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Andrzej KULKA

# Arni sedimentological model in the Tatra Eocene

The facies distribution in the Tatra Eocene conforms well the Arni model. The similarities are demonstrated by faunal content and petrographic composition. The relation between the size and shape of nummulite and discocycline tests and energy of depositional environment has been confirmed. The interpretation of the vertical sequence of nummulite faunas according to the Arni model, modifies the stratigraphic evaluations of the index forms of the hemeras I, II and III of F. Bieda. The species *Nummulites brongniarti*, *N. perforatus* and *N. millecaput* lived simultaneously and their consecutive appearance in the sections reflects the lateral, transgressive facies migration.

## INTRODUCTION

Nummulites were benthic organisms of limited motility, living at the bottom or close to it, on kelp, attached with pseudopodia. They were stenothermal, thermohaline animals, requiring water temperatures above 20°C. Investigations of the $^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios in shells of pelecypods concurrent with nummulites in the Eocene strata of the Paris Basin indicate water temperatures 25 – 27°C and normal salinity. Nummulite faunas disappeared landward if the land supplied excess quantities of fresh water, or in contrary, if the salinity increased due to intense evaporation. Water depth was equally important for the distribution of nummulite faunas which preferred shallow bottoms, not more than 50 – 80 m deep. Remains of shallow water organisms are commonly found accompanying nummulites. Some authors (W. Deecke, 1914; P. Rozlozsnick, 1927) explain the symmetrical structure of nummulite tests by their vertical life position. R. Pavlovec (1961) is of a contrary view, implying that any preferred position would result in assymetric structure of tests. R. Pavlovec (*l. c.*) suggests that pseudopodia are capable of causing test motility.

The water immediately above the bottom, with suspended particles of carbonate mud, is of greater density that average seawater. A nummulite test was not completely filled with cytoplasm; this was situated in the last chamber, together with cell nucleus.

The remaining empty chambers could contain gas, increasing nummulite's buoyancy. It is likely that nummulites remained in hydrostatic equilibrium with environment and could easily change their position using pseudopodia.

## NUMMULITES AND FACIES

Nummulites, as most benthic organisms, were dependent on type of bottom and quickly reacted to changes in type of sediment. They are most frequently encountered in shallow-water limestones, where tests are more numerous and greater than in coeval nearshore sandy deposits, or in muds of deeper sea. Nummulites did not well in shallow littoral zones, and their occasional rich accumulations in conglomerates and coarse sandstones are due to water movements, as is indicated by their chaotic arrangement and presence of fragmented and rounded tests of larger foraminifers and of other skeletal debris. In a paper on nummulite palaeoecology, G. Nemkov (1962) presents a scheme of distribution of various groups of nummulites (morphologically differentiated) according to the type of sediment and distance from the shore (Fig. 1). The species with very large tests (*Nummulites distans*, *N. millecaput*, *N. gizehensis* et al.) are found almost exclusively in sublittoral limestones. Another species, with small tests (*N. praelusaci*, *N. bouillei*, *N. orbignyi* et al.) are found in bathial argillaceous deposits. Nummulites of various sizes, but invariably smaller than those from the sublittoral limestones, occur in nearshore sandy sublittoral deposits. The more coarse-grained and shallow-water is the deposit, the more dumpy are the nummulite tests found in it, the more frequent are granulated forms with robust tests (*N. gallensis*, *N. perforatus*, *N. partschi*, *N. laevigatus*).

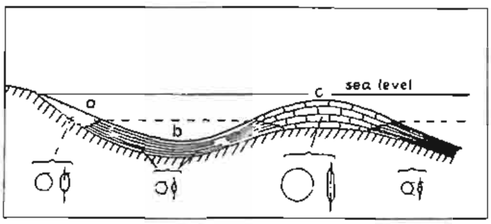



Fig. 1. Diagram showing the size-distribution of nummulites in neritic deposits

Rozmieszczenie numulitów różnej wielkości w osadach nerytycznych

a – sandy sublittoral sediments with dumpy, middle-sized nummulites; b – pseudoabyssal muds with small, flattened nummulites; c – shallow-water limestones of open sea with large discoidal nummulites (G. Nemkov, 1962)

a – piaszczyste osady sublitoralu z wypukłymi numulitami średnich rozmiarów; b – pseudoabisalne iły z małymi, płaskimi numulitami; c – płytkowodne wapienie otwartego morza z wielkimi numulitami o dyskoidalnym kształcie (G. Nemkov, 1962).

## ARNI MODEL

During Micropalaeontological Colloquium in Dakar in 1963, P. Arni (1965) presented a scheme of platform sedimentation of „nummulitic" Lower and Middle Eocene strata of the Mediterranean area (Fig. 2).

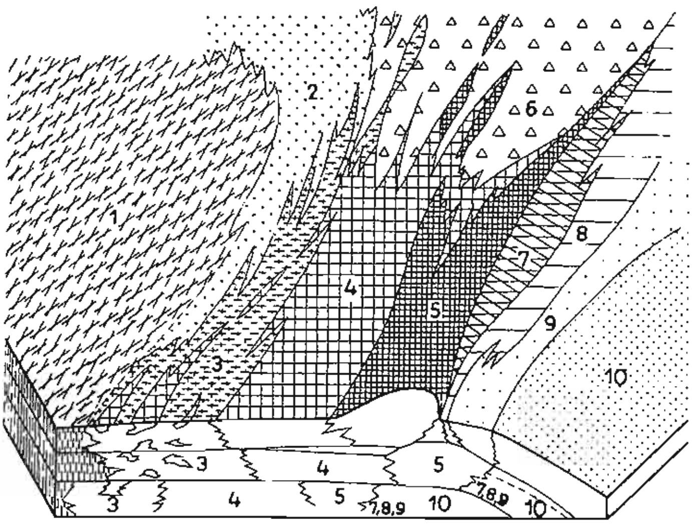



Fig. 2. Arni model

Model Arniego

1 – zone of dolomitization and evaporites; 2 – limestone with miliolids; 3 – transitional facies; 4 – back-bank facies; 5 – nummulite bank; 6 – limestone with foraminifers *Peneroplidae;* 7 – fore-bank facies; 8 – limestones and marls with operculins and nummulites; 9 – para-pelagic deposits; 10 – pelagic deposits

1 – strefa dolomityzacji i ewaporytów; 2 – wapień z miliolidami; 3 – facja przejściowa; 4 – facja zalawicona; 5 – ławica numulitowa; 6 – wapień z otwornicami *Peneroplidae*; 7 – facja przedławicowa; 8 – wapienie i margle z operkulinami i numulitami; 9 – osady parapelagiczne, 10 – osady pelagiczne

Arni's results were based on investigation of samples from boreholes drilled in the Sirte Basin of Libya. The purpose of these investigations was to study larger foraminifer faunas of the Palaeogene of Libya and to establish a practical biostratigraphical scheme based on them. Reconstructing the sedimentary environment of the nummulite-bearing strata P. Arni (*l. c.*) constructed a palaeogeographic synthesis of the nummulitic sediments of the littoral zone. Most earlier studies of larger foraminiferal faunas dealed with their variation in vertical section, in time. Current publications only rarely deal with the lateral variability of these faunas. P. Arni (*l. c*) studied the effect of environmental changes on the development of characteristic nummulitic faunas. His paper revealed the importance of lateral variability and provided a base for recognition of the conditions which determined the lateral modifications within a selected part of the basin. The following characteristics were taken into account: burial of fossil remains, their accumulation or dispersion, size selection, distribution of biotopes with nummulites, with miliolids and alveolins, with operculins and discocyclins, with small neritic-pelagic foraminifers. The biotopes mentioned above are related to determined types of bottom, with determined rock types, the distribution of nummulitic faunas is clearly related to lithofacies. Biotopes are in forms of patches or strings.

The greatest development of nummulite faunas took place over extensive shallow sea bottoms in the area from the Northern Africa through Near East to Pakistan's Sind during the period from the later part of the Early Eocene to the earliest Late Eocene. The Oligocene time was characterized by intense orogenic activity, which prevented development of extensive shelves, favourable for the development of larger foraminifers. The development of nummulites over such carbonate platforms, especially along the outer shelf margins, resulted in deposition of thick carbonate sequences. The optimum conditions for nummulites were limited to narrow „belts" and for this reason the nummulitic sediments formed elongated „banks".

As the „nummulitic bank" once formed, it acted as a barrier affecting the sedimentation in the adjoining areas. The nummulite bank, a reef-like accumulation of loose nummulite tests, forms at greater depth than a coral reef, but in similar manner determines the facies distribution. Dominating biotope of the sediments between the nummulite bank and the shore is different from the biotopes situated between the bank and the deposits of the deep, open sea. Hence the back-bank and fore-bank facies are clearly distinguishable. The lateral sequence of facies from the shore off is as follows:

1. The zone of dolomitization and evaporites.
2. Facies of limestone with miliolides. Typical lagoonal limestone, often dolomitized. It is often laterally transitional to evaporite sediments, and its area of occurrence is of irregular outline.
3. Transitional facies. Micro- or cryptocrystalline chalklike limestone with numerous orbitolins and alveolins. In many cases this is genuine alveolina limestone. Nummulites may be rather frequent in the microcrystalline limestones of this facies, but may also be absent. When matrix is enriched in miliolids, the rocks becomes hard biosparite.
4. Back-bank facies. Calcareous sediment, rich in skeletal debris of echinoderms, pelecypods, coelenterates and numerous nummulite tests. Biotopes are differentiated with increasing distance from the nummulite bank. Nummulites are represented by medium-sized forms with robust tests (*Nummulites beaumonti*, *N. discorbinus*, *N. bullatus*, *N. inkermanensis*, *N. rotularius* et al.). Frequent are foraminifers: *Gypsina*, *miliolids*, *Dictyoconoides* and *Linderina*.
5. Nummulite bank. Nummulitic limestone is built of tests of one or two nummulite species, of which at least one attains large dimensions (e.g. *N. gizehensis s.l.*, *N. perforatus s.l.*). The bank can be in some cases consolidated by red algae.
6. Facies with foraminifers *Peneroplidae*.
7. Fore-bank facies. Limestone with nummulite bank debris. Allochtonous nummulites found here have exceptionally fine tests (*N. planulatus*, *N. spirectypus*, *N. bouillei* et al.), in contrast with those in the back-bank facies. Discocyclins occur sporadically. Assilins are abundant in this facies in the areas of alpine folding.
8. Facies of limestones and marls with operculins and nummulites.
9. Deep-water facies of sublittoral zone (parapelagic facies), with characteristic small benthic foraminifers.
10. Pelagic facies with numerous globigerins.

Nummulite banks can form in two distinct general situations:

1. In „ideal" conditions, on extensive stable continental platforms (e.g. northern coast of the African continent).
2. In conditions of an unstable platform, in areas subject to strong and frequent tectonic movements, e.g. within geosynclines.

In the geosynclinal zones, with narrow shelves and frequent tectonic movements, a nummulitic bank once formed, become soon subject to erosion and its detrite reached to the deeper parts of the basin.

The platforms situated in orogenic zones were supplied with increased amounts of clastics, due to the erosion and deformation occurring on land. If conditions favourable for deposition of nummulite sediments occurred in some areas of such a platform, at the same time, the deposition of the nummulite sediments was controlled by contemporaneous deposition of clastic material and orogenic movements. The clastic material was supplied by fresh waters, which lowered the seawater salinity in marginal parts of the basin. The sublittoral zone with a nummulite bank and with increased supply of clastics was not likely to develop lagoons. Typical lagoonal conditions in such areas were as rare as were typically developed nummulite banks. While the individual nummulitic biotopes are rather well represented within the areas of irregular development of the nummulitic facies, the facies with alveolins and the facies of limestones with miliolids are only rarely encountered.

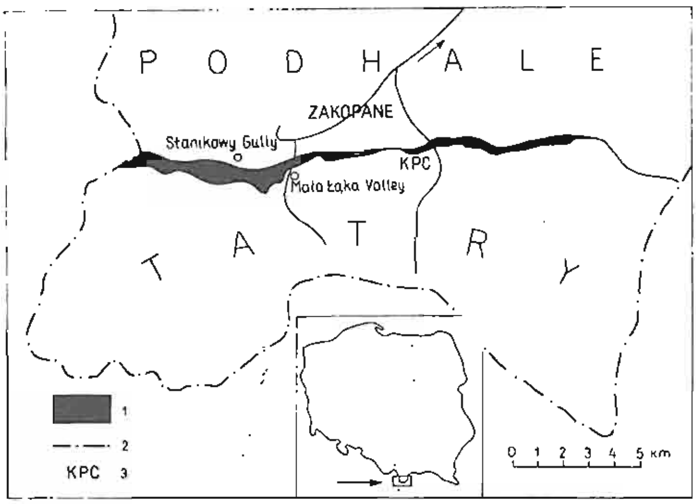



Fig. 3. Map of distribution of the Nummulite Eocene in the Podhale region of the Carpathians (northern boundary of the Tatra Mts, vicinity of Zakopane)

Występowanie eocenu numulitowego na Podhalu w Karpatach (północne obrzeżenie Tatr, okolice Zakopanego)

1 – Tatra Eocene; 2 – state boundary; KPC – Pod Capkami quarry

1 – eocen tatrzański; 2 – granica państwa; KPC – kamieniołom Pod Capkami

This overview of the formation of irregular nummulitic facies within the areas of Alpine orogenic movements does not present the whole spectrum of possible variations in lithology of sediments, including intervals of denudation, periods of non-sedimentation, sometimes marked by enrichment in glauconite or appearance of Discocyclina limestones directly over a nummulite bank. Lithic fragments of nearly all the mentioned facies, more or less consolidated, can be found redeposited at significant distances from the nummulite bank in deposits of quite different type, e.g. as accumulations of nummulites within a flysch facies.

A subsequent paper of P. Arni, written jointly with E. Lanterno, appeared in 1972 and described the occurrence of a nummulite bank in the Middle Eocene carbonate sequence near Verona in Italy.

According to P. Arni (*l. c.*), the large flattened nummulites (*Nummulites gizehensis*, *N. millecaput*, *N. laevigatus*) preferred the area of the platform margin, if this was elevated enough. The conditions in this zone were optimal for explosive development of the nummulite species mentioned above, and for numerous discocyclins, in terms of both, the biomass production and phylogenetic evolution. Accumulation of foraminiferal tests was controlled by wave activity. It redeposited the organic remains, often in form of elongated elevations, oriented transversally to the shoreline. In their higher parts the elevations reached the tidal zone, and provided substratum for red algae.

P. Arni and E. Lanterno (1976) dealed once again with the problem of nummulite bank formation, when studying the Eocene strata at the Gargano Peninsula in Southern Italy. They found that the Middle Eocene is represented there by a fragmentary and partly redeposited nummulite bank. A rapid transgression of a microbioclastic neritic-pelagic facies over the frontal part of the bank destroyed partly the bank and completely removed the fore-bank facies.

Following the death of P. Arni, studies on sedimentation of nummulitic Eocene were conducted by D. Decrouez and E. Lanterno (1979). They found in Libya another confirmation of the Arni model, in a series of boreholes (F.T. Barr, A.A. Weegar, 1972). D. Decrouez and E. Lanterno (*l. c.*) found also, by a literature survey, that the development of the platform Eocene strata in Egypt conforms the Arni model. The facies of nummulite bank is represented there by the Mokattam Formation with mass occurrences of *Nummulites gizehensis*. Next in Tunisia, G. Castany in 1961, distinguished, within a formation named by him „carbonate Eocene" (Mtlaoui Formation), the facies with globigerins, facies with nummulites, coquina limestones, and lagoonal facies with gypsum. He concluded: „... this formation was laid down at an extensive continental platform with strongly differentiated sedimentation, expressed by distinct and rapid facies changes, controlled more by biological factors than by any significant variations in water depth". D. Decrouez and E. Lanterno applied the Arni model in the Eocene strata of Algeria, Morocco, Senegal, and Madagascar, and apart of the African platform, in the Haut-Karst zone and Dalmatia in Yugoslavia, in the Ionian zone of Greece and Albania, and in the Preapulian zone of Greece".

A cross-section Bakonypoloske – Varaslod – Urkut west of Bakony in Hungary (E. Szots, 1956) also displays analogy to the Arni model.

## LITHOLOGY AND STRATIGRAPHY OF THE TATRA EOCENE

The nummulitic Eocene outcrops in Poland form a narrow zone at the northern slopes of the Tatra Mts. Farther to the north they plunge under the sandstones and shales of the Podhale flysch (Fig. 3).

The main structural elements of the Tatra include: the Palaeozoic crystalline basement (magmatic and metamorphic rocks) and Mesozoic sedimentary rocks (Triassic, Jurassic and Cretaceous).

The folded and uplifted area of the Tatra Mountains was eroded since the Turonian till the Early Eocene. During the Middle Eocene time, a marine transgression occurred, depositing conglomerates and carbonates of the Tatra Eocene (Middle and Upper Eocene) and the Podhale flysch (Upper Eocene – Oligocene).

The basal conglomerates are partly of continental and partly of marine origin. They are overlain by organogenic limestones, dolomitic limestones, rarely dolomites. The dolomitic component of the rocks is derived from the fragmentation of the Triassic dolomites of the substratum. In some sections the Nummulitic Eocene terminates with the upper conglomerate of small thickness and with organodetritic limestones.

There are a few papers regarding petrography of the Tatra Eocene. J. Tokarski and A. Oberc (1953) describe the rocks dominating in the Pod Capkami quarry, a representative section of the Nummulitic Eocene, as detritic dolomite or dolomitic limestone. They distinguished four main lithological varieties. Volumetrical percentages of the components for each type respectively, determined by microscope study, are as follows:

| | I | II | III | IV |
|---|---|---|---|---|
| – pebbles of carbonate rocks | 17 | 12 | 7 | 8 |
| – pebbles of carbonate rocks with clay | 17 | 14 | 11 | 21 |
| – skeletal debris | 42 | 61 | 69 | 63 |
| – quartz | 15 | 8 | 9 | 5 |
| – crystalline carbonate and cement | 9 | 5 | 4 | 3 |

The analysis of mineral composition revealed that the type I (termed dolomitic rock) contains 51.65% $CaCO_3$, 37.76% $MgCO_3$ and 13.04% of clay and quartz. The rock type II (calcareous dolomite) contains 64.43% $CaCO_3$, 26.58% $MgCO_3$ and 9.72% of clay and quartz. The type III (dolomitic limestone) contains 73.43% $CaCO_3$, 16.17% $MgCO_3$ and 10.22% of other elements. The composition of the type IV (limestone with insignificant dolomitic admixture) is as follows: $CaCO_3$ – 89.77%, $MgCO_3$ – 5.56%, clays and quartz – 4.70%.

P. Roniewicz (1969) in his description of the Tatra Eocene applies terms specific for clastic rocks, so for the rocks in the Pod Capkami section he uses the terms: fine conglomerate, fine grained carbonate sandstone, and carbonate mudstone. The dominating type in the section is termed dolomitic sandstone. P. Roniewicz (1979) in explanations of the Tatra Eocene section, presented in the Guidebook of LI Congress of the Polish Geological Society, states that dolomitic sandstones, locally transitional to organodetritic limestones, dominate in the Pod Capkami section. On the *Geological Map of Polish Tatra Mountains* 1:30,000 (1979), however, these strata are distinguished as limestones.

In this paper, the terms relating to carbonate roeks are applied, as the allogenic material is, as a rule, not prevailing.

Larger foraminifers, especially nummulites and discocyclins, are dominating fossils in the Tatra Eocene. Less frequent are foraminifers: *Operculina*, *Grzybowskia*, *Asterocyclina*, *Assilina*, rare *Alveolina*, *Operculinoides*, *Spiroclypeus*, *Baculogypsinoides*, *Actinocyclina*.

Apart of larger foraminifers there occur some small foraminifers, debris of echinoderms, pelecypods, bryozoans, annelids, continental flora and algae. The algae form greater accumulation in some exposures.

F. Bieda (1959, 1960), after a study of larger foraminifers, distinguished four stratigraphic horizons, featured by index species of nummulites, and ranging from Upper Lutetian to Lower Priabonian:

– horizon IV (uppermost) with *Nummulites fabianii* Prever – Lower Priabonian;

– horizon III with *N. millecaput* Boubée – uppermost Lutetian/Priabonian;

– horizon II with *N. perforatus* (Montfort) – Upper Lutetian;

– horizon I (lowermost) with *N. brongniarti* d'Archiac et Haime – Upper Lutetian.

The index species, listed above, occur in great quantities. They are found also younger horizons, but in smaller proportions. The species from the higher horizons do not occur in the lower ones. Noteworthy is observation of F. Bieda (1960) that the index forms of the first three horizons of the Tatra Eocene (*Nummulites brongniarti*, *N. perforatus*, *N. millecaput*) are found together in other areas. The sequence of these species, different or even reverse than in the Tatra, is found in Slovakia and in vicinities of Vicenza in Northern Italy. F. Bieda (1960) explains „... that our area was gradually colonized by species, which found here conditions favourable, developed exuberantly, and changed successively. The sedimentation area of the

North-Tatra Eocene was small and for this reason its colonisation by the succesively immigrating species occurred in short time over all the area".

The examination of 23 sections of the Tatra Eocene demonstrated that all the four horizons occur only in the section of the Pod Capkami quarry, in the Mała Łąka Valley, and in the section of the Hruby Regiel Mountain. According to F. Bieda (1960), individual horizons are missing, or faunal content is different, in the other sections. In some sections, the sedimentation of the Tatra Eocene starts with the horizon II, or even with the horizon with *N. millecaput* (horizon III). The lack of the horizons with *N. brongniarti* and *N. perforatus* is explained by emergence of some fragments of the Tatra island during the sedimentation of the older horizons, and by oceanographic conditions at the shore and bottom, that precluded accumulation of sediments. Fragments of limestones from the older horizons of the Tatra Eocene are found in the younger horizons and in the Podhale flysch.

F. Bieda (*l. c.*) noted also the relation between the nummulite faunas and the lithological type of rock. The fauna of the horizon I occurs in the upper part of the lower conglomerates and sandstones, rather rich in $MgCO_3$. The fauna of the horizon II occurs in different rocks, these are either sandstones and fine conglomerates rich in dolomite fragments, or limestones consisting almost entirely of larger foraminifer tests („jarzec" – the regional name for it, used also for the nummulitic limestone with *Nummulites perforatus*). Horizon III is represented by limestones, sandy limestones, sometimes conglomerates (so called upper conglomerates). The fauna of the horizon IV occurs in the deposits similar to those of the horizon III. Horizon IV occurs also in the Zakopane Shales of the Podhale flysch as thin intercalations or lenses of fine conglomerate. F. Bieda (1960) concludes: „... Nummulites, living in shallow waters, close to the shoreline, are however independent, or dependent to a small degree only, on the sedimentary facies ...". In a detailed study of the larger foraminifer fauna of the Tatra Eocene, F. Bieda (1963) introduced a concept of „hemeras" – stratigraphic divisions finer than the horizons. This name was than applied to the nummulitic horizons distinguished earlier in the Eocene of the Tatra.

According to F. Bieda (*l. c.*), not all the nummulite species appeared simultaneously in the Tatra area and not all of them remained there during all the period of the Tatra Eocene sedimentation. The correlation of the foraminifer faunas with the petrography of rocks was repeated. The presented listing indicates that: „... The nummulite faunas are independent on the character of the sediments, only the hemera I comprises uniform sediments, but this hemera represents the beginning of a transgression, and the lack of differentiation in its sediments is natural ...".

The later papers related to the Nummulite Eocene, and dealing also with the problems of larger foraminifers (P. Roniewicz, 1969; S. Sokołowski, 1973; S. Liszka, T. Śmigielska, 1974) did not modify the basic conclusions of F. Bieda (1963), i.e. dating the hemeras and the opinion on the independence of the larger foraminifer assemblages from the type of sediment.

The recent literature indicates that the ranges of the nummulites found in the Tatra Mountains are the following: *Nummulites brongniarti*, *N. perforatus*, and *N. millecaput* are coeval and occur in the highest Lutetian, in the *N. perforatus* zone and do not reach into the Priabonian. *N. fabianii* is not an index species for the lowermost Priabonian. In its phylogenetic line *N. praefabiani* appears in the Upper Lutetian, while in the lowermost Priabonian occurs a species described as *N.* aff. *fabiani*, a precursor form for *N. fabiani*.

In the section of the Hruby Regiel Mountain, *N.* aff. *praefabiani* was described in the assemblage with *N. perforatus*, by T. Śmigielska (S. Liszka, T. Śmigielska, 1974). *N. fabianii* occurs rarely and only at the top of the Tatra Eocene, in the upper conglomerate, and in organodetritic limestones and conglomerates intercalated among the Zakopane Shales. It is more common in the Chochołów Beds.

## ARNI MODEL IN THE EOCENE OF TATRA

The present author performed detailed study of outcrops and thin sections, based on detailed measuring of the Tatra Eocene sections in the Przyporniak Brook, Broniarski Gully, Skalnite Brook, at Chłabówka in the Sucha Valley, in the „Bluff above Chapel" in Jaszczurówka, in the Olczyska Valley, Pod Capkami quarry, Białe Valley, Spadowiec Brook, Ku Dziurze Valley, Strążyska Valley, Sucha Gully, Za Bramką Valley, Małe Gully, Mała Łąka Valley, Staników Gully, Kościeliska Valley, Jaroniec Brook, Lejowa Valley, Macicki Brook and at the Molkówka alp.

This study led the author to the conclusion that the spatial distribution of the foraminiferal facies of the carbonate Eocene conforms the Arni model.

There is also a relation between the test shape and size of the dominant foraminifer in the assemblage and the energy of water in the environment of sediment deposition and accumulation.

Three of the sections listed above deserve a special attention because of their distinctive characters, lithological differentiation and of lithology and faunal content. These are the sections of the Tatra Eocene in the Pod Capkami quarry, in the Mała Łąka Valley and in the Staników Gully. The most important of these is inquestionably the exposure Pod Capkami, a reference standard for the Nummulite Eocene (Fig. 4).

The following main units can be distinguished in the section:

0 – 2 m. Fine conglomerate, equivalent to the basal conglomerate.

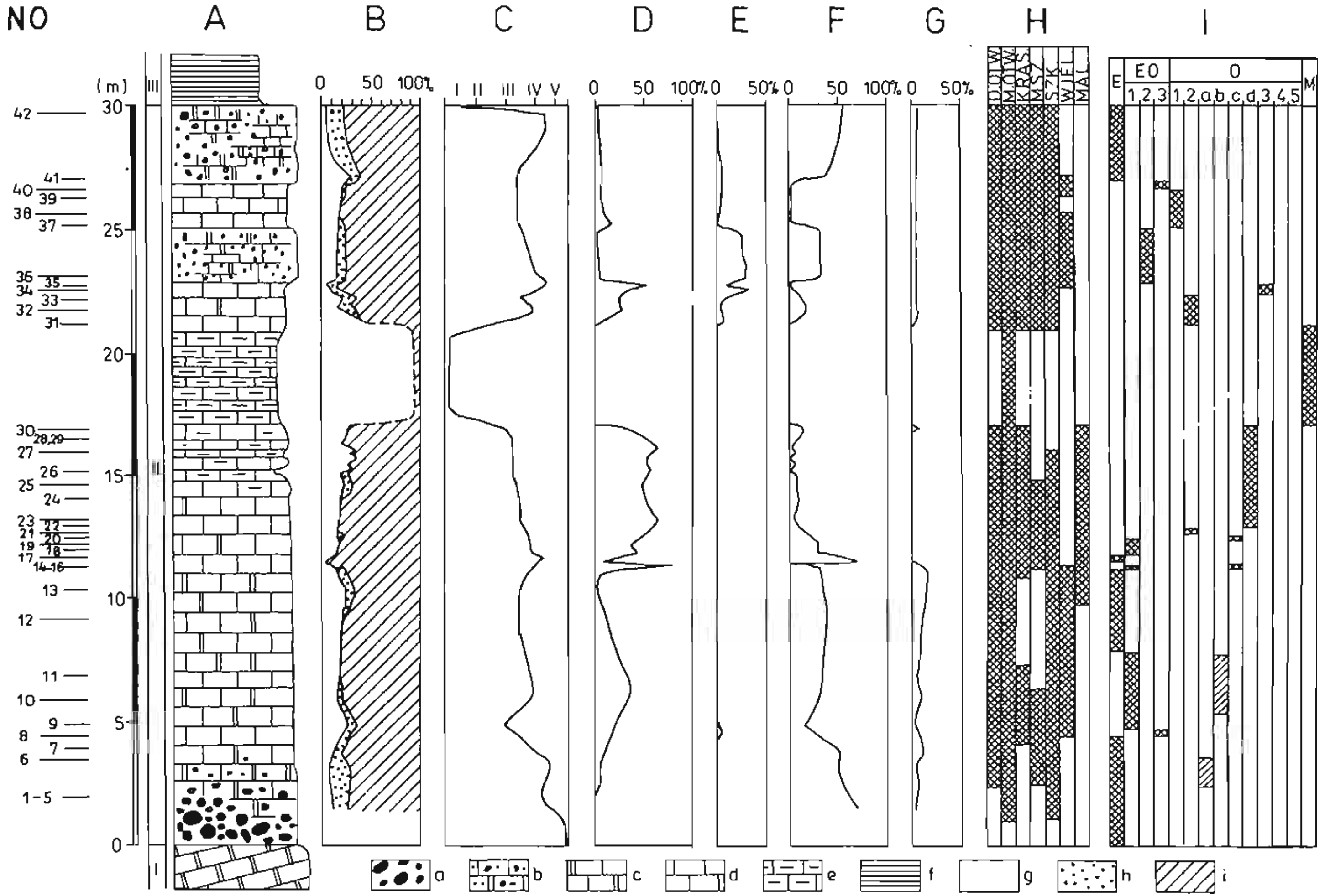
2 – 4 m. Dolomitic limestone with *Nummulites brongniarti* (Table I). The dolomite content is related to the presence of carbonate extraclasts – fragments of Ladinian dolomites of the substratum (Fig. 4, column F). The vertical range of frequent occurrence of *N. brongniarti* is shown in Fig. 4, column I – 0 – 2a. The fragments of substratum decrease in size upwards. *N. puschi* and *N. striatus* occur rarely.

4 – 11 m. Dolomitic limestone with *Nummulites puschi* (Table II). Nummulites become more frequent with specimens of *N. puschi* prevailing (Fig. 4, column I – 0 – 2b): numerous are *N. incrassatus*, *N. striatus*, *N. semicostatus*, *N. perforatus* (Fig. 4, column D).

11 – 12 m. Nummulitic limestone (Table III). Limestone bed several tens of centimetres thick, built almost entirely of *N. perforatus* tests. A rapid change in large forminifer content of the rock is marked in Fig. 4, column D. It corresponds to the bed of nummulitic limestone. The vertical extents of mass occurrences of *N. perforatus* are shown in Fig. 4, column I – 0 – 2 c

12 – 17 m. Marly Discocyclina limestone with *N. millecaput* (Table IV). Large foraminifers, mainly discocyclins make up above 50% of the rock mass (Fig. 4, column D). They belong to species *Discocyclina pratti*, *D. ephippium*, *D. discus*, *D. nummulitica*, *D. douvillei*, *Nummulites millecaput* (attaining 85 mm of test diameter), *N. perforatus*, *N. ratularius*, *N. ataticus*, *N. striatus*, *N. anomalus*, *N. incrassatus* and *N. semicostatus*. The vertical extent of *N. millecaput* is shown in Fig. 4, column I – 0 – 2d.

17 – 21 m. Marl. Yellowish-grey rock, rich in small foraminifers. Planktonic forms are numerous, especially *Globigerapsis index* (Finlay) and *Porticulasphaera mexicona* (Cushman). Less numerous are benthic foraminifers *Lagaenidae*, *Anomalinidae* and *Rotalidae*, rare are agglutinated forms (S.W. Alexandrowicz, S. Geroch, 1963). The quantitative composition of the assemblage and the nearly total absence of larger foraminifers and calcareous algae suggest deposition in deeper water (lower part of neritic zone) than the underlying marly Discocyclina limestones. In one part of the outcrop the Discocyclina limestone is transitional to beds of glauconitic mudstone, 1.5 m thick (M. Turnau-Morawska, M. Lindner, 1959).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21 – 30 m. Upper conglomerate. It contains, at intervals 21 – 23 m and 25 – 27 m, fine and coarse detrital limestones with a rich fauna of larger foraminifers, algae and bryozoans (Tables V, VI). Pebbles of underlying limestones, including the nummulitic limestones, are scattered within the conglomerate. Organodetritic limestones adjoin the upper conglomerate or terminate the sedimentation of the carbonate Eocene (e.g. in the Sucha Valley in Chłabówka). They occur also in forms of lenses in the Zakopane Shales of the Podhale flysch (Staników Gully – Table VII, Jaroniec Brook). Only these sediments, with strong indications of redeposition, contain sporadic specimens of *Nummulites fabianii*, characteristic for the hemera IV of F. Bieda (1963). *N. millecaput, N. incrassatus, N. perforatus, N. pulchellus, N. semicastatus, Spiroclypeus carpaticus, S. granulosus. Grzybowskia multifada, G. resticulata, Discocyclina discus, D. nummulitica, Asterocyclina stellata, Ast. stella, Ast. pentagonalis* and *Sphaerogypsina glubulus* occur in the upper conglomerate and in the detritic limestone.

Assuming that the vertical facies sequence reflects their lateral distribution, one notes that some palaeontological features of the section conform the features of some facies of the Arni model. It is especially true of the nummulite bank, fore-bank facies, „parapelagic zone" and back-bank facies. The conditions prevailing on land did not permit the development of the dolomitization zone and evaporites, facies with miliolids and transitional facies with alveolins. The nummulite bank of the Tatra Eocene formed on unstable carbonate platform of the Alpine zone and the absence of the mentioned elements seems justified.

The back-bank facies is represented in the Tatra Eocene by the dolomitic limestone with *Nummulites puschi*. This biofacies includes also the middle-sized nummulites with thick, dumpy tests: *N. incrassatus*, *N. semicostatus*, characteristic of the back-bank facies of Arni.

The nummulite bank facies of the Arni model is represented by the nummulitic limestone with *N. perforatus*, sparitic-micritic limestone with a minimum admixture of extraclasts. Larger foraminifer tests make up 60 – 80% of the rock. These are almost exclusively specimens of *N. perforatus*, accompanied by rare *N. striatus*. The specimens are the largest hitherto found of this species in the Polish Carpathians.

The fore-bank facies is represented by the marly Discocyclina limestone with *N. millecaput*.

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Fig. 4. Tatra Eocene section in the Pod Capkami quarry
Profil eocenu tatrzańskiego w kamieniołomie Pod Capkami

NO – sequential number and position of sample; I – substratum of the Eocene; II – Tatra Eocene; III – Podhale flysch; A – section in the quarry: a – conglomerate, b – conglomeratic limestone, c – dolomitic limestone, d – limestone, e – marl, f – shale; B – content of: g – micrite cement, h – sparitic cement, i – other constituents; C – variation of energy index (EI); D – content of larger foraminifers; E – content of algae; F – content of carbonate extraclasts; G – content of non-carbonate extraclasts and quartz; h – content of fossils; D.OTW. – larger foraminifers, M.OTW. – small foraminifers, KRAS – red algae, MSZ – bryozoans, SZK – echinoderms, WIEL – polychaetes, MAL – pelecypods; I – microfacies: E – extraclastic, EO – extraclastic-organogenic: 1 – extraclasts and larger foraminifers, 2 – extraclasts and red algae, 3 – extraclasts, red algae and others; O – organogenic microfacies: 1 – bryozoan, 2 – with larger foraminifers: a – with *Nummulites brongniarti*, b – with *N. puschi*, c – with *N. perforatus*, d – with discocyclins and *N. millecaput*, 3 – foraminifer-algal, 4 – algal, 5 – mixed (microfacies 4 and 5 occur in the Mała Łąka Valley and the Staników Gully sections); M – marl with small foraminifers

NO – numer i pozycja próbek; I – podłoże eocenu; II – eocen tatrzański; III – flisz podhalański; A – profil odsłonięcia; a – zlepieniec, b – wapień zlepieńcowaty, c – wapień dolomityczny, d – wapień, e – margiel, f – łupek; B – zawartość w skale: g – spoiwa mikrytowego, h – sparytowego, i – pozostałych składników; C – zmienność wskaźnika energii (*EI*) w profilu; zawartość: D – dużych otwornic; E – glonów; F – ekstraklastów węglanowych; G – ekstraklastów niewęglanowych i kwarcu; H – udział fauny; D.OTW. – duże otwornice, M.OTW. – małe otwornice, KRAS – krasnorosty, MSZ – mszywioły, SZK – szkarłupnie, WIEL – wieloszczety, MAL – małże; I – mikrofacje: E – ekstraklastowa, EO – ekstraklastowo-organogeniczna: 1 – ekstraklasty i duże otwornice, 2 – ekstraklasty i krasnorosty, 3 – ekstraklasty, krasnorosty i inne; O – mikrofacja organogeniczna: 1 – mszywiołowa, 2 – z dużymi otwornicami: a – z *Nummulites brongniarti*, b – z *N. puschi*, c – z *N. perforatus*, d – dyskocyklinowa z *N. millecaput*, 3 – otwornicowo-glonowa, 4 – glonowa, 5 – mieszana (mikrofacje 4 i 5 występują w profilach Doliny Małej Łąki i Stanikowego Żlebu); M – margiel z małymi otwornicami

More external zones (limestone and marl zone, „parapelagic zone") are represented by the marls with small foraminifers.

The upper conglomerates and organodetritic limestones, overlying the marls, evidence a sudden change in sedimentation, increase in tectonic activity in this area, and start of a new stage of the geological evolution of the region – the flysch sedimentation.

The facies of the Arni model, recognized in the Eocene section of the Pod Capkami quarry, are present also in the other investigated sections. Typical limestones with *Nummulites brongniarti*, 2–4 m thick, are present in the sections of the Skalnite Brook, Sucha Valley, Olczyska Valley, and on top of Hruby Regiel.

The limestone with *N. puschi* are reported from the sections in the Olczyska Valley, Spadowiec Brook, and Staników Gully.

The nummulitic limestone, 0.5–1 m thick, occurs in the Olczyska Valley, Spadowiec Brook (two beds), Staników Gully, and Kościeliska Valley.

The Discocyclina limestones occur in the Sucha Valley, Olczyska Valley, Spadowiec Brook, Ku Dziurze Valley, Strążyska Valley, Staników Gully, and Kościeliska Valley.

The above recount indicates that the most typical development of the Arni model elements is found in the western part of the Tatra Eocene outcrop zone, between the Skalnite Brook and the Ku Dziurze Valley. Farther to the west appears a thick (up to 20 m) characteristic facies of fine detritic limestone with numerous algae, discocyclins and small nummulites. Apart of the facies mentioned, there occur frequently detritic dolomites with poor faunal content, and rarely limestones with small foraminifers, limestones with echinoderms, and mudstones with plant remains.

As mentioned above, the typical transitional facies with alveolins and facies of limestone with miliolids have not been encountered in the Eocene of the Tatra. It is interesting to quote here a fragment of the microfaunistic study of the foraminifers from the borehole Hruby Regiel (S. Liszka, T. Śmigielska, 1974): „... Begining from the depth 431.6–436.0 (below the nummulitic limestones), a marked impoverishment in larger foraminifer fauna is observed. There are visible sections of small foraminifers *Miliolidae*. Below, from the depth 436.0–453.6 m on, there occur relatively numerous alveolins including the species: *Alveolina bosci*, *A. elongata*, *A.* cf. *fusiformis* ...".

The present author encountered also some lenses of the limestone with alveolins in the upper part of the lower conglomerate in the section of the Macicki Brook (Table VIII). They point to the local development of restricted zones of lagoonaltype sedimentation. The presence of the limestones with miliolids and limestones with alveolins provides another analogy in the facies distribution between the Eocene of the Tatra and the Arni model.

Taking into consideration the differences in size and shape between the larger foraminifers dominating in the individual facies, stressed on by G. Nemkow (1962) and P. Arni (1965) it is instructive to plot together the most important measurable parametres – test diameter (*D*) and test thickness (*E*) in milimetres, for the macrosphaeric (f. A), and for microsphaeric (f. B) generations.

The Discocyclina limestone (fore-bank facies) with the mass occurrence of discocyclins: *Discocyclina pratti*, f. A $\frac{D}{E} = \frac{6-11}{1.5}$; *D. ephippium*, f. A $\frac{D}{E} = \frac{7-10}{1-1.5}$; *D. discus*, f. A $\frac{D}{E} = \frac{10-15}{2}$; *D. nummulitica*, f. A $\frac{D}{E} = \frac{2.5-5.5}{1-1.5}$; less frequently are encountered characteristic nummulites of the species *N. millecaput*, f. A $\frac{D}{E} = \frac{4-8.5}{2-3.5}$; f. B $\frac{D}{E} = \frac{30-80}{2.5-5}$.

The limestone with *N. perforatus* (reef-like nummulitic bank of Arni) consists of the *Nummulites perforatus* tests, f.A $\frac{D}{E} = \frac{4-6}{2-3.2}$; f.B $\frac{D}{E} = \frac{8.5-24}{3.5-9}$.

The limestone with *N. puschi* (equivalent of the back-bank facies) is characterized by the numerous occurrence of the species *N. puschi*, f.A $\frac{D}{E} = \frac{4-15}{1-1.8}$; f.B $\frac{D}{E} = \frac{15-35}{2-3}$. The other nummulites, also numerous, but not so characteristic, are the following: *N. incrassatus* f.A $\frac{D}{E} = \frac{2-4.5}{1-2.5}$ and *N. striatus* f.A $\frac{D}{E} = \frac{2.5-6.0}{0.8-2}$.

The limestone with *N. brongniarti*, which occupies the position of the transitional facies of the Arni model, corresponds rather to the shallow-water, sublittoral sandy deposits of the Nemkow scheme (Fig. 1A). The dominating species is *N. brongniarti* f.A $\frac{D}{E} = \frac{2.5-6.5}{1-2}$; f.B $\frac{D}{E} = \frac{14-25.}{3-4}$.

The analysis of the graphic presentation of the above data (Fig. 5) corroborates the remarks of P. Arni (1965) and G. Nemkow (1962). The foraminifers with large and flattened, and hence the most delicate tests, are characteristic for the fore-bank facies – the marly Discocyclina limestone with *N. millecaput*. Somewhat more agitated environment is characteristic for the back-bank facies – the limestone with *N. puschi* and with small nummulites. The nummulites with thick robust are found in the nummulitic limestone (*N. perforatus*) and in the limestone with *N. brongniarti*.

It should be remembered, when comparing the biofacies mentioned above, that they have different faunal contents. The foraminifers are plentiful in the nummulitic and the Discocyclina limestone, less frequent in the limestone with *N. puschi* and still less frequent in the limestone with *N. brongniarti*.

The comparison of the energy index values for the typical accumulation environments of the foraminiferal biofacies of the Tatra Eocene provides further analogies with the Arni model. The energy index (*EI*), first introduced by W.I. Plumley et al. (1962), characterizes the dynamics of water movements accompanying the deposition of a given carbonate rock. Five main classes of limestones were distinguished: type I – is deposited in quiet water environment, type II – in environment of quiet water, occasionally agitated, type III – in feebly agitated environment, type IV – in moderately agitated environment, type V – in strongly agitated environment.

The determination of the type is based on the ratio of sparitic to micritic cement, type of texture and the stratification.

The percentage of micrite (g), sparite (h) and other constituents of the rock (i), are shown in Fig. 4, column B.

The column C shows the vertical variability of the energy index, determined here as the ratio of organodetritic remains and extraclasts to the micritic and sparitic cement. The individual types of limestones correspond to the following contents of the organogenic and extraclastic material in the rock: V – 90–100%, IV – 75–90%, III – 50–75%, II – 25–50%, I – below 25%.

The *EI* values indicate that the biofacies with *N. brongniarti* was deposited in

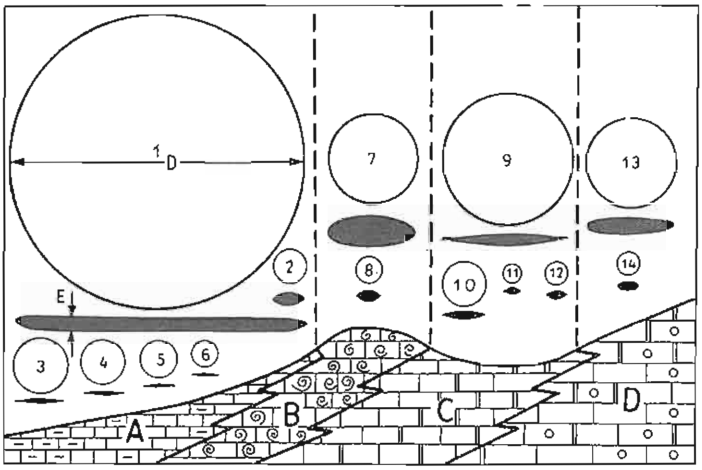


Fig. 5. Phaenotypic variability of larger foraminifers in the Tatra Eocene

Fenotypowa zmienność dużych otwornic w osadach eocenu tatrzańskiego

*D* – test diameter; *E* – test thickness; 1 – *Numulites millecaput*, f.B; 2 – *N. millecaput*, f.A.; 3 – *Dyscocyclina pratti*; 4 – *D. ephippium*; 5 – *D. discus*; 6 – *D. nummulitica*; 7 – *N. perforotus*, f.B; 8 – *N. perforatus*, f.A.; 9 – *N. puschi*, f.B.; 10 – *N. puschi*, f.A.; 11 – *N. incrassatus*; 12 – *N. striatus*; 13 – *N. brongniarti*, f.B.; 14 – *N. brongniarti*, f.A; A – Discocyclina limestone with *N. millecuput* (fore-bank facies); B – nummulitic limestone (numulite bank); C – dolomitic limestone with *N. puschi* (back-bank facies); D – dolomitic limestone with *N. brongniarti*

*D* – średnica skorupki; *E* – grubość skorupki; A – dyskocyklinowy wapień z *N. millecaput* (facja przedławicowa), B – wapień numulitowy (ławica numulitowa), C – dolomityczny wapień z *N. puschi* (facja zalawicowa), D – dolomityczny wapień z *N. brongniarti*; 1–14 objaśnione wyżej

a strongly agitated environment. The limestones with *N. puschi* and the nummulitic limestones were laid down in conditions of moderate turbulence (IV). The Discocyclina limestone was deposited in a weekly agitated environment (III). The carbonate rock type representing the least agitated environment (I) is the marl with small foraminifers. The *EI* indicates the content of extraclastic and organogenic components in the limestone but it was earlier mentioned that the nummulitic and the Discocyclina limestones contain plentiful foraminiferal tests *in situ*, and for this reason they should be not considered equally as the extraclasts. Thus the *EI* values for these two biofacies should be considered somewhat overestimated.

## CONCLUSIONS

1. The facies distribution in the Tatra Eocene conforms well the Arni model. The similarities are demonstrated by faunal content and petrographic composition of the Eocene sections in the Pod Capkami quarry, Sucha Valley, Skalnite Brook, Olczyska Valley, Spadowiec Brook, Strążyska Valley, Ku Dziurze Valley, Staników Gully, Kościeliska Valley.

2. The relation between the size and shape of nummulite and discocycline tests and energy of depositional environment has been confirmed. This relation is marked in the phenotype differentiation of the dominating foraminiferal species of individual facies.

3. The interpretation of the vertical sequence of nummulite faunas according to the Arni model, modifies the stratigraphic evaluations of the index forms of the

hemeras I, II, and III of F. Bieda (1963). The species *Nummulites brongniarti*, *N. perforatus* and *N. millecaput* lived simultaneously and their consecutive appearance in the section reflects merely the lateral, transgressive facies migration.

*Translated by G. Haczewski*

Oddział Karpacki
Instytutu Geologicznego
Kraków, Skrzatów 1
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REFERENCES

ALEXANDROWICZ S.W., GEROCH S. (1963) — Zespół małych otwornic w eocenie tatrzańskim. Rocz. Pol. Tow. Geol., 33, p. 219—227, z. 2.

ARNI P. (1965) — L'évolution des Nummulitinae en tant que facteur de modification des dépôts littoraux. Mém. B.R.G.M., nr 32, p. 7—20.

ARNI P., LANTERNO E. (1972) — Considérations paléoécologiques et interprétation des calcaires de l'Eocène du Veronais. Arch. Sc. Genève, 25, p. 251—283, nr 2.

ARNI P., LANTERNO E. (1976) — Observations paléoécologiques dans l'Eocène du Gargano (Italie méridionale). Arch. Sc. Genève, 29, p. 287—314, nr 3.

BARR F.T., WEEGAR A.A. (1972) — Stratigraphic nomenclature of the Sirte Basin Libya. Petrol. Expl. Soc. Libya. Tripoli.

BIEDA F. (1959) — Paleontologiczna stratygrafia eocenu tatrzańskiego i fliszu podhalańskiego. Biul. Inst. Geol., 149, p. 215—224.

BIEDA F. (1960) — Fauny numulitowe w eocenie tatrzańskim. Biul. Inst. Geol., 141, p. 5—31.

BIEDA F. (1963) — Duże otwornice eocenu tatrzańskiego. Pr. Inst. Geol., 37.

CASTANY G. (1961) — Lexique stratigraphique international, Tunisie, Afrique, 4, fasc. 1c.

DECROUEZ D., LANTERNO E. (1979) — Les „bancs à Nummulites" de l'Eocène mésogéen et leurs implications. Arch. Sc. Genève, 32, p. 67—94, nr 1.

DEECKE W. (1914) — Palaontologische Betrachtungen, VI. Über Foraminiferen. Neues Jb. Miner. Geol. Paleont., 11.

GEOLOGICAL MAP OF THE POLISH TATRA MOUNTAINS (1979) — 1:30,000. PAN. Warszawa.

LISZKA S., ŚMIGIELSKA T. (1974) — Opracowanie mikrofauny i stratygrafii utworów eoceńskich w otworach badawczo-poszukiwawczych „Hruby Regiel" i „Siwa Woda" w rejonie Zakopanego. Arch. Inst. Geol. Kraków.

NEMKOV G. (1962) — Remarques sur la paléoécologie des Nummulites. Vopr. Micropaleont. SSSR, 6, p. 64—72.

PAVLOVEC R. (1961) — K poznavanju eocenskih in oligocenskih numulitov Jugoslavije. Razprave, VI, p. 369—416.

PLUMLEY W.I., RISLEY G.A., GRAVES J.R., KOLEY M. E. (1962) — Energy index for limestone interpretation and classification. In: Classification of carbonate rocks. Am. Ass. Petrol. Geol. Mem., 1.

RONIEWICZ P. (1969) — Sedymentacja eocenu numulitowego Tatr. Acta Geol., Pol., 19, p. 503—608, nr 3.

RONIEWICZ P. (1979) — Paleogen Tatr i Podhala. W: Przew. 51 Zjazdu Pol. Tow. Geol., Zakopane 13—15 września 1979. Wyd. Geol. Warszawa.

ROZLOZSNICK P. (1927) — Einleitung in des studiem der Nummulinen und Assilinen Mitt. Jb. Ung. Geol. Aust., **26**.

SOKOŁOWSKI S. (1973) — Geologia paleogenu i mezozoicznego podłoża południowego skrzydła niecki podhalańskiej w profilu głębokiego wiercenia w Zakopanem. Biul. Inst. Geol., **265**, p. 5—103.

SZOSTS E. (1956) — Magyarorszag eocén (paleogén) képzdomenysi, rétegtani és osfoldrajszi tanulmány. Geol. Hungar., Ser. Geol., 9.

TOKARSKI J., OBERC A. (1953) — Z petrografii eocenu Tatr (Kamieniołom „Pod Capkami"). Rocz. Pol. Tow. Geol., **21**, p. 337—353, z. 4.

TURNAU-MORAWSKA M., LINDNER M. (1959) — Mułowce glaukonitowe eocenu tatrzańskiego. Acta Geol. Pol., 9, p. 147—163, пг 2.

Анджей КУЛЬКА

## СЕДИМЕНТОЛОГИЧЕСКАЯ МОДЕЛЬ АРНИ В ЭОЦЕНЕ ТАТР

Резюме

Разпределение биофаций в эоцене Татр в большой степени совпадает с моделью Арни. Сходство наблюдалось по фаунистическому составу и по результатам петрографического изучения разрезов эоцена в каменоломне Под Цапками, в Долине Сухей, в потоке Скалните, в Долине Ольчицкой, в потоке Спадовец, в Долинах Стронжиской, Ку Дюже, в Станиковом Жлебе и в Долине Косцелиской.

Фации, осадившиеся за отмелью, в эоцене Татр представлены доломитовым известняком, содержащим *Nummulites puschi*. Остальными компонентами биофации являются, характерные для фаций Арни за отмелью, нуммулиты среднего размера с толстой массивной раковиной *Nummulites incrassatus* и *N. semicostatus*.

Нуммулитовой отмели в модели Арни соответствует нуммулитовый известняк, содержащий *N. perforatus*, спаритово-микритовый известняк с незначительной примесью экстракластического материала. Крупные фораминиферы составляют 60—80% породы. Кроме немногих экземпляров *N. striatus* в составе фауны преобладает вид *N. perforatus*. Они являются самыми большими экземплярами этого вида из всех найденных до сих пор в польских Карпатах.

Отложениям фации, осадившейся перед отмелью, соответствует мергелистый дискоциклиновый известняк, содержащий *N. millecaput*. Более внешним зонам (зона известняков и мергелей, „парапелагическая зона") отвечает мергель с мелкими фораминиферами.

Верхние конгломераты и органодетритические известняки, осадившиеся на мергелях, являются свидетельством резкой смены условий седиментации, тектонической активизации района и начала нового этапа геологического развития региона — седиментации флиша.

Подтверждена связь между величиной и формой раковин нуммулитов и дискоциклин и энергией среды осаждения. Эта связь проявляется в фенотипной дифференциации фораминифер, преобладающих в отдельных фацях.

Интерпретация преемственности нуммулитовой фауны по модели Арни изменяет стратиграфическое значение индексных нуммулитов для I, II и III генеры Ф. Беды (1963). Виды *N. brongniarti*, *N. perforatus*, *N. millecaput* существовали одновременно, а их появление в разрезе в данной очередности явилось результатом горизонтального трансгрессивного смещения фаций.

Не исключено, что зависимость ассоциаций нуммулитов от фациального типа пород, приводила к ошибочной трактовке и других видов нуммулитов при стратиграфическом датировании разреза.

Andrzej KULKA

## SEDYMENTOLOGICZNY MODEL ARNIEGO W EOCENIE TATRZAŃSKIM


Streszczenie

Rozmieszczenie biofacji eocenu tatrzańskiego wykazuje dużą zgodność z modelem Arniego. Podobieństwa zostały stwierdzone podczas analizy składu faunistycznego i badań petrograficznycb w profilach eocenu w kamieniołomie Pod Capkami, w Dolinie Suchej, Potoku Skalnite, Dolinie Olczyskiej, Potoku Spadowiec, Dolinie Strążyskiej, Dolinie Ku Dziurze, Stanikowym Żlebie oraz w Dolinie Kościeliskiej.

Osady facji załawicowej są tam reprezentowane przez wapień dolomitowy z *Nummulites puschi*. Pozostałe składniki biofacji to numulity średniej wielkości o grubej, krępej skorupce: *N. incrassatus* i *N. semicostatus*.

Ławicy numulitowej z modelu Arniego odpowiada wapień numulitowy z *N. perforatus*, sparytowo-mikrytowy z minimalną domieszką materiału ekstraklastycznego. Duże otwornice stanowią 60–80% skały. Poza nielicznymi okazami *N. striatus* występuje prawie wyłącznie *N. perforatus*. Jest on największy spośród dotychczas znalezionych okazów tego gatunku w polskich Karpatach.

Osadom facji przedławicowej odpowiada marglisty wapień dyskocyklinowy z *N. millecaput*, natomiast strefom bardziej zewnętrznym (strefa wapieni i margli, „strefa parapelagiczna") margiel z małymi otwornicami. Osadzone na marglach górne zlepieńce i wapienie organodetrytyczne świadczą o gwałtownej zmianie charakteru sedymentacji, tektonicznej aktywizacji obszaru i zapoczątkowaniu nowego etapu geologicznej historii regionu – sedymentacji fliszu.

W opracowaniu został potwierdzony związek między wielkością i kształtem skorupek numulitów oraz dyskocyklin a energią środowiska sedymentacji osadu. Zależność ta jest widoczna w fenotypowym zróżnicowaniu otwornic dominujących w poszczególnych facjach.

Interpretacja następstw numulitów według modelu Arniego zmienia stratygraficzną wartość numulitów indeksowych dla I, II i III hemery F. Biedy (1963). *Nummulites brongniarti*, *N. perforatus* i *N. millecaput* żyły równocześnie, a ich pojawienie się w profilu w wymienionej kolejności wynikło z poziomego, transgresywnego przesunięcia facji. Nie można wykluczyć, że zależność zespołów numulitowych od typu facjalnego skały prowadziła do błędnego datowania również innych gatunków numulitów.

TABLE I

Fig. 6. Dolomitic limestone with *Nummulites brongniarti* (Pod Capkami quarry)
Wapień dolomitowy z *Nummulites brongniarti* (kamieniołom Pod Capkami)

Fig. 6

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TABLE II

Fig. 7. Dolomitic limestone with *Nummulites puschi* (Pod Capkami quarry)
Wapień dolomitowy z *Nummulites puschi* (kamieniołom Pod Capkami)

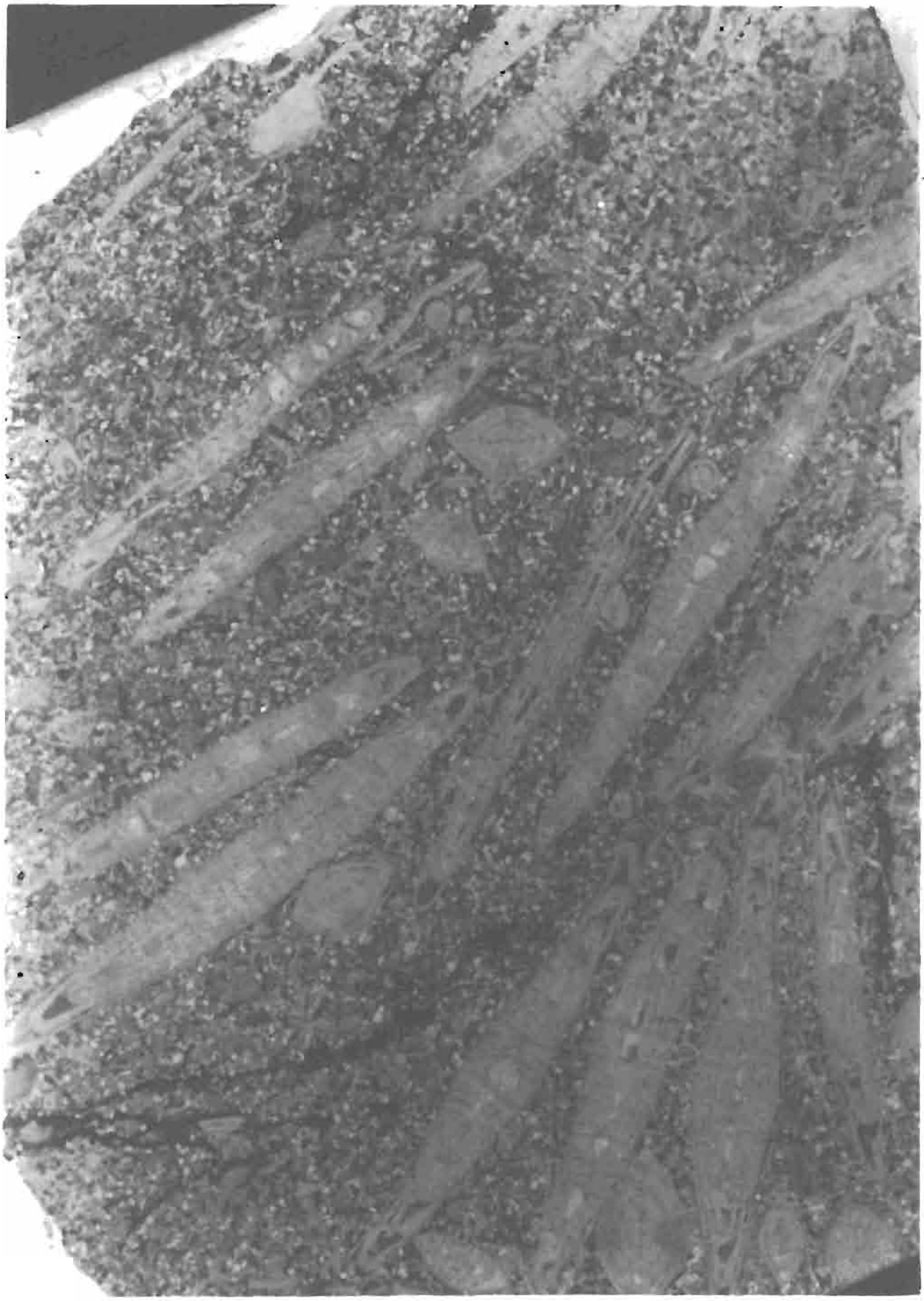

Fig. 7

TABLE III

Fig. 8. Nummulitic limestone (Staników Gully)
Wapień numulitowy (Staników Żleb)

Fig. 8

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TABLE IV

Fig. 9. Discocyclina limestone (Staników Gully)
Wapień dyskocyklinowy (Staników Żleb)

Fig. 9

TABLE V

Fig. 10. Detritic limestone with extraclasts, nummulites, discocyclines, small foraminifers, algae and bryozoans (Sucha Valley at Chłabówka)
Wapień okruchowy z ekstraklastami, numulitami, dyskocyklinami, małymi otwornicami, glonami i mszywiołami (Dolinka Sucha na Chłabówce)

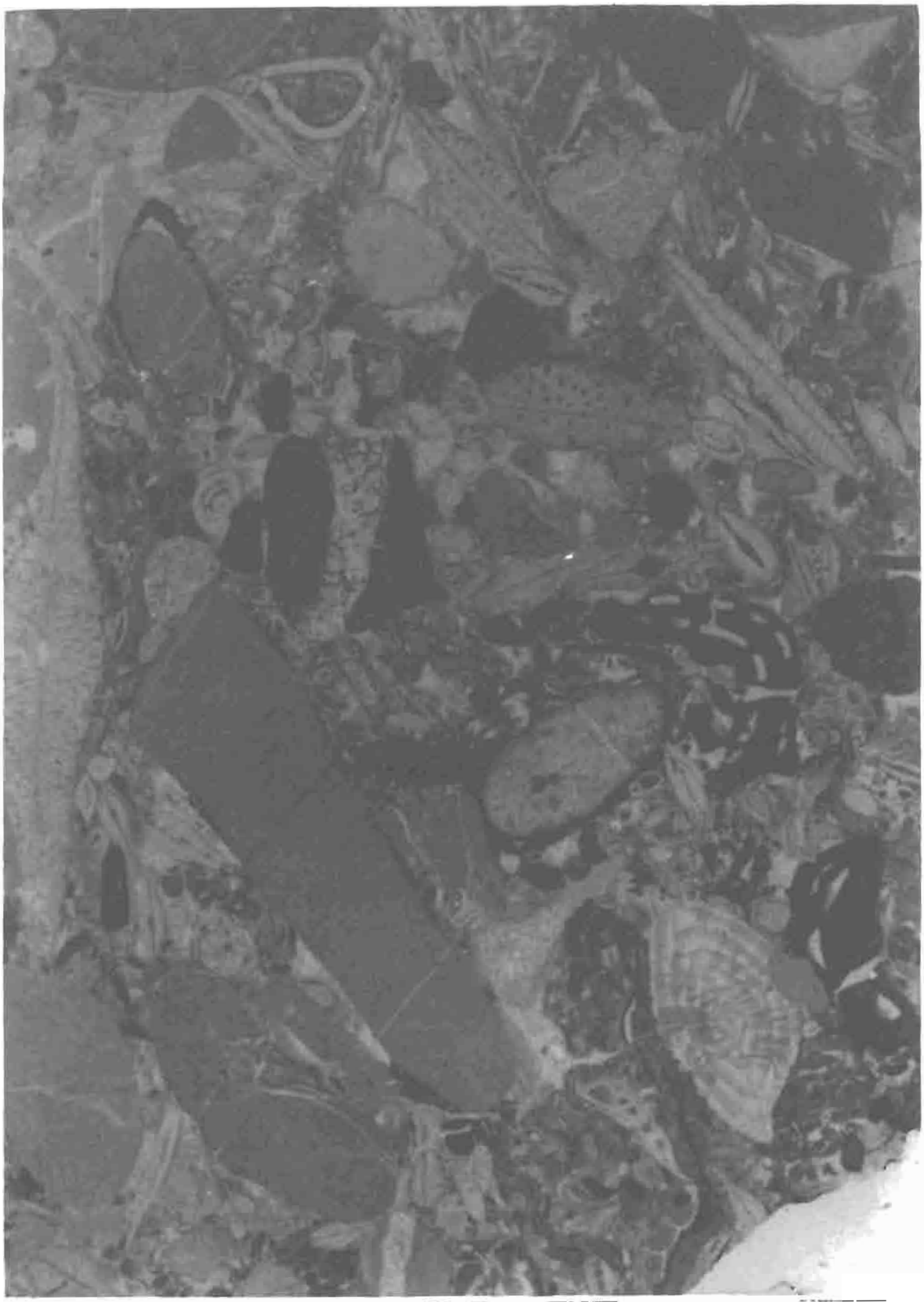

Fig. 10

TABLE VI

Fig. 11. Bryozoan-foraminiferal detritic limestone (Pod Capkami quarry)
Mszywiołowo-otwornicowy wapień detrytyczny (kamieniołom Pod Capkami)

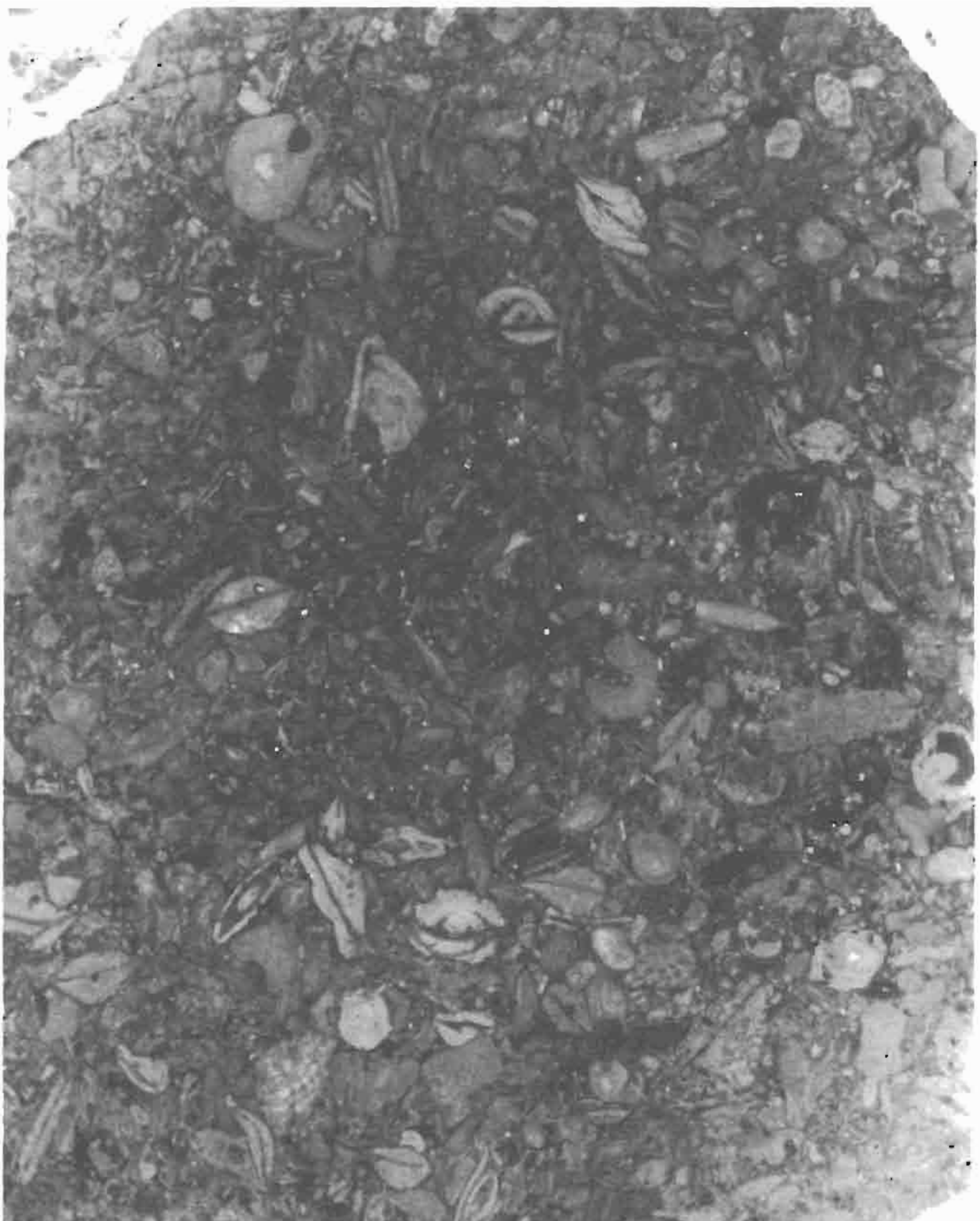

Fig. 11

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## TABLE VII

Fig. 12. Detritic limestone with numerous *Nummulites fabiani* (intercalation in the Zakopane Shales of the Podhale flysch, Staników Gully, Nędzówka)
Wapień detrytyczny z licznymi *Nummulites fabiani* (wkladka wapienia w łupkach zakopiańskich fliszu podhalańskiego, Staników Żleb, Nędzówka)

Fig. 12

TABLE VIII

Fig. 13. Limestone with alveolines and *Nummulites perforatus* (Macicki Brook)
Wapień z alweolinami i z *Nummulites perforatus* (Macicki Potok)

Fig. 13

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