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UPPER CRETACEOUS "ECHINOIDLAGERSTÄTTEN" IN THE KRAKÓW AREA

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Abstract: Accumulations of echinoid tests, the most numerous and characteristic macrofossils of Upper Cretaceous of Kraków area, appear in form which can be classified as "Echinoidlagerstätten".

Geometric and microfacies relationships between the fossils and the sediment, and the results of palaeoenvironmental analysis point out the strict dependence of this accumulations on energy conditions of their depositionary environment.

Echinoid assemblages were deposited: in high energy-environment of their life or after short transport (Cenomanian), in rather quiet environment of their life after very short distance or no post-mortal transport (Turonian), redeposited (Santonian), in quiet sedimentation environment of their life (Campanian).

An analysis of paleoenvironments allows to correlate the Cretaceous environments with modern echinofacies from eastern coast of the Adriatic Sea. The Cenomanian assemblage (*Phymosoma*, *Pyrina*, *Pygaulus*) may be correlated with Arbacia+Paracentrotus, Paracentrotus, and/or Sphaerechinus facies, the Turonian assemblage (mainly *Conulus*) with Echinocardium+Spatangus facies, the Santonian (*Micraster*, *Echinocorys*, *Conulus albogalerus*) and Campanian (*Micraster*, *Echinocorys*) assemblages should be placed deeper and/or farther from the shore than Echinocardium+Spatangus facies.

Abstrakt: Nagromadzenia pancerzy jeżowców, najliczniejszych i najbardziej charakterystycznych skamieniałości górnej kredy okolic Krakowa, mogą być zaklasyfikowane jako „Echinoidlagerstätten".

Geometryczne i mikrofacjalne zależności pomiędzy skamieniałościami i otaczającą je skałą oraz analiza paleośrodowiskowa wskazują na bezpośrednią zależność sposobu nagromadzenia pancerzy od warunków dynamicznych i energii środowiska.

Zespoły jeżowcowe po śmierci były: składane w środowisku swojego życia o wysokiej energii bez przemieszczania pancerzy, ewentualnie po krótkim transporcie (cenoman); składane w dość spokojnym środowisku po bardzo krótkim transporcie lub w miejscu życia (turon); redeponowane (santon); pogrzebane w środowisku spokojnej sedymentacji w miejscu życia lub bardzo blisko niego (kampan).

Analiza paleośrodowisk daje możliwości korelacji środowisk życia jeżowców kredowych ze współczesnymi echinofacjami ze wschodnich wybrzeży Adriatyku. Zespół cenomański (*Phymosoma*, *Pyrina*, *Pygaulus*) odpowiada facjom: Arbacia+Paracentrotus, Paracentrotus i(lub) Sphaerechinus, zespół turoński (głównie *Conulus*) – facji Echinocardium+Spatangus, santoński (*Micraster*, *Echinocorys*, *Conulus albogalerus*) i kampański (*Micraster*, *Echinocorys*), usytuowane są dalej od brzegu, i(lub) głębiej niż facja Echinocardium+Spatangus.

Key words: echinoids, "Echinoidlagerstätten", Upper Cretaceous, Kraków area.

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INTRODUCTION

Echinoid tests are the most numerous and characteristic group of macrofossils in the Upper Cretaceous deposits in the vicinity of Kraków. Many authors noticed a high frequency of echinoid remains in the Upper Cretaceous of the Kraków region (Zaręczny, 1878; Smoleński, 1906; Barczyk, 1956; Bukowy, 1956; Małecki, 1976, 1979; Kudrewicz, 1991) and the NW part of the Miechów Trough (Sujkowski, 1926, 1934; Kowalski, 1948; Marcinowski, 1974).

Some echinoid groups have their own monographic descriptions. Kongiel (1939) described regular echinoids from the Cenomanian of Korzkiew and Sudół, from the Turonian of Glanów, and rare specimens from the Upper Campanian of Bibice and Młodziejowice. Mączyńska (1962, 1972, 1977) described Cenomanian echinoids from the genus:

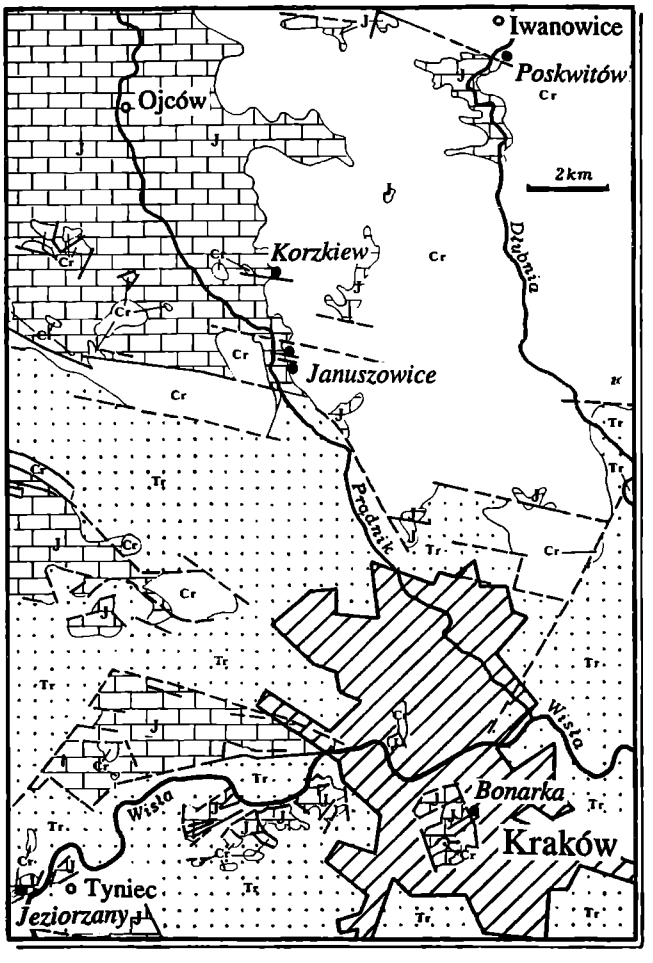


Fig. 1. Location sketch map (after Gradziński, 1972, slightly simplified); discussed outcrops printed in italics; J – Jurassic, Cr – Cretaceous, Tr – Tertiary

Pyrina, *Pygaulus*, *Catopygus*, and Cenomanian and Turonian ones from the genus *Discoidea* (Mączyńska, 1958). Upper Cretaceous genus *Micraster* also has its large monograph (Mączyńska, 1968). Popiel-Barczyk (1958, 1962) described the echinoids from the genus *Conulus* from the Turonian and Santonian of the Kraków–Miechów area. Sobczyk (1990) constructed a key for determination of Upper Cretaceous echinoids from the Kraków area.

Hynda and Mączyńska (1979) described echinoids from the genus *Micraster*, very numerous in Santonian of Korzkiew, establishing a new species *Micraster (Micraster) maleckii* Mączyńska, 1979, connected with *Micraster (Micraster) rogalae* Nowak, 1909. Kudrewicz (1992) analysed the morphology and stratigraphic distribution of *Micraster (Micraster) maleckii*, placing this species after *Micraster (Micraster) rogalae* in the – *rogalae* evolutionary lineage considered by Ernst (1970c) as a lateral lineage of the genus *Micraster*.

The authors of this contribution studied in the field-conditions geometric relationships between fossils, and microfacies relationships between sediments inside and outside the tests throughout the Upper Cretaceous sequence.

Palaeoenvironmental conditions were interpreted basing on comparison of fossil forms with modern genetically related, similar morphotypes.

Material was collected from some, in the authors opinion representative, outcrops in the vicinity of Kraków (Fig. 1). It comes from the Cenomanian of Korzkiew, Turonian of Januszowice and Jeziorzany, Santonian of Korzkiew, and Campanian of Bonarka and Poskwitów.

GEOLOGIC SETTING

All outcrops described in this paper are located no farther than 19 km, mostly northwards from the centre of Kraków (*see* Fig. 1), and represent Cenomanian to Campanian sediments (*see* Fig. 2).

On the left side of the river Wisła at **Jeziorzany**, at the side of an ox-bow, there are white walls built of Upper Jurassic biohermal limestones (Fig. 3). Yellow-gray limestones, dated Turonian (Alexandrowicz, 1954), organodetrital, nodular, not laminated, up to 1 m thick, crop out in depressions in the rough top of these limestones. The detrital material of the rock consists of inoceramid and echinoderm detritus with quartz sand and (particularly in the bottom part)

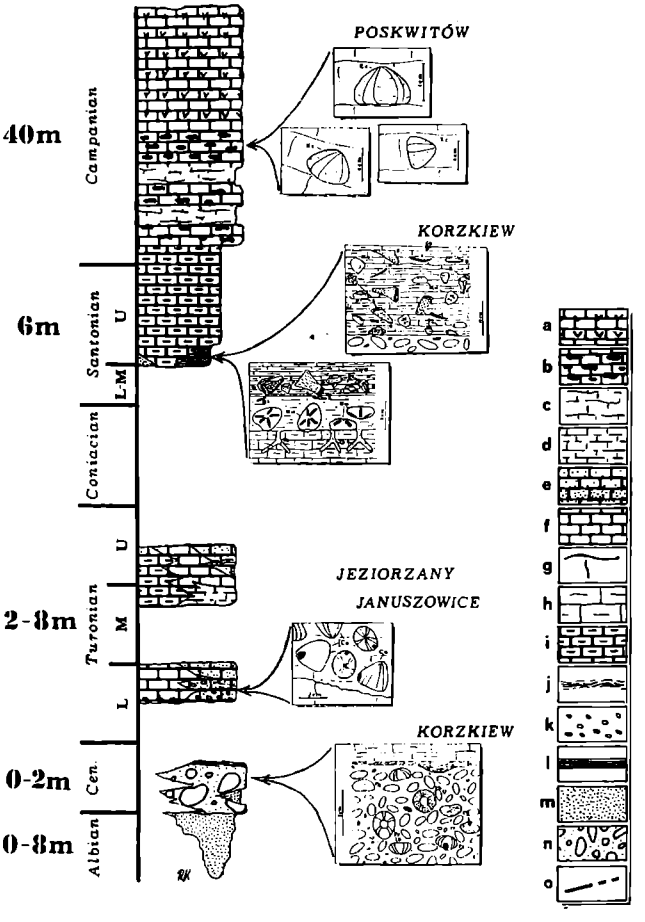


Fig. 2. Synthetic section through Cretaceous sediments in Kraków region; *a* – silicious chalk, *b* – marly limestones and marls with cherts and flints, *c* – marly limestones, *d* – calcarenites and nodular limestones, *e* – sandy limestones and limestones with sand addition, *f* – pelitic limestones, *g* – biohermal limestones, *h* – thick laminated marls, *i* – marls, *j* – stromatolites, *k* – pebbles, *l* – clays and marly clays, *m* – sands, *n* – conglomerates, *o* – faults; insets are magnified and explained in next figures

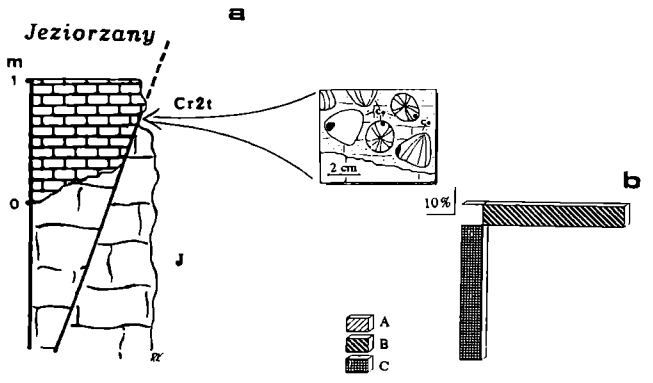


Fig. 3. Jeziorzany. **a** – section; J – Jurassic, Cr2t – Turonian (lithology see Fig. 2), **b** – test orientation diagram; *A* – normal position, *B* – on side, *C* – reversed; inset shows type of echinoid tests accumulation; Co – *Conulus*

quartz and flint pebbles (*see also* Alexandrowicz, 1954).

The Turonian limestones contain, especially in the lower part, numerous tests of echinoids from the genus *Conulus*.

In the Prądnik valley near **Januszowice** village, there are three outcrops of Turonian deposits. The best exposure is in the old abandoned quarry at Januszowice (Fig. 4), where the abrasion surface of the Upper Jurassic biohermal limestones is overlain by:

1.1 m yellow-gray sandy limestones with quartz pebbles, dated as upper part of Lower Turonian – Mytiloides labiatus zone (*see* Walaszczyk, 1992), truncated by a rough abrasion surface;

0.7 m white, slightly sandy, nodular limestones with quartz and flint pebbles, capped with a thin stromatolite;

1.3 m white pelitic limestones;

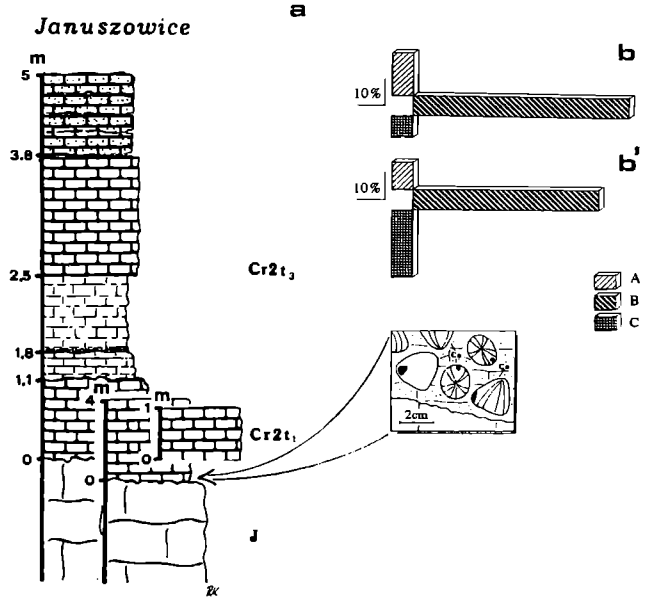


Fig. 4. Januszowice. **a** – synthetic section; $Cr2t_1$ – Lower Turonian, $Cr2t_3$ – Upper Turonian; **b**, **b'** – test orientation diagrams (two samples), inset shows type of echinoid tests accumulation; other explanations in Figs. 2–3

1.3 m gray, and yellow-gray, grain and nodular limestones;

1.2 m brown, sandy limestones with clay intercalations.

The part of the sequence, above the abrasion surface which cuts limestones of the M. labiatus zone, is dated Inoceramus costellatus zone or uppermost I. lamarckii and I. costellatus zone (*see* Walaszczyk, 1992).

The other two outcrops (one of them is illustrated by Gradziński, 1972) represent only the lower (M. labiatus zone) part of the sequence with which an appearance of *Conulus* remains is connected. Mączyńska (1958) described also an assemblage of *Discoidea* from this place. A large number of tests is concentrated in the Turonian deposits above the abrasion surface in a small outcrop a few meters southwards from the old quarry.

At **Korzkiew** a 2.5 m thick section crops out (Fig. 5):

0.85 m Lower (*according* to Panow, 1934; Bukowy, 1956) or Middle (*according* to Kudrewicz, 1991) Cenomanian marly quartz-flint conglomerates;

0.75 m Middle Turonian light gray marls with glauconite;

0.06 m Santonian green, glauconitic clays;

0.80 m Santonian to Lower Campanian glauconitic marls.

Concentrations of echinoids from the genus: *Pyrina*, *Pygaulus*, and *Phymosoma* (rare) occur in the Cenomanian conglomerates, and from the genus *Micraster* with accompanying rare *Echinocorys* and *Conulus albogalerus* in the Santonian glauconitic clays. The clay layer was described in detail by Kudrewicz (1992), that is why more attention will be paid only to the Cenomanian conglomerates here.

The Cenomanian conglomerates are known from two

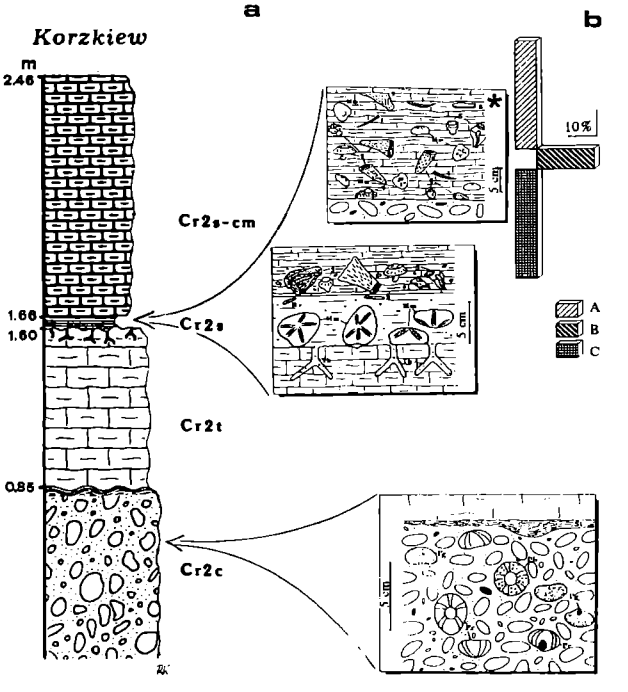


Fig. 5. Korzkiew – exposure "U Krzywdy". **a** – section; Cr2c – Cenomanian, Cr2t – Turonian, Cr2s – Santonian, Cr2s-cm – Santonian through Campanian, **b** – test orientation diagram for Santonian echinoids; insets show type of test accumulations (asterisked situation from exposure "Above the Castle"); Mm – *Micraster (Micraster) maleckii*, Pr – *Pyrina*, Pg – *Pygaulus*, Ph – *Phymosoma cenomanense*, S – sponges, B – belemnites, I – inocerams; other explanations in Figs. 2–3

outcrops called: "Above the Castle" (Małecki, 1980) and "U Krzywdy" (for detailed location *see* Kudrewicz, 1992). The outcrop "U Krzywdy" shows exposed 0.85 m thick, quartz-flint marly conglomerates, with addition of quartz sand, and large (about 1 mm) glauconite grain aggregates. The pebbles are well rounded, spheroidal and ellipsoidal in shape, 0.5 – 2.5 cm in diameter. They make about 50% of rock volume. The rock is grain supported with no traces of lamination or direction-indicative structures and no evidence of dissolution, recrystallization, or other diagenetic processes. The pebbles are chaotically distributed in the rock. Conglomerates exposed "Above the Castle" are identical in their petrographic and sedimentary character to those from the exposure "U Krzywdy".

On **Bonarka**-Hill there is an abandoned quarry – now a nature reserve. Detailed descriptions of the quarry were published by Smoleński (1906), Panow (1934), Alexandrowicz (1954), Barczyk (1956) and Gradziński (1960). In 1990 an excavation was made, eastwards from the monument on the top of the hill, which made it possible to extend the section (Fig. 6).

Just above the Upper Jurassic thick layered biohermal limestones, truncated by an abrasion surface, rest thin (about 0.2 m) gray sandy limestones with quite numerous quartz pebbles (locally the limestones are conglomeratic). The authors did not found any fossils in this layer, though Barczyk (1956) gives a list of Lower Turonian fossils from the same layers exposed in the quarry (*cf.* Gradziński, 1960). Above the limestones, rest 0.8 m thick greenish glauconitic marls (Barczyk, 1956), 0.3 m of them were exposed during the excavation. The glauconitic marls are covered with gray marls 3 m thick. The fossils (Barczyk, 1956) indicate Santonian age of the greenish marls, and earliest Campanian for the gray marls (*cf.* Gradziński, 1960, 1972).

The Bonarka section ends with white limestones and marly limestones, 3.5 m thick, which include numerous

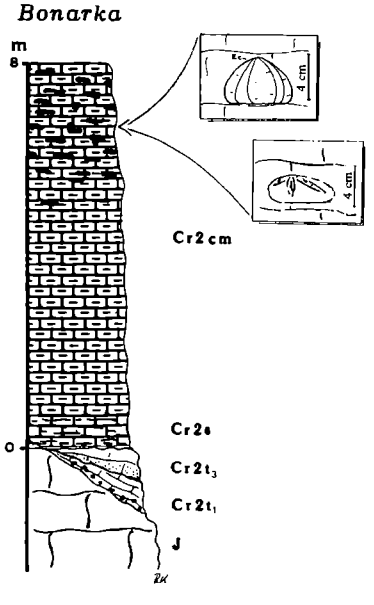


Fig. 6. Bonarka, section. Insets show type of test accumulation; Ec – *Echinocorys*; other explanations in Figs. 2–5

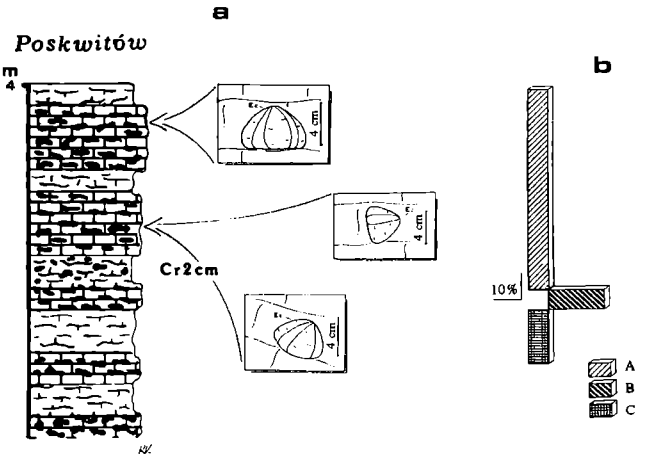


Fig. 7. Poskwitów. **a** – section, **b** – test orientation diagram; explanations in Figs. 2–6

cherts and flints, and are determined as Lower Campanian (Barczyk, 1956). Remains of echinoids from the genus *Echinocorys* and *Micraster* have been collected from marly limestones and marls with flints. Mączyńska (1984) described also infrequently specimens of *Offaster* and *Galeola* from the same place.

At **Poskwitów**, white marls and marly limestones with cherts and flints crop out along the road (Fig. 7). Three lithologic types can be seen in the section:

1 – marly limestones and marls with well developed flints,
2 – marly limestones with cherts,
3 – marls and marly limestones, which form intercalations between layers rich in flints (lithotype 1).

Thickness of layers varies from 15 to 60 cm.

Sediments formed in this lithofacies type have been developed similarly to the Lower Campanian deposits throughout the Kraków region (Gradziński, 1972) and SW margin of the Miechów Trough (Rutkowski, 1965).

Echinoids genera *Echinocorys* and *Micraster* are generally found in marly limestones, and marls with flints (like on Bonarka-Hill). Mączyńska (1984) mentioned from this place also very rare *Cardiaster*. The best preserved specimens are filled with chalcedony which also impregnates the tests. Fossils are rather rare in the marly intercalations, where they are very often deformed.

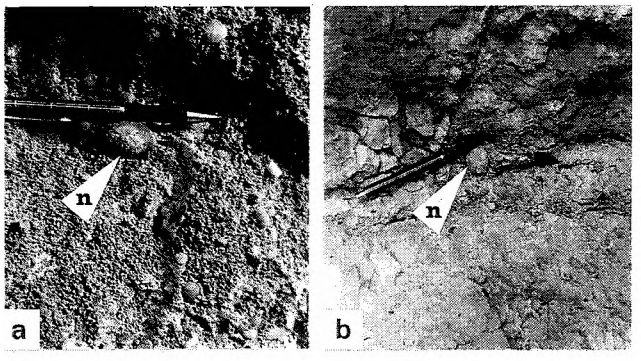
GEOMETRIC, MICROFACIES AND PALAEOENVIRONMENTAL ANALYSIS

Cenomanian at Korzkiew

Echinoid tests in the Cenomanian conglomerates are rather well preserved, some are slightly crushed and partly dissolved, colored with glauconite, iron oxides and hydroxides. Many tests have quite well and well preserved ornamentation. Some tests bear traces of encrustation by benthic organisms, e.g. bryozoans.

The echinoid tests rest in random positions (*see* in-set Fig. 5), on the oral, aboral and both lateral sides (Fig. 8a, b).

KORZKIEW - *Cenomanian*



JANUSZOWICE - *Turonian*

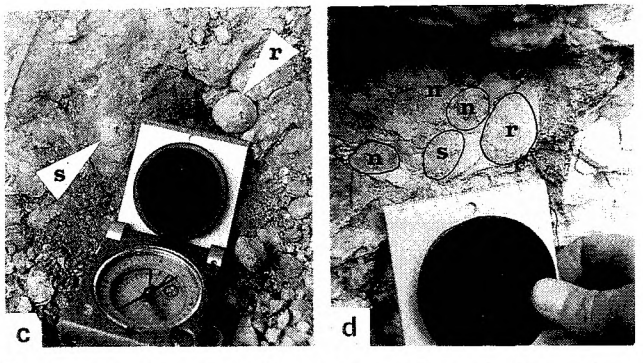


Fig. 8. **a** – An echinoid from the genus *Pyrina* in the conglomerates; **b** – An echinoid from the genus *Pyrina* in the conglomerates; other specimen; **c** – Two echinoids from the genus *Conulus* in the nodular limestones; **d** – A "nest" of echinoids from the genus *Conulus* in the nodular limestones; on the arrows lettered position of the test: n – normal, s – on side, r – reversed

KORZKIEW - *Cenomanian*

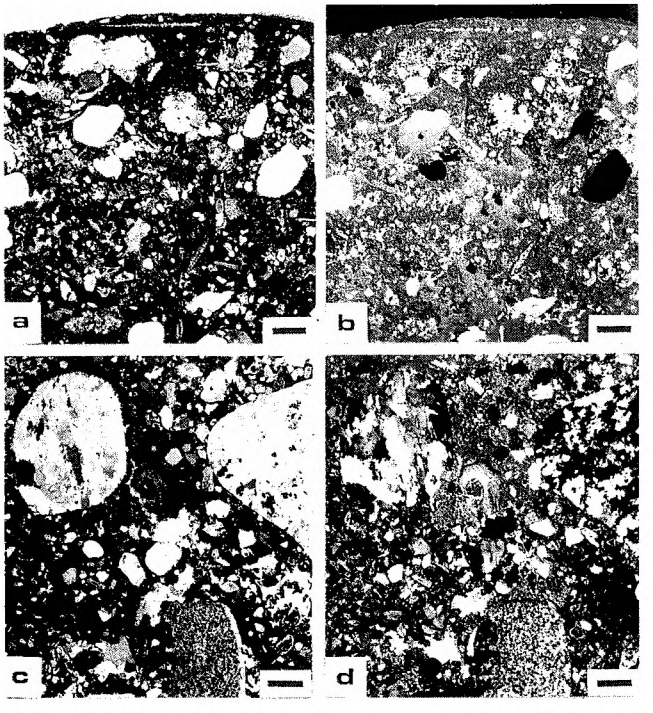


Fig. 9. Microfacies of infillings and surroundings of echinoid tests. **a** – Test infilling of the echinoid from the genus *Pyrina*; parallel nicols; **b** – The same sample; crossed nicols; **c** – Conglomerate surrounding the test of *Pyrina*, notice the quartz pebbles; parallel nicols; **d** – The same sample; crossed nicols; scale bars = 1 mm

They are irregularly distributed – especially *Pyrina* and *Pygaulus*, and locally they are clustered in nests (particularly in the outcrop "Above the Castle").

The tests are filled with material which is similar to the cement of the surrounding conglomerate (*see* Fig. 9). Though, their microfacies slightly differ in proportion of components.

Modern morphotypes of Echinoneidae and Cassiduloidae, similar and genetically related to *Pyrina* and *Pygaulus*, prefer habitats of coarse- and very coarse-grained sediments (Hawkins, 1919; Mortensen, 1948; Kier, 1966; Wagner & Durham, 1966).

The described features and analogies may indicate that echinoids had lived in the same sedimentary environment in which they were buried.

Thick tested regular *Phymosoma*, rather rare in this assemblage, carries indices of damage of the test surface. The *Phymosoma*'s nearest modern descendants, e.g. Stomechinidae and Arbacidae, live on shallow and extremely shallow-water rocky bottoms (Smith, 1984) and so probably did *Phymosoma*. Therefore, and taking under consideration results of study of Chave's (1964) experiment, rare appearance of *Phymosoma* may be a result of transport from a fairly distant littoral zone.

Turonian at Jeziorzany, Trojanowice and Januszowice

Echinoid (mainly *Conulus*) tests found in Turonian strata occur in the bottom parts of the sections at Jeziorzany and Januszowice. They are irregularly distributed in the host rock and often clustered (Fig. 8 d). The tests are poorly preserved, many of them are recrystallized, and some bear traces of dissolution. Almost none of them rest in their normal position, and generally they lie on their sides (*see* Figs. 3–4, 8 c–d, 10).

Comparing several pairs infilling-surrounding of the test, there were noticed differences between the samples, resulting from a considerable microfacies variability of Turonian sediments in the Kraków–Miechów area (Alexandrowicz, 1954; Barczyk, 1956; Marcinowski, 1974; Marcinowski & Radwański, 1983; Kudrewicz, 1991; Walaszczyk, 1992). Each test is filled with the same sediment in which it was resting. All infillings represent the same microfacies type as the surrounding limestone (*see* Figs. 11, 12).

The echinoid genus *Conulus* occur usually in arenite facies (Ernst, 1970a). In the Turonian of Saxony, the open shelf calcarenite Conulus-Facies appears in areas of halokinetic synsedimentary elevations on the sea bottom (*see* Ernst *et al.*, 1979). Studies of modern *Echinoneus* (Hawkins, 1919; Rose, 1978) point out coarse grained substratum as its environmental preference. It may be assumed that morphologically and functionally similar *Conulus* had the same environmental requirements.

JANUSZOWICE - *Turonian*

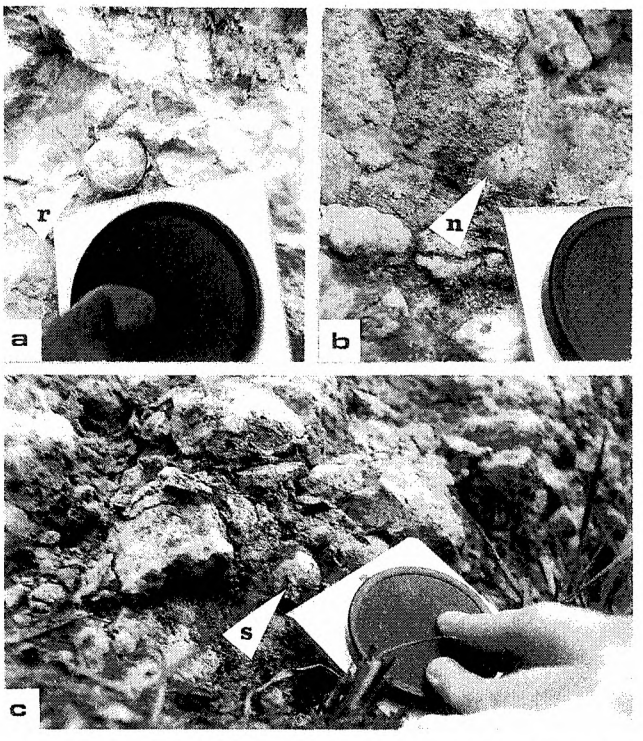


Fig. 10. **a–c** – Echinoids from the genus *Conulus* in the nodular limestones. On the arrows lettered position of the test: n – normal, s – on side, r – reversed

JANUSZOWICE - *Turonian*

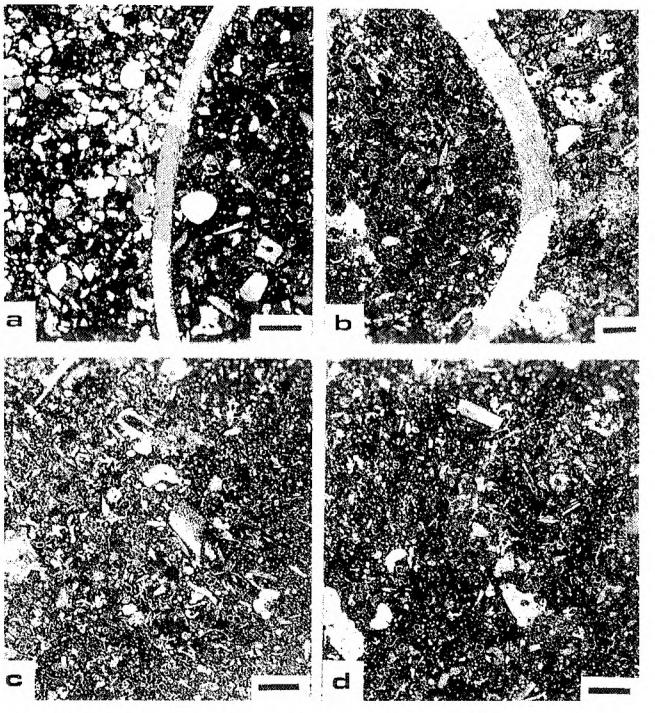


Fig. 11. Microfacies of infillings and surroundings of echinoid tests. **a** – The infilling and surrounding of the *Conulus* test; both sandy wakestones in calcisphaere (pithonellid) – foraminiferal microfacies type; **b** – The infilling and surrounding of the *Conulus* test; both wakestones in calcisphaere (pithonellid) – foraminiferal microfacies type without detrital material; **c** – The infilling of the *Conulus* test; microfacies type like Fig. 11b; **d** – Limestone surrounding the *Conulus* test; microfacies type like Fig. 11b–c: scale bars = 1 mm

Relationships between the microfacies of the infilling of the tests and their host-sediment, and *Conulus* environmental requirements indicate that the echinoids were finally buried in the environment of their life, and never exhumed. Possibly, a very short transport may have taken place only within the area of deposition of the same microfacies.

Santonian at Korzkiew

The Santonian echinoids (numerous *Micraster*, rare *Echinocorys* and *Conulus albogalerus*) found at Korzkiew rest in various positions (for distribution *see* Figs. 5b, 13) in a completely different sediment to that they are filled with. The tests and moulds are often phosphatized and slightly silicified. Surrounding clays are soft and plastic, and have entirely different microfacies (*see* Figs. 14, 18 a–b; for detailed description *see* Kudrewicz, 1992).

Diagenetic processes (phosphatization and silification) have altered the primary test infillings. Traces of benthic organisms attachment over the whole surface of the tests, and the microfacies of the infillings and the moulds (Fig. 14c)

JEZIORZANY - *Turonian*

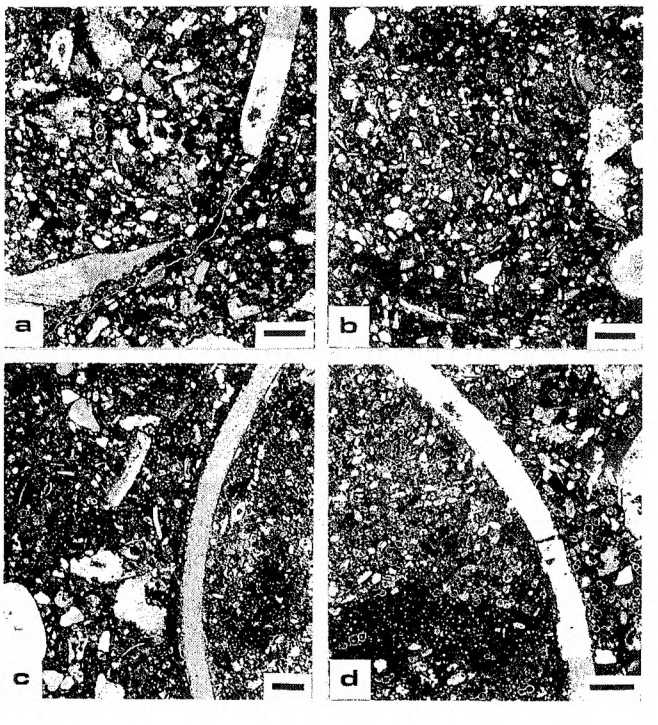


Fig. 12. Microfacies of infillings and surroundings of echinoid tests. **a** – The infilling and surrounding of the *Conulus* test; **b** – The limestone surrounding the *Conulus* test; **c–d** – The infilling and surrounding of the *Conulus* tests; all samples represent the calcisphaere (pithonella) – foraminiferal microfacies;
scale bars = 1 mm

K O R Z K I E W - *Santonian*

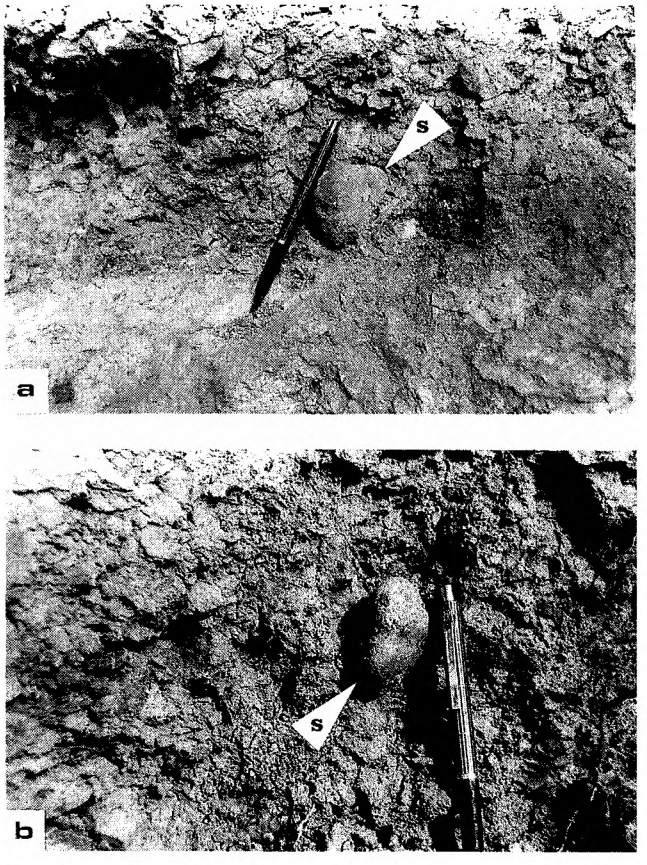


Fig. 13. **a–b** – Echinoids from the genus *Micraster* in the glauconitic marly clays. Both specimens rest on their sides (lettered – s)

K O R Z K I E W - *Santonian*

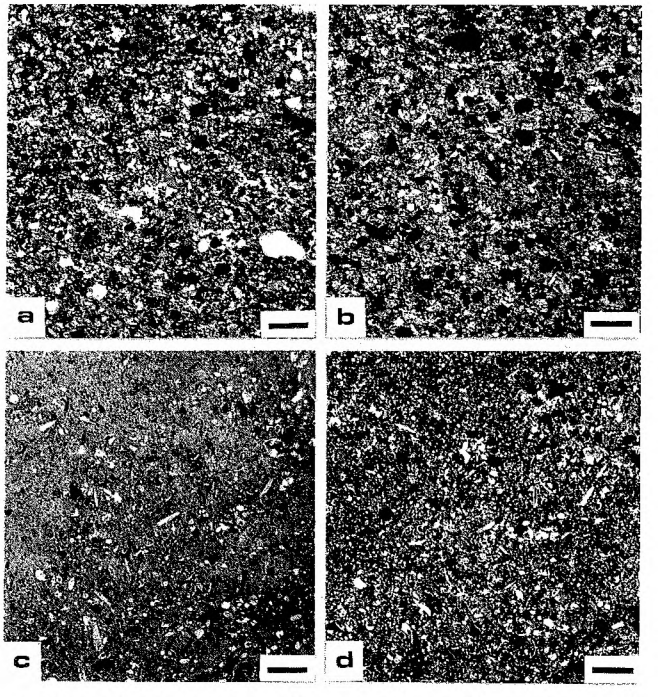


Fig. 14. Microfacies of infillings and surroundings of echinoid tests. **a** – Glauconitic marly clays surrounding of *Micraster* tests, black grains – glauconite; parallel nicols; **b** – The same sample; crossed nicols; **c** – Infilling of the *Micraster* test – phosphatized glauconitic marly wakestone in foraminiferal microfacies type with several *Pithonella* and sponge spicules; parallel nicols; **d** – The same sample; crossed nicols; scale bars = 1 mm

different from the surrounding marly clays (Fig. 14a) which generally lack echinoids (Ernst, 1970b), point out that the fossils were redeposited.

Because of exhumation and redeposition, a reconstruction of Santonian environments can be only done by interpretation of some features of *Micraster* tests. The whole system of *Micraster*'s adaptations as a mud-dwelling morphotype shows fine-grained carbonate sediments as environment of their life (*see* Smith, 1984). *Echinocorys* appear as epifauna (Smith, 1984) very often in the same facies as *Micraster*. Morphology of Santonian *Conulus albogalerus* considerably differs from the Turonian forms of *Conulus*. Hawkins (1919) proves that *Conulus* during its evolution adapted to life in even finer sediments and deeper facies. It may be suggested that *C. albogalerus* lived in the same environment as *Micraster* and *Echinocorys*.

Taphonomy and burial history of the echinoid assemblage from the Santonian of Korzkiew was described in detail by Kudrewicz (1992).

Campanian at Bonarka and Poskwitów

Most echinoid tests (*Echinocorys*, *Micraster*) found in the Campanian sediments occur in silicified layers, rich in flints and cherts. Statistic distribution of test orientations (Fig. 7b) shows that they rest generally in normal life position or on their lateral sides (*see also* Figs. 15–17). Well preserved specimens are silicified (Fig. 18 c–d).

There is no indication that environmental preferences of *Micraster* and *Echinocorys* had changed since Santonian.

The facies and microfacies of a quite deep marine sediment, without land influence, the nature of test accumulations, and environmental requirements of echinoids indicate that the echinoid remains were buried in the same chalky sediment in which they lived.

FINAL REMARKS

Two considerations may result from the material presented and analysed here.

Even though the echinoid tests are the most numerous macrofossils in the Cretaceous of the Kraków region, they are not easy to find, because of the kind of their accumulation called here "Echinoidlagerstätte", and their occurrence limited to some layers and places. They are irregularly distributed in the rocks, and assigned to some characteristic surfaces and layers. The mode of deposition of the tests depended on the energy of environment and facies conditions.

This dependence may be summarised as follows:

Cenomanian. The echinoids (*Pyrina* and *Pygaulus*) lived in coarse and very coarse grained sediments, and after

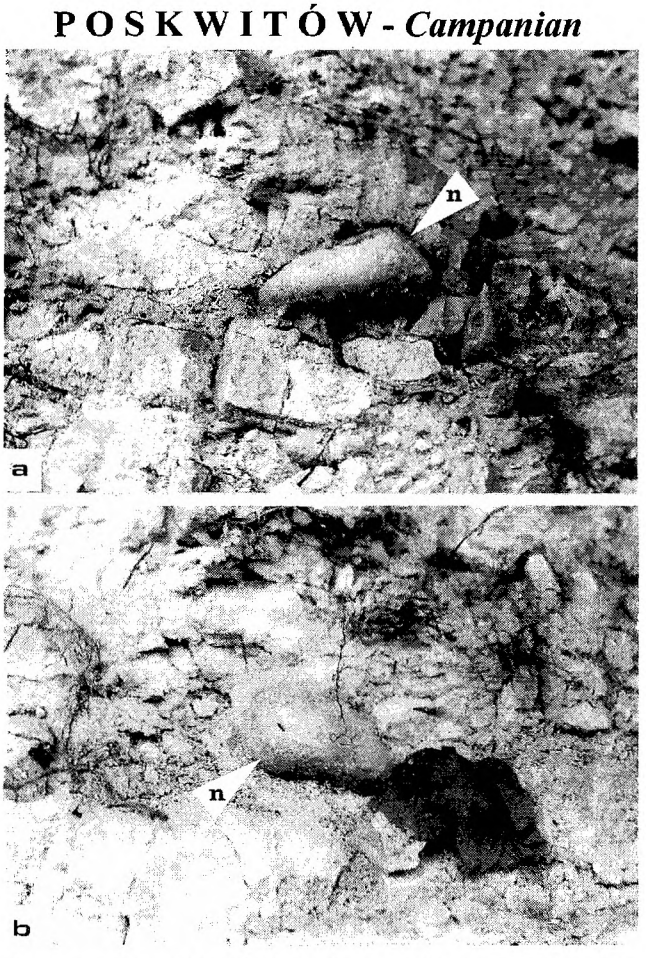


Fig. 15. **a–b** – Echinoids from the genus *Micraster* in the marly limestones with flints. Both specimens in normal position (lettered – n); 0.3 of natural size

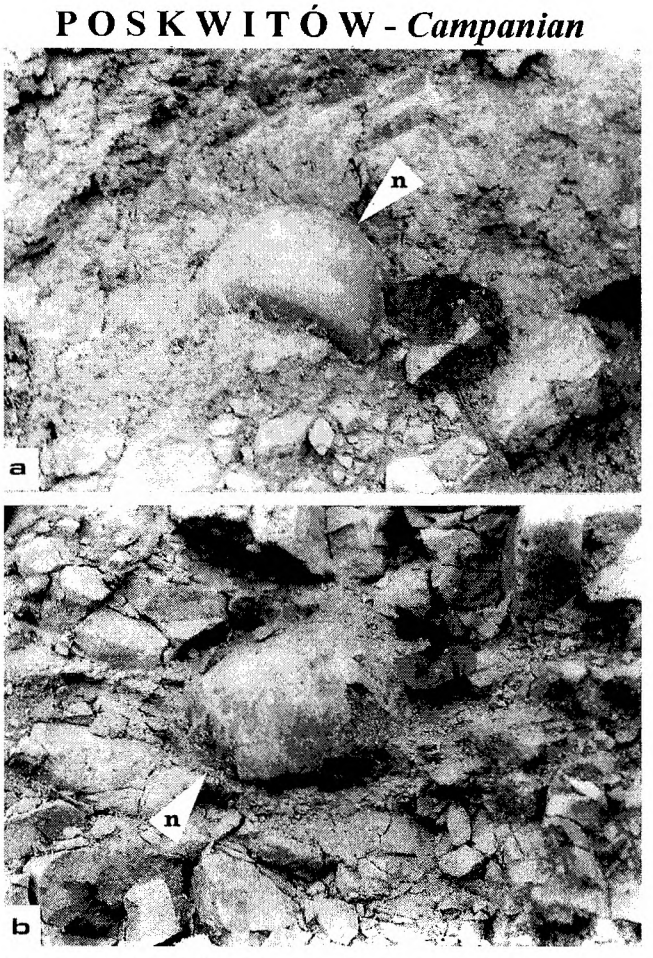


Fig. 16. **a–b** – Echinoids from the genus *Echinocorys* in the marly limestones with flints. Both specimens in normal position (lettered – n); 0.3 of natural size

death they might be transported for very short distances and finally buried in high energy environments. Remains of *Phymosoma* were transported from the littoral zone.

Turonian. The echinoids (mainly *Conulus*) lived in calcarenite sediments and were finally buried in a rather low-energy environment. The tests were transported for very short distances or only slightly reworked in their habitat.

Santonian. The echinoids (mainly *Micraster*, and rare *Echinocorys* and *Conulus albogalerus*) lived in fine-grained, chalky and marly-chalky sediments, in low energy conditions. After primary burial, they were exhumed and redeposited due to a high energy event, and finally buried in a quiet clayey sedimentation environment.

Campanian. The echinoids (*Echinocorys* and *Micraster*) lived and were finally buried in chalky and/or marly-chalky facies of a quite deep marine, quiet environment. Generally they rest in place of their life.

In interpretation presented here another possibility for the formation of "Fossillagerstätte" is not mentioned, which may be important. Namely, fossil accumulation may be the result of postmortal transportation of empty tests floated by surface and deep water current (Stanley & Raup, 1978; Ernst *et al.*, 1973). In such a case, the infilling of the test can not be treated as an indicator of the environment in which echinoids lived and died. Taking under consideration echinoid environmental requirements it is very likely that postmortal floating of empty echinoid tests did not take place.

The analysis of relationships between lithofacies and echinoid tests found within them, makes possible the correlation (Fig. 19) of Cretaceous environments with recent echinofacies from the Adria Sea (Ernst *et al.*, 1973).

Thick tested, with massive spines, Cenomanian *Phymosoma* lived in the zone of shallow water and high energy. This environment can be compared with Arbacia+Paracentrotus zone of Ernst *et al.* (1973).

Occurring in the same layers as *Phymosoma* echinoids from genera *Pyrina* and *Pygaulus* lived in environments similar to the Paracentrotus or Sphaerechinus zones.

The rather low-energy, with coarse grained carbonate sedimentation, Turonian environment of *Conulus* life can be placed within Echinocardium+Spatangus zone.

Santonian (*Micraster*, *Echinocorys*, *Conulus albogalerus*) and Campanian (*Echinocorys* and *Micraster*) assemblages do not fit within the echinofacies scheme of Ernst *et al.* (1973). The quite deep, quiet environments of marly-chalky sedimentation should be placed farther from the shore and deeper than Echinocardium+Spatangus zone of Ernst *et al.* (1973).

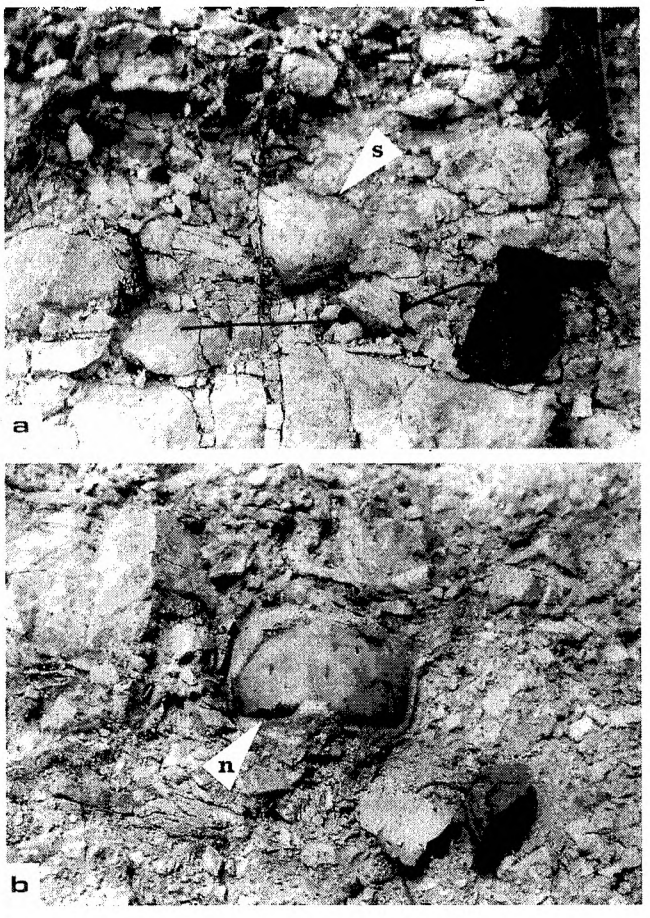


Fig. 17. **a–b** – Echinoids from the genus *Echinocorys* in the marly limestones with flints. Position of the tests lettered on the arrows: n – normal, s – on side; 0.3 of natural size

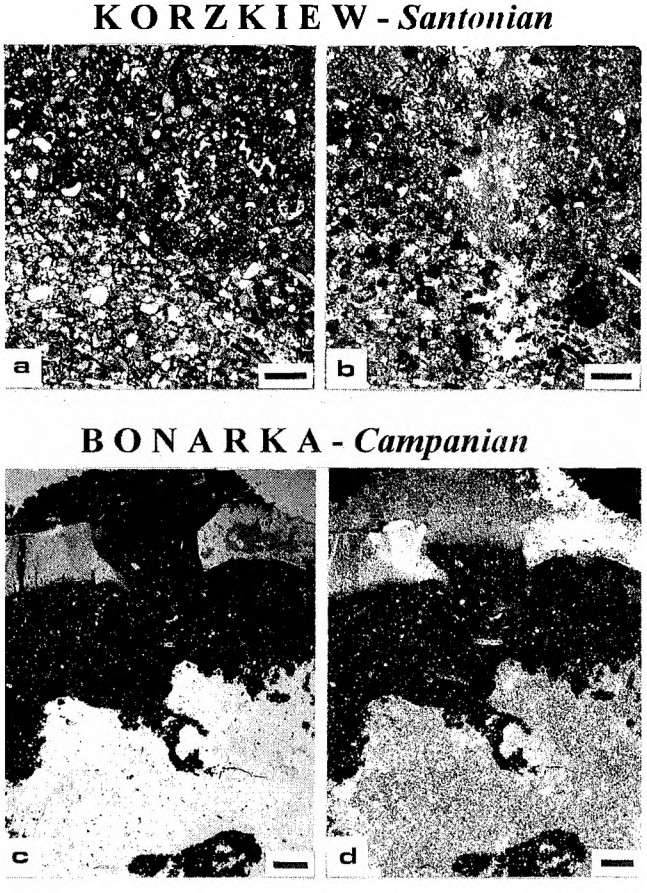


Fig. 18. Microfacies of infillings and surroundings of echinoid tests. **a** – Infilling of the *Micraster* test, slightly phosphatized marly wakestone (pithonella – foraminiferal microfacies); parallel nicols; **b** – The same sample; crossed nicols; **c** – Infilling of the *Echinocorys* test; test filled with the chalcedony – the result of early diagenetic processes; parallel nicols; **d** – The same sample; crossed nicols; scale bars = 1 mm

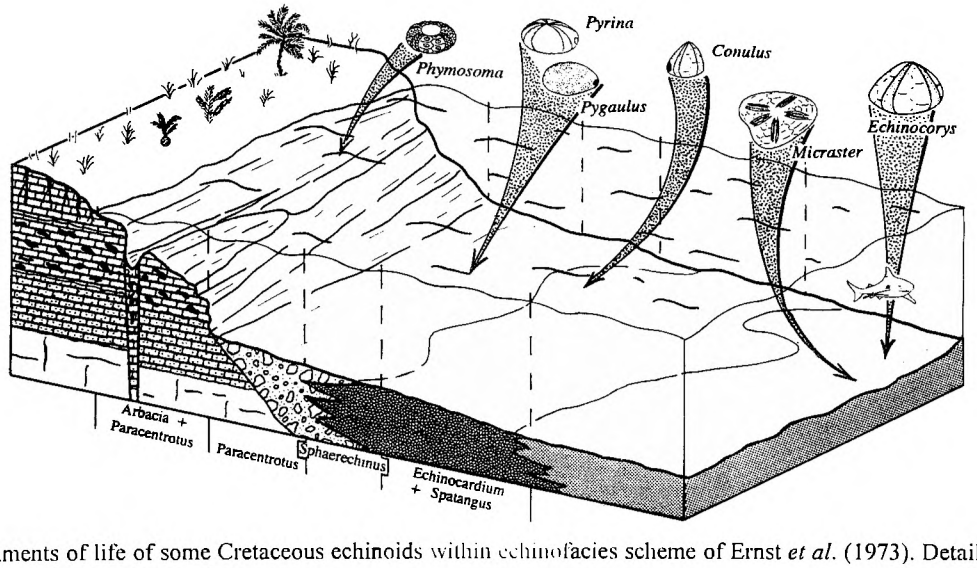


Fig. 19. Environments of life of some Cretaceous echinoids within echinofacies scheme of Ernst *et al.* (1973). Detailed description in text; **the scheme is not related to the time**

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Streszczenie

NAGROMADZENIA PANCERZY JEŻOWCÓW W GÓRNEJ KREDZIE OKOLIC KRAKOWA

Rafał Kudrewicz & Danuta Olszewska-Nejbert

Jeżowce stanowią najliczniejszą i najbardziej charakterystyczną grupę makroskamieniałości w utworach górnej kredy (cenoman – kampan) okolic Krakowa. Wielu badaczy zwracało uwagę na ich liczne występowanie w tym rejonie (Zaręczny, 1878; Smoleński, 1906; Barczyk, 1956; Małecki, 1976, 1979; Kudrewicz, 1991), oraz na całym terenie Niecki Miechowskiej (Sujkowski, 1926, 1934; Kowalski, 1948; Marcinowski, 1974). Część jeżowców doczekała się obszernych opracowań taksonomicznych (Kongiel, 1939; Mączyńska, 1958, 1962, 1968, 1972, 1977; Popiel-Barczyk, 1958, 1962; Hynda & Mączyńska, 1979).

W niniejszej pracy autorzy przedstawili rozmieszczenie i sposób ułożenia jeżowców w utworach górnej kredy, zależności mikrofacjalne pomiędzy wypełnieniem pancerzy jeżowców, a skałą je otaczającą, oraz próbę interpretacji środowiska życia jeżowców poprzez porównanie form kopalnych z podobnymi współczesnymi morfotypami, będącymi równocześnie formami pokrewnymi. Przedstawiono wyniki badań z kilku odsłonięć z okolic Krakowa, uznanych przez autorów za reprezentatywne (Fig. 1). Zespół jeżowców cenomańskich opracowano na podstawie materiału z Korzkwi, turońskich z Januszowic i Jeziorzan, santońskich z Korzkwi, kampańskich z Bonarki i Poskwitowa (Fig. 2). Sposób nagromadzenia jeżowców pozwala opisać je jako „Echinoidlagerstätten".

Cenoman. Utwory cenomanu w okolicach Krakowa są wykształcone w postaci marglisto-krzemionkowych zlepieńców kwarcowych (Fig. 5). Stosunkowo liczne jeżowce znajdowane w zlepieńcu reprezentują rodzaje: *Pyrina* i *Pygaulus*. Bardzo rzadko pojawia się rodzaj *Phymosoma*. Położenie jeżowców w skale jest przypadkowe, spoczywają na stronach oralnej, aboralnej lub w pozycji bocznej (Fig. 8 a–b). Pancerze wypełnia skała podobna do otaczającego je zlepieńca (Fig. 9). Różnice mikrofacjalne polegają jedynie na innych proporcjach składników, gdyż większe otoczaki nie mogły dostać się do środka pancerza przez małe otwory perystomu i periproktu. *Pyrina* należy do rodziny Echinoneidae, a *Pygaulus* do Cassiduloidae. Współcześnie żyjący przedstawiciele obu tych rodzin, morfotypowo odpowiadający rodzajom *Pyrina* i *Pygaulus* preferują jako środowisko życia dno o gruboziarnistym osadzie, przede wszystkim żwirowym (Hawkins, 1919; Mortensen, 1948; Kier, 1966; Wagner & Durham, 1966). Można przypuszczać, iż wspomniane formy kopalne również preferowały takie środowiska. Charakter skały otaczającej i wypełniającej pancerze potwierdza powyższe przypuszczenie, co pozwala stwierdzić, iż jeżowce z rodzaju *Pyrina* i *Pygaulus* znajdowane są w miejscu, w którym żyły, a ich pancerze nie uległy długiemu transportowi. Wyjątkiem jest *Phymosoma*, której współcześni krewni np. z rodzin Stomechinidae i Arbacidae żyją w płytkich lub skrajnie płytkich środowiskach (Smith, 1984). Można zatem przypuszczać, iż *Phymosoma* została przytransportowana ze strefy litoralnej.

Turon. Utwory turonu wykształcone są w postaci wapieni organodetrytycznych i wapieni gruzłowych, z domieszką kwarcu i krzemieni (Fig. 3–4). Dominujące jeżowce z rodzaju *Conulus* najliczniej występują w warstwie wapienia organodetrytycznego kilkanaście centymetrów nad powierzchnią abrazyjną tnącą biohermalne wapienie wieku jurajskiego (Fig. 8c, 10). Rozmieszczenie jeżowców w obrębie tej warstwy jest dość nieregularne. Gdzieniegdzie większe ilości okazów (Fig. 8d) występują w skupieniach – „gniazdach". Jeżowce przyjmują przeważnie położenie boczne (Fig. 3b, 4b–b'). Wszystkie pancerze rodzaju *Conulus* wypełnione są takim samym, pod względem mikrofacjalnym, materiałem jak otaczająca je bezpośrednio skała (Fig. 11, 12). W utworach kopalnych jeżowce z rodzaju *Conulus* znajdowane są z reguły w detrytycznych skałach wapiennych reprezentujących facje dość płytkiego morza (Ernst, 1970a; Ernst *et al.*, 1979). Pod względem morfotypowym rodzaj *Conulus* można porównać do współczesnego rodzaju *Echinoneus*. Badania nad tym rodzajem (Rose, 1978) pokazują, że preferuje on jako środowisko życia ziarniste, kalkarenitowe podłoże. Wymienione fakty przemawiają za tym, iż jeżowce z rodzaju *Conulus* zostały pogrzebane w środowisku swojego życia, bez wyraźnego przemieszczenia.

Santon. Utwory santonu w okolicach Korzkwi, skąd pochodzi bogaty materiał jeżowcowy, wykształcone są w postaci marglistych iłów glaukonitowych (Fig. 5). Wśród jeżowców dominuje rodzaj *Micraster*. Rzadziej spotykane są: rodzaj *Echinocorys* i gatunek *Conulus albogalerus*. Jeżowce ułożone są w różnych pozycjach (Fig. 5b, 13). Skała wypełniająca pancerze jest sfosfatyzowana i lekko zsylifikowana, podczas gdy otoczenie stanowią miękkie, plastyczne, margliste iły glaukonitowe (Fig. 14, 18 a–b). Jeżowce unikają środowisk o dużym udziale iłu (Ernst, 1970b). Cały system cech adaptacyjnych rodzaju *Micraster* wskazuje na przystosowanie do życia w środowisku bardzo drobnego mułu wapiennego (Smith, 1984), dlatego też rodzaj ten najczęściej znajdowany jest w osadach wapiennych, marglisto-wapiennych lub kredzie piszącej. W tych samych osadach występuje rodzaj *Echinocorys*. Powyższe fakty świadczą, iż pancerze jeżowców z rodzajów *Micraster* i *Echinocorys* musiały odbyć dłuższy transport i zostały złożone w innym środowisku niż żyły. *Conulus albogalerus* mógł żyć w podobnym środowisku jak *Micraster* i *Echinocorys*, gdyż jak twierdzi Hawkins (1919) rodzaj *Conulus* w czasie swojego rozwoju przystosowywał się do życia w coraz głębszej wodzie i w coraz drobniejszym osadzie.

Kampan. Utwory kampanu w okolicach Krakowa wykształcone są w postaci margli, wapieni marglistych oraz wapieni z licznymi czertami i krzemieniami (Fig. 6, 7). Jeżowce, reprezentowane głównie przez rodzaje *Micraster* i *Echinocorys*, związane są z poziomami wapienia marglistego z krzemieniami. Pancerze jeżowców ułożone są przeważnie w pozycji normalnej na stronie oralnej, rzadziej w pozycji bocznej (Fig. 7b, 15–17). W trakcie di-

agenezy jeżowce uległy sylifikacji. Najlepiej zachowane okazy wypełnione są krzemionką drobnokrystaliczną (Fig. 18 c–d). Wymogi środowiskowe rodzajów *Micraster* i *Echinocorys* nie zmieniły się od santonu. Można przypuszczać, iż kampańskie jeżowce zostały pogrzebane w środowisku swojego życia, bez wyraźnego przemieszczenia.

Analiza zależności litofacjalnych, mikrofacjalnych oraz wymogów paleośrodowiskowych pozwala na skorelowanie poszczególnych środowisk późnokredowych (Fig. 19) ze współczesnymi echinofacjami z Adriatyku (Ernst *et al.*, 1973). Środowisko życia cenomańskiego rodzaju *Phymosoma* jest porównywalne z najpłytszą zoną Arbacia+Paracentrotus. Rodzaje *Pyrina* i *Pygaulus* żyły nieco głębiej, w osadzie gruboziarnistym, żwirowym i odpowiadają współczesnej zonie Paracentrotus lub Sphaerechinus albo obu tym zonom. Rodzaj *Conulus* z utworów turonu, związany z facjami kalkarenitowymi, dobrze koreluje sie z zoną Echinocardium+Spatangus. Rodzaje *Micraster* i *Echinocorys* z santonu i kampanu oraz gatunek *Conulus albogalerus* z santonu zamieszkiwały bardzo drobnoziarniste, węglanowe osady środowisk poniżej strefy odpowiadającej współczesnej zonie Echinocardium +Spatangus, zatem nie mieszczą się w schemacie Ernsta *et al.* (1973).