Annales Societatis Geologorum Poloniae (2005), vol. 75: 199–210.

DEVELOPMENT OF THE TURONIAN *Conulus* LAGERSTÄTTE IN THE WIELKANOC QUARRY, MIECHÓW UPLAND (SOUTH POLAND)

Danuta OLSZEWSKA-NEJBERT

Institute of Geology, University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, e-mail: don&uw.edu.pl

Olszewska-Nejbert, D., 2005. Development of the Turonian *Conulus* Lagerstätte in the Wielkanoc quarry, Miechów Upland (South Poland). *Annales Societatis Geologorum Poloniae*, 75: 199–210.

Abstract: Turonian sandy limestones and organodetrital limestones exposed in the Wielkanoc quarry, Miechów Upland, South Poland, lie on Oxfordian massive limestones, truncated with an abrasion surface. The bed situated ca. 2.5 m above the abrasion surface contains a parautochthonous and monotypic assemblage of the species *Conulus subrotundus* Mantell, 1822; thus the concentration can be referred to as the *Conulus* Lagerstätte. The microfacies analysis of the *Conulus* Lagerstätte indicates its development to have been determined by the existence of eco-events producing an increased population of *Conulus subrotundus*, and of sedimentological factors, that is waning of the loose sediment from the sea floor and erosion of the consolidated deposit rich in the earlier fossilised echinoids. The episodes of material accumulation, its consolidation and erosion in high-energy environment (action of bottom current) led to the increase of amount of echinoids as the intraclasts according to the model of lag sediment deposition.

Key words: *Conulus* Lagerstätte, lag sediment, Turonian, Miechów Upland, South Poland.

Manuscript received 15 January 2005, accepted 23 August 2005

INTRODUCTION

Echinoids of the genus *Conulus* occurring in the Turonian deposits in the Kraków–Wieluń Upland were noted already in the 19th century (Zaręczny, 1878). Later authors describing the Turonian deposits also noted numerous occurrences of this genus in the Kraków–Wieluń Upland (Smoleński, 1906; Alexandrowicz, 1954; Barczyk, 1956; Bukowy, 1956; Małecki, 1976, 1979; Sobczyk, 1990) and Miechów Upland (Sujkowski, 1926, 1934; Kowalski, 1948; Marcinowski, 1974). Popiel-Barczyk (1958) presented the most complete palaeontological description of the genus *Conulus* from the Kraków–Wieluń and Miechów Uplands. However, not till in the late 90-ties, Kudrewicz and Olszewska-Nejbert (1997) pointed out the specific occurrence of echinoids in the Cretaceous deposits in the vicinity of Kraków and showed the link of the increased echinoid frequency with some horizons. Furthermore, they referred to the echinoid concentration as the "Echinoid Lagerstätten".

In 1993 and 1999–2000, the author conducted fieldworks in the Miechów Upland, studying a lithological section of the Turonian deposits exposed in the Wielkanoc quarry. Echinoids of the genus *Conulus* occur in a few parts of the section, one bed, however, reveals a particularly high frequency of echinoids.

Seilacher *et al.* (1985) pointed out that there is no distinct boundary between "normal" beds containing fossils and beds that can be considered as the fossil Lagerstätten. It is rather the specific fossil preservation or facts, which draw attention to the fossils, which eventually allow refer to certain beds as fossil Lagerstätten. This condition is fulfilled by the concentration of the *Conulus* echinoids at the Wielkanoc quarry. From the total of 124 medium and well-preserved specimens in the whole Turonian section, 118 were encountered in one, not so thick (0.45–0.5 m) bed. This allows referring to this bed as an "Echinoid Lagerstätte" or even as the "*Conulus* Lagerstätte" *sensu* Seilacher *et al.* (1985). The term "Lagerstätte"derived from economical deposit nomenclature (Seilacher *et al.*, 1985) is the most accurate for the bed with Turonian echinoids from the Wielkanoc quarry.

The purpose of this study is to reconstruct the sedimentological conditions and scenario which led to development of the *Conulus* Lagerstätte in this locality.

GEOLOGICAL SETTING

The studied section is located in the south-western flank of the Miechów Synclinorium, a tectonic unit within the southern part of the West European Platform. This area together with an adjacent north-eastern part of the Great Monocline was an uplifted, submarine palaeographic unit called the Kraków Swell (Walaszczyk, 1992) during the whole Turonian to Santonian times. It was restricted by the deeper basins of the Opole Through (OT) to the south-west and the Danish-Polish Trough (DPT) to the north-east. The submarine erosion or non-deposition was common on the Kraków Swell during the Turonian through the Santonian (Walaszczyk, 1992, Olszewska-Nejbert, 2004). In the adjacent OT and DPT basins, occupying the present-day central and north-eastern flank of the Miechów Synclinorium, the continuous marly/opoka (siliceous limestones) sedimentation took place during the Late Cretaceous (Walaszczyk, 1992; Olszewska-Nejbert, 1996). In the DPT basin, closer to the Kraków Swell, the Turonian and Coniacian siliceous limestones (opoka facies) are intercalated with organodetrital limestones representing redeposited materials transported from the Kraków Swell (Walaszczyk, 1992). The Kraków Swell is considered as tectonically active area during the early Late Cretaceous, due to Subhercynian movements (Marcinowski, 1974; Walaszczyk, 1992). The final drowning of the Kraków Swell took place in the late Santonian (Marcinowski, 1974; Walaszczyk, 1992).

The Turonian deposits of the south-western flank of the Miechów Synclinorium, exposed on the Miechów Upland (Fig. 1) does not exceed 10 m, and usually are much lower (Walaszczyk, 1992). The Wielkanoc quarry is a large abandoned quarry in SW part of the Wielkanoc village, located ca. 31 km northwards from the centre of Kraków (Fig. 1). The Wielkanoc section exceeds 10 m and is the thickest exposed Turonian section in the Miechów Upland. It comprises the uppermost Middle Turonian *Inoceramus lamarcki* Zone and the lowermost Upper Turonian *I. costellatus* Zone (Walaszczyk, 1992).

MATERIAL AND METHODS

The author collected a total number of 124 specimens of medium and well preserved echinoids of the genus *Conulus* from the section at Wielkanoc; 118 specimens were found in bed 8 (Fig. 2). Six specimens were collected from beds 6, 7, 14 and 15. Bed 8 was also the source of numerous poorly preserved specimens, which were not included in the studied material. Twenty two echinoids from bed 8 were cut to investigate their internal sediment contents.

Polished thin sections were prepared: one from the pelitic limestone of bed 6, one from the sandy limestone of bed 7, five from the various samples of bed 8, and one from the organodetrital limestone of bed 9. The best section was observed and measured of the southern wall of the quarry in 1993 (Figs 2, 3). At present, the level of the quarry just above the Upper Jurassic (Oxfordian) and Upper Cretaceous (Turonian) boundary does not exist.

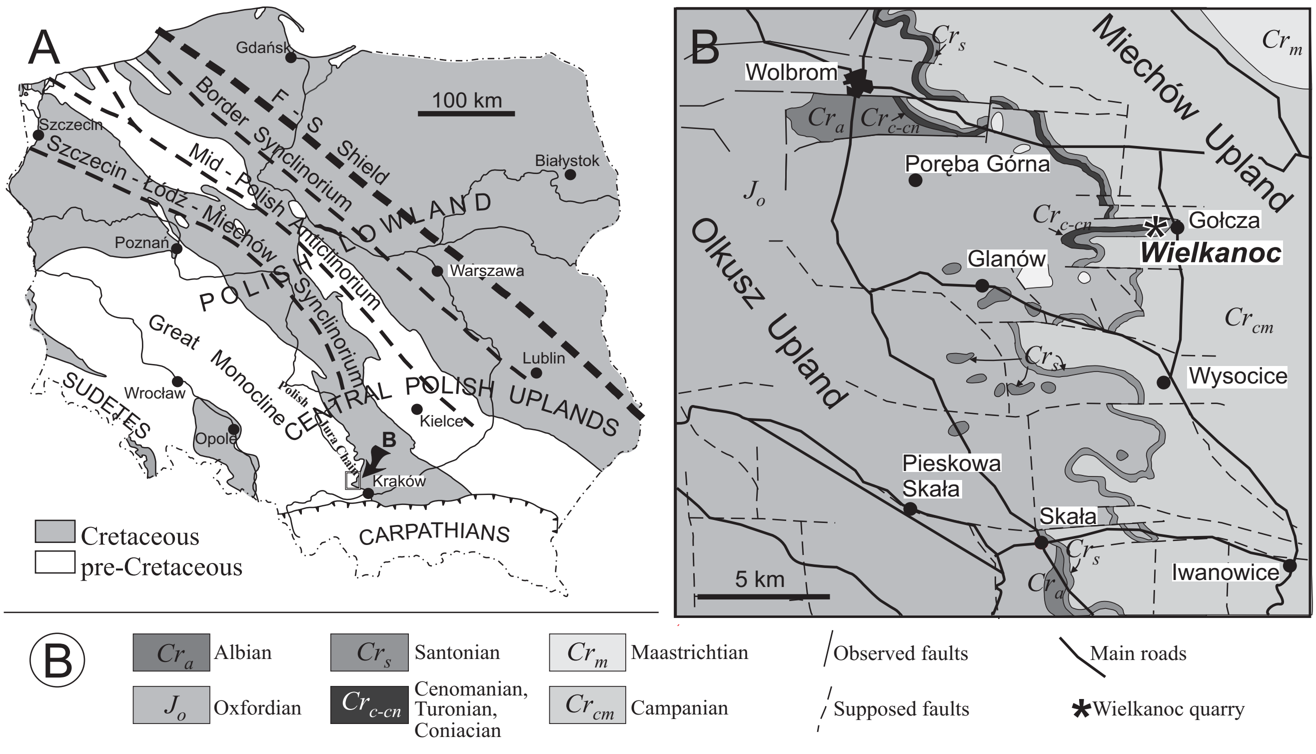

Fig. 1. **A** – Tectonic sketch-map of Poland without Cenozoic cover, explanations do no refer to Carphatians deposits; F–S Shield – thick broken line (“Tornquist line”) indicates a generalized outline of stable margins of the Fenno-Sarmatian Shield (*after* Marcinowski & Radwański, 1983, simplified); **B** – Geologic sketch-map of the investigated area with the location of the Wielkanoc quarry (after Kaziuk 1978, modified and simplified)

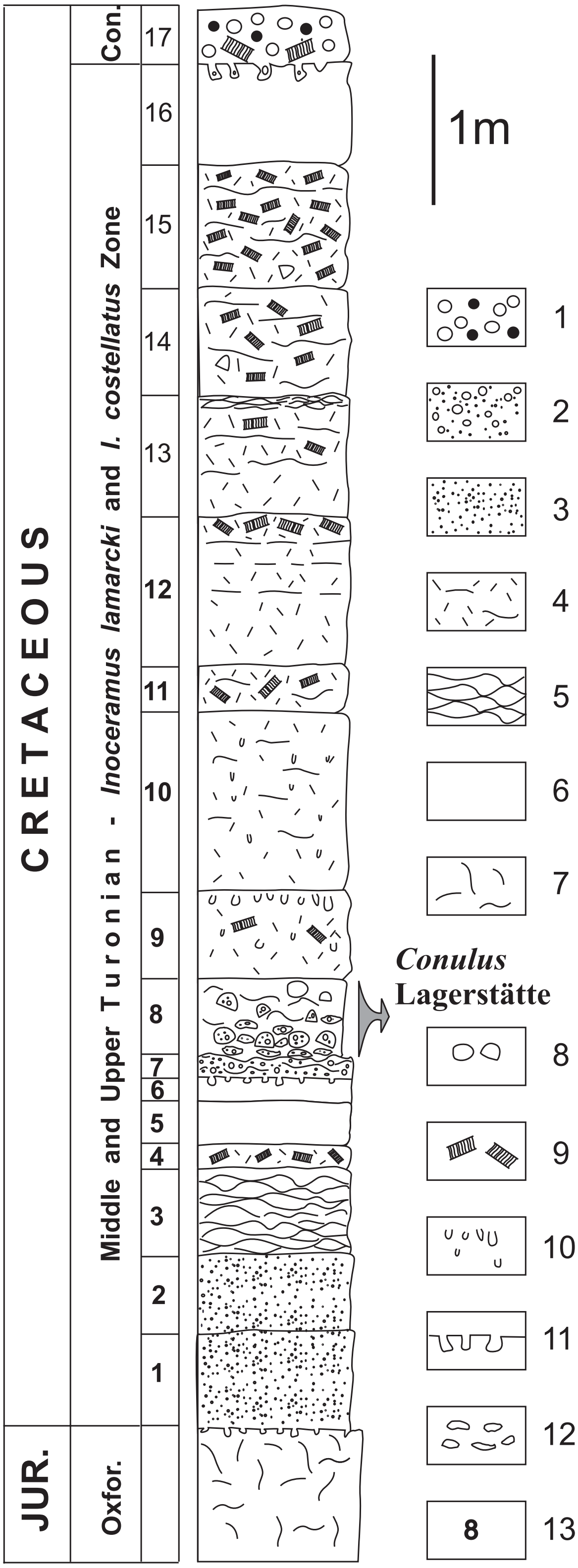

Fig. 2. Detailed lithologic and stratigraphic column (stratigraphy after Walaszczyk, 1992) of the Wielkanoc quarry section: *1* – sandy-glauconitic limestones, *2* – sandy limestones, *3* – sandy-organodetrital limestones, *4* – organodetrital limestones, *5* – nodular limestones, *6* – pelitic limestones, *7* – massive limestones, *8* – echinoids, *9* – inoceramid debris, *10* – burrows, *11* – discontinuity surfaces, including omission surfaces, hardgrounds, and abrasion surfaces, *12* – intraclasts, *13* – arabic numeral denoting the beds distinguished in section. Oxfor. – Oxfordian, Con. – Coniacian

DESCRIPTION OF SECTION

Inoceramus lamarcki and I. costellatus Zone (Turonian)

Bed 1: thickness 0.6 m. Sandy-organodetrital limestone with glauconite, green in colour, overlying the abrasion surface developed on Oxfordian limestones. The abrasion surface with borings is infilled with sandy limestone including glauconite, similar as the entire bed 1. Numerous burrows infilled with greenish sandy limestone occur in the lowermost part of the bed.

Bed 2: thickness 0.45 m. Sandy-organodetrital limestone with glauconite, green in colour.

Bed 3: thickness 0.6 m. Sandy limestone with glauconite, light green in colour, with numerous burrows infilled with the same material as the surrounding; the bed partly resembles nodular limestone; numerous crushed inoceramid shells are present.

Bed 4: thickness 0.15–0.2 m. Organodetrital limestone with admixture of quartz sand, grey to light-green in colour, numerous debris of inoceramids are present.

Bed 5: thickness 0.2–0.3 m. Pelitic limestone, grey in colour, with distinct ferruginous mineralization at the top of the bed.

Bed 6: thickness 0.15 m. Pelitic limestone, grey to pinkish in colour, strongly fractured, with distinct ferruginous mineralization and traces of an omission surface (firm- or hardground zone) at the top of the bed, including *Thalassinoides* traces; scarce echinoids of the genus *Conulus*.

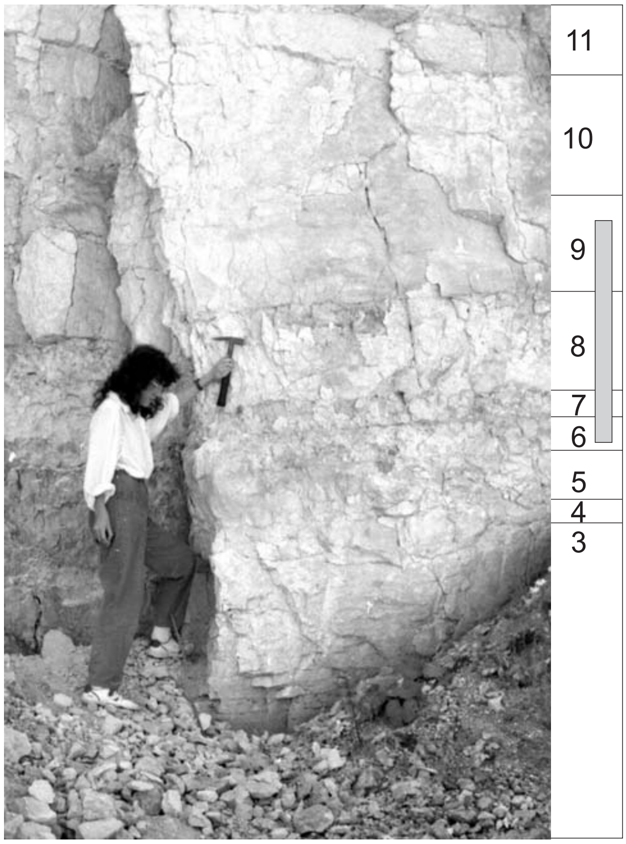

Fig. 3. Lower part of the Turonian series of the Wielkanoc section at southern wall of the quarry; grey bar indicates investigated interval

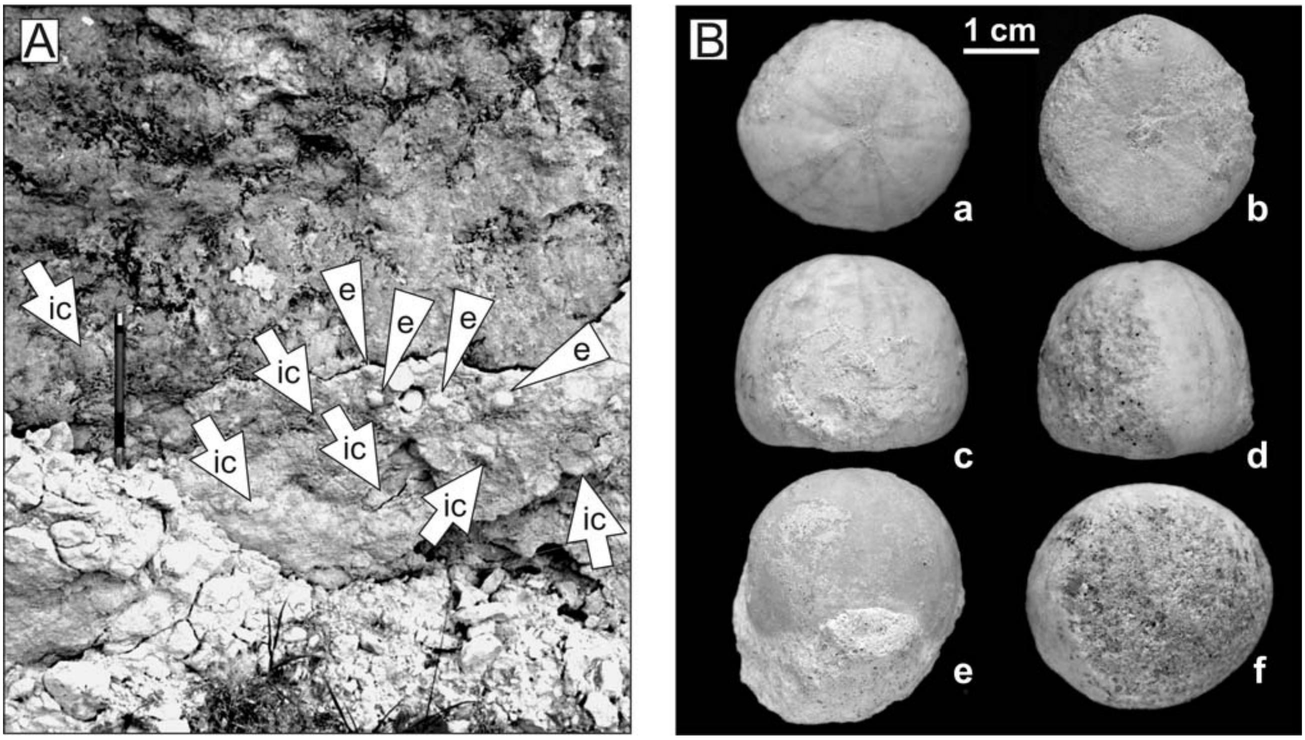

Fig. 4. **A** – Close-up of the *Conulus* Lagerstätte (bed 8); e – echinoids, ic – intraclasts of sandy limestone; **B** – *Conulus subrotundus* Mantell from bed 8; a – aboral side, b – adoral side, c – lateral side, d – posterioral side, e – intraclast with the test of *Conulus subrotundus*, f – traces of chemical corrosion on the test of *Conulus subrotundus*, aboral side

Bed 7: thickness 0.1–0.15 m. Nodular-like limestone with admixture of quartz sand, light-grey to light-green in colour, very rare echinoids of the genus *Conulus*.

Bed 8: thickness 0.45–0.50 m. Organodetrital limestone, poorly cemented, almost white in colour, with numerous irregular scattered intraclasts (up to 10 cm in size) of limestone with admixture of quartz sand, light-green in colour; abundant echinoids of the genus *Conulus*, commonly in the form of small clusters containing 3 to 6 specimens in one group.

Bed 9: thickness 0.5–0.6 m. Organodetrital slightly sandy limestone, light-creamy in colour, quite strongly cemented but fragile and strongly fractured; burrows occur in the whole bed, and are the most numerous at the top of the bed, abundant inoceramid shell debris.

Bed 10: thickness 1.2 m. Organodetrital limestone, grey to light-green in colour, with small and rare burrows, including greenish irregular zones.

Bed 11: thickness 0.3 m. Organodetrital limestone, grey in colour, very similar to the limestone in bed 10, but with abundant inoceramid shell debris, and seldom with greenish irregular zones.

Bed 12: thickness 1.0–1.2 m. Organodetrital limestone, grey to pinkish in colour, with abundant inoceramid debris; the topmost part of the layer contains large fragments of thick-shelled inoceramids; the upper part of the layer consists of thinner irregular beds.

Bed 13: thickness 0.8 m. Organodetrital limestone, grey in colour, with inoceramid debris, larger fragments of inoceramids, top of the bed nodular in appearance, with irregular greenish zones.

Bed 14: thickness 0.6 m. Organodetrital limestone, grey in colour, with numerous inoceramid debris, some fragments of inoceramid shells quite large in size, with few echinoids of the genus *Conulus*.

Bed 15: thickness 0.8 m. Organodetrital limestone, grey in colour, with numerous inoceramid debris, some fragments of inoceramid shells quite large in size, rare echinoids of the genus *Conulus*; the bed is similar to bed 14.

Bed 16: thickness 0.6 m. Pelitic limestone, grey to white in colour with hardground at the top, well visible burrows and borings infilled with material from the overlying bed (Olszewska-Nejbert, 2004). A single echinoid, probably *Sternotaxix plana* (Mantell, 1822), was found here.

***Cremnoceramus crassus* Zone (Coniacian)**

Bed 17: thickness 0.5–0.6 m. Sandy glauconitic limestone, green in colour, with numerous inoceramid thick-shelled debris, covered by Pleistocene loess.

Conulus LAGERSTÄTTE BED

Bed 8, referred to as the *Conulus* Lagerstätte (Fig. 3) is laterally widely distributed. It was observed in the whole southern wall of the quarry on distance of about 80 m, where the Turonian deposits are exposed. Its thickness is uniform and varies between 45–50 cm.

The echinoid-bearing bed is non-uniform in composition (Fig. 4). In general, the bed is composed of organodetrital limestone with intraclasts of sandy limestone. The intraclasts are poorly rounded and commonly irregular in shape.

The bed is rich in echinoids of the genus *Conulus*. The echinoids do not form a very dense concentration, as in the case of some Miocene deposits (Moffat & Bottjer, 1999; Radwański & Wysocka, 2001, 2004). The echinoids occur in small clusters (Fig. 4A), scattered 1 to 3 m one from the other. According to the biostratinomic classification by Kidwell *et al.* (1986), this *Conulus* Lagerstätte can be referred to as a bed concentration (see Kidwell *et al.* 1986). The preliminary palaeontological study of the collected echinoid material allows to state that the assemblage is monotypic, represented by the species *Conulus subrotundus* (Fig. 4B). The echinoids are variably oriented within the bed. Among the 65 oriented specimens, 57% were lying on the side, 31% in a normal position, whereas only 12% were inverted.

MICROFACIES OF THE *Conulus* LAGERSTÄTTE AND ASSOCIATED BEDS

The microfacies of the successive beds from 6 to 9 (Fig. 5) in stratigraphic order may be characterised as follows:

Bed 6. The inoceramid-foraminiferal-calcisphere wackestone/packstone (Figs 5a, 6); the main components are inoceramid debris with the average size of 0.1–0.2 mm, larger fragments are very rare; the second skeletal component are planktonic foraminifers of similar or smaller size in comparison to the inoceramid debris; calcispheres (calcareous dinoflagellate cysts) are relatively common in this microfacies; glauconite is very rare.

Bed 7. The foraminiferal-calcisphere wackestone (Figs 5b, 7A) with admixture of quartz (common) and glauconite (rare); the main components include planktonic foraminifers with chambers infilled with micrite, and small calcispheres infilled mainly with sparite; inoceramid debris and echinoderm fragments are less common.

Bed 8 – The bed yielding the mass occurrence of echinoids shows very complex assemblage of microfacies (Figs 5c–h, 7B–F). Different microfacies occur within particular parts of the bed. It is possible to distinguish: (i) matrix, (ii) intraclasts without echinoids, (iii) intraclasts with echinoids, and (iv) echinoids.

(i) Matrix. The inoceramid packstone (Figs 5h, 7F) with rare planktonic foraminifers; the main components include inoceramid debris with the average size of 0.3–0.6 mm.

(ii) Intraclasts without echinoids. The foraminiferal-calcisphere wackestone (Figs 5c, 7B) with admixture of quartz (common) and glauconite (rare); inoceramid debris and echinoderm fragments are of the minor importance; the same type of microfacies as bed 7.

(iii) Intraclasts with echinoids (Figs 5d–g). The intraclasts containing the echinoid test always represent the formaniferal-calcisphere wackestone with large admixture of quartz and small of glauconite; inoceramid debris and echinoderm fragments are of lesser importance (Figs 5d, f; 7D, E). Commonly the rock infilling the test of the echinoid represents the same microfacies as the surrounding rock of intraclasts (Figs 5e, 7E). Very rarely the infilling of the test represents the foraminiferal-calcisphere wackestone, where the quartz and glauconite are absent or appear as traces (Figs 5g, 7C). In a few cases, the infilling of echinoids is mixed; half of the test is infilled with the foraminiferal-calcisphere wackestone with large admixture of quartz and small of glauconite, whereas the other half is filled with the foraminiferal-calcisphere wackestone.

(iv) Echinoids. The rock infilling the echinoid tests represents the foraminiferal-calcisphere wackestone with admixture of quartz (common) and glauconite (rare); inoceramid debris and echinoderm fragments are of minor importance. This is the same type of microfacies as in bed 7.

Bed 9. The inoceramid packstone (Figs 5i, 8); main components are inoceramid debris with the average size of 0.2–0.7 mm; larger fragments up to 0.8 mm are rare; the second skeletal component are very rare planktonic foraminifers, usually smaller in size in the comparison to the inoceramid debris. This microfacies resembles the microfacies of the matrix in bed 8.

RECONSTRUCTION OF THE *Conulus* LAGERSTÄTTE ORIGIN

The field description and microfacies analysis of bed 8 and the over- and underlying beds allow me propose the following scenario leading to the concentration of echinoid tests (Fig. 9).

After the formation of bed 6, decrease in sedimentation rate or even break in sedimentation took place. This led to the formation of an omission surface with *Thalassinoides* traces. The following sedimentation was related to mutual relation in depositional rate and supply of the intrabasinal (IB) and detrital (DC) components. The intrabasinal components (IB) include: planktonic foraminifers and calcispheres, subordinate echinoderm plates, crushed inoceramid prisms, very rare benthic foraminifers, calcareous mud, small glauconite grains, autochthonous in origin, and rare broken fragments of larger glauconite grains, supposedly para-autochthonous (allochtonous) in origin (Amorosi, 1997). The supplied detrital components (DC) include quartz grains, mainly in the fine-psephitic fraction.

A fine-grained calcarenite sand basement was favourable for the growth and development of *Conulus subrotundus* (Fig. 9A). In the fossilised state, echinoids of the genus *Conulus* were typically encountered in detrital limestone rocks, representing shallow marine facies (Ernst, 1967, 1970; Ernst *et al.*, 1979; Kudrewicz & Olszewska-Nejbert, 1997). It seems that the development of echinoid eco-events took place when the optimum conditions led to the rich bloom of *Conulus subrotundus*. Most probably, during low-energy sedimentation stage, the fine-grained bottom was populated by *Conulus subrotundus* echinoids. After the death of the animal, the spines of echinoids fall off after several hours, what is a typical feature of irregular echinoids with small spines (Smith, 1984). On the other hand, the test was rigid and could lie of the sea floor for as long as several months until it was buried (Smith, 1984). The next stage was thus the filling of echinoid tests with the IB or DC components.

During following sedimentation, there must have been a stage with almost exclusively IB components supply (Fig. 9B), whereas the supply of the DC particles either was

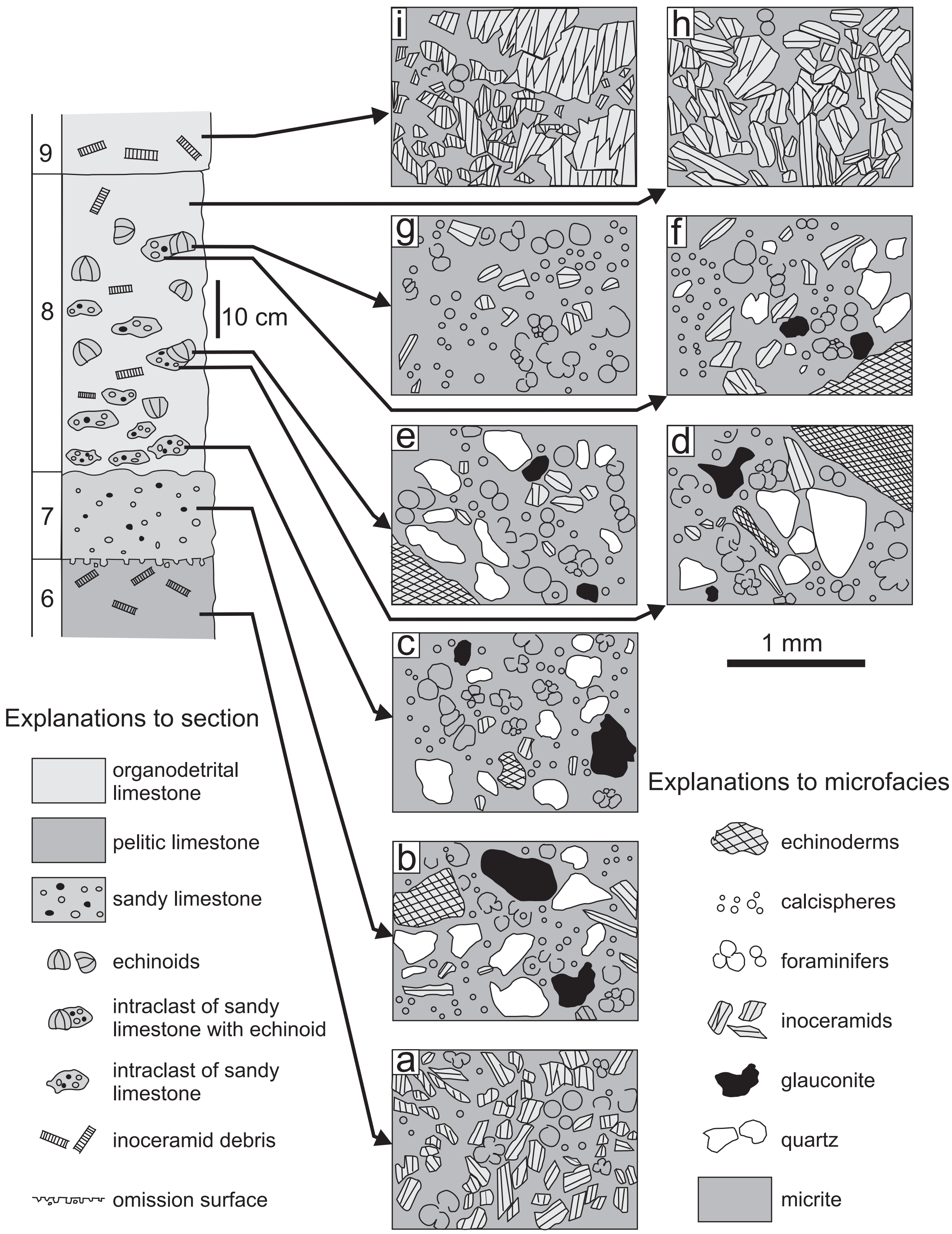

Fig. 5. Microfacies of the *Conulus* Lagerstätte with under- and overlying deposits; a – inoceramid-foraminiferal wackestone, bed 6; b – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, bed 7; c – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, intraclast in bed 8; d – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, infilling of echinoid, intraclast in bed 8; e – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, surrounding of echinoid, intraclast in bed 8; f – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, surrounding of echinoid, intraclast in bed 8; g – foraminiferal-calcisphere wackestone, infilling of echinoid, intraclast in the bed 8; h – inoceramid packstone, matrix of bed 8; i – inoceramid packstone, bed 9

stopped or strongly restricted. The tests of earlier buried echinoids, which protruded above the sediment-water interface, could undergo chemical corrosion.

The development of next generations of echinoids was accompanied with the low-energy sedimentation and dominated supply of IB components. Therefore the tests were not destroyed, but filled with IB components. Some tests were filled entirely, others only to some degree. Winnowing and removal of grains and calcareous mud by water currents followed this episode, and the original deposit from this stage is only preserved within the echinoid tests (Fig. 9C).

A new supply of DC components, and a simultaneous deposition of the IB components, filled the tests of yet another generation of dead echinoids (Fig. 9D–F). At slow sedimentation rate or even its break, the chemical corrosion (Fig. 4B) of the protruding above the sediment-water interface echinoids took place (Fig. 9D). The next eco-event was again favourable for the development of echinoids (Fig. 9E), after which the dead echinoid tests were infilled with IB and DC components, whereas tests partly infilled with IB components in the earlier phases were eventually filled up during this phase with the IB and DC components.

The sediment comprising IB and DC components, as well as the echinoid tests infilled with DC and IB components (most common case), or partly with IB components, and filled up with DC and IB components (rare specimens) or only with IB components (very rare specimens) underwent early lithification (Fig. 9F). This was followed by erosion, during which intraclasts were developed (Fig. 9G). Some intraclasts are composed of sandy material, some comprise echinoids with surrounding rock, and a large group of intraclasts comprises isolated echinoids. This led to the concentration of echinoids within a particular interval of the section, a sort of "condensation" representing a not so long period of time, because only this process encompassed a small part of the Turonian. The described event led to the concentration of echinoids within single bed and such a concentration can be referred to as an *Conulus* Lagerstätte.

The discussed events are overlapped by the sedimentation of intrabasinal components in the form of inoceramid debris, leading to the formation of packstone, which might be the evidence of the increasing dynamics of the environment (Fig. 9H).

ECOLOGY AND STRATIGRAPHICAL SIGNIFICANCE OF *Conulus subrotundus* MANTELL

Conulus subrotundus is commonly known in the Turonian of the Cretaceous North European Province, but its occurrence was strongly depended on the type of sediment on the sea-bottom. This species preferred fine-grained, calcarenite bottom of shallow marine basins (Hawkins, 1919; Popiel-Barczyk, 1958; Ernst, 1967; Ernst *et al.*, 1979; Smith, 1988; Olszewska-Nejbert, 1996; Kudrewicz & Olszewska-Nejbert, 1997) and had an epifaunal mode of life (Smith, 1988; Olszewska-Nejbert, 1996; Kudrewicz & Olszewska-Nejbert, 1997).

Ernst *et al.* (1983) described two *Conulus* ecoevents

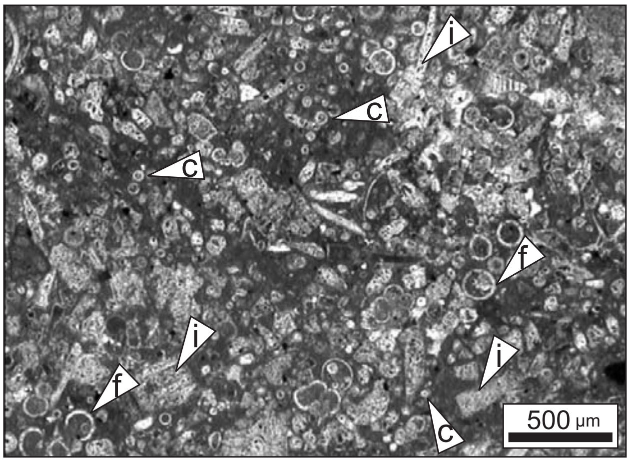

Fig. 6. Inoceramid-calcisphere wackestone, microfacies of bed 6 (compare Fig. 5a); c – calcispheres, f – foraminifers, i – inoceramid debris

(macrofossil layers) in the Middle–Upper Turonian of NW Germany and connected them with the eustatic sea level changes (in these cases with regressions). The Lower *Conulus*-eustatoevent is noted in the uppermost Middle Turonian *Inoceramus lamarcki* – *I. cuvierii* Zone and the Upper *Conulus*-eustatoevent most probably occurs within the lowermost Upper Turonian *I. costellatus* cf. *pietzschi* – *I.* ex gr. *cuvierii* (large forms) Zone in the NW Germany (Ernst *et al.*, 1983). The stratigraphical position of *Conulus* Lagerstätte from the Wielkanoc section (the undivided uppermost Middle Turonian *Inoceramus lamarcki* Zone and the lowermost Upper Turonian *I. costellatus* Zone according to Walaszczyk 1992) is almost the same. Thus, it is possible that the *Conulus* Lagerstätte from the Wielkanoc section represents alternatively: (i) Lower *Conulus*-eustatoevent, (ii) Upper *Conulus*-eustatoevent, or (iii) is condensed mixed deposits containing reworked echinoid test derived from the both mentioned events, described earlier by Ernst *et al.* (1983).

Kudrewicz and Olszewska-Nejbert (1997) described the echinoid Lagerstätte from the Turonian organodetrital limestone at Januszowice and Jeziorzany sections near Kraków. The increased *Conulus* test frequency in beds from these localities was interpreted as the result of the eco-events during the Turonian time. However, up to now, it is not possible to correlate precise the Turonian of Januszowice and Jeziorzany sections with the Turonian section of the Wielkanoc quarry.

THE NATURE AND CAUSES OF THE *Conulus* LAGERSTÄTTE

The *Conulus* Lagerstätte from the studied section can be considered as a product of non-depositional and erosional events, and more precisely as an example of the marine lag sediments and shell concentrations characterized by Einsele (1998) and Kidwell (1993). Kidwell (1993) and Einsele (1998) showed several models of the fossil concentration origin, however, none of them can be directly used

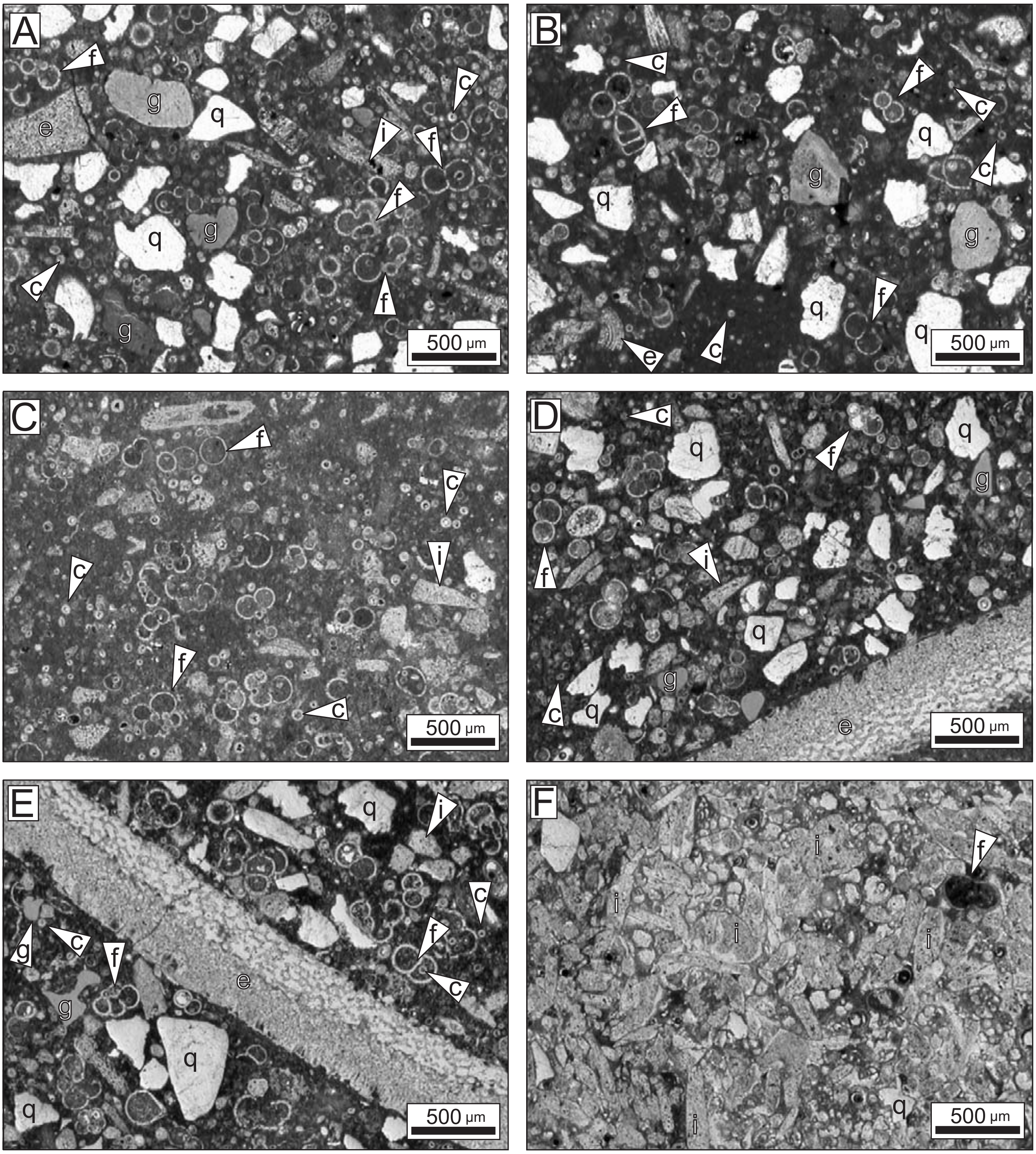

Fig. 7. Microfacies of bed 7 (A) and bed 8 with *Conulus* Lagerstätte (B–F); **A** – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite (compare Fig. 5b), **B** – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, microfacies of intraclast (compare Fig. 5c); **C** – foraminiferal-calcisphere wackestone infilling of echinoid (compare Fig. 5g); **D** – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, surrounding echinoid presented on Fig. 7C (compare Fig. 5f); **E** – foraminiferal-calcisphere wackestone with admixture of quartz and glauconite, microfacies infilling and surrounding of echinoid in intraclast (compare Fig. 5e, d); **F** – inoceramid packstone (compare Fig. 5h); c – calcishperes, e – echinoderms, f – foraminifers, g – glauconite, i – inoceramid debris, q – quartz

for description of the studied *Conulus* Lagerstätte. Only three models are worth of discussion: (i) non-skeletal lag sediments, (ii) skeletal hiatal concentration, and (iii) skeletal lag concentration.

Non-skeletal lag sediments. The lag sediments commonly develop under wave action both during transgression and regression. They are also known from isolated subaqueous highs affected by waves and currents (Einsele, 1998). Submarine Kraków Swell was a subaqueous highs during the Turonian time (Walaszczyk, 1992) and presumably the sea bottom on this swell was subjected to action of currents, and probably also waves. The *Conulus* Lagerstätte contains intraclasts typical of non-skeletal lag but also very numerous echinoid tests which are the skeletal components. Therefore it can not be called the non-skeletal lag.

Skeletal hiatal concentration. The hiatal concentrations are characterized by *in situ* accretion and amalgamation of sediment layers, mixed fauna and slow net sedimentation (Kidwell, 1991, 1993). The hiatal concentration deposit is thin relative to coeval strata (Kidwell, 1993; Einsele, 1998). The bed 8 from the Wielkanoc section seems to be the product of *in situ* accretion and amalgamation of pre-existing layers. But there is no good stratigraphic evidences documenting the stratigraphic condensation within this bed. The echinoids represent only one species. The deposits coeval with this bed are not recognized.

Skeletal lag concentration. The lag concentrations are characterized by exhumation and concentration of mechanically and chemically resistant hard parts of pre-existing sediments representing different ages and indicating the significant stratigraphical truncation (Kidwell, 1993; Einsele, 1998). The bed 8 contains the mechanically and chemically resistant and hard intraclasts and tests of fossilized echinoids. However, they are not so different in age, and the truncation of the pre-existing sediments seems to be not significant.

The described sedimentary evidences univocally indicate that the echinoid concentration was caused by erosion and washing out of some host sediments rich in echinoids. Erosion of the host sediments produced intraclasts, some of them containing echinoid tests, which together with separate exhumed echinoid tests were deposited on the sea floor as a kind of lag. The sedimentary microfacies found in the interior of the echinoid tests, within the intraclats, and in the underlying bed 7, indicate relatively calm, low energy depositional environment for both the bed 7 and the host sediments which were the source of intraclats in the bed 8. The intraclasts and echinoid tests in the bed 8, enclosed within the matrix including well sorted, strongly crushed and fragmented shells, suggest that depositional environment was high energetic. Consequently, the studied sequence reflects transition from low to high energy environment. The common presence of planktonic forms (foraminifers and calcispheres) in the bed 7 and in the host sediments of the lag (found in intraclasts and interiors of echinoid tests) and the dominance of benthic forms (inoceramids) in the matrix of the lag and in the top parts of the bed 8 suggest that the transition can be connected with a slight shallowing, although direct evidences for such interpretation are lacking.

There are two possible causes of the transition from the low energy to high energy environment which determined the origin of the echinoid concentration: (i) the echinoid concentration was produced by storm events or (ii) by increased action of bottom currents, which eroded loose and partly lithificated and consolidated sediments. The first possibility can not be confirmed in the studied deposits by any sedimentary structures typical of carbonate tempestites such as: graded intraclasts, plane lamination, hummocky cross-stratification, wave ripples (e.g., Einsele, 1998; Johnson, 1989; Skompski & Szulczewski, 1994).

The second possibility, a strong bottom currents, is here regarded as the main cause of the echinoid concentration due to occurrence of intraclasts (differentiated in size and mixed together, and randomly scattered in the bed 8) and lack of any graded deposits. Strong currents could erode the pre-existing sediments overlying the bed 7, sweep and winnow the fine-grained loose sediments from the sea floor, and rest the coarse and consolidated or partly lithified fragments of sediments (intraclasts) *in situ* as a kind of lag (cf. Einsele, 1998). The repeated action of currents led to concentration of those components of the lag, which were the most resistant for mechanical and chemical destruction. In the case of the studied lag, these components enclosed echinoid tests in form both of separate forms and parts of the intraclasts.

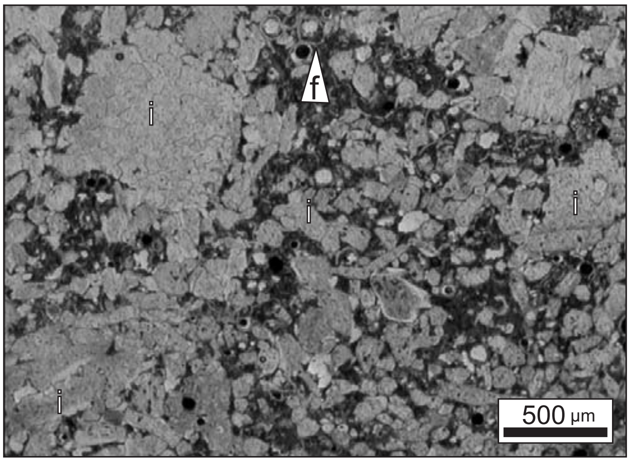

Fig. 8. Inoceramid packstone, microfacies of bed 9; f – foraminifers, i – inoceramid debris

SUMMARY

The concentration of echinoid tests of the genus *Conulus* in the Turonian sediments of Wielkanoc quarry is interpreted as a para-autochthonous assemblage *sensu* Kidwell *et al.* (1986), as the specimens are reoriented, but not transported out of the original life habitat. The echinoid tests regarded here as the lag deposit *sensu* Einsele (1998) originated by coincidence of the specific ecological and sedimentological factors.

Ecological factors were closely related to the specific environmental conditions established on the subaqueous swell of the Turonian sea, within the southern part of the West European Platform. These conditions were optimal for the life of *Conulus subrotundus*. The substrate was composed of calcarenite sand and the bottom waters were to some extent calm (typical of the deposition of foraminiferal-calcisphaere wackstone) and dynamic (with inputs of quartz and glauconitic grains). It is highly probable that the increase of the population of the *Conulus* species was related to one or more eco-events in the study area.

Sedimentological factors were connected with the episodes of non-deposition and erosion. During non-deposition the sediment underwent early consolidation and lithification which affected also echinoid tests infilled with internal sediment. The subsequent current erosion led to winnowing of the non-consolidated sediments and exhumation of the me-

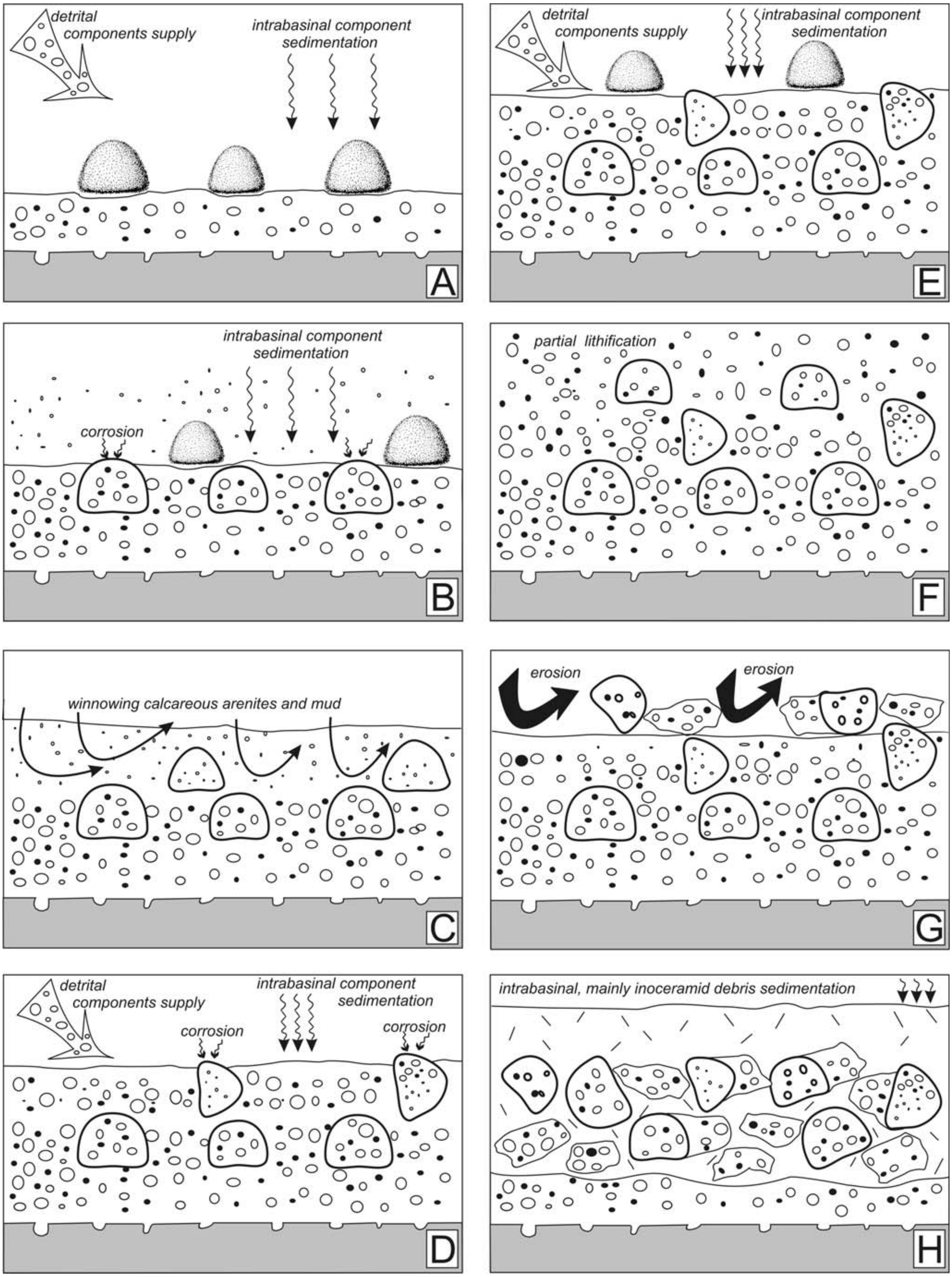

Fig. 9. Reconstruction of the development of the *Conulus* Lagerstätte in the Wielkanoc section; detailed description in the text

chanically and chemically resistant lithified or consolidated fragments of sediments: intraclasts and echinoid tests. They were reworked *in situ* and formed the lag deposit. These processes led to increase of the *Conulus* test frequency in the lag, because echinoid tests infilled with internal sediments were elements resistant for redeposition.

Conulus Lagerstätte from the Wielkanoc quarry shows transitional features between the model of fossil accumulation by Kidwell (1991, 1993), referred to as the hiatal accumulation, and the lag accumulation *sensu* Kidwell (1993) and Einsele (1998). The most adequately the *Conulus* Lagerstätte can be compared with non-skeletal lag sediments *sensu* Einsele (1998). The crucial in the origin of the Lagerstätte was however time necessary for lithification or, at least, consolidation of sediments, so that the echinoid tests did not undergo destruction but were included within intraclasts or became interaclasts themselves.

The lag deposits with echinoid test concentration originated on the uplifted area of the so-called Kraków Swell, which was a place of shallow water sedimentation since the Middle Turonian. Marcinowski (1974) and Walaszczyk (1992) believed that Subhercynian tectonic movements controlled the evolution of the Kraków Swell during Turonian–Santonian times. It is unlikely that tectonic movements themselves could generate currents responsible for development of the *Conulus* Lagerstätte. However, it is not unlikely that some tectonic uplift or tilt could forced some changes in the pattern of bottom currents which could flowed on the study area during the *Conulus* lag deposition. Regional studies are necessary to test this hypothesis.

Acknowledgements

The author wishes to thanks three anonymous reviewers and Katarzyna Król for helpful comments and criticism, and to Krzysztof Bąk for constructive remarks. The author is greatly indebted to Anna Świerczewska and Krzysztof Nejbert for the help in the field work, to Maciej Bąbel, Edyta Jurewicz, Bogusław Waksmundzki, Stanisław Skompski, and Anna Żylińska for fruitful discussion during the preparation of the paper, and to Grzegorz Widlicki for preparation of the polished thin sections. Warm thanks are also to Colleagues from the Palaeontological Section of the Institute of Geology for kind and patience, during my several and hour-long visiting their laboratory. The Institute of Geology (University of Warsaw) BW grants no. 1484/12 and no. 1527/04 supported this research.

REFERENCES

Alexandrowicz, S., 1954. Turonian of the southern part of the Cracow Upland. *Acta Geologica Polonica*, 4: 361–390.

Amorosi, A., 1997. Detecting compositional, spatial, and temporal attributes of glaucony: a tool for provenance research. *Sedimentary Geology*, 109: 135–153.

Barczyk, W., 1956. On the Upper Cretaceous deposits on Bonarka near Cracow. *Studia Societatis Scientiarum Torunensis, Sectio C (Geographia-Geologia)*, 3: 1–23.

Bukowy, S., 1956. Geology of the area between Cracow and Korzkwia. (In Polish, English summary). *Biuletyn Instytutu Geologicznego*, 108: 17–82.

Einsele, G., 1998. Event stratigraphy: Recognition and interpretation of sedimentary event horizons. In: Doyle, P. & Bennett, M. R. (eds), Unlocking the Stratigraphical Record: Advances in Modern Stratigraphy, John Wiley & Sons Ltd, Chichester, pp. 145–193.

Ernst, G., 1967. Über Fossilnester in *Pachydiscus*-Gehäusen und das Lagenvorkommen von Echiniden in der Oberkreide NW-Deutschlands. *Paläontologische Zeitschrift*, 41: 211–229.

Ernst, G., 1970. The stratigraphical value of the echinoids in the boreal Upper Cretaceous. *Newsletters on Stratigraphy*, 1: 19–34.

Ernst, G., Schmid, F. & Klischies, G., 1979. Multistratigraphische Untersuchungen in der Oberkreide des Raumes Braunschweig - Hannover. In: Wiedmann J. (ed.), *Aspekte der Kreide Europas*. *International Union of Geological Sciences*, *Series* A, 6: pp. 11–46.

Ernst, G., Schmidt, F. & Seibertz, E., 1983. Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. *Zitteliana*, 10: 531–554.

Hawkins, H. L., 1919. Morphological studies on the Echinoidea. Holectypoidea their allies. IX. *Pyrina*, *Conulus* and *Echinoneus*. *Geological Magazine*, 6: 442–452.

Johnson, M. E., 1989. Tempestites recorded as variable *Pentamerus* layers in the Lower Silurian of southern Norway. *Journal of Paleontology*, 63: 195–205.

Kaziuk, H., 1978. Mapa Geologiczna Polski 1:200000; Arkusz Kraków, B – Mapa bez utworów czwartorzędowych. Wydawnictwa Geologiczne, Warszawa.

Kidwell, S., 1991. Taphonomic feedback (live/dead interactions) in the genesis of bioclastic beds: keys to reconstructing sedimentary dynamics. In: Einsele, G., Ricken, W. & Seilacher, A. (eds), *Cycles and Events in Stratigraphy*, Berlin, Springer-Verlag, pp. 268–282.

Kidwell, S., 1993. Taphonomic expressions of sedimentary hiatuses: field observations on bioclastics concentrations and sequence anatomy in low, moderate and high subsidence settings. *Geologische Rundschau*, 82: 189–202.

Kidwell, S. M., Fürsich, F. T. & Aigner, T., 1986. Conceptual framework for the analysis and classification of fossil concentrations. *Palaios*, 1: 228–238.

Kowalski, W. C., 1948. Geological outline of Cretaceous deposits in the environs of Solca. (In Polish, English summary). *Biuletyn Instytutu Geologicznego*, 51: 5–52.

Kudrewicz, R. & Olszewska-Nejbert, D., 1997. Upper Cretaceous 'Echinoidlagerstätten' in the Kraków area. *Annales Societatis Geologorum Poloniae*, 67: 1–12.

Małecki, J., 1976. Jeżowce nieregularne z margli senońskich okolic Krakowa. (In Polish). *Sprawozdania z Posiedzenia Komisji Naukowej PAN Oddział Kraków*, 19: 140–141.

Małecki, J., 1979. Rozwój jeżowców górnokredowych (cenoman–turon) okolic Krakowa i ich znaczenie dla stratygrafii. (In Polish). *Sprawozdania z Posiedzenia Komisji Naukowej PAN Oddział Kraków*, 21: 183–185.

Marcinowski, R., 1974. The transgressive Cretaceous (Upper Albian through Turonian) deposits of the Polish Jura Chain. *Acta Geologica Polonica*, 24: 117–217.

Marcinowski R. & Radwański A., 1983. The Mid-Cretaceous transgression onto the Central Polish Uplands (marginal part of the Central European Basin). *Zitteliana*, 10: 65–95.

Moffat, H. A. & Bottjer, D. J., 1999. Echinoid concentration beds: two examples from the stratigraphic spectrum. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 149: 329–341.

Olszewska-Nejbert, D., 1996. *Jeżowce nieregularne turonu i koniaku Mangyszłaku (zachodni Kazachstan) i kredy opolskiej*. (In Polish). Unpubl. Ph.D. Thesis, Warsaw University, 163 pp.

Olszewska-Nejbert, D., 2004. Development of the Turonian/Coniacian hardground boundary in the Cracow Swell area (Wielkanoc quarry, Southern Poland). *Geological Quarterly*, 48: 159–168.

Popiel-Barczyk, E., 1958. The Echinoid genus *Conulus* from the Turonian in the vicinty of Kraków, Miechów and Wolbrom. *Prace Muzeum Ziemi*, 2: 41–79.

Radwański, A. & Wysocka, A., 2001. Mass aggregation of Middle Miocene spine-coated echinoids *Echinocardium* and their integrated eco-taphonomy. *Acta Geologica Polonica*, 51: 295–316.

Radwański, A. & Wysocka, A., 2004. A farewell to Świniary sequence of mass aggregation, spine-coated echinoids *Psammechinus* and their associates (Middle Miocene; Holly Cross Mountains, Central Poland). *Acta Geologica Polonica*, 54: 381–399.

Seilacher, A., Reif, W.- E. & Westphal, F., 1985. Sedimentological, ecological and temporal patterns of fossil Lagerstätten. *Philosophical Transactions of the Royal Society of London*, B, 311: 5–23.

Skompski, S. & Szulczewski, M., 1994. Tide-dominated Middle Devonian Sequence from the northern part of the Holly Cross Mountains (Central Poland). *Facies*, 30: 247–265.

Smith, A. B., 1984. *Echinoid Palaeobiology*. George Allen & Unwin, London, 190 pp.

Smith, A. B., 1988. Echinoids. In: Smith A. B., Paul C. R. C., Gale A. S. & Donovan S. K. (eds), *Cenomanian and Lower Turonian echinoderms from Wilmington, south-east Devon, England. Bulletin of the British Museum (Natural History), Geology series*, 42: 16–189.

Smoleński, J., 1906. Dolny senon na Bonarce, I. Głowonogi i inoceramy. (In Polish). *Rozprawy Wydziału Matematyczno-Przyrodniczego Akademii Umiejętności*, *Seria B*, 6: 1–34.

Sobczyk, W., 1990. Klucz do oznaczania jeżowców górnokredowych okolic Krakowa. *Zeszyty Naukowe Akademii Górniczo-Hutniczej – Geologia*, 16: 75–97.

Sujkowski, Z., 1926. Sur le Jurassique, le Crétacé et le Quaternaire des environs de Wolbrom. (In Polish, French summary). *Sprawozdania Państwowego Instytutu Geologicznego*, 3: 382–434.

Sujkowski, Z., 1934. Roches crétacées entre les villes Pilica et Szczekociny. (In Polish, French summary). *Sprawozdania Państwowego Instytutu Geologicznego*, 8: 39–75.

Walaszczyk, I., 1992. Turonian through Santonian deposits of the Central Polish Uplands; their facies development, inoceramid paleontology and stratigraphy. *Acta Geologica Polonica*, 42, 1–122.

Zaręczny, S., 1878. O średnich warstwach kredowych w Krakowskim okręgu. (In Polish). *Sprawozdanie Komisji Fizjograficznej Akademii Umiejętności*, 12: 176–246.

Streszczenie

GENEZA NAGROMADZENIA JEŻOWCÓW RODZAJU *Conulus* W SKONDENSOWANEJ WARSTWIE WAPIENI TUROŃSKICH W KAMIENIOŁOMIE WIELKANOC (POŁUDNIOWA POLSKA)

Danuta Olszewska-Nejbert

W kamieniołomie Wielkanoc (Wyżyna Miechowska), położonym na granicy Jury Polskiej i Niecki Miechowskiej (Fig. 1) odsłania się 10 m profil utworów środkowego i górnego turonu (Fig. 2), leżących na powierzchni abrazyjnej, ścinającej oksfordzkie wapienie skaliste. Utwory turońskie są wykształcone w dolnej części profilu w postaci wapieni piaszczysto-organodetrytycznych, organodetrytycznych lub piaszczystych, podczas gdy w górnej przeważają wapienie organodetrytyczne. Profil turonu kończy warstwa wapieni pelitowych z twardym dnem w stropie, nad którym leżą wapienie piaszczysto-glaukonitowe koniaku.

Około 2,5 m nad powierzchnią abrazyjną znajduje się warstwa z wyraźnie większą frekwencją jeżowców (Fig. 3, 4), które stanowią paraautochtoniczny i monotypowy zespół gatunku *Conulus subrotundus* Mantell, 1822. Nagromadzenie jeżowców *Conulus* w jednej warstwie o znacznym rozprzestrzenieniu horyzontalnym pojawia się tylko raz w profilu turonu kamieniołomu Wielkanoc. Wykonane badania pokazały niejednorodną budowę warstwy z jeżowcami (Fig. 5–8). W obrębie tła skalnego występują intraklasty bez jeżowców, intraklasty, w których jeżowiec stanowi część intraklastu oraz jeżowce. Tło skalne jest packstonem inoceramowym (Fig. 5h, 7F), podobnie jak utwory leżące powyżej warstwy z jeżowcami (Fig. 5i, 8). Intraklasty nie zawierające jeżowców są zbudowane z wakstonu otwornicowo-kalcisferowego z dużą domieszką kwarcu oraz podrzędnie glaukonitu (Fig. 5c, 7B). Litologicznie odpowiadają osadom podścielającym warstwę z jeżowcami (Fig. 5b, 7A). Intraklasty z jeżowcami charakteryzują się nieco bardziej złożoną budową. Skała otaczająca pancerz wykształcona jest jako wakston otwornicowo-kalcisferowy z dużą domieszką kwarcu oraz podrzędną glaukonitu (Fig. 5d, f; 7D, E). Ten sam rodzaj osadu wypełnia większość pancerzy jeżowców (Fig. 5e, 7E). Znacznie rzadziej spotykane są okazy, gdzie skała wypełniająca pancerz jeżowca w całości jest wakstonem otwornicowo-kalcisferowym bez domieszek kwarcowo-glaukonitowych (Fig. 5g, 7C), lub też wypełnienie pancerza ma charakter mieszany, tzn. część okazu wypełniona jest wakstonem otwornicowo-kalcisferowym z dodatkiem dużej ilości kwarcu i niewielkiej glaukonitu, zaś pozostała część, tej domieszki jest pozbawiona. Jeżowce nie będące częścią intraklastu wypełnione są wakstonem otwornicowo-kalcisferowym z dużą domieszką kwarcu i niewielką glaukonitu. Nieliczne okazy są wypełnione wakstonem otwornicowo-kalcisferowym, który nie zawiera domieszek kwarcowo-glaukonitowych.

Obserwacje terenowe i analiza mikrofacjalna pozwoliły stwierdzić, iż do nagromadzenia jeżowców w analizowanej warstwie przyczyniły się czynniki ekologiczne i złożone czynniki sedymentologiczne. Do tych pierwszych należą zdarzenia ekologiczne, kiedy w środowisku stosunkowo niskoenergetycznym powstały optymalne warunki rozwoju *Conulus subrotundus* Mantell. Na czynniki sedymentologiczne złożyło się zarówno wymywanie świeżo złożonego luźnego osadu jak i erozja już skonsolidowanego osadu, bogatego w sfosylizowane wcześniej jeżowce (Fig. 9). Proces ten polegał na epizodach akumulacji materiału, jego konsolidacji i erozji w środowisku wysokoenergetycznym, co doprowadziło do powstania bruku rezydualnego (*ang.* lag deposit) składającego się ze sfosylizowanych wcześniej jeżowców.

Opisane procesy zachodziły na podmorskim progu krakowskim, który funkcjonował jako jednostka paleogeograficzna od turonu po santon. Próg krakowski rozdzielał dwa głębsze baseny, położony na NE basen bruzdy duńsko-polskiej od basenu opolskiego na SW. W generalnie transgresywnych utworach późnej kredy, na progu krakowskim osadzały się utwory płytkowodne. Osadzanie tych utworów było przerywane częstymi epizodami erozji, gdyż próg krakowski, zanim został ostatecznie pogrążony w późnym santonie, podlegał okresowo silnej działalności falowania i prądów dennych.