

## EVOLUTION OF THE GENUS WHITEINELLA AND THE OCEANIC ANOXIC ENVIRONMENT (OAE)

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**Abstract. Evolution of the genus whiteinella and the oceanic anoxic environment (OAE).**

**Kh. Mikadze, Z. Chkhaidze.** The appearance of the genus *Whiteinella* was first recorded after the anoxic oceanic event (OAE 1d). This genus appeared in the Middle Cenomanian and continued to exist until the beginning of the Campanian. In this work, we tried to analyze the evolutionary development of this genus.

Key words: Archaeocretacea; Abasha; Carbonate.

საკვანძო სიტყვები: არხეოკრეტაცია; აბაშა; კარბონატი.

### გაფართოებული რეზიუმე

გვარი *WHITEINELLA* - ს ევოლუციური განვითარება და ოკეანური ანოქსიური მოვლენები, **ხ. მიქაძე, ზ. ჩხაიძე**. სამუშაოს მიზანია გვარის *Whiteinella* შესწავლა. გვარი *Whiteinella* პირველად აღწერილია ე. ა. პესაგნოსმიერ (Pessagno, 1967). გვარს სახელწოდება *Whiteinella* მიენიჭა ამერიკელი გეოლოგის, მ. უაითის პატივსაცემად.

გვარის *Whiteinella* წარმომადგენლებს სპირალურ-კონუსური, ხოლო კამერებს კი სფერული აგებულება აქვს. ამ გვარის პირველი წარმომადგენლები გვხვდება ალბურ-სენომანურის საზღვარზე, უფრო ზუსტად, შუა სენომანურიდან. ეს პერიოდი დაკავშირებულია ანოქსიური მოვლენის დასასრულთან. ანოქსიური პერიოდი ეს არის ოკეანურ სივრცეში ჟანგბადის ნაკლებობა და მას Ocean Anoxic Event (OAE 1d) დაერქვა. ცარცულ პერიოდში, რამდენიმე ასეთი ანოქსიური მომენტი იყო (თითოეული ასეთი ციკლი გრძელდება დაახლოებით 1 მლნ. წ.). მათ შორის, ალბურ-სენომანურის საზღვარზე დაფიქსირდა ბრეისტოფერი (OAE 1d). სწორედ ამ ეტაპის დამთავრებას უკავშირდება გვარი *Whiteinella*-ს წარმოშობა. მორფოლოგიური მახასიათებლების მიხედვით, გვარი *Whiteinella* გვარის *Hedbergella* ერთ-ერთ მოდიფიკაციას წარმოადგენს.

ახალი გვარის *Whiteinella Pessagno* წარმომადგენლების კამერებს ქედი არ გააჩნია, რითაც ეს გვარისგან *Marginotruncana Hofker* განსხვავდება. მნიშვნელოვნად განსხვავდება აგრეთვე ზომებით, კამერების რაოდენობით და პირველადი და დამატებითი აპერტურის აგებულებით. გვარს *Whiteinella* მსხვილ გლობიგერინელებსაც უწოდებენ, რომლებიც გავრცელებული იყო შუასენომანურიდან-სანტონამდე. *Whiteinella* გავს *Hedbergella*-ს ნიჟარის სფერული აგებულებით, მაგრამ მისგან განსხვავებით, უფრო რთული პერიაპერტურული სტრუქტურები აქვს, რომლებიც ბაგის ანფლაპისგან შედგება. ეს ორი გვარი საჭიროებს დამატებით შესწავლას, მათ შორის ძირითადი და დამხმარე აპერტურების აგებულების თვალსაზრისითაც. პლანქტონური ფორამინიფერების კლასიფიკაცია პირველად ჩამოყალიბდა ლოებლიკისა და ტაპანის მიერ (1961). მორფოლოგიურ

ნიშანთვისებათა შემდგომი შესწავლის საფუძველზე, სხვადასხვა დროს გვხვდება განსხვავებული კლასიფიკაციები. აღსანიშნავია, კორჩაგინის (2001), გეორგესკუსა (2010) და მარსელეზოუდაგერ-ფადელის (2015) ბოლო პერიოდის კლასიფიკაციები.

გვარის *Whiteinella* შესწავლა საქართველოში მიმდინარეობს: აბაშის და ოდიშის ბლოკებში, ლოქისა, ხრამისა და ძირულის მასივების მიმდებარე ტერიტორიებზე ზედა ცარცულ ნალექებში მოპოვებული მასალაზე დაყრდნობით.

შესწავლილია როგორც ქანებიდან დეზინტეგრირებული ნიჟარა, ასევე პეტროგრაფიულ შლიფებში ნიჟარების კვეთები. ზედაცარცული ნალექები ტეთისის ზოლში, ძირითადად წარმოდგენილია კაჟიანი კირქვებით, მერგელებისა და თიხების შუაშრეებით. კაჟიანი კირქვებიდან ნამარხი ფორმების დეზინტეგრაცია საკმაოდ რთულ პროცესს წარმოადგენს. ქანების გარეცხვის მეთოდიკა რამდენიმე ეტაპად მიმდინარეობს. გამოყენებულია: ტექნიკური სოდა ( $\text{NaHCO}_3$ ), ყინულოვანი ძმარმჟავა ( $\text{CH}_3\text{COOH}$ ), შაბიამანი ( $\text{CuSO}_4 \cdot \text{H}_2\text{O}$ ), გლაუბერის მარილი ( $\text{Na}_2\text{S}_2\text{O}_4 \cdot 10\text{H}_2\text{O}$ ) და წყალბადის ზეჟანგი ( $\text{H}_2\text{O}_2$ ). შესწავლილია დაახლოებით 1500 ნიმუში.

პრობლემა, რომლის გამოსარკვევად იქნა დაწყებული გვარის *Whiteinella* შესწავლა, ეფუძნება მსოფლიო ოკეანეში (OAE) ჟანგბადის დეფიციტის არსებობას. პირველად, ეს გვარი დაფიქსირდა სწორედ ამ უჟანგბადო მოვლენის (OAE 1d - Breistiffer) დასრულების შემდეგ. ცარცულ პერიოდში დაფიქსირებულია ჟანგბადის ნაკლებობის მოვლენების 6 ეტაპი. უჟანგბადო მოვლენის - ბრეისტოფერის (ალბურ-სენომანური) დასრულების შემდეგ, ოკეანურ სივრცეში მოხდა მკვეთრი ლითოლოგიური, ფაუნისტური და გეოქიმიური ცვლილებები. წამყვანი პლანქტონური ფორმები: *Thalmaninella* და *Rotalipora* (K-სტრატეგისტები) გადაშენდა და მათი ადგილი დაიკავა *Whiteinella*, *Hedbergella*, *Heterohelix* და *Praeglobotruncana* (r-სტრატეგისტები). გარდა ამისა, ჩნდება ძლიერ წაგრძელებული სფერულკამერებიანი ფორმები (გვარი *Schackoina*). მათი არსებობაც ჟანგბადის დეფიციტს უკავშირდება.

სენომანურ-ტურონულის საზღვარზე პლანქტონური ფორმინიფერების კომპლექსი ხასიათდება შედარებით ღარიბი ტაქსონომიური შედგენილობით. კომპლექსში ფართოდაა გავრცელებული r-სტრატეგისტები: *Whiteinella* და *Hedbergella*.

მოცემული შრომა არის r-სტრატეგისტების გაჩენისა და მათი ევოლუციური განვითარების კვლევის დასაწყისი. ვინაიდან მათ, ცოცხალი სამყაროს ევოლუციურ განვითარებაში მნიშვნელოვანი როლი აქვთ. პრიმიტიული აგებულების ფორმები უძლებს ყველანაირ კატასტროფას, მუდმივად არსებობს და შემდგომ, მათ საფუძველზე აგრეთვე, ჩნდება რთული აგებულების K-სტრატეგისტები, რომლებიც მცირე პერიოდში აღწევს სწრაფ ევოლუციურ განვითარებას და მცირედი ევოლოგიური ცვლილებების შედეგად მალევე ქრება.

შრომაში განხილულია გვარის *Whiteinella* და 9 სახეობა, რომელიც შესწავლილ ჭრილებში გვხვდება. ესენია: *Whiteinella aprica*, *Wh. archaeoglobigerina*, *Wh. aumalensis*, *Wh. baltica*, *Wh. bornholmensis*, *Wh. brittonensis*, *Wh. inornata*, *Wh. paradubia*.

## INTRODUCTION

The genus *Whiteinella* was first identified by Pessagno (1967) and was named after the famous geologist White M.P., White due to his early contribution to the Upper Cretaceous and Lower Tertiary stratigraphy of the Tampico area in Mexico.

The purpose of the work was to study the genus *Whiteinella*, as one of the representatives of the genera of spiral-conical shells with spherical chambers. The origin of its first representatives is associated with the end of the oceanic anoxic event (OAE 1d) and according to morphological features represents one of the modifications of the genus *Hedbergella*.

*Whiteinella* Pessagno, new genus differs from *Marginotruncana* Hofker, by lacking single or double carinae. It differs from *Hedbergella*, by possessing much larger portici and by the more umbilical position of the primary aperture. *Whiteinella* resembles *Hedbergella* in the gross test architecture, but it differs from it by having more complex periapertural structures (a lip or a flap). The definition of these two genera requires further study, including a critical perspective on the separation based on the periapertural structure morphology. The genus *Hedbergellita* differs from the genus *Whiteinella* by a less number of whorls and chambers in the last whorl.

It is likely that *Globigerina holzli* Hagn and Zeil (1954) should be included in *Whiteinella*, new genus (the Turonian). Likewise, *Ticinella aprica* Loeblich and Tappan is from the Turonian (not Cenomanian as stated by Loeblich and Tappan, 1961). Arcadia Park formation should be assigned to *Whiteinella*, new genus instead of *Ticinella* as it lacks sutural supplementary apertures umbilically. The umbilical view of the holotype (*T. aprica* Loeblich and Tappan, pl. 4, the fig. 16b) clearly shows the large portici with intralaminar supplementary apertures characteristic of *Whiteinella*, n. gen., and indeed of all well-preserved *Marginotruncanidae*. The primary aperture of *T. aprica* Loeblich and Tappan is described as being extraumbilical-umbilical in position oriented somewhat toward the plane of coiling. It is also possible that *T. aprica* Loeblich and Tappan is a junior synonym of *G. holzli* Hagn and Zeil.

Studies of the classification of planktonic foraminifera were carried out by the following authors: Loeblich A.R., and Tappan Jr.H. (1961, 1987), Pessagno E.A. (1967), Douglas R.G., Rankin C. (1969), Sigal J. (1977), Robaszynski F., Caron M. (1979, 1984)(Fig. 1), Maslakova N. (1978), Robaszynski, F. & Caron, M. (1995), Korchagin O. A. (1982, 2001), M. Dan Georgescu (2010), Marcelle K., BouDagher-Fadel (2015) (Fig. 1).

## MATERIAL AND METHODS

The material of the present study includes the shells from Cretaceous sections (Upper Cenomanian-Santonian) of the Abasha and Odishi blocks, the Loki and Khrami massifs and the Dzirula crystalline massif. The material for studying the morphology of the shells of the genus *Whiteinella* was data published in the literature.

Foraminiferal shells were extracted from samples up to 100g of weight by mechanical decomposition to 0.1–0.5-cm-thick fragments and, then, elutriation of clayey component in water. Some most clayey components of rocks were boiled with technical soda  $\text{NaHCO}_3$ . Samples were dried at room temperature or weak heating of at most 50°–60°C. Carbonate limestones with multi-colored flints were treated with glacial acetic acid ( $\text{CH}_3\text{COOH}$ ) and copper sulfate

( $\text{CuSO}_4 \cdot \text{H}_2\text{O}$ ) with the addition of 6% hydrogen peroxide. Then, they were divided into fractions using sieves with 32, 63, 125, and 250  $\mu\text{m}$  mesh. The samples obtained were studied under a binocular microscope to select foraminiferal shells. In total, about 1,500 samples were processed.

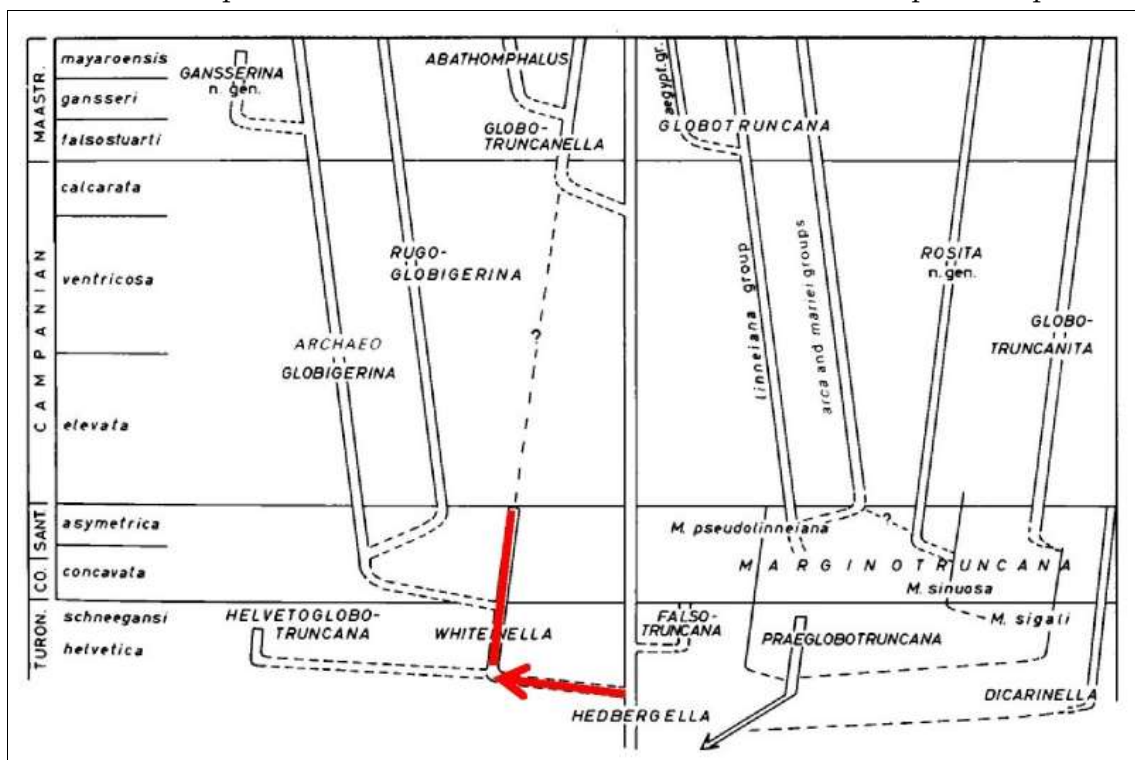


Fig 1. Phyteny of Late Cretaceous Globotruncanids at the generic group level (Robaszynski F., Caron M., 1984).

## GENERAL CHARACTERISTICS

The oxygen deficiency conditions of the World Ocean (OAE 2 - Bonarelli) of the late Cenomanian-early Turonian time were reflected in the lithological, faunistic and geochemical characteristics of marine sediments. The composition of planktonic foraminifera (PF) underwent drastic changes. Highly specialized genera disappeared: *Thalmaninella* and *Rotalipora* (crisis of k and k / r-strategists). Morphologically more primitive forms continued to exist, they are as follows: *Hedbergella*, *Whiteinella*, *Praeglobotruncana*, and *Heterohelix*. In the euphotic zones, where the oxygen minimum was recorded, small ones continued to exist: *Hedbergella*, *Globigerinelloides*, *Whiteinella*, *Praeglobotruncana*, and *Heterohelix*. The appearance of PF with strongly elongated chambers of the genus *Schackoina* is associated with oxygen deficiency. The Cenomanian-Turonian boundary interval was a typical oligotaxonic stage in the development of PF with dominance of primitive taxa.

The Cenomanian-Turonian boundary is also connected with a relatively low taxonomic diversity of PF and total prevalence of r-strategists (Kopaeovich L.F., Gorbachik T.N., 2017). Certain species are adapted to eutrophic or unstable conditions (opportunists, R-strategists). If such conditions prevail, equilibrium taxa (K-strategists) such as *Rotalipora*, *Thalmaninella* or *Praeglobotruncana* become rare or even disappear from the area. *Whiteinella* and *Hedbergella* that connect both groups therefore are called intermediate species. Dominance of K-Strategists

is therefore indicative for stable, meso- to highly oligotrophic conditions (Premoli Silva and Sliter, 1999; Coccioni and Luciani, 2005; Friedrich et al., 2008a). Prominent r-strategists are *Heterohelix* and *Gümbelitra*. Particularly *Gümbelitra* is known to thrive under conditions where no other planktic foraminifera survive; it is amongst the first to colonize new seaways and has blooms in shallow waters points to nutrient-rich surface waters (Keller et al., 2001, 2008) or indicates ecologic disasters (Keller & Pardo, 2004).

Seventy five percents of the surviving taxa of planktonic foraminifera were globular, surface water-dwelling hedbergellids that had tests, which were already adapted to low-oxygen conditions, having enlarged perforations (e.g., *Hedbergella*, *Whiteinella*) and/or elongate chambers (e.g., *Asterohedbergella*).

For the rare flattened *Praeglobotruncana* and *Dicarinella*, which migrated over considerable vertical distances within the upper water column, survival is likely to have been due to their selective adaptation of strong keels that enabled the capture and disaggregation of the large particles found at these depths. Among the other survivors of the Cenomanian–Turonian boundary anoxic events were the biserial *Heterohelix*, an oxygen-minimum zone dweller, and the triserial *Guembelitra*, a eutrophic surface dweller. This peak of extinction is considered to be due to the major OAE, but these events might also have been affected by another major submarine volcanic eruption (the Wallaby eruption) in the Indian Ocean, which again would have been associated with the high emission of CO<sub>2</sub> contributing to the global warming peak and greenhouse climates during that period.

#### SYSTEMATIC DESCRIPTIONS

The polyphyletic nature of *Whiteinella* was demonstrated with the taxonomic revision of *Anaticinella* Eicher, 1973 (Georgescu 2008a, 2008b, 2010a, 2011). *Anaticinella* was redefined in an evolutionary classification to accommodate a late Albian–early Turonian lineage that gradually develops a faint peripheral keel, complex umbilical system consisting of portici and ornamentation exhibiting fused pustules and, occasionally, vermicular structures in the terminal species. A significant outcome of this study is that it demonstrated that the whiteinellid stage of this lineage is transitional from the hedbergellid stage to the anaticinellid one. Moreover, the study demonstrated the necessity of a higher accuracy in evaluating the taxonomic significance of detailed morphological features (e.g. ornamentation elements and their distribution, pore characteristics, etc.). Three groups of species can be recognized among the *Whiteinella* representatives, excepting *A. aprica*, based on high resolution morphological features. *Whiteinella baltica* group of species apparently represents the stem of the whiteinellid group, with the first evolutionary occurrence in the late Cenomanian (*Rotalipora cushmani* Biozone) and having generalized features, such as globular chambers, broad periphery without peripheral structures and ornamentation consisting of scattered pustules. This group includes *W. baltica*, *W. brittonensis* and *W. paradubia*. The *Whiteinella archaeocretacea* group, which includes *W. archaeocretacea* and, probably, *W. inornata*, evolved in the latest Cenomanian with the development of a subangular periphery and incipient peripheral structures comprising agglomerated pustules.

The genus *Whiteinella*, distinguished in the family Hedbergellidae, differs from the genus *Marginotruncana* Hofker by the absence of a peripheral keel. It differs from the closely related genus *Hedbergella* by larger dimensions and a primary or main aperture close to the navel.

There are three diversifications and two large drops in planktic foraminifera diversity, with several second-order fluctuations superimposed on this first-order diversity trend. Species diversity slowly increases in the early Cretaceous (Berriasian–Barremian), then rises more quickly during the Aptian, only to drop at the Aptian–Albian boundary. Species-level diversity recovers during the late Albian and Cenomanian, drops again across the Cenomanian–Turonian boundary, and then increases for a third time during the Turonian and Coniacian. There is a short-lived decrease in diversity across the Santonian–Campanian boundary, but diversity increases dramatically during the ensuing Campanian and Maastrichtian.

The Cretaceous radiation of planktic foraminifera is not a monotonic rise in diversity, and previous studies have divided the Cretaceous radiation into successive faunal associations (Bandy, 1967, Premoli Silva & Sliter, 1999). These associations partition the Cretaceous radiation into four primary diversifications: the late Aptian, late Albian–early Cenomanian, Turonian–Santonian, and Campanian–Maastrichtian. Most conceptual models devised to explain these diversifications, and intervening extinctions, have invoked changes in oceanic thermal stratification and pelagic trophic structure (e.g., Hart, 1980a, Caron & Homewood, 1983). Premoli Silva & Sliter (1999) described how each diversification was interrupted by pulses of extinction and/or faunal turnover associated with major oceanographic changes, many of which coincided with OAEs. Many of these previously recognized events register as significant increases in both origination and extinction rates in this study (Fig. 2).





by chambers added in a trochospiral coil. Chambers are subglobular to globular and rarely present an axial elongation. Sutures are depressed and radial on both test sides. Periphery is broadly rounded and simple, without peripheral structures. Aperture has the shape of an arch, is situated in umbilical- extraumbilical position and is bordered by a lip or a flap; relict periapertural structures occur in the umbilical region. The chamber surface is ornamented with scattered dome-like pustules that can fuse to form rugosities and costellae; in general there is no preferential orientation of the ornamentation, but a meridional pattern can occur on some chambers and especially on the spiral side. But no tegillum, and the umbilicus is broad (~25% or more of test diameter) and many relict apertures are visible. A weak keel is seen on the periphery of later chambers only, but not extending into dorsal features. Wall is calcitic, finely porous, hyaline and perforate. The surface is spiny, especially on the chambers of the early whorl.

Remarks – *Whiteinella* Pessagno, new genus differs from *Marginotruncana* Hofker, by lacking single or double carinae. It differs from *Hedbergella*, by possessing much larger portici and by the more umbilical position of the primary apertyre.

Note. The genus *Whiteinella* includes the same group of shells commonly referred to as “gross globigerines” (Sigal, 1967; van Hinte, 1965; Robaszynski et al., 1982), which is common in the terminal Cenomanian and lowermost lower Turonian.

Composition - The genus *Whiteinella* includes 8 species: *Whiteinella aprica*, *Wh. archaeocretacea*, *Wh. aumalensis*, *Wh. baltica*, *Wh. bornholmensis*, *Wh. brittonensis*, *Wh. inornata*, *Wh. paradubia*.

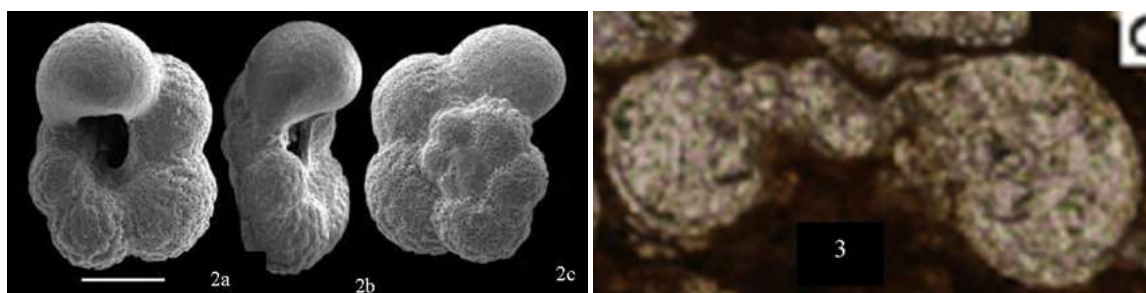
Age: Middle-Upper Cenomanian to Early Campanian.

### ***Whiteinella aprica* (Loeblich and Tappan, 1961)**

2a-2c; 3

*Ticinella aprica* Loeblich and Tappan, 1961, p. 292, pl. 4, figs. 16 (Cenomanian, U.S. Highway 80, west of Dallas, Texas).

*Whiteinella aprica* Loeblich and Tappan, 1961, Leckie, 1985, p. 144, pl. 1, figs. 1-4 (upper Cenomanian, Rock Canyon Anticline, Pueblo, Colorado).



Description: Low trochospiral test with globulous chambers. 5-7 moderately inflated globular chambers, rounded peripheral margin, strongly depressed and straight sutures on both sides, umbilicus wide and shallow, umbilical to extraumbilical primary aperture. Lobate periphery, surface of the chambers ornamented with pustules arranged into a pseudo-keel.



Distinguishing features: it differs from *W. brittonensis* and *W. paradubia* in having a lower trochospire and from *W. aumalensis* in having rounded peripheral margin.

Remarks - It differs from *Whiteinella brittonensis* in having a lower spire, from which the early spire does not protrude, a wider umbilicus and flaps in the umbilicus. It differs from *Whiteinella paradubia* in having a lower trochospire, *W. archaeocretacea* - in having radial sutures and a rounded periphery without an imperforate band.

Stratigraphic distribution: it appears in the upper part of *Th. reicheli* Zone till the top of the middle part of the *Th. globotruncanoides*.

Range: Upper Cenomanian to Middle – Upper Turonian.

Occurrence: Rare to very abundant.

### ***Whiteinella archaeocretacea* Pessagno, 1967**

4a-4b; 5

*Whiteinella archaeocretacea* Pessagno, 1967. P. 298–299, pl. 51, figs. 2–4; pl. 54, fig. 19–25; pl. 100, fig. 8.

*Whiteinella archaeocretacea* (Pessagno). Robaszynski & Caron, 1979, v. 1, p. 161, 167–168, pl. 33, figs. 1–3, pl. 34, figs. 1–2.

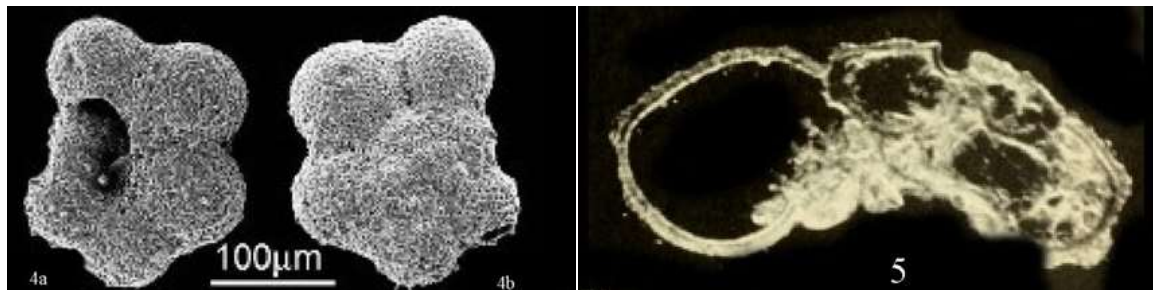
*Whiteinella archaeocretacea* (Pessagno). Wonders, 1980, p. 129, pl. 3, fig. 1a–c.

*Whiteinella archaeocretacea* (Pessagno). Leckie, 1985, p. 146, pl. 1, fig. 5–6.

*Hedbergella (Whiteinella) archaeocretacea* (Pessagno). 1989, Koutsoukos, p. 234, pl. 27, fig. 7–12.

*Whiteinella archaeocretacea* (Pessagno). 1996, Dupont, p. 113, pl. 9, fig. 10.

*Whiteinella archaeocretacea* (Loeblich & Tappan). 2004. Premoli-Silva & Verga, p. 215–216, pl. 145, fig. 3–4; pl. 146, fig. 1.



Description: A low trochospire, flat biconvex test; peripheral border imperforate. Final whorl with 5 chambers increasing fairly rapidly, initial chambers globose, becoming elongate in the direction of coiling; outline lobate; sutures deep, radial and straight in early chambers, becoming curved and oblique in final parts. Umbilicus wide, about one-fourth of the maximum diameter; aperture more umbilical, portici present.

Remarks: Differs from other *Whiteinella* species in having an imperforate periphery, final chambers elongated and later sutures deep and curved.

Distinguishing features: It differs from *W. inornata* in having rounded peripheral margin and thinner edge view. It can be distinguished by *W. baltica* in having thinner edge view.

Remarks: It is a very rare species.

Stratigraphic distribution: Occurs in the upper part of *Th. reicheli* Zone.

Age: Uppermost Upper Cenomanian and lowermost Lower Turonian.

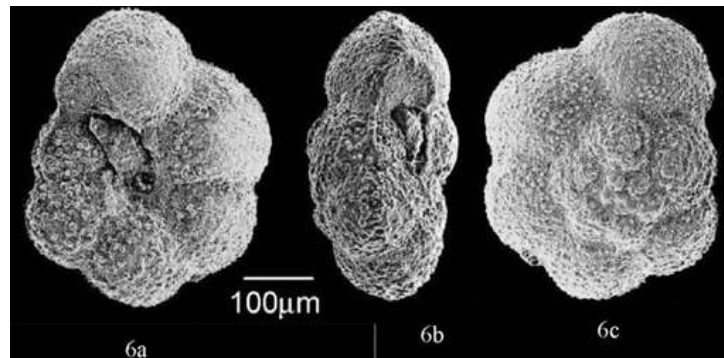
Occurrence: Rare to frequent.

**Whiteinella aumalensis (Sigal, 1952)**

6a -6c

*Globigerina aumalensis* Sigal, 1952, p. 28, fig. 29 (Middle Cenomanian, probably Aumale, southeast of Algiers, northern Algeria).

*Praeglobotruncana aumalensis* Sigal, 1952, Robaszynski and Caron et al., 1979, p. 28, pl. 42, fig. 1 (Loeffre-Lewarde, north of France).



Test morphology: Middle trochospiral test, spiroconvex, gently lobate profile and sub-circular outline, 6-7 chambers petaloid on the spiral side and trapezoidal on the umbilical side, pinched margin, sutures depressed and slightly curve on the spiral side and depressed and straight on the umbilical side, umbilicus quite wide and deep, umbilical to extraumbilical primary aperture.

Distinguishing features: It differs from *Praeglobotruncana* in having more uniform pustules, no alignment in lateral view and larger umbilicus. Moreover, it can be distinguished by *P. delrioensis* in having a higher trochospire and by *P. stephani* because it has depressed spiral sutures. It differs from *W. aprica* in having a pinched peripheral margin.

Remarks: It is a quite abundant species with continuous stratigraphic record. *Whiteinella aumalensis* is not a distinctive species and it shows a wall texture less pustulose respect to other specimens of *Whiteinella*. Moreover, it is easily misidentified with *P. stephani*.

This is a fairly abundant species with a continuous stratigraphic record. *Whiteinella aumalensis* is not a distinctive species and shows a less pustular wall texture than other *Whiteinella* specimens. Furthermore, it is easily misidentified with *P. stephani* due to its pinched outline. For this reason, in this study, the appearance of the genus *Whiteinella* is attributed to the first appearance of non-pinched species.

Stratigraphic distribution: It appears from the middle of Th. reicheli Zone till the top of the Monte Petrano section.

Range: Middle Cenomanian.

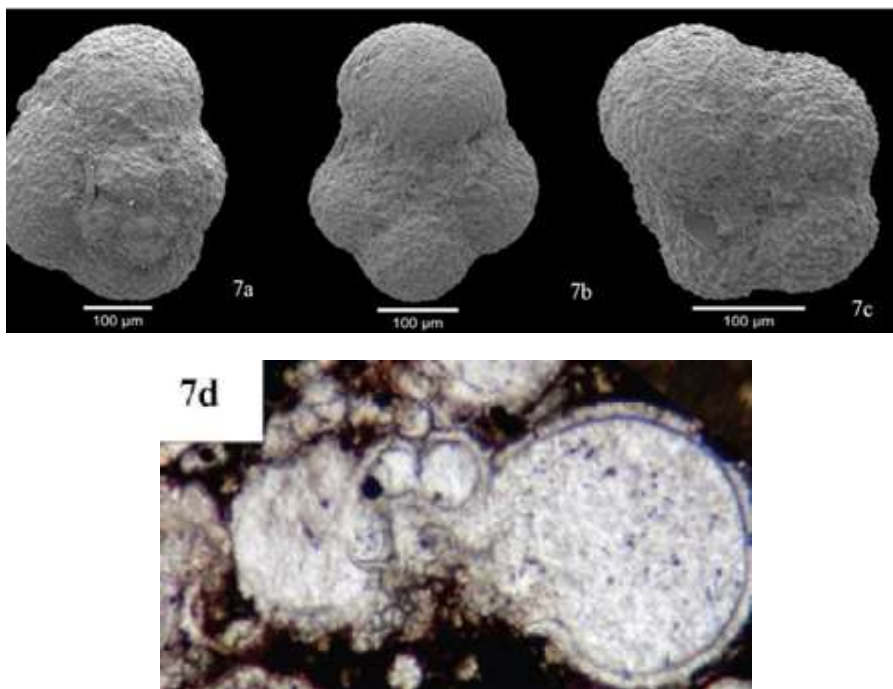
**Whiteinella baltica Douglas and Rankin, 1969**

7a - 7c, 7d

*Whiteinella baltica* Douglas and Rankin, 1969, p. 193, pl. 9, fig. A-C (lower Santonian, east of Bavnodde Pynt, Bornholm, Denmark).

*Whiteinella baltica* Douglas and Rankin, 1969, Robaszynski and Caron et al., 1979, p. 174, pl. 25, figs. 1-5 and pl. 36, figs. 1-2 (east of Bavnodde Pynt, Bornholm, Denmark; Poland).

*Whiteinella baltica* Douglas and Rankin, 1969, Leckie, 1985, p. 144, pl. 2, fig. 4, 5, 8, 11 (upper Cenomanian, Rock Canyon Anticline, Pueblo, Colorado).



Test morphology: low trochospiral test, equally biconvex, strongly lobate profile, 4 moderately inflated globular chambers, rounded peripheral margin, strongly depressed and straight sutures on both sides, umbilicus shallow partially covered by a lip, umbilical to extraumbilical primary aperture.

Distinguishing features: It differs from *W. aprica*, *W. brittonensis*, *W. paradubia* in having less chambers and a lower trochospire. It can be distinguished by *W. inornata* in having a rounded peripheral margin.

Remarks: It is a rare species and is observed only in the Monte Petrano. It is easily distinguishable from the other species belonging to the *Whiteinella* genus, but it can be confused with small *M. delrioensis* because they show the same number of chambers in the last whorl especially when the difference in wall texture is not visible because of poor preservation.

Stratigraphic distribution: It appears in the upper part of *Th. reicheli* Zone till the top of the Monte Petrano section.

Range: Upper Cenomanian.

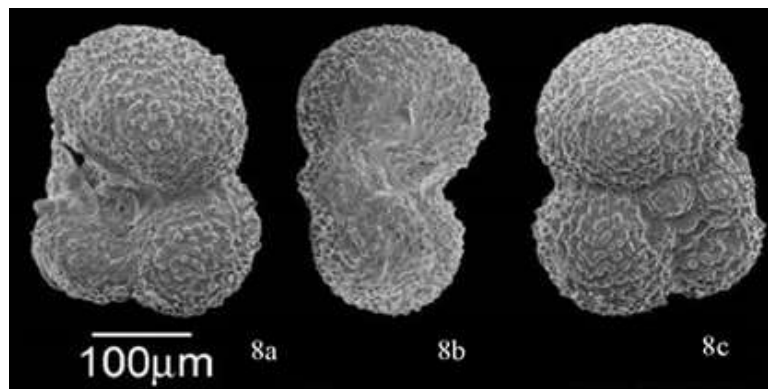
### ***Whiteinella bornholmensis* Douglas and Rankin, 1969**

8a - 8c

*Hedbergella bornholmensis* Douglas and Rankin; Douglas and Rankin, 1969, 193, fig. 6.

*Hedbergella bornholmensis* Douglas and Rankin ; Hanzlikova, 1972, 100, pl. 25: 5-7.

*Hedbergella bornholmensis* Douglas and Rankin; Norling, 1973, 109-110, pl. 5: 1a-c.



Test morphology: Test free, low trochospiral, equatorial periphery strongly lobulate, axial periphery rounded. Chambers subglobular to subspherical, 3 1/2 – 4 in the final whorl; initial chambers increasing gradually in size, final three or four are increasing very rapidly, last formed chamber is much larger than penultimate, giving test a trilobate appearance. Spiral and umbilical sutures are radial to slightly curved, depressed, distinct. Wall is calcareous, perforate, surface is covered with small spines. Umbilical is deep and narrow in juvenile stage, becoming shallower in adult stage. Primary aperture is a high interiomarginal-umbilical arch with a narrow bordering lip.

Distinguishing features: The species is similar to *Whiteinella baltica*, Douglas and Rankin, but may be differentiated by, (1) the trilobate shape of the test, (2) the rapid whorl expansion in the final volution, and (3) more extra-umbilical position of the primary aperture. *Hedbergella portsdownensis* (Williams-Mitchell) (*Globigerina portsdownensis*, 1948) is more strongly spiroconvex, has a smaller and deeper umbilicus and lacks the distinctive spinose surface. Apart from Bornholm Island, the species has been found in northern Germany and its presence is supposed in other parts of the Polish-Danish seaway."

Remarks: *Wh. bornholmensis* is somewhat similar to *Whiteinella ballica* Douglas and Rankin, but differs in having the extraumbilical-umbilical primary aperture, trilobate test and a sharper rate of chamber expansion in the final whorl.

Occurrence - Denmark (Bornholm): Coniacian-Lower Santonian; South Sweden: Coniacian-Lower Santonian; Czechoslovakia (Moravia): Coniacian-Lower Santonian; Central Poland (Wesolowka, Dorotka, Ciszycia Kolonia): Turonian-Campanian.

### ***Whiteinella brittonensis* (Loeblich and Tappan, 1961)**

9a - 9c; 10

*Hedbergella brittonensis* Loeblich and Tappan. Loeblich and Tappan, 1961, 274-275, pl. 4: 1-8.

*Hedbergella brittonensis* Loeblich and Tappan. Pessagno, 1967, 282, pl. 52: 9-12.

*Hedbergella Brittonensis* Loeblich and Tappan. Neagu, 1969, 139, pI. 13: 7-13, pI. 14: 1-6, 16-18, pl. 15: 1-2.

*Hedbergella brittonensis* Loeblich and Tappan. Barr, 1972, 13, pI. 1: 9.

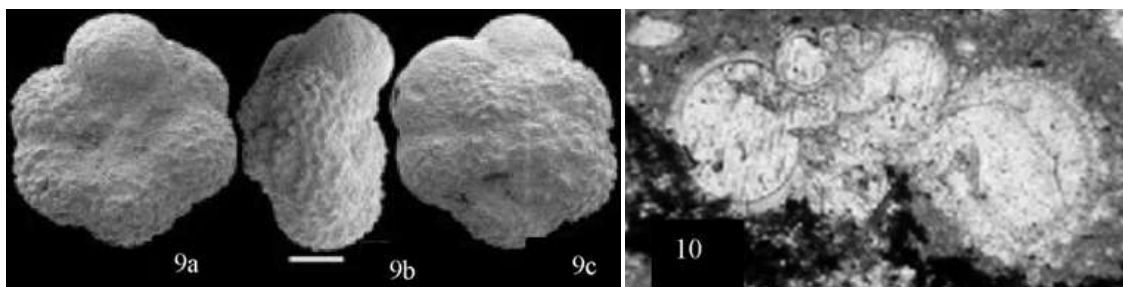
*Hedbergella brittonensis* Loeblich and Tappan. Heller, 1975, 239, pl. 1: 19.

*Hedbergella postdownensis* (Williams-Mitchell). North and Caldwell, 1975, pl. 5: 2a-c, 3a, b.

*Hedbergella brittonensis* Loeblich and Tappan. Luterbacher, 1975, pl. 2: 1.

*Whiteinella brittonensis* Loeblich and Tappan. Robaszynski and Caron et al., 1979, p. 180, pl. 38, figs. 1-2

*Whiteinella brittonensis* Loeblich & Tappan. Van Eijden & Smit, 1991, p.108



Description: Test trochospiral of not very high spiral, consisting of 2 to 2 1/2 whorls; chambers much inflated, nearly spherical; final whorl consisting of 5-6 chambers increasing regularly in size as added; sutures distinct, depressed, radial to slightly curved; wall distinctly pustulose; aperture extraumbilical, bordered by distinct flaps.

Remarks: *Wh. brittonensis* differs from *H. delrioensis* (Carsey) in being larger, higher spired and less hispid. It differs from *H. portsdownensis* (Williams-Mitchell) in having a less elevated spire.

Stratigraphic distribution: It appears in the middle of *Th. reicheli* Zone till the top of the Monte Petrano section.

Occurrence - USA (Texas), Mexico: Coniacian; Libya: Upper Cenomanian-Lower Turonian; Canada: Cenomanian; Eastern Carpathians: Cenomanian; Poland - Lodz region: Upper Albian-Turonian, Central Poland (Jakubowice, Karsy, Opoczka, Slupia Nadbrzezna, Kol. Slupia Nadb., Wesolowka 31-40): Turonian-Santonian.

### ***Whiteinella inornata* (Bolli, 1957)**

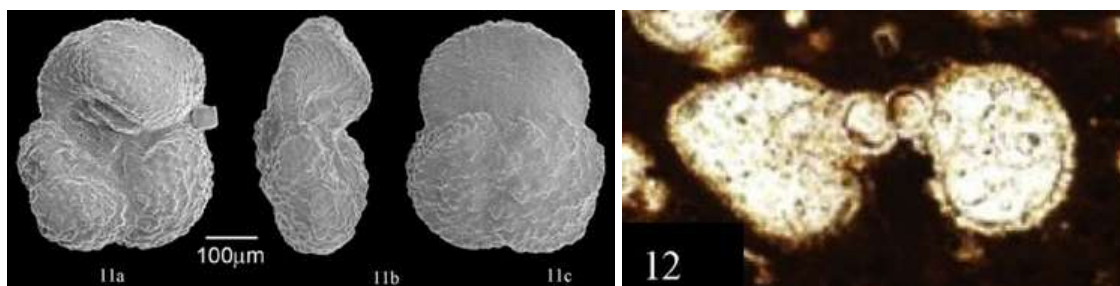
11a – 11b; 12

*Globotruncana inornata* Bolli, 1957, p. 57, pl. 13, figs. 5

*Praeglobotruncana inornata* Bolli, 1957, p. 143, pl. 2, figs. 6-7

*Whiteinella inornata* (Bolli), Pessagno 1967, p. 299, pl. 71, figs. 3-5, Caron 1985, p. 79, pl. 37, figs. 6-7.

Robaszynski & Caron 1990, p. 28, figs. 7, 9; Neagu 2006, p. 118, pl. 1, figs. 1-15.



Test morphology: low trochospiral test, equally biconvex, lobate outline and subcircular outline, subangular edge view, 4-4 1/2 slightly inflated and petaloid chambers, pinched margin, sutures depressed and straight on both sides, umbilicus wide and shallow, umbilical to extra-umbilical primary aperture.

Distinguishing features: It differs from *W. baltica* in having a pinched margin, a less pustulose wall texture and in being more angular in lateral view.

Remarks: From the beginning, the diagnosis of this species shows its distinction from *Globotruncana* Pessagno 1967, put forward the opinion that this species belongs to the genus *Whiteinella* that was confirmed later.

Stratigraphic distribution: Upper Turonian – Lower Coniacian.

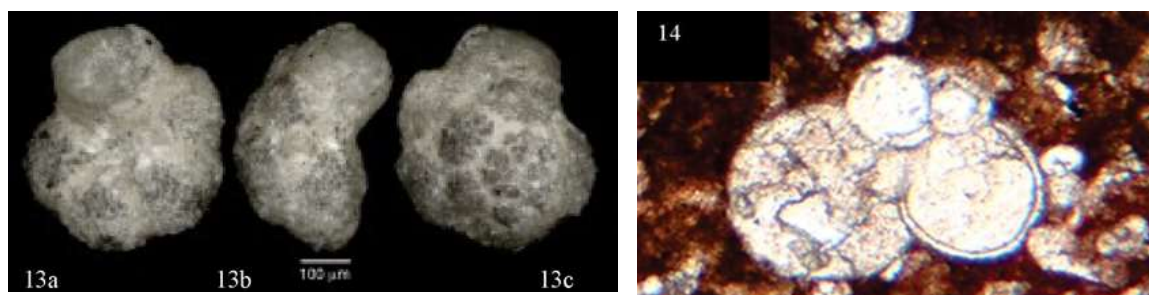
### ***Whiteinella paradubia* (Sigal, 1952)**

13a – 13c; 14

*Globigerina paradubia* Sigal, 1952, p. 28, figs. 28 (Cenomanian, probably northern Algeria).

*Whiteinella paradubia* Sigal, 1952, Robaszynski and Caron et al., 1979, p. 184, pl. 39, figs. 1-2 (upper Cretaceous, Hodgeman County, Kansas, U.S.A.).

*Whiteinella brittonensis/paradubia* Sigal, 1952, Leckie, 1985, p. 144, pl. 1, figs. 13-16 (upper Cenomanian-lower Turonian (?), Rock Canyon Anticline, Pueblo, Colorado).



Test morphology: high trochospiral test, spiroconvex, gently lobate profile and sub-circular outline, 6-7 inflated globular chambers, rounded peripheral margin, depressed and straight sutures on both sides, umbilicus narrow and deep, wide and shallow umbilicus, umbilical to extraumbilical primary aperture. Distinguishing features: It shows the highest trochospire among species belonging to the *Whiteinella* genus. Moreover, it can be distinguished from *W. brittonensis* in having a wider and shallower umbilicus.

Remarks: It is a quite rare species with a discontinuous stratigraphic record that is observed only in the Monte Petrano.

Stratigraphic distribution: From *Dicarinella algeriana* subzone (late Cenomanian) to *Dicarinella concavata* (Coniacian).

## CONCLUSION

1. The Bonarelli event (OAE 2) (Cenomanian/Turonian boundary) had the most significant impact on the morphology and taxonomic composition of the PF. The evolutionary prosperity of the Thalmanninella-Rotalipora groups was stopped due to oxygen deficiency. At the same time, the *Whiteinella* genus overcame environmental barriers and began to flourish. *Heterohelix*, *Globigerinelloides*, *Muricohedbergella* and other genera of r-strategists also successfully coexisted.
2. The timing of the Santonian turnover is roughly correlative with the termination of OAE3, which is generally considered to be the last of the major OAEs (Jenkyns 1980). OAE3 was a protracted event (Coniacian–Santonian) that involved the deposition of numerous, localized



black shales throughout the tropical Atlantic Ocean and adjacent basins (Wagreich 2012). The termination of OAE3 during the early Campanian has been attributed to increased exchange and ventilation of deep-water masses via the progressive opening of the equatorial gateway between the North and South Atlantic Ocean basins (Friedrich et al. 2012). Thus, it has been

3. Postulated that the Santonian turnover within the planktic foraminifera may reflect tectonically forced changes in ocean circulation (Premoli Silva & Sliter 1999).
4. The Santonian has long been recognized as a period of wholesale taxonomic turnover that affected all trophic groups within the planktic foraminifera (Wonders 1980). Significant increases in both origination and extinction rates within the *Dicarinella asymetrica* Zone support this view. This turnover entailed the extinction of many planktic taxa: Whiteinellids, Dicarinellids, and Marginotruncanids, at the close of the Santonian, and diversification of the genera *Globotruncana*, *Globotruncanita*, and *Contusotruncana* during the early Campanian.
5. A sharp climate change led to significant changes in the composition of the PF complexes and also affected the morphology of their shells.

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