediments of Glauconitic Calcarene Formation in association with displaced tribirolepidine *Nephrolepidina*.

In the whole Central Apennines area, Paleogene to Lower Miocene sediments were involved in turbiditic and gravity flows, complicated by the occurrence of channels and canyons. The source area of the allochthonous components is still a conundrum, since there are no records of in situ shallow-water platform in the whole area except for some isolate evidences of seagrasses (e.g., Tomassetti et al. 2016). Brandano (2017) hypothesized the existence of a shaved-isolated platform exposed to intense wave action that eroded and contributed to remobilize down-slope shallow-water material. Bispiralled morphotypes of miogypsinids, such as *Miogypsinina globulina*, not occurring in the herein investigated succession, are documented from SW sedimentary successions such as Monte Torretta (Delicati and

Schiavinotto 1985) and Monte La Serra (Schiavinotto 1979), thus suggesting that these zones were possibly more close to the originating distribution of this shallow water taxa.

The identification of the source area is not an aim of this work, but it is possible to conclude that Venacquaro Formation was probably deposited along the base of a slope where turbiditic flow periodically remobilized uncemented material from shallower environments (middle-distal ramp). Glauconitic calcarenites are the results of resedimentation of shallow-water components in a prograding system following a transgressive phase.

The block-diagram of text-figure 13 is a schematic representation of the Miocene scenario of the Gran Sasso slope. Evolved bispiralled miogypsinids and tribirolepidine morphotype of *Nephrolepidina* settled in outer inner ramp to middle ramp environments. The shallow-water LBF, except the more proximal, undisturbed, bispiralled miogypsinids, were frequently displaced by different kind of currents and fluxes, mainly turbidity flows, downslope, where they were mixed with reworked material (also unispiralled miogypsinids and isolepidine morphotypes of *Nephrolepidina*) eroded from submarine canyons. The base of slope calcarenite deposit suffers from the mixture of coeval allochthonous (displaced shallow benthic organisms) and autochthonous (mainly planktonic foraminifera) taxa with exhumed and reworked isolated taxa coming from as yet poorly consolidated sediments deposited along the ramp slope.



TEXT-FIGURE 12

a) Ai vs FD5 scatter diagram; b) Ai vs SI5 scatter diagram. Symbols as in previous figures. PR1: mean measures taken on the photographs of the figured topotypic material available for *N. praemarginata* (Vervloet 1966; De Mulder 1975; Ellis and Messina 1940-et seq.); MO1: mean measures taken on the photographs of the topotypes of *N. morgani* (De Mulder 1975; Ellis and Messina 1940-et seq.); TO1: mean measures taken on the photograph of the topotypes of *N. tournoueri* (Drooger and Socin 1959; De Mulder 1975; Ellis and Messina 1940-et seq.).

Biostratigraphic remarks

The deposits of Venacquaro Formation are characterized by autochthonous pelagic biota and allochthonous shallow-water bioclasts mainly composed by *Nephrolepidina*. No (or very little) account was done by van Konijnenburg (1997) to previous researches in the same area or its neighbours, focused on the planktonic foraminifera (Sartoni 1974), nannoplankton (Baumann 1970) and LBF (Renz 1936; Pieroni 1965; Matteucci and Schiavinotto 1978). The same issue is reflected in the age assigned to Venacquaro and Glauconitic Calcarene Formations in Cardello and Doglioni (2015).

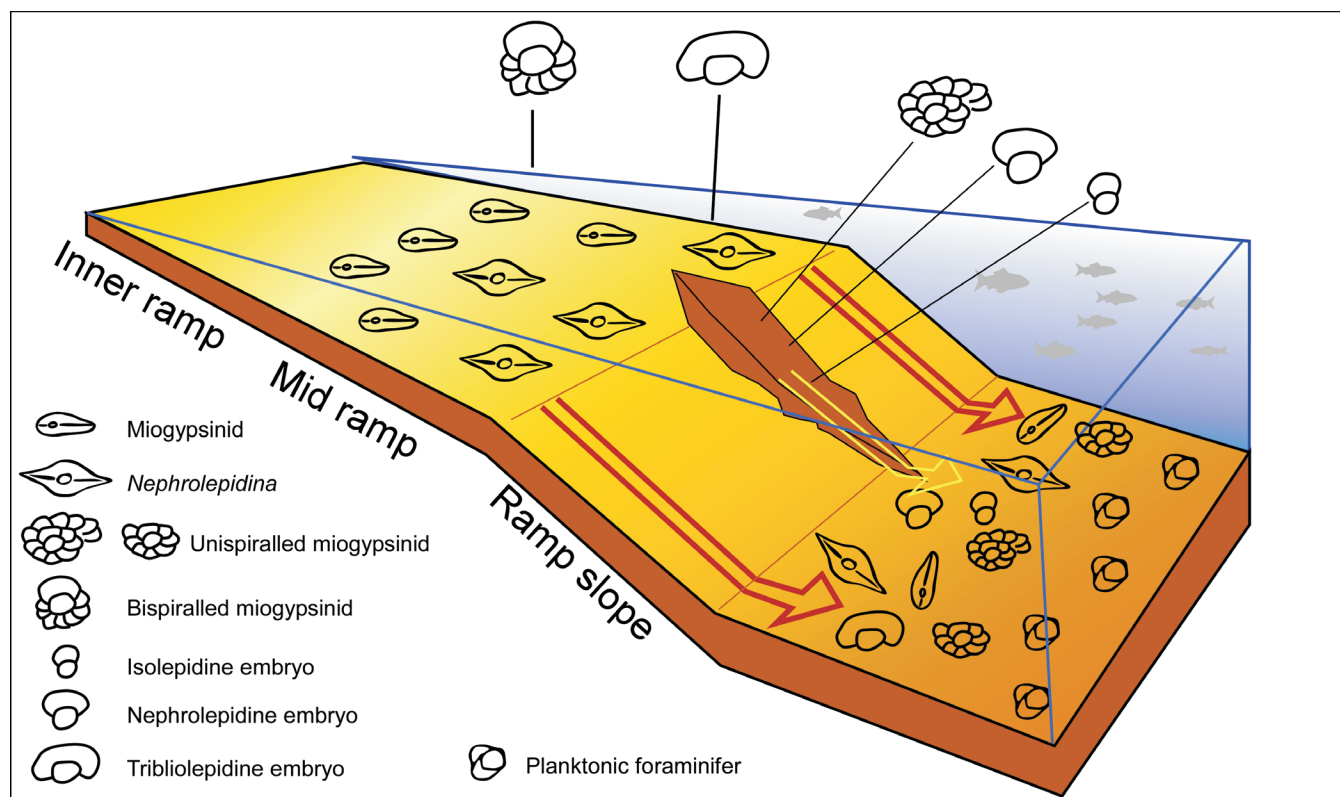
Van Konijnenburg et al. (1998; 1999) based their biostratigraphy of the base of slope sedimentary units on planktonic organisms in pelagic limestones, determined in thin sections and considered LBF occurring in redeposited limestone to be of limited use. Their biozone subdivision (Fig. 5 of van Konijnenburg et al. 1999) follows, with modifications, the zonal scheme for the Gran Sasso by Dela Pierre and Clari (1994), which is correlated with the chronostratigraphic scheme of Haq et al. (1988).

Genera and groups of species of planktonic foraminifera date the Venacquaro Formation as middle to late Oligocene P2- P22 which is in line with the age of the redeposited LBF *Eulepidina* sp. and *Nephrolepidina* sp. (van Konijnenburg et al. 1999, p. 308).

Indeed, LBF are proved to be useful biostratigraphic markers also in absence of autochthonous fossils when they are considerably recognizable as displaced and not reworked (e.g., Benedetti 2010; Benedetti et al. 2018).

The reliable data obtained here allow to complete a large part of the biostratigraphic correlation between *Miogypsina* and *Nephrolepidina* in the central Apennines. Only the co-occurrence of the opposite sides of the time-ranges of both Mediterranean lineages remain undetected, that is the more primitive *Miogypsinoides complanatus-formosensis* (early stages) and *Nephrolepidina praemarginata* (early-intermediate stages) and the more evolute *Miogypsina cushmani-mediterranea* with the final stages of *Nephrolepidina tournoueri*.

The *Nephrolepidina* population in TV9 may be referred to the middle Chattian (upper SBZ22B) since it is at an evolutionary stage close to that in the sample TRMn of Monte la Rocca, the



TEXT-FIGURE 13
Hypothetical reconstruction of the Gran Sasso toe of slope during the Miocene with the depositional model.

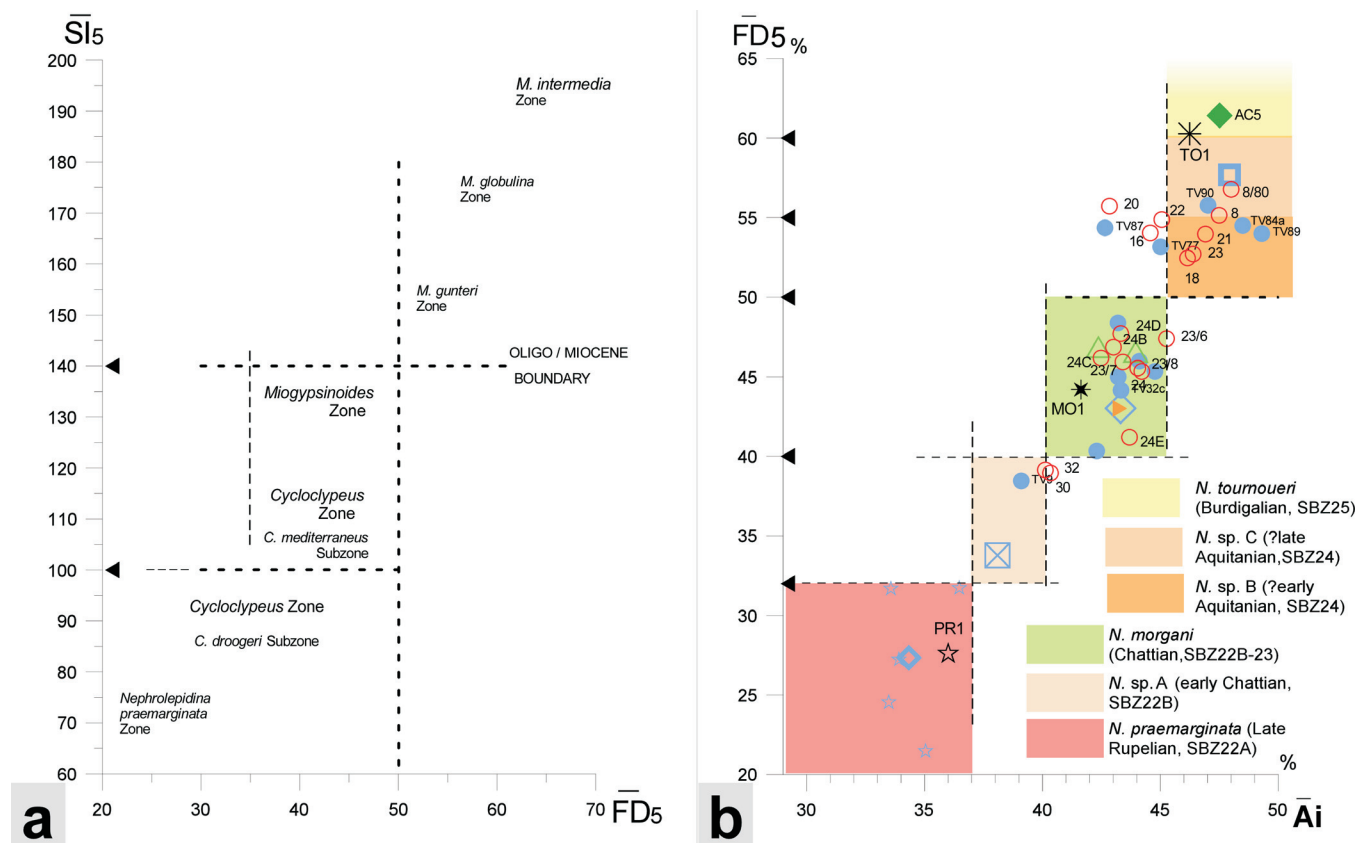
type level of *Cyclocypeus droogeri* (Matteucci and Schiavinotto 1978; 1985). There, *Cyclocypeus* has an average value of the number of nepionic chambers higher than that of other populations in the Mediterranean area (Laagland 1990); therefore, a reference of TV9 rather close to the middle part of the *Cyclocypeus droogeri* subzone (middle-high part of the *G. opima opima* Zone) seems reliable. The biometric analysis of the miogypsinids allows to confirm the sequence of unispiralled species reported in Schiavinotto and Verrubbi (1994). The presence of *Cyclocypeus* in the samples TV9 to TV55 suggests at least a Chattian age for the deposits. Miogypsinidae appear in Sample TV52, with few specimens of *Miogypsinoides* cf. *complanatus* (Pl. 1, fig. 1, not investigated biometrically herein), and associated with lepidocyclinids referable to *N. morgani*, detected biometrically in the samples immediately below (TV32c) and above (TV55). A direct use of the vertical distributions of *Cyclocypeus* in the Gran Sasso section is hampered by its bad state of preservation, thus preventing biometric assignment at species rank. The occurrence of genus *Miogypsinoides* is however sufficient to constrain the age of sample TV52 at least to SBZ23 (Cahuzac and Poignant 1997).

According to the absence of miogypsinids, the presence of *Cyclocypeus* and *N. morgani* samples TV32c to TV42 may be referred to SBZ22B of Cahuzac and Poignant (1997). The occurrence of *Miogypsina basraensis* in association with *Miogypsinoides* ex.interc. *formosensis-complanatus* and *Cyclocypeus* in sample TV55 suggest a late Chattian age (SBZ23 of Cahuzac and Poignant 1997). An almost similar assemblage is found in TV69.

The sample TV77 can be assigned to the lowermost Aquitanian (lowermost SBZ 24), in absence of *Cyclocypeus* and miogypsinid markers, by the occurrence of an advanced stage of *N. morgani* according to data of embryo-nepionic acceleration (*N. ex. interc. tournoueri-morgani*) assigned to *N. sp. B* according to the values of neanic acceleration (see below and in the systematic paleontology).

According to Cahuzac and Poignant (1997) and Özcan et al. (2009a; 2010), *N. morgani* has a long stratigraphic range from the upper Chattian to the lower Burdigalian (SBZ 22B to the earliest part of SBZ 25) while *N. tournoueri* spans from the uppermost Aquitanian to the whole Burdigalian (late SBZ 24 and SBZ 25).

Nephrolepidina at the maximum evolutionary degree of Ai and C, characteristic of *N. tournoueri* according to the embryo-nepionic acceleration, reached in populations TV84a, TV89 and TV90, is found again associated with the first evolutionary stages of *Miogypsina gunteri* and of *Miogypsinoides bantamensis*; the same evolutionary degree had been recognized previously only in populations associated with *M. globulina* and *M. intermedia* and referred to the upper Aquitanian-Burdigalian (Drooger and Socin 1959; Drooger and Freudenthal 1964; De Mulder 1975; Schiavinotto 1979; Drooger and Laagland 1986; Giovagnoli and Schiavinotto 1990). No significant statistical differences among these populations are recognizable by values of Ai and C. According to some data, however, the nepionic acceleration seems to happen at a lower rate than does the embryonic acceleration; for exam-



TEXT-FIGURE 14

Biostratigraphic constraints in FD5-SI5 according to Laagland (1990) (a) and Ai-FD5 (b) scatter diagrams according to Cahuzac and Poignant (1997).

ple, in TV84a, C is significantly lower in comparison with the population TLS76 of Monte La Serra (Schiavinotto 1979), while the values of Ai are perfectly comparable. These LBF assemblages are referred to the SBZ 24 Zone of Cahuzac and Poignant (1997) mainly based on the miogypsinids indicating an Aquitanian age.

The transition between Vanacquaro and Glauconitic Calcarene Formations is not well-defined in the herein investigated section, respect to the literature data (van Konijnenburg et al. 1998; 1999; Cardello and Doglioni 2015), but it is only marked by a lithological variation (Schiavinotto and Verrubbi 1994a). The limit between the two formations corresponds to the first occurrence of *M. gunteri*, thus suggesting that it may coincide with the Chattian-Aquitanian boundary or possibly the uppermost Venacquaro Formation includes part of the lowermost Aquitanian. The occurrence of *Miogypsina gunteri* and *Miogypsinoidea bantamensis* up-section suggests an Aquitanian age also for the Glauconitic Calcarene Formation. Despite the statistical methodologies adopted in this work, as concern the uppermost samples some kind of undetected reworking, that contributes to decrease the stratigraphic potential of LBF, cannot be ruled out. On the basis of the present knowledge, it could not been also excluded that these populations also are the result of shifting from the trends caused by environmental factors. (Schiavinotto and Verrubbi 1994a; 1994b). Consequently, according to all the collected data, it seems useful to

focus the attention on the neanic characters of *Nephrolepidina*, i.e., shape of equatorial chamberlets, in order to improve the stratigraphic potential of this LBF in the Mediterranean area.

Therefore, from the scatter diagrams in text-figure 14 the following biostratigraphic subdivision is suggested:

the mean values FD5 = 32 and SI5 = 80 as boundaries between Rupelian and Chattian;

the mean values FD5 = 50 and SI5 = 140 as possible boundary between Chattian and Aquitanian (some other measurements are needed to confirm);

the mean values FD5 = 55 and SI5 = 180 as boundary between Aquitanian and Burdigalian.

According to these proposals, the populations generally attributed to the species *N. praemarginata* following the criteria by De Mulder (1975) can be referred to the upper Rupelian (SBZ22A) when FD5 = 32 and SI5 = 80; *Nephrolepidina praemarginata* with 35 < FD5 = 50 and 100 < SI5 = 110, namely *N. sp. A* in this work, marks the lower Chattian (SBZ22B); *N. morgani* remains a long-ranging taxon spanning from the Chattian to the Aquitanian; *Nephrolepidina tornoueri* with 50 < FD5 < 55 and 140 < SI5 < 160 as indicators of Aquitanian (here named *N. sp. B*); whereas *N. tournoueri* with

FD5>55 and SI>160 characterize the whole Burdigalian (*N. sp. C* and *N. tournoueri* s.s.).

Considering again the $\bar{A}i$ - FD5 scatter diagram, redrawn in text-figure 14, three main fields might be seen, placing a first tentative boundary at $\bar{A}i = 45$ and FD5 = 50.

This may be the indication of a new, still rough path towards a tentative reassessment of the *Nephrolepidina* Mediterranean lineage, that must be checked by means of new data on calcareous nannofossils, planktonic foraminifera and/or geochemical methods.

SYSTEMATIC PALEONTOLOGY

Order Rotaliida Delage and Hérouard 1896

Family Miogypsinidae Vaughan 1928

Genus *Miogypsinoides* Yabe and Hanzawa 1928

Miogypsinoides formosensis Yabe and Hanzawa 1928

Plate 1, figures 4-5

Miogypsina (Miogypsinoides) dehaartii van der Vlerk var. *formosensis* YABE and HANZAWA 1928, p. 534, figs. 1 a-b.

Miogypsina (Miogypsinoides) complanata Schlumberger.– PIERONI 1965, p. 168, pl. 3, figs. 4-7.

Miogypsina formosensis (Yabe and Hanzawa).– TJALSMA 1971, p. 118.

Miogypsina (Miogypsinoides) formosensis Yabe and Hanzawa.– DE BOCK 1976, p. 15. – FERRERO MORTARA 1987, p. 140, fig. 4c-d, pl. 2, figs. 1-8 pars, pl. 3, figs. 1-3.

Miogypsinoides formosensis Yabe and Hanzawa.– FERRÁNDEZ-CANADELL and BOVER-ARNAL 2017, p. 101, figs. 11A-11K.– AL NUAIMY 2017, p. 542, figs. 5-8; pl. 3, figs. 1-6.

Description: Bilocular embryo in apical position with a relatively long nepionic spiral consisting of 9 to 24 chambers occurs (mean 16.25) in the investigated population. The protoconch ranges from 85 to 239 μm (mean 152 μm). The fan-like apparatus is characterized by the occurrence of intraseptal canal system necessary to discriminate between

Miogypsina and *Miogypsinoides* from oriented equatorial sections (De Bock 1976).

Biometric boundaries: $13 < X_{\text{mean}} < 17$.

Distribution: *Miogypsinoides formosensis* is commonly described in association with *Miogypsina basraensis* (e.g., Ferrero Mortara 1987; Al Nuaimy 2017). It is a marker of upper Chattian (SBZ23) of Spain (Ferrández-Cañadell and Bover-Arnal 2017), Southern, Central and Northern Italy (Pieroni 1965; Serpagli and Sirotti 1966; Ferrero Mortara 1987; Wildenborg 1991) and Iraq (Al Nuaimy 2017).

Miogypsinoides ex. interc. *complanatus* Schlumberger 1900 et *formosensis* Yabe and Hanawa 1928

Plate 1, figures 2-3

Description: The more primitive population in our samples in term of number of nepionic chambers (10–23, mean 17). The mean value of X recorded fits perfectly with the boundary between two chronospecies. The protoconch measures 85 μm (mean 141 μm).

Biometric boundaries: $X_{\text{mean}} = 17 \pm \text{Se}$.

Distribution: It occurs associated with *Miogypsina* ex. interc. *basraensis-gunteri* and *Nephrolepidina morgani* in the upper Chattian of Venacquaro Formation.

Miogypsinoides bantamensis Tan Sin Hok, 1936

Plate 1, figures 6-9

Miogypsinoides complanata forma *bantamensis* TAN SIN HOK 1936, pp. 48-50.

Miogypsina (Miogypsinoides) bantamensis Tan Sin Hok.– DE BOCK 1976, p. 15, pls. 1-14, 26, 33, 41.

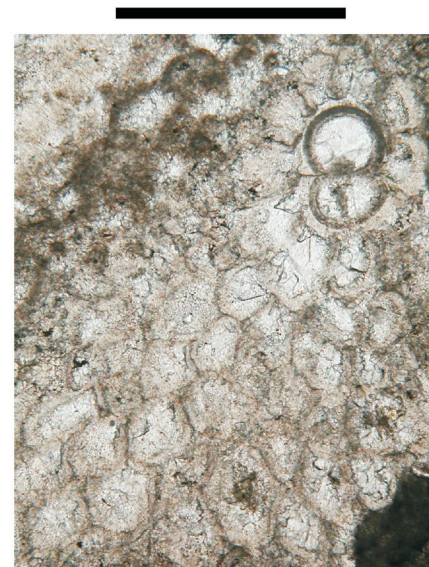
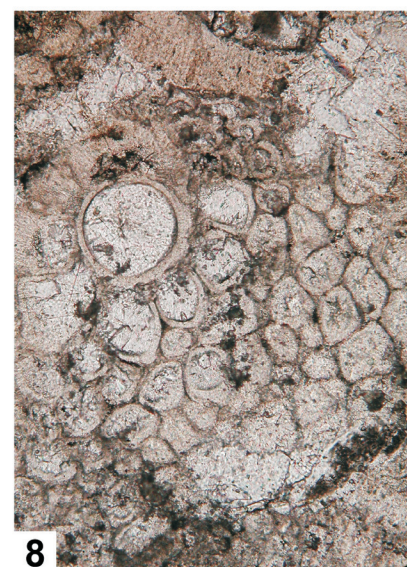
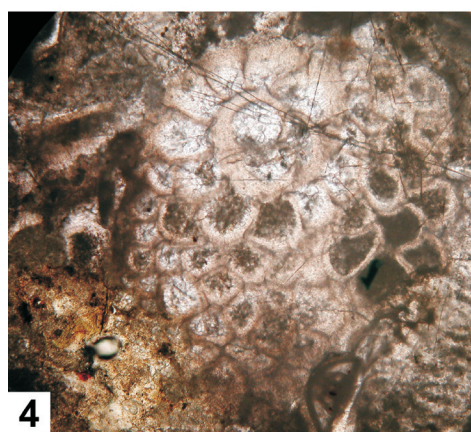
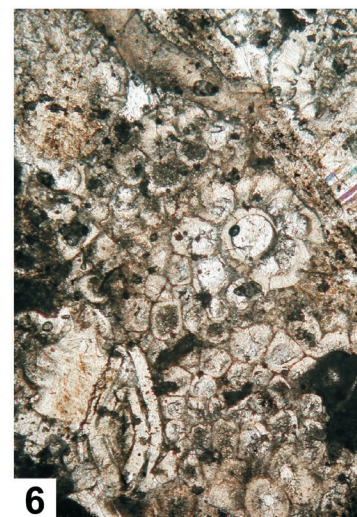
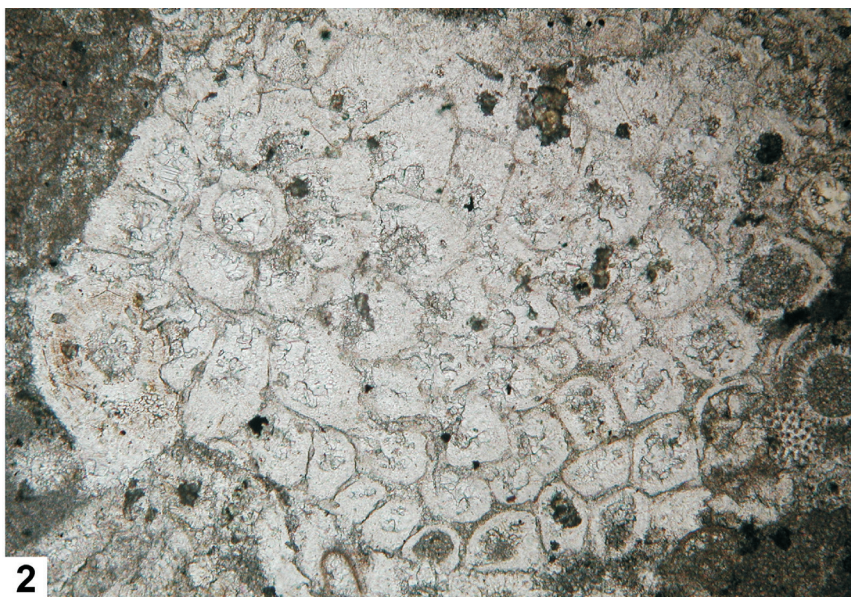
– SCHIAVINOTTO 1985, pl. 1., figs. 1-6.– FERRERO MORTARA 1987, p. 142, fig. 4e, pl. 3, figs. 4-5, pl. 4, figs. 4-8.– ÖZCAN et al. 2009b, p. 569, pl. 2, figs. 30-31; pl. 3, figs. 1-6, 20-24; text-fig. 10.

Description: Bilocular embryo in apical position. The protoconch size ranges from 74 to 341 μm (mean: 154–186

PLATE 1

Selected individuals of *Miogypsinoides* from Tre Valloni section. Scale bar = 0.5 mm.

- | | |
|--|--|
| <p>1 <i>Md. cf. complanatus</i>, incomplete equatorial section, TV52;</p> <p>2-3 <i>Md. ex. interc. complanatus-formosensis</i>, equatorial sections showing the intraseptal canal system, 2. TV61A_5-1; 3. TV61A_3-1;</p> | <p>4-5 <i>Md. formosensis</i>; 4. TV55_1-1; 5. TV55_1-3;</p> <p>6-9 <i>Md. bantamensis</i>; 6. TV130_4-1; 7. Oblique section passing through the embryo, T114_11-1; 8. TV114_7-1; 9. TV87_9-1.</p> |
|--|--|



µm). A spiral consisting of 9–28 chambers (mean: 11.7–13.8) is followed by fan-like chambers with intraseptal canals.

Biometric boundaries: $10 < X_{\text{mean}} < 13$.

Distribution: The species usually occurs associated with *Miogypsina gunteri* from Aquitanian of Aquitaine, Italy and Turkey (e.g., De Bock 1976; Ferrero Mortara 1987; Özcan et al. 2009b). Bassi et al. (2007) reported *Md. bantamensis* from the upper Chattian of Northern Italy, and following Cahuzac and Poignant (1997) it should range from upper SBZ23 to lower SBZ25. In our sample it occurs in an assemblage with *Miogypsina gunteri*, *M. ex. interc. gunteri-tani*, *Nephrolepidina* sp. B and *Nephrolepidina* sp. C from samples assigned to Aquitanian SBZ24.

Genus *Miogypsina* Sacco 1893

Miogypsina basraensis Brönnimann 1940
Plate 2, figures 1–2

Miogypsina (Miogypsina) basraensis BRÖNNIMANN 1940, p. 86, pl. 6, figs. 2–4, pl. 8, figs. 13–17. – DE BOCK 1976, p. 17. – FERRERO MORTARA 1987, p. 143.

Miogypsina basraensis Brönnimann. – DROOGER 1952, pp. 21, 51, pl. 2, figs. 6–10, fig. 10. – AL NUAIMY 2017, pl. 2, figs. 13–15.

Description: Bilocular embryo in apical position consisting of a subspherical protoconch varying in size from about 80 to 200 µm (mean=122.08 µm). A relatively long single nepionic spiral is developed around the embryo with mean values falling within biometric boundaries below 15 and above 12.5 (range –16, mean=13.15). Later chambers become fan-like arranged.

Biometric boundaries: $12.5 < X_{\text{mean}} < 15$.

Distribution: Firstly reported here from the upper Chattian (SBZ 23) of Central Italy. This primitive taxon has been previously described from Central America (Drooger 1952), Morocco (Brönnimann 1940), Aquitaine (De Bock 1976), Iraq (Al Nuaimy 2017) and Northern Italy (Ferrero Mortara 1987).

Miogypsina ex. interc. basraensis Brönnimann 1940 et *gunteri* Cole 1938

Plate 2, figure 3

cf. *Miogypsina ex. interc. gunteri* Cole 1938 et *basraensis* Brönnimann 1940. – ÖZCAN et al. 2009b, p. 568, pl. 1, figs. 8–12, text-fig. 10.

Distribution: Population with mean number of nepionic spiral chambers close to the limit values of species *M. basraensis* and *M. gunteri*.

Biometric boundaries: $X_{\text{mean}} = 12.5 \pm \text{Se}$.

Distribution: Described from lower Aquitanian of Central Turkey (Özcan et al. 2009b). At Tre Valloni it occurs in sample TV61a associated with *Miogypsinoides ex. interc. complanatus-formosensis* and *Nephrolepidina morgani* possibly in the uppermost Chattian.

Miogypsina gunteri Cole 1938
Plate 2, figures 4–5

Miogypsina gunteri COLE 1938, pp. 1–73. – ÖZCAN et al. 2009b, p. 567, pl. 1, figs. 1–7, 13–30; pl. 2, figs. 1–5; pl. 3, figs. 26, text-figs. 9–10 (cum syn.). – AL NUAIMY 2017, pl. 1, figs. 1–17.

Miogypsina (Miogypsina) gunteri Cole. – VERVLOET 1966, p. 61, pl. 12, fig. 6. – DE BOCK 1976, p. 17, pl. 5. – DELICATI and SCHIAVINOTTO 1985, p. 107, pl. 1, figs. 1–6, pl. 2, figs. 1–4. – FERRERO MORTARA 1987, p. 143.

Description: A miogypsinid with embryonic chambers situated in apical position. The bilocular embryo is followed by a single principal adauxiliary chamber and by a 8–18 spiral chambers (mean values 10.0–12.3, Tab. 1). The proloculus diameter varies between 74 and 210 µm (mean: 131–139 µm). A thick marginal fringe occur in some unbroken specimens. The equatorial chamberlets are ogival to rhombic.

Biometric boundaries: $9 < X_{\text{mean}} < 12.5$, negative values of γ .

Distribution: The first occurrence of *M. gunteri* marks the base of SBZ25 according to Cahuzac and Poignant (1997). In our samples it occurs in assemblage with *Miogypsinoides bantamensis* and *Nephrolepidina* sp. B. It is also signalled from the Aquitanian of Sicily (Wildenborg 1991), Central Italy

PLATE 2

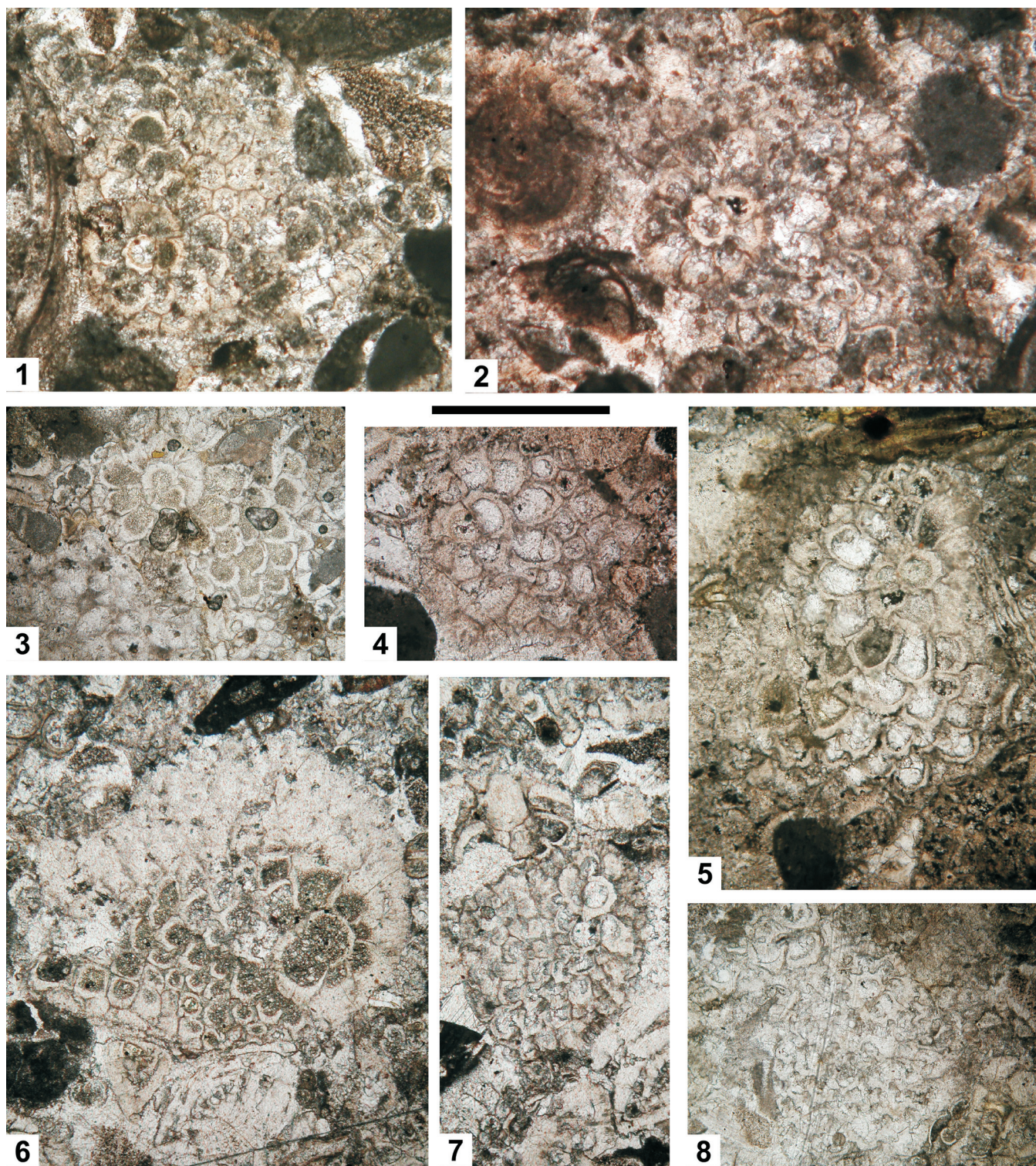
Selected individuals of *Miogypsina* from Tre Valloni section. Scale bar = 0.5 mm.

1–2 *M. basraensis*, sample TV55_2-1; 2. TV55_3-1;

3 *M. ex. interc. basraensis-gunteri*, please note the stolon between contiguous chamberlets, TV61A_12-1;

4–5 *M. gunteri*; 4. TV114_17-1; 5. TV89_14-1;

6–8 *M. ex. interc. gunteri-tani*, 6. TV130_5-1; 7. TV130_3-1; 8. TV87_17-1.



(Delicati and Schiavinotto, 1985), Northern Italy (Vervloet 1966; Serpagli and Sirotti 1967; Ferrero-Mortara 1987), Turkey (Özcan et al. 2009b), and Iraq (Al Nuamy 2017).

Miogypsina ex. interc. *gunteri* Cole 1938 et *tani* Drooger 1952
Plate 2, figures 6-8

Miogypsina ex. interc. *tani* Drooger 1952 et *gunteri* Cole 1938.–
ÖZCAN et al. 2009b, p. 568, pl. 2, figs. 6-10; text-fig. 9.

Description: Populations with mean number of nepionic spiral chambers close to the limit values of species *M. gunteri* and *M. tani*. The mean values of X measures 8.90–8.97; the protoconch varies between 74–216 µm (mean 137–141 µm).

Biometric boundaries: Xmean=9 ± Se.

Distribution: This taxon occurs in the uppermost samples of the investigated stratigraphic section of Tre Valloni. The *gunteri-tani* group is considered typical of SBZ24 (Cahuzac and Poignant 1997) although it can reach the base of SBZ25. Özcan et al. (2009b) reported populations with similar biometric values from middle Aquitanian of Turkey. We here also refer this taxon to the Aquitanian.

Family Lepidocyclinidae Scheffen 1932

Genus *Nephrolepidina* Douvillé 1911

Type species: *Nummulites marginata* Michelotti 1841

Nephrolepidina praemarginata (Douvillé 1908)

Lepidocyclina praemarginata DOUVILLÉ 1908, p. 91-92, figs. 1, 2, 4a. *Nephrolepidina praemarginata* (Douvillé).– SCHIAVINOTTO 1978, pl. 75, figs. 1-6.– BENEDETTI 2010, p. 207, pl. 4, figs. 5-6; text-fig. 9, figs. 1-4.– BENEDETTI et al., 2010, fig. 7., pl. 1, figs. 1-5, pl. 2, figs. 1-5.– BENEDETTI and D'AMICO 2012, figs. 4.7-4.12, 7.1-7.3.– BENEDETTI and PIGNATTI 2013, fig. 5a-f, fig. 6a-f.

Description: A lepidocyclinid with almost isolepidine embryo and very few adauxiliary chamberlets around the deuterococonch (up to 3). Equatorial chamberlets are arcuate to rhombic giving the optic effect of the so called “engine-turned” pattern of growth.

Biometric boundaries: Ai<37%, FD5<32% and SI5<80%.

Distribution: Usually found in the upper Rupelian (SBZ22A of Cahuzac and Poignant 1997) in Northern (Schiavinotto 1976), Central (Benedetti et al. 2010) and Southern Italy (Benedetti and D'Amico 2012; Benedetti and Pignatti 2013), Greece (De Mulder 1975) and Turkey (Özcan et al. 2010).

Nephrolepidina Schiavinotto and Benedetti **n. sp. A**
Plate 3, figures 1-2

Lepidocyclina (Nephrolepidina) praemarginata Douvillé – MATTEUCCI and SCHIAVINOTTO 1978, pl. 1, figs. 1-4.

Description: A lepidocyclinid with isolepidine- to nephrolepidine-type embryo and 1 to 4 adauxiliary chamberlets around the deuterococonch. Equatorial chamberlets forms intersecting curves (engine-turned) and concentric rings (Schiavinotto 1987).

Biometric boundaries: 37% <Ai<40%, 32%<FD5<40% and 80%<SI5<110%.

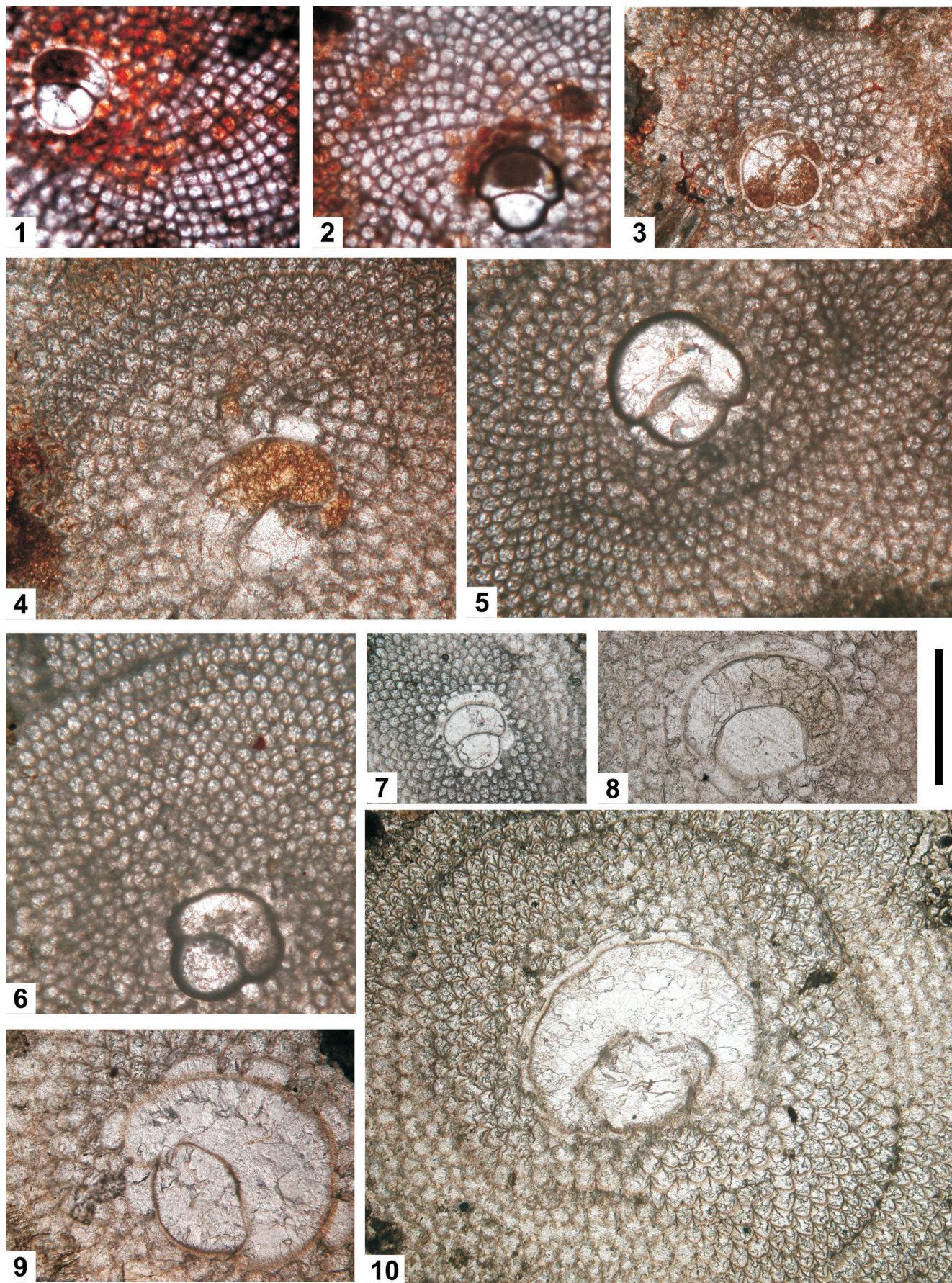
Distribution: Lower Chattian (SBZ22B) in assemblage with *Cyclocypeus droogeri*, *Eulepidina dilatata*, *Operculina* sp. and *Heterostegina* sp. (Matteucci and Schiavinotto 1985).

Remarks: *N. praemarginata* has been recently reported for the first time from the lower Chattian (SBZ22B) of Iran (Akbar-Baskalayeh et al. 2020). The study of neanic apparatus

PLATE 3

Selected individuals of *Nephrolepidina* from Tre Valloni section. Scale bar = 0.5 mm.

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| <p>1-2 <i>Nephrolepidina</i> sp. A; 1. TV9_2-5; 2. TV9_5-4;</p> <p>3-4 very different morphotypes within the <i>N. morgani</i> population TV32A; 3. Reniphorm deuterococonch embracing the protoconch, ogival neanic chamberlets, T32A_5-1; 4. Tribliolepidine specimen with hexagonal chamberlets, TV32A_1-4;</p> <p>5-6 Specimens belonging to populations referred to <i>N. sp. B</i> with clearly hexagonal chamberlets: 5. TV77_7-4b; 6. T77_1-8;</p> | <p>7 Isolepidine morphotype in sample TV32C with ogival to subhexagonal chamberlets;</p> <p>8 Subquadrate protoconch embraced by a sickle-shaped deuterococonch, TV42_64;</p> <p>9-10 <i>Nephrolepidina</i> sp. B; five adauxiliary chamberlets are clearly visible on the deuterococonch, TV84A_3-7; 10. Almost eulepidine morphotype embryo with a very large value of degree of embracement, and with hexagonal equatorial chamberlets, TV89_11. Scale bar=0.5 mm.</p> |
|--|---|



of these easternmost forms should be performed to understand whether these populations belong to *Nephrolepidina* n. sp. A.

Nephrolepidina morgani (Lemoine and R. Douvillé 1904)
Plate 3, figures 3-4, 7-8

Lepidocyclina (*Nephrolepidina*) *morgani* LEMOINE and R. DOUVILLÉ 1904, p. 12, 15, 17, pl. 1: 12, 15, 17; pl. 2: 4, 12; pl. 3: 2.–MATTEUCCI and SCHIAVINOTTO 1978, pl. 2, figs. 1-4.

Nephrolepidina morgani Lemoine and R. Douvillé.–SCHIAVINOTTO and VERRUBBI 1994a, pl. 4, figs. 3-5.–SCHIAVINOTTO 2015, pl. 1, figs. 1-6.–PARENTE and LESS 2019, p. 255, figs. 20f-h.

Description: A lepidocyclinid with nephrolepidine-type embryo and up to 9 chamberlets around the deuterocoel. Equatorial chamberlets are arranged in concentric rings, but rarely intersecting curves occur in the early neanic stage (e.g., Schiavinotto 1987).

Biometric boundaries: 40%<Ai<45, 40%<FD5<50% and 110%<SI5<140%.

Distribution: This is a long-ranging species spanning from the lower Chattian to the Aquitanian (Cahuzac and Poignant 1997; Parente and Less 2019).

Nephrolepidina Schiavinotto and Benedetti, n. sp. B
Plate 3, figures 5-6, 9-10

Nephrolepidina ex. interc. *ournoueri-morgani*.–SCHIAVINOTTO 2016, p. 80.

Description: A lepidocyclinid with tribliolepidine-type embryo and more than 5 adauxiliary chamberlets around the deuterocoel. Equatorial chamberlets are generally arranged in concentric rings around the embryo-nepionic apparatus.

Biometric boundaries: Ai>45%, 50% <FD5<55%, 140%<SI5<160%.

Distribution: Late Chattian to Aquitanian, in assemblage with *Miogypsinoides bantamensis-formosensis* and *Miogypsina gunteri*.

Nephrolepidina n. sp. C
Lepidocyclina (*Nephrolepidina*) *ournoueri* Lemoine and R. Douvillé.–SCHIAVINOTTO 1979, pl. 4, figs. 1-6.

Description: A lepidocyclinid with tribliolepidine-type embryo and more than 5 adauxiliary chamberlets around the deuterocoel. Equatorial chamberlets are arranged in concentric rings that tend to become polygonal concentric along the periphery.

Biometric boundaries: Ai>45%, 55%<FD5<60% and 160%<SI5<180%.

Distribution: Aquitanian (SBZ24) in assemblage with *Miogypsina gunteri* and *Miogypsinoides bantamensis* up to lowermost Burdigalian in assemblage with *Miogypsina globulina* (Schiavinotto 1979).

Nephrolepidina ournoueri (Lemoine and R. Douvillé 1904)
Lepidocyclina ournoueri LEMOINE and R. DOUVILLÉ 1904, p. 19, pl. 1, fig. 5.

Lepidocyclina (*Nephrolepidina*) *ournoueri* Lemoine and R. Douvillé.–DROOGER and SOCIN 1959, p. 417, pl. 1, figs. 1-4, pl. 2, figs. 1-6.–PIERONI 1965, p. 165, pl. 1, fig. 7, pl. 2, figs. 1-4, 6-8.

Nephrolepidina ournoueri Lemoine and R. Douvillé.–GIOVAGNOLI and SCHIAVINOTTO 1990, pl. 1, figs. 1-5, pl. 2, figs. 1-6.

Description: Tribliolepidine embryo, the protoconch is enveloped by a very large deuterocoel surrounded by more than 5 adauxiliary chamberlets. Equatorial plane is characterized by a polygonal concentric pattern of growth.

Biometric boundaries: Ai>45%, FD5>60% and SI5>180%.

Distribution: Burdigalian (SBZ25) in assemblage with *Miogypsina globulina* or *M. intermedia* (Giovagnoli and Schiavinotto 1990).

CONCLUSIONS

The use of LBF to date sedimentary successions is pivotal also for those depositional settings in which the planktonic foraminifera and nannofossils are lacking or in bad preservation state (e.g., Benedetti 2010; 2017). Statistical and typological analysis of Oligocene–Miocene miogypsinids from Tre Valloni (Gran Sasso) permit the recognition of statistical outliers derived from reworking, thus providing evidences of realistic stratigraphic consecutive events.

Miogypsinids are proved to be good biostratigraphic markers in having a rapid biometric evolution with short-ranged chronospecies spanning from the upper Oligocene to the Burdigalian of the Mediterranean area (Drooger 1993). The main *Nephrolepidina* lineage is instead characterized by three long-ranged species from the upper Rupelian to Burdigalian, thus preventing their use for detailed biostratigraphic correlation. The currently adopted degree of enclosure of the deuterocoel on the protoconch (Ai) and number of adauxiliary chamberlets (C) appear insufficient to describe the three known species. Also, Özcan et al. (2009a), about difficulties in discriminating *N. morgani* from *N. ournoueri*, 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-lived taxonomic problem, affecting also the biostratigraphy. In this work an integration of embryo-nepionic acceleration with neanic acceleration is proposed and the boundaries fixed according to the degree of stolon distalization (FD5). The erection of new species is then recommended by means of Ai, FD5 and SI5 values, with the aim to provide more detailed biostratigraphic constraints.

According to the collected data, the investigated succession spans from the Chattian Venacquo Formation to the lowermost Burdigalian Glauconitic Calcarenite Formation. Although the boundary between the two sampled formations is not clearly visible in the Tre Valloni section, a transgressive phase may be recorded in the Aquitanian by both lithological (e.g., van Konijnenburg 1997) and micropaleontological data.

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