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GLAUCONY FROM THE CONDENSED LOWER-MIDDLE JURASSIC DEPOSITS OF THE KRIŽNA UNIT, WESTERN TATRA MOUNTAINS, POLAND

Renata JACH & Krzysztof STARZEC

Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, 30-063 Kraków, Poland;
R.J. e-mail: jach@ing.uj.edu.pl, K.S. e-mail: star@ing.uj.edu.pl

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Abstract: Lower-Middle Jurassic glaucony-bearing deposits crop out in the Polish part of the Križna Unit in the Western Tatra Mts. These deposits, up to 20 cm thick, consist of glaucony-rich marls and limestones. The glaucony grains constitute up to 30% volume of the deposits. They represent an evolved stage of glauconitization since they contain more than 7% K_2O. The content of Al_2O_3 is high (up to 19.97%, average 16.98%) while the content of Fe_2O_3 is low (not more than 23.48%, average 12.84%). These features are interpreted as a product of diagenetic processes. The glaucony-bearing deposits were formed at an upper bathyal depth and their rate of deposition was very low, what allowed long-lasting evolution of the glaucony grains. The K-Ar age of the glaucony grains is much younger than the biostratigraphic age of the studied section. The lowering of the K-Ar dates is interpreted as a result of loss of radiogenic Ar from the lattice of the glaucony.

Key words: High-Al autochthonous glaucony, K-Ar dating, Carpathians, Tethys.

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INTRODUCTION

A large body of literature concerns the origin and development of glaucony (see Odin & Matter, 1981; Odin & Fullagar, 1988; Amorosi, 1997 and references therein). It is widely accepted that glaucony is an autochthonous component developed in marine conditions in shelf or slope zones at a depth between 50 and 500 m (Odin & Fullagar, 1988, but for exceptions see Chafetz & Reid, 2000, and Wiewióra *et al.*, 2001). Very low sedimentation rate and sub-oxic conditions are important factors controlling the formation of glaucony (Odin & Fullagar, 1988; Kelly & Webb, 1999). The presence of suitable initial substrates is also important for the glauconitization process (Odin & Matter, 1981).

Condensed Jurassic horizons of the Križna Unit in the Tatra Mts. have been known so far only from red, partly nodular, limestones belonging to the Kliny Limestone Member (Lefeld *et al.*, 1985). They contain pelagic stromatolites, ferrugineous macrooncoids and concentrations of nectonic fossils (Gradziński *et al.*, 1997; Wieczorek, 2001). They were dated as Middle Toarcian on the ground of the ammonite *Hildoceras bifrons* (Lefeld *et al.*, 1985; Jach, 2003). However, during detailed geological field work in the Western Tatra Mts., a different type of condensed sequence has been encountered (Jach, 2003) which probably represents a lateral facies being equivalent to a part of the above mentioned red limestones. It is characterized by the occurrence of phosphatic stromatolites, abundance of fish teeth and a very high content of glaucony.

The main aim of our study was to determine the origin of the glaucony from the Jurassic condensed deposits, and the environmental conditions that favoured glauconitization.

GEOLOGICAL SETTING

The glaucony-bearing deposits crop out in the Polish part of the Križna Unit (Lower Sub-Tatric Succession) in the Western Tatra Mts. (Fig. 1). The Križna Unit (Fatricum) is a fully allochthonous unit, which occupies a higher structural position than the locally allochthonous units and the autochthonous sedimentary cover of the High-Tatric units (Tatricum domain). It was detached from its substratum and thrust over the Tatricum in Early Turonian times (Plašienka & Prokešová, 1996). The deposits of the Križna Unit accumulated in the Križna basin, which was situated on the north-western margin of the Tethys.

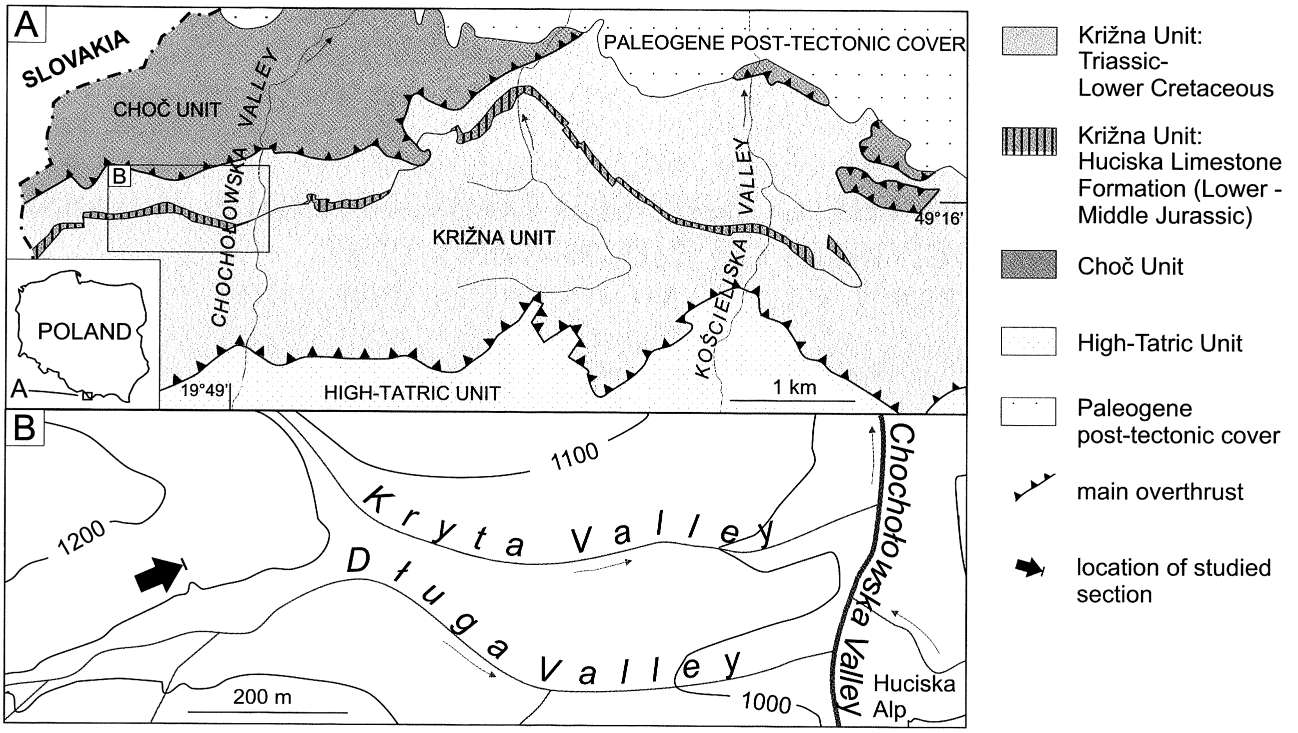

Fig. 1. Geological sketch map of the Polish part of the Tatra Mountains showing location of the studied section (after Bac-Moszaszwili *et al.*, 1979, simplified)

In the Western Tatra Mts., the Križna Unit is represented by a large thrust sheet distinguished as the Bobrowiec Unit (Andrusov, 1959). It is a faulted slab, dipping monoclinally to the north (Bac, 1971; Bac-Moszaszwili *et al.*, 1979), which extends from the Osobita mountain in the west to the Kościeliska Valley in the east. It comprises a nearly complete sequence from the Lower Triassic to the Lower Cretaceous deposits (Bac, 1971).

The Lower-Middle Jurassic sequence of the Bobrowiec Unit consist of various carbonate and siliceous deposits (Figs 2, 3). The glaucony-bearing condensed deposits occur only locally. They overlie a series of alternating limestones

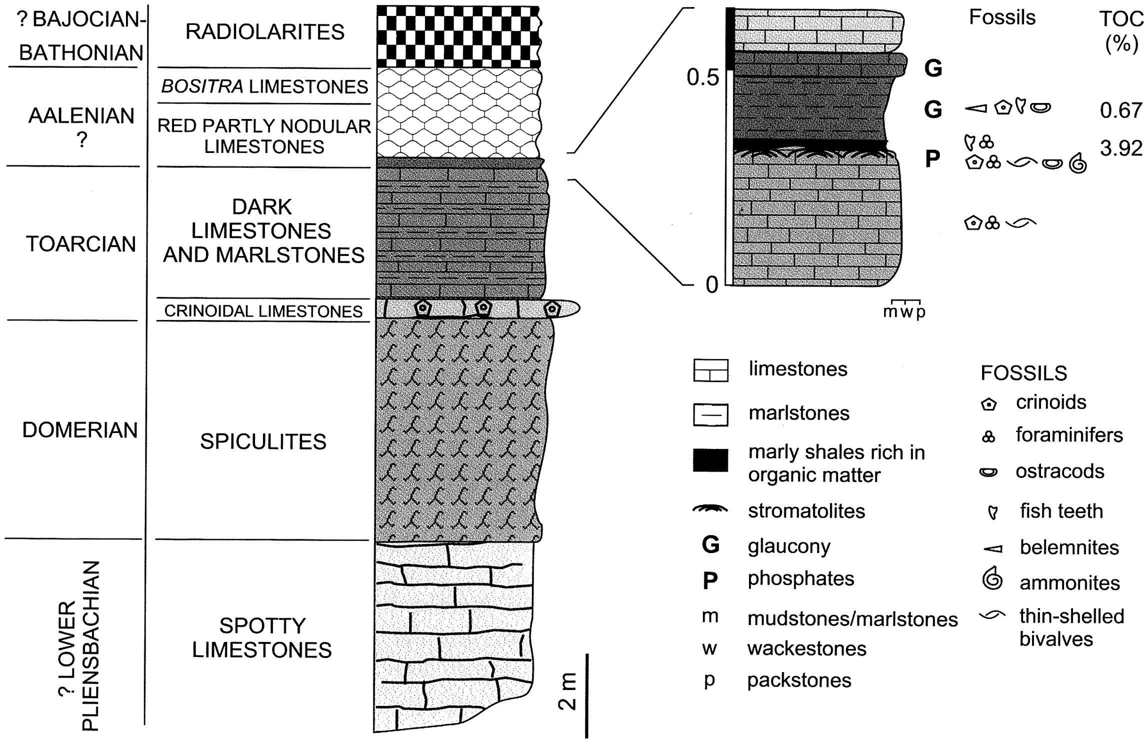

Fig. 2. Lithological log of the studied Lower-Middle Jurassic deposits (after Jach, 2003; modified)

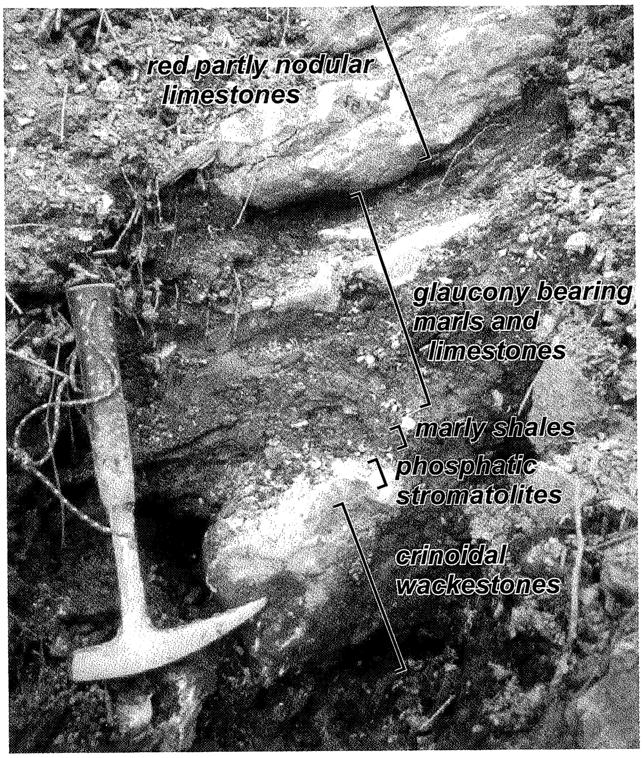

Fig. 3. Glaucony-bearing deposits, field photograph

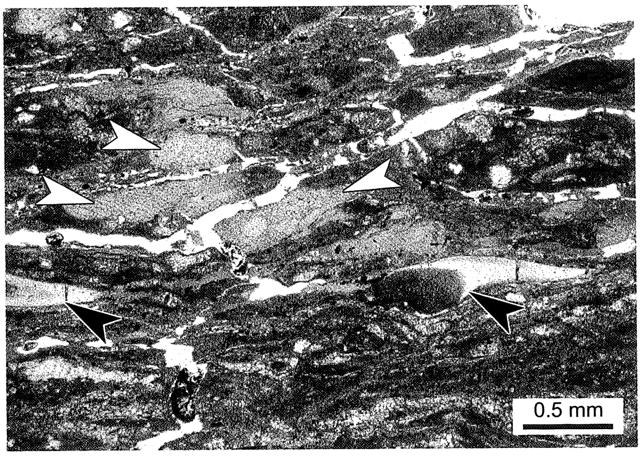

Fig. 4. Glaucony-bearing marls; glaucony grains (white arrows) and fish teeth (black arrows) are visible; thin section, parallel nicols

and marlstones which is probably Toarcian in age (Jach, 2003). The glaucony-bearing deposits are, in turn, covered with red, partly nodular, limestones.

The glaucony-bearing condensed section consists of, from the bottom to the top: (1) wackestone with crinoid ossicles, ammonite molds, thin-shelled bivalves, echinoid spines and foraminiferal tests, (2) phosphatic stromatolites, (3) marly shales rich in organic matter (up to 3.92% of $C_{org.}$) with abundant fish teeth and some foraminiferal tests, (4) marls and limestones with crinoidal ossicles, abundant fish teeth, belemnite guards and foraminiferal tests, and (5) crinoidal wackestones (Figs 2, 3; Jach, 2003). The whole condensed section attains 60 cm in thickness.

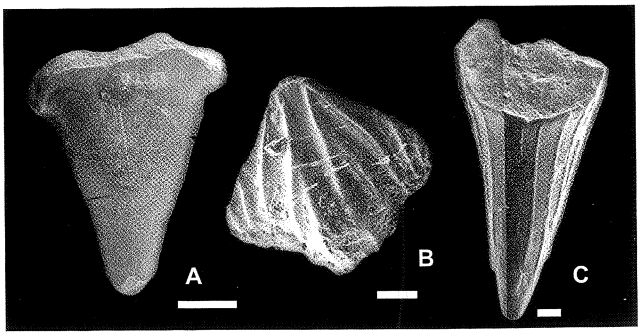

Fig. 5. Selected fish teeth from the studied deposits; SEM image, scale-bars equal to 100 μm

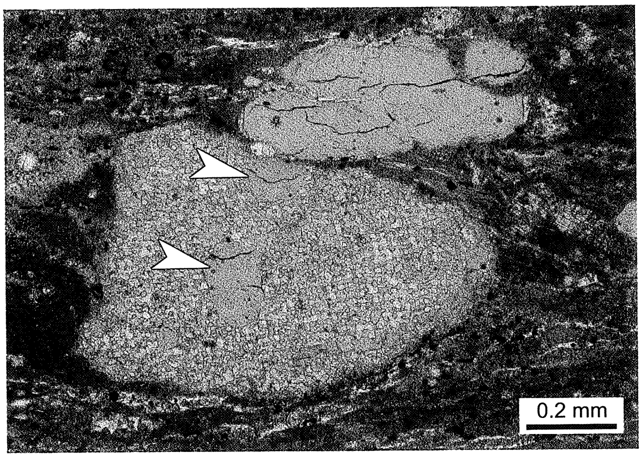

Fig. 6. Two glaucony grains, the lower developed due to the replacement of crinoidal ossicle, the calcite skeleton structure is still visible. Glaucony has also filled the microborings (arrows); thin section, parallel nicols

Glaucony is particularly abundant in the marls and wackestones forming the upper part of the section (Figs 4, 6). These deposits are up to 20 cm thick. The limestones and marls are greenish in colour, homogenous, and do not show any selective spatial distribution of glaucony grains. They differ from each other only in the content of non-carbonate components. Both these deposits display wackestone texture, comprise abundant crinoidal ossicles, high amount of fish teeth, and belemnite guards (Figs 4, 5). The tests of foraminifers and ostracods are less common. The assemblage of benthic foraminifers contains *Lenticulina* sp. and *Nodosaria* sp.

MATERIAL AND METHODS

The studied section containing glaucony-bearing deposits crops out on the left (northern) slope of the Długa Valley, which is a left-side tributary valley of the Chochołowska Valley (Fig. 1). The section was examined bed by bed. Samples were taken and polished slabs and thin sections were made. The observations were then supplemented by microfacies analysis.

The collected samples were dried and then disintegrated in solution of Glauber's salt. Residuum has been analysed to

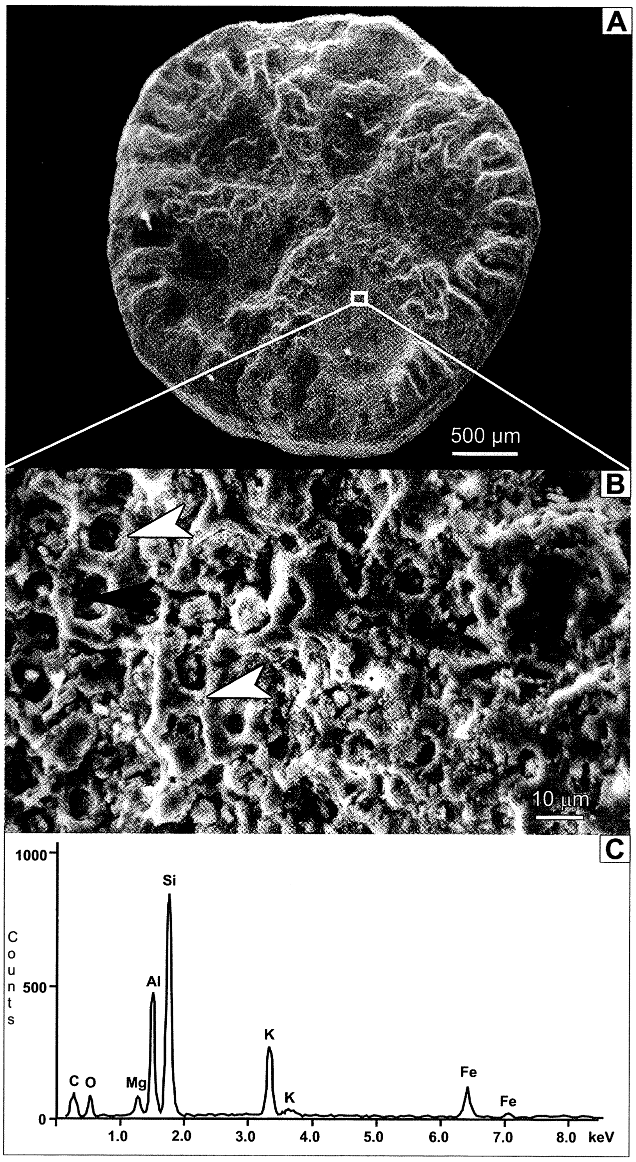

Fig. 7. **A**. Crinoidal ossicle, the primary pores are filled with glaucony; **B.** Close view, the primary calcite skeleton is visible (white arrows); **C.** EDS spot analyses of the glaucony filling the primary pore (black arrow in Fig. 7B)

find out relative abundance of bioclasts within the deposits. Disintegrated samples were sieved through a 105 µm mesh sieve. All bioclasts were analysed (crinoid and echinoid fragments, fish teeth, benthic foraminifers, ostracods, belemnite guards). The foraminifers were determined by Dr. J. Tyszka.

To separate glaucony grains, the collected rock samples were disaggregated by means of the standard micropalaentological technique. The samples were sieved, and the fraction >0.63 mm was subject to magnetic separation which was repeated several times. Subsequently, non-glauconitic grains were removed by hand-picking under a binocular biological microscope. Samples were then purified using an ultrasonic cleaner for 5 minutes. Before the X-ray diffraction study the sample was subjected to HCl acid treatment to remove carbonates.

Physical properties of separated grains were analysed in detail using optical microscope and scanning electron microscope (SEM) JEOL 5410. Chemical composition of the glaucony was examined by means of the energy dispersive spectrometer Voyager 3100 (NORAN product) coupled with SEM. Mineralogical composition of green grains was examined using X-ray powder diffraction (XRD) of separated grains in the air-dry and glycolated state using a vertical goniometer XPert APD Philips (PW 1830) with Cu-Kα radiation and a graphite monochromator.

K-Ar dating of separated glaucony grains was made in the Kraków Research Centre Laboratory of the Institute of Geological Sciences, Polish Academy of Sciences. The sample was split into two aliquots: a 100 mg one for K determination, and 43.4 mg one for Ar analysis. K was determined by flame photometer FLAPO. The photometer measurements were calibrated with KCl solutions and international standard Plastic Clay was used to control the procedure. The isotopic composition of Ar was determined using the method of Bonhomme *et al.* (1975). The sample was fused in Ti-Ta crucible, and the released gases were purified by freezing and on Ti getter. The measurements were performed on MS20 mass spectrometer (AEI product). The analytical precision was controlled by the measurements of the international standard GLO 525. The mean of four measurements was 24.89±0.2 (2σ) 10^{-6}cm^{3}/g STP, while the broadly accepted value is 24.85 ± 0.4. The precision of the date, which is calculated using the decay constants recommended by Steiger and Jäger (1977), is better than 0.5%.

RESULTS

MORPHOLOGY AND MICROSTRUCTURES

The colour of glaucony grains ranges from pale to dark-green. The grains are mainly 0.1–0.5 mm across, though some grains are more than 1.5 mm across (Figs 4, 6). Grains smaller than 0.1 mm are absent.

The described grains display various shapes. Subrounded, irregular or well-rounded ovoidal grains are most common (Figs 6–10). Tabular shapes were rarely observed. According to the morphological classification by Triplehorn (1966), the dark-green glaucony grains represent the spheroidal, ovoidal and mammilated pellet categories. The glaucony also forms thin film coatings within studied deposits.

Several stages of the glaucony filling of primary porosity in skeletal carbonate substrate, substrate dissolution and its subsequent replacement (cf. Odin & Lamboy, 1988; Rao *et al.*, 1993) can be observed in the studied material. In the first stage, the glaucony fills only the chambers in foraminiferal tests as well as internal pores and microborings in crinoidal ossicles (Figs 6, 7). The carbonate skeleton is well visible. In the second stage, the dissolution of carbonate skeleton starts probably due to increasing acidity during absorption of potassium (Kelly & Webb, 1999). The newly formed voids are filled with glaucony (Fig. 6). The final stage of this process brings about a complete dissolution and replacement of carbonate skeleton by glaucony (Figs 8, 10;

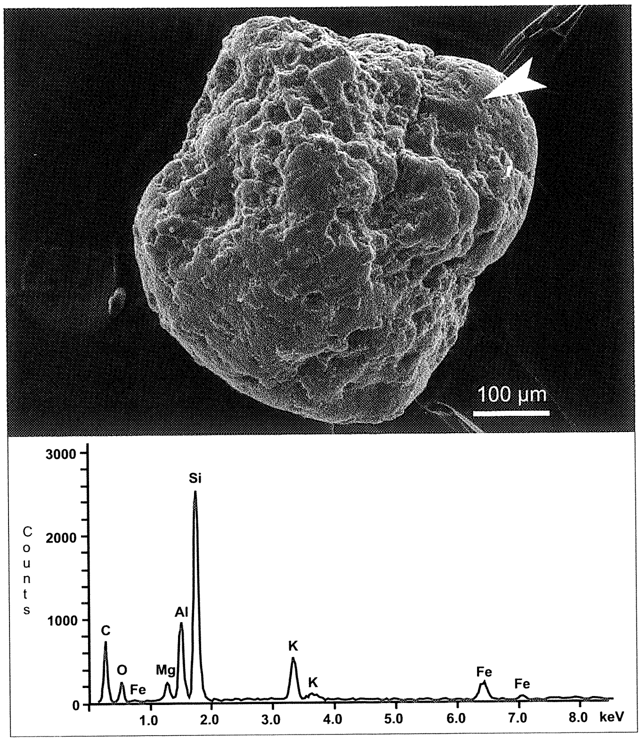

Fig. 8. Irregularly shaped glaucony grain; rough surface (left side) is built of calcite and most probably represents the calcite skeletal precursor; SEM image; white arrow indicates the point of EDS spot analysis presented in the lower part of the figure

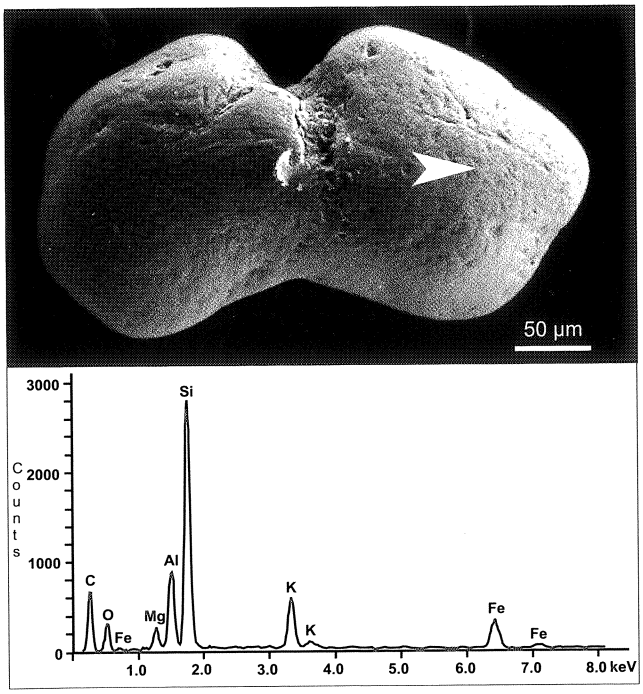

Fig. 9. Glaucony grain with smooth surface, its shape suggests that the grain represents internal mold of a foraminifer, SEM image; white arrow indicates the point of EDS spot analysis presented in the lower part of the figure

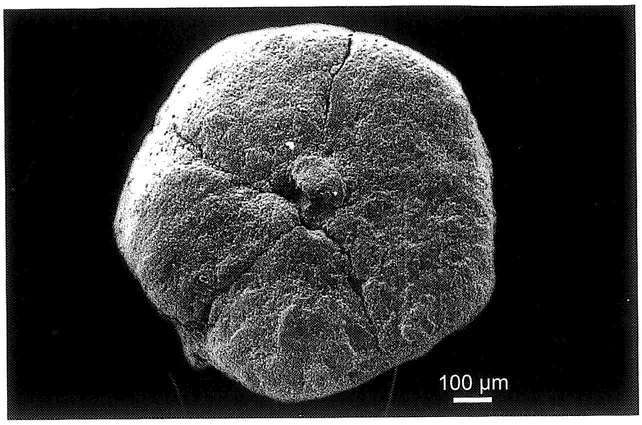

Fig. 10. Crinoidal ossicle almost completely replaced by glaucony; SEM image

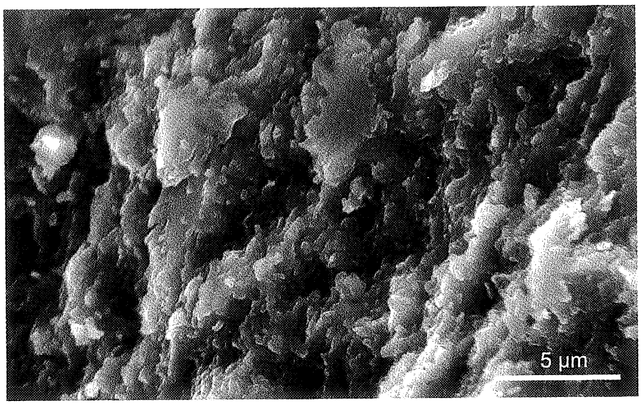

Fig. 11. Internal microstructure of a glaucony grain; parallel aggregate of flakes is visible; SEM image

cf. Odin & Matter, 1981). However, the shape of some glaucony grains resembles the shape of the primary carbonate skeleton (Fig. 9). These grains belong to fossil casts – internal molds category in the classification of Triplehorn (1966).

The surface of dark-green grains is mostly smooth and the grains are well rounded, whereas pale-green grains have most often earthy surface. Some parts of dark-green grains are fractured. The dark-green grains reveal unit extinction in polarized light, also scanning electron microscope observation displays oriented arrangement of flakes in one direction (Fig. 11). The pale-green grains are characterized by random microcrystalline internal structure, which is well visible under petrographic microscope.

MINERALOGICAL AND CHEMICAL COMPOSITION

Almost all important reflections characteristic for mineral glauconite, that is the basal reflections 001, 002, 003, also the reflections $11\bar{2}$, 112, and 060 reflection at 1.511 Å are seen on the diffractogram (Fig. 12). Some evidence indicates the presence of smectitic layers in the studied glaucony. First of all, the basal 001 reflection at 10.39 Å displays an asymmetric shape. According to Wiewióra and

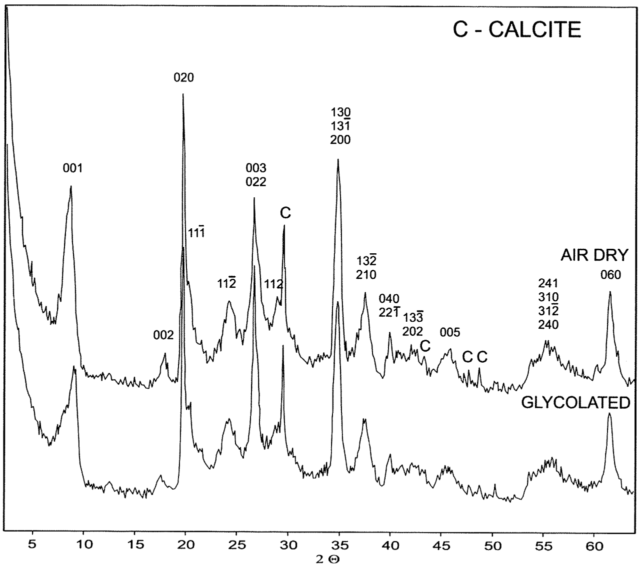

Fig. 12. X-ray diffraction pattern of the studied glaucony

Łącka (1980), glauconitic material consisting of nonexpanding layers is characterized by the symmetrical 001 reflection at 9.97 Å. Moreover, in the glycolated sample this reflection is broader and it is shifted toward higher angles. Furthermore, there is a lack of 11$\bar{3}$, 021 and 023 reflections which are diagnostic for well-ordered glauconitic minerals (cf. Odin & Matter, 1981). The intensity of the 002 reflection is relatively high. It suggests a relatively low amount of Fe (cf. Odin & Matter, 1981) and high amount of Al (cf. Berg-Madsen, 1983).

Some amount of calcite is also present in these grains, as shown by characteristic peaks (Fig. 12). They are probably the remnants of incompletely glauconitized carbonate substrate.

The chemical composition of the green grains was determined by 36 EDS spot analyses. Mostly dark-green grains were selected for the measurement, but some light-green were analysed as well. The chemical composition of the studied glaucony is presented in Table 1.

The Si content is a little higher than reported in the literature (cf. Wiewióra & Łącka, 1980; Odin & Fullagar, 1988). The Al_2O_3 content varies from 13.13% to 19.97% while the reported values are between 3.5 and 11.0% (see Odin & Fullagar, 1988, table 2; but for exceptions see Smulikowski, 1936; Wiewióra & Łącka, 1980; Berg-Madsen, 1983; Ireland *et al.*, 1983). On the other hand, the studied material reveals relatively low amount of Fe_2O_3 (mean 12.84%). On the basis of $Fe_2O_3/Fe_2O_3+Al_2O_3$ ratio, which equals of 43.05%, the studied glaucony can be classified as the "aluminic glauconite" *sensu* Smulikowski (1936), while this ratio exceeds 50% in the "ferruginous glauconites".

MgO content varies from 3.04 to 5.09%. It agrees perfectly well with the opinion of McRae (1972), as well as Odin and Matter (1981) that percentage of Mg in the glaucony is very constant and ranges from 3.0 to 5.1%.

Table 1

Chemical composition of the studied glaucony grains based on 36 EDS spot analyses. Total Fe expressed as Fe_2O_3

oxide	range [wt. %]	average [wt. %]
SiO_2	49.27–58.27	56.86
Al_2O_3	13.13–19.97	16.98
Fe_2O_3	9.09–23.48	12.84
MgO	3.04–5.09	4.23
K_2O	6.99–10.66	8.29

Odin and Matter (1981) report that of all the cations in glaucony the content of K is the most variable one. The studied samples display quite stable and high content of K (K_2O up to 10.66%). Thus, they are in the evolved stage of glauconitization *sensu* Amorosi (1997).

There is a relationship between the structure and the chemical composition of glaucony (Odin & Matter, 1981). The distance '*d*' between the 020 peak, whose position is very stable, and the 001 peak reflects the K_2O content. One can estimate the percentage of potassium in the studied samples by measuring the '*d*' distance and using the diagram presented by Odin and Fullagar (1988, fig. 8). The estimated K content in the studied glaucony ranges from 6.5 to 7.5%. Thus, the studied material shows a lower K_2O content by X-ray diffraction analysis than by the electron microprobe analyses. The difference is probably caused by selective hand-picking (mostly dark-green grains were picked for chemical analyses).

Based on the EDS chemical analyses of the studied glaucony, its chemical formula is as follows: $(K_{0.67}\,Ca_{0.06})_{0.73}\,(Al_{0.94}\,Fe^{3+}_{0.63}\,Mg_{0.41})\,(Si_{3.66}\,Al_{0.34})\,O_{10}(OH)_2$. Comparing the above formula with data reported earlier (Smulikowski, 1954; Odin & Matter, 1981; Odom, 1984) we find the high Al content as the most important difference. It should be stressed out that the number of Al cations in the tetrahedral sheet is similar to the average data but in the octahedral one it is twice as much as in the references (McRae, 1972; Odin & Matter, 1981), even 2.30 per formula unit. Al is the major ion in the octahedral sheet of the studied glaucony while the content of iron is very low. A strong antipathetic relationship between Fe and Al is visible in the studied samples (Fig. 13). A similar relationship was

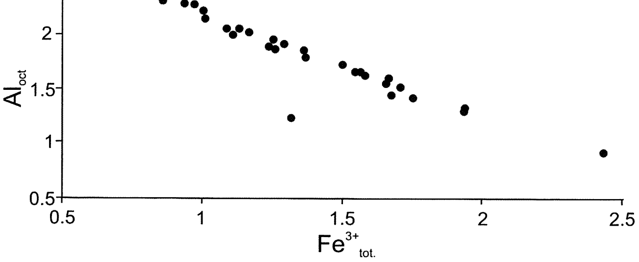

Fig. 13. Relationship between Fe and Al, determined by EDS spot analyses. All values ploted are based on analyses calculated on the basis of 22 oxygen atoms

Table 2

K-Ar age of the studied glaucony

K_2 [%]	radiogenic Ar [%]	radiogenic Ar[10-6cm^3/g]	Age [Ma]
7.13	86.7	1236	116.6 ± 0.8

noted earlier for example by Berg-Madsen (1983), Ireland *et al.* (1983) and by Bornhold and Giresse (1985).

K-Ar DATING

The glaucony was tested whether it fulfills the criteria of material suitable for radiometric dating. It was checked and confirmed that the glaucony is autochthonous (see below) and mature. The latter inference follows from the K_2O content of more than 7% (cf. Odin & Dodson, 1982; Amorosi, 1997; Amireh *et al.*, 1998). An attempt at dating the glaucony was made. The obtained result is presented in Table 2.

DISCUSSION

AUTOCHTHONOUS *VS.* ALLOCHTHONOUS ORIGIN OF GLAUCONY

Amorosi (1997) listed and discussed several criteria useful in solving the question whether the glaucony is autochthonous or allochthonous in origin, such as: grain size, sorting, roundness and spatial distribution. The variable grain size (bad sorting) of the studied glaucony grains suggests their *in situ* origin. In such a case the dimensions of glaucony grains do not depend on hydraulic processes which should cause good sorting of the grains in question. The critical factor which controls the dimensions of glaucony grains was the dimensions of accessible precursor grains acting as the substrate for glauconitization (Odin & Matter, 1981). Crinoidal ossicles served as a precursor for the largest glaucony grains found in the studied samples (Figs 6, 7, 10). Since their dimensions exceed 2 mm, they are larger than the glaucony grains commonly found (cf. Odin & Matter, 1981; Odin & Fullagar, 1988). Their development was possible only due to the very high primary porosity of the crinoidal skeleton (Lucia, 1962), which enabled migration of ions into the interior of such a large grain.

Some of the discussed glaucony grains are irregular-shaped and non-abraded, which also suggests their autochthonous origin. Such an origin is also confirmed by the lack of glaucony grains smaller than 100 μm, considered as the product of fragmentation of the larger ones. Another argument for the above interpretation is the non-selective spatial arrangement of the grains in question within the bed and the occurrence of thin film coatings.

On the other hand, the smooth, seemingly polished surfaces of glaucony grains, which characterize a part of the studied material, are commonly regarded as being an effect of abrasion during transport (Fig. 9). However, it can be also caused by prolonged contact with sea water during advanced evolution of the glaucony. The occurrence of such surfaces in dark-green grains only i.e., those which, according to Amorosi (1997), represent more mature glaucony, confirms the latter interpretation.

DEPOSITIONAL ENVIRONMENT OF GLAUCONY

According to Jach (2003), the glaucony-bearing deposits were laid down at the upper bathyal depth within the aphotic zone. This interpretation is based on sedimentological and palaeontological characteristics of the discussed deposits. It is in conformity with the commonly accepted depositional milieu of glaucony, which has been placed between 50 and 500 m (Odin & Fullagar, 1988).

Odin and Fullagar (1988) claimed that the evolved glaucony needs about 100,000 years or more to develop. During all this time the developing glaucony grain must be situated on the sea-floor or buried at a very shallow depth. Thus, the occurrence of evolved autochthonous glaucony indicates that the rate of deposition of the studied section was extremely slow or the deposition was periodically halted. The co-occurrence of glaucony with phosphatic stromatolites, as well as abundant fish tooth and bone debris also confirm the above interpretation (Fig. 5; cf. Jenkyns, 1971; Amorosi, 1995).

The studied sequence was deposited on the edge zone of a fault-bounded pelagic carbonate platform surrounded by a basin (Jach, 2003). Thus, it is probable that in this zone the winnowing processes have exhumed the developing glaucony grains and prevented them from being completely buried. The deficiency of oxygen occurred periodically in the bottom water in the basin (Jach *et al.*, 2002; Jach, 2003). It is worth mentioning that the occurrence of glaucony/phosphate association is usually found in the surroundings of such basins (cf. Föllmi, 1989).

Al CONTENT OF GLAUCONY

The most conspicuous chemical feature of the studied glaucony is the very high amount of Al and relatively low content of Fe (Table 1). High-Al glaucony has been rarely reported (cf. chemical data compiled by Odin & Matter, 1981). It is known, for example, from the Cambrian deposits of Baltoscandia (Berg-Madsen, 1983). The high amount of Al in the Baltoscandia glaucony was interpreted as dependent upon the depositional environment. Berg-Madesen (1983), following the opinion of Owen and Sohl (1973), claimed that high-Al glaucony develops in shallow water environment (<50 m). However, this could not have been the case of the discussed glaucony because the sedimentological context clearly shows that the studied sequence was deposited at the upper bathyal depth within the aphotic zone (Jach, 2003). Moreover, such autochthonous glaucony formed in very shallow-marine conditions has definitely lower content of Al (4.56 to 7.06%; Chafetz & Reid, 2000). Thus, it seems that high-Al content in the autochthonous glaucony can not be regarded as an indicator of shallow depositional environment.

Berg-Madsen (1983) suggested that the high-Al content in glaucony from the Baltoscandia supports the layer-structure theory of Burst (1958). However, since Odin and Matter (1981) published their fundamental paper, the verdissement theory explaining the origin of glaucony has been widely accepted. In the light of this theory, the glaucony is an automorphous mineral phase independent from the chemistry of the substrate. However, Clauer *et al.* (1992), basing on Sr and Rb isotope measurements, claimed that glaucony developed in a twofold process. At the first stage glaucony is dependent upon older precursor material. This first stage ends when the K_2O content in glaucony reaches 4%. The studied glaucony has definitely higher amount of K_2O. Thus, accepting the opinion by Clauer *et al.* (1992), it is not possible to explain the high amount of Al in the studied glaucony by the inheritance from an older precursor.

Ireland *et al.* (1983) claimed that Al can be incorporated into the glaucony structure during burial diagenesis and replace Fe in the octahedral sheets. This process caused the anthipathetic relationships of the above elements in the studied glaucony (Fig. 13). In the present authors' view it is the most probable explanation of the high content of Al in the studied glaucony. However, this aspect of the described glaucony needs further investigation.

K-Ar AGE OF GLAUCONY

The obtained K-Ar age equals to 116.6±0.8 Ma (Table 2). It is definitely too low radiometric age and it is incompatible with the biostratigraphic age of the studied section. The lowering of K-Ar dates is caused by the loss of radiogenic Ar from the lattice of glaucony. This, in turn, can result from several reasons, such as: (1) diagenesis, (2) heating, (3) tectonic stress or (4) weathering (Amireh *et al.*, 1998). From the above listed reasons, heating should be excluded. The glaucony needs to remain in the temperature over 150 °C for prolonged time to lose argon (McRea, 1972). The study of the organic matter preservation and the mixed-layer illite/smectite minerals from the host deposits proves that they were not heated to such an high temperature (Jach, 2003). Microscopic observations show that the studied glaucony is not weathered. The lack of kaolinite and iron oxides, which are the common products of glaucony weathering, adds an indirect evidence of this. Thus, the burial diagenesis of the glaucony and/or tectonic stress seem to be responsible for the loss of Ar. The former hypothesis is consistent with possible diagenetic enrichment in Al, which was discussed above. On the other hand Dapples (1967) and Kreuzer *et al.* (1980) suggested that glaucony is unstable during tectonic deformations. Thus, the K-Ar clock of glaucony may have been reset under stress connected with the thrusting of the Križna Unit during the Late Cretaceous.

CONCLUSIONS

1. Sedimentological and palaeontological features of glaucony-bearing deposits prove that they were formed in the marginal zone of a pelagic carbonate platform during periods of very low rate of deposition. The mineralogical and geochemical evidence shows that the discussed glaucony represents the autochthonous type.

2. The glaucony is evolved and contains more than 7% of K_2O. The high amount of Al in glaucony is most probably caused by diagenetic processes. During diagenesis Al replaced Fe in the octahedral layers of glaucony.

3. The K-Ar clock of glaucony was reset due to diagenetic recrystallization and/or under stress related to the thrusting of the Križna Unit during the Late Cretaceous.

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Streszczenie

GLAUKONIT ZE SKONDENSOWANYCH OSADÓW DOLNEJ-ŚRODKOWEJ JURY JEDNOSTKI KRIŻNIAŃSKIEJ TATR ZACHODNICH, POLSKA

Renata Jach & Krzysztof Starzec

Przejawy kondensacji, takie jak stromatolity, żelaziste makroonkoidy i koncentracja fauny nektonicznej, były dotychczas znane w jednostce kriżniańskiej z czerwonych wapieni stanowiących ogniwo wapieni z Klinów (og) (Lefeld *et al.*, 1985; Gradziński *et al.*, 1997; Wieczorek, 2001). Inny typ równowiekowych w przybliżeniu osadów skondensowanych został znaleziony w tej jednostce podczas szczegółowych prac terenowych. Osady te zawierają stromatolity fosforanowe, liczne zęby ryb i dużą ilość glaukonitu. Odsłaniają się one w Dolinie Długiej, która jest odgałęzieniem od Doliny Chochołowskiej (Fig. 1). Badane osady znajdują się w stropie kilkumetrowej miąższości kompleksu naprzemianległych wapieni i margli (Fig. 2). Glaukonit jest skoncentrowany w marglach i wapieniach, których łączna miąższość dochodzi do 20 cm (Fig. 3–6).

Glaukonit został wyseparowany i poddany badaniom w mikroskopie optycznym, dyfrakcyjnym badaniom rentgenowskim i badaniom w skaningowym mikroskopie elektronowym połączonym z analizatorem do badania składu chemicznego.

Badane ziarna glaukonitu mają wielkość od 0,1 mm do 0,5 mm, jednakże niektóre przekraczają 1,5 mm (Fig. 5, 7–10). Obserwuje się zastępowanie przez glaukonit pierwotnych pustek w szkieletach węglanowych, na przykład pierwotnych porów lub mikrodrążeń w trochitach a także komór otwornic. Powierzchnia ziarn glaukonitu jest zazwyczaj gładka, jednakże ziarna jaśniejsze mają często powierzchnię nierówną. Dyfraktogram badanych ziarn cechuje się obecnością niemal wszystkich refleksów charakterystycznych dla glaukonitu (Fig. 12; por. Odin & Matter, 1981 i Odin & Fullagar, 1988). Pozycja refleksu 001 i jego asymetryczny kształt sugerują pewną zawartość pakietów smektytowych w badanym glaukonicie (por. Wiewióra & Łącka, 1980) natomiast wysoka intensywność refleksu 002 wskazuje na dużą zawartość Al (por. Berg-Madsen, 1983). Skład chemiczny badanego glaukonitu jest przedstawiony w Tabeli 1. Glaukonit ten charakteryzuje się wysoką zawartością Al i K.

Złe wysortowanie, nieregularne kształty i chaotyczne rozmieszczenie ziarn glaukonitu w osadach otaczających sugerują jego autochtoniczny charakter (por. Amorosi, 1997 i literatura tam cytowana). Gładka powierzchnia ziarn glaukonitu jest interpretowana jako efekt długotrwałej ewolucji glaukonitu a nie mechanicznej abrazji podczas transportu.

Sedymentologiczna interpretacja wskazuje, że osady zawierające glaukonit były deponowane w strefie krawędzi pelagicznej platformy węglanowej zapewne na głębokościach górnego batiału (Jach, 2003). Obecność autochtonicznego, dojrzałego glaukonitu wskazuje, że tempo przyrostu osadów było w tej strefie bardzo wolne (por. Odin & Fullagar, 1988; Amorosi, 1995, 1997). Wysoka zawartość Al w badanym glaukonicie jest tłumaczona jako efekt diagenezy, kiedy to Al zastępuje Fe w warstwie oktaedrycznej glaukonitu (Fig. 13; por. Ireland *et al.* 1983). Podjęto próbę datowania glaukonitu metodą K-Ar. Otrzymany wynik zawiera Tabela 2. Otrzymany radiometryczny wiek glaukonitu jest zdecydowanie odmłodzony. Jest to spowodowane ucieczką radiogenicznego argonu z jego struktury krystalicznej podczas późnej diagenezy i/lub nacisków tektonicznych (por. Amireh *et al.*, 1998).