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ARAGONITE OF JURASSIC AMMONITE SHELLS FROM ŁUKÓW (POLAND)

A b s t r a c t. This paper deals with the results of mineralogical examination of shells and moulds of Jurassic ammonites from Łuków, well known locality, situated ca. 100 km E of Warsaw. The investigations were carried out using optical and scanning microscopy, as well as X-ray and infrared spectroscopic methods. The shells were found to be predominantly aragonitic, showing typical layered structure and containing fairly abundant organic matter and framboidal pyrite.

INTRODUCTION

Aragonite is a common constituent of shells and skeletons of numerous recent organisms. During diagenesis this metastable form of calcium carbonate usually transforms into calcite. Under specific geological conditions aragonite can be preserved for a long period of time. Such "fossil" aragonite constitutes e.g. some ammonite shells as reported by Cornish and Kendall (1888). Layered structure of ammonite shells was characterized by Hyatt (1872, 1883); Böhmers (1936) and Hölder (1952). Cayeux (1916) and Bøggild (1930) described prismatic aragonite crystals forming individual layers of shells. Considerable progress in these studies was due to the application of electron microscopy (Birkelund 1967, Erben *et al.* 1969, Druszcic and Hiami 1970, Kulicki 1979, Kennedy and Hall 1967).

More than 10 chemical compounds participate in the structure of shells and skeletons of invertebrate animals. The most important of them are: calcium carbonate – CaCO_3 , silica – SiO_2 and apatite – $\text{Ca}_5[(\text{F}, \text{OH})|(\text{PO}_4)_3]$. These compounds occur in various proportions together with organic matter. Actually, they are studied in detail. Reconstruction of their formation processes should be based on cytologic and chemical mechanisms of secretion of these compounds in epithelial tissues. Roger (1974) indicated that some organic substances under specific pH conditions may influence the dissolution and precipitation of mineral compounds.

Calcium carbonate occurs mainly in skeletons of invertebrates in the form of calcite or aragonite. Earlier classifications of fossil shells into calcitic and arago-

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gonitic were found to be not justified by later studies. Aragonite occurs in recent nautiloid *Argonauta*, in the shells of the majority of cephalopods, in otoliths of vertebrates, in skeletons of *Hexacorallia (Scleractinia)* and in *Chlorophyta plants*. Skeletons of numerous animals, as e.g. bryozoans, bivalvs, gastropods and foraminifers, consist of both calcite and aragonite. So e.g. in recent bivalve *Mytilius* the prismatic layer is calcitic whereas the pearly one aragonitic, similarly as in such gastropods as *Fissurella* or *Haliotis*.

In fossils it is often difficult to determine the primary mineral composition of their hard parts due to frequent transformation of aragonite into calcite during diagenesis. Synthetic aragonite transforms into calcite in water solution at 40°C during several hours (Kennedy and Hall, 1967) whilst the fossil one, under specific conditions, can be preserved for a fairly long period of time.

In recent years, the structure of ammonite shells was examined by numerous authors what was mainly connected with studies on ontogenetic evolution of these animals (Birkelund 1980, Kulicki 1979, Tanabe *et al.* 1979, Druszcic and Hiami 1970, etc.). Advanced studies of remnants of ammonite shells were initiated by Birkelund (1967) but already Grégoire (1958) has described the details of their pearly layer. In later publications we find detailed descriptions of these shells illustrated by SEM photographs (*fide*: Birkelund and Hansen 1974).

Suggestions on originally aragonitic nature of shells result from the studies of recent cephalopode Nautilus, phylogenetically related with ammonites (Erben *et al.* 1969). Recent nautiloids have aragonitic shells. Numerous findings of well preserved ammonites (Paleozoic to Cretaceous in age) have confirmed earlier suggestions that actually calcitic shells were originally aragonitic in nature (Birkelund and Hansen 1974, Erben 1972, Grandjean *et al.* 1964, Grégoire 1966, Kennedy and Hall 1967, Mutvei 1967 etc.). It should be emphasized that in these studies the most useful were perfectly preserved ammonitic shells as e.g. these contained in calcareous and arenaceous Upper Cretaceous marls of Hokkaido in which even original colouration was preserved (Tanabe, Kanie 1978) or *Promicroceras planicosta* (Sow.) species described by Mutvei (1967).

Detailed studies of ammonite shells, using first of all the SEM technique, allowed to distinguish three layers in them: a thin outer prismatic, thick central pearly and inner prismatic one which may consist of several laminae. The latters, in turn, can be separated by thin intercalations composed of conchioline.

LOCALISATION OF SAMPLING SITES

The specimens studied come from Łapiguz brick-yard in Łuków, situated ca. 100 km E from Warsaw. Black and dark grey clays exploited here contain spherosideritic concretions filled predominantly with ammonite and bivalve shells. In the environs of Łuków these rocks occur as tectonic blocks within Quaternary glacial deposits of Varsovien I (Kosmulska 1973). In geological literature this occurrence is called "glacitectonic Jurassic scale".

The spherosideritic concretions were found at the end of 19th century by Krzyżtowicz whilst detailed geological and paleontological characteristics of this site were presented by Makowski (1952) and, subsequently, by Kosmulska (1973). Kulczycki and Parafiniuk (1978) have described vivianite occurring in these clays.

Very characteristic feature of this accumulation of spherosideritic and calcareous concretions is the presence of very abundant fossils: ammonites, bivalve,

scaphopods, gastropods and foraminifers, showing perfect state of preservation (Makowski 1952). Ammonite shells, sometimes up to a dozen cm in diameter, often have well preserved test, up to 5 mm thick, particularly in specimens representing gerontic stage. The shells display pearly lustre and their surfaces are often finely porous. These fossils are Uppermost Callovian in age.

Ammonite specimens (*Quenstedtoceras*, *Cardioceratidae* family) with preserved shells (Pl. I, Phot. 1, 2) were used for detailed study. One of them represents a well preserved large specimen of *Quenstedtoceras rybinskinianum* (Nikitin) sp. (Pl. I, Phot. 1). Outer whorls of this specimen (a part of living chamber is preserved) are filled with a deposit, whereas the inner whorls are empty. The latters were deformed due to load of sediment. The whole ammonite has well preserved shell, whereby in outer whorls it is thin and in living chamber thicker, up to 5 mm. In this specimen only the pearly layer showing characteristic lustre is preserved, whilst the outer prismatic one is lacking. This pearly layer consists of several superposing laminae. A part of this shell is covered by pyrite grains and locally overgrown by serpulcs. Samples for analytical study were taken from the last whorl of ammonite where shell is the thickest.

The second analyzed specimen (Pl. I, Phot. 2) represents a part of inner whorl of ammonite of *Quenstedtoceras carinatum* (Eichwald). Its outer whorls are filled with siderite-clayey substance, whilst the inner ones are often empty, showing distinct suture (lobe) lines. In this specimen a thin shell, up to 1 mm thick, was locally preserved. Samples for analytical examinations were taken from ventral side of the shell.

EXPERIMENTAL

Mineralogical study was carried out using optical and scanning microscopy, as well as X-ray and infrared spectroscopic methods. Both transparent and reflected light techniques were applied in optical study of oriented preparations. X-ray analyses were performed by means of TUR-M-62 diffractometer using monochromatic CoK_α radiation and standardization of precision method. Flat powder preparations were used. Besides, direct X-ray studies of pearly surfaces of ammonite shells were carried out. The conditions were adapted experimentally depending on the angular range of recording. The results of X-ray study were supplemented by infrared spectroscopy using C. Zeiss (Jena) UR-10 instrument and KBr disc technique. Infrared spectra were recorded in the wave number ranges 400–1800 and 2800–3800 cm⁻¹. Identification of phases was performed by comparison with standard spectra. Moreover, selected specimens of shells were additionally examined using "Cambridge Stereoscan 54-10" scanning microscope whereby specimen surfaces were shadowed with gold.

RESULTS

X-ray patterns of powdered and averaged material of shells show typical reflections of aragonite (Fig. 1). Some weak peaks (e.g. $d_{hkl} = 3.02 \text{ \AA}$) indicate trace admixture of calcite. Direct X-ray analysis of pearly surfaces of shells has shown that aragonite is the only crystalline substance in them. The changes in intensity of individual reflections indicate oriented position of aragonite crystals

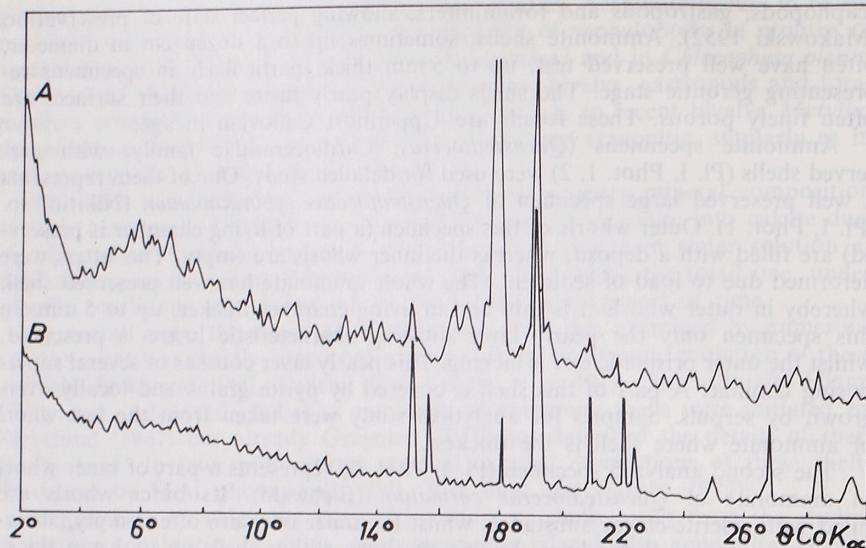


Fig. 1. X-ray diffraction pattern of aragonite of ammonite shells from Łuków

A – diffraction pattern obtained directly from pearly surface of shell (effect of orientation of aragonite crystals is marked), B – diffraction pattern of powdered sample of aragonite studied

in the analyzed specimens. Identic X-ray pattern was obtained for matt surfaces of shells (showing no effects of pearly mass). We observe here exactly the same orientation of aragonite crystals as in the former case, but a weak diagnostic calcite peak indicate some admixture of this polymorph, which is lacking at the surface of pearly mass.

X-ray pattern of iron sulphide separated from the shell and treated with HCl is typical of pyrite (Fig. 2).

Infrared spectroscopic data have confirmed aragonitic nature of the ammonitic shells in question (Fig. 3).

Optical microscopic study were carried out on thin sections cut parallel and perpendicular to the surface of selected fragments of shells. The samples were sealed in epidian and, subsequently, in Canada balsam, using moderate heating.

Two varieties of carbonate minerals were found to occur in thin sections cut parallel to the surface of shells: crystalline and cryptocrystalline. The former is dominating and represents oriented aragonite crystals forming a system of layers showing irregular shape (Phot. 3). Parallel orientation of intergrown aragonite crystals, marked on X-ray patterns, is confirmed by microscope observations at crossed nicols. Parallel laminae of crystalline aragonite are cemented by cryptocrystalline carbonate minerals, forming very thin intercalations between them (Plate II, Phot. 3). In these carbonate concentrations no orientation of grains is observed and some their optical features (e.g. slightly lower refractive indices when compared with aragonite) suggest them to consist of calcite, the admixture of which was evidenced by X-ray pattern. Pyrite usually forms larger, massive concentrations on the surfaces of tests, penetrating inside along the boundaries of aragonite crystals.

Microscopic observations in thin sections cut parallel to the surfaces of shells have confirmed preferred orientation of aragonite grains. Besides, a system of

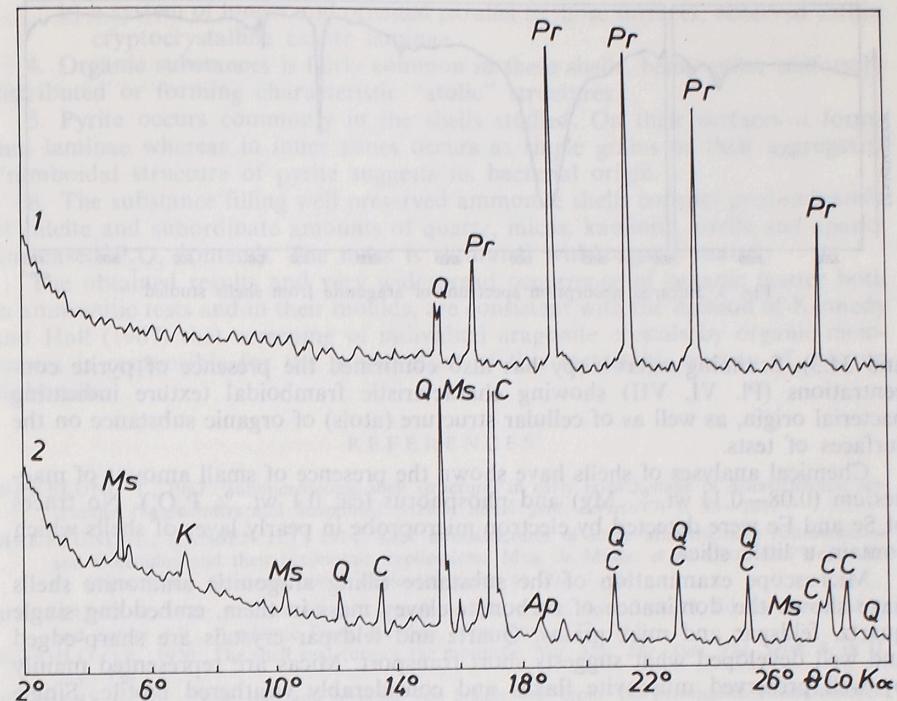


Fig. 2. X-ray diffraction pattern of

1 – pyrite separated from aragonitic shell (Pr – pyrite, Q – quartz), 2 – mould – material filling interior of a shell (Ms – micas, hydromicas, K – kaolinite, Q – quartz, C – calcite, Ap – apatite)

small channels, oriented perpendicularly or slightly obliquely to these surfaces, was observed when using higher magnifications. They are localized in aragonitic layers. Much less common is another system of channels which are longer, curved and oriented parallel to the surfaces of shells. This more chaotic system seems to be connected with calcitic mass cementing aragonitic laminae.

Particular attention was paid to organic substance which, in parallel sections, distinguishes by brown colouration of different intensity. It is either unevenly distributed or forms circular concentrations around decoloured centres (atolic concentrations – Pl. II, Phot. 4, Pl. III, Phot. 5). Pyrite is fairly common in shells, occurring in separate grains or as framboidal aggregates (Pl. III, Phot. 6).

Scanning microscopic examination was carried out in sections cut parallel and perpendicular to the surfaces of tests. Observations of pearly surfaces of ammonite shells using magnification 5000 \times have shown the presence of parallel thin laminae of calcium carbonate (Pl. IV, Phot. 7, 8). In transverse sections, oriented arrangement of aragonite crystals was observed (Pl. V, Phot. 9, 10). Attention was paid to the outlets of small channels at pearly surfaces, already observed by optical microscope when using higher magnifications. In scanning microscopic image (Pl. IV, V and VI), these channels are circular in sections and aragonite crystals occurring at their margins display not sharp edges (dissolution effect?). According to Dr. Kulicki's oral information, they are the products of activity of algae (*Chlorophyta*) or mushrooms (fide: Kulicki 1979 – Pl. 33.2

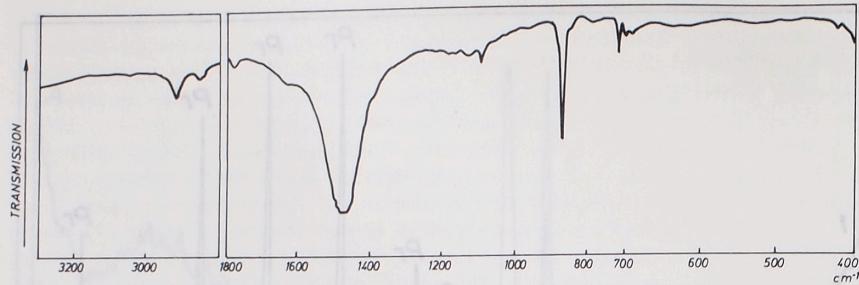


Fig. 3. Infrared absorption spectrum of aragonite from shells studied

and 34.3). Scanning microscopy has also confirmed the presence of pyrite concentrations (Pl. VI, VII) showing characteristic frambooidal texture indicating bacterial origin, as well as of cellular structure (atols) of organic substance on the surfaces of tests.

Chemical analyses of shells have shown the presence of small amount of magnesium (0.08–0.11 wt. % Mg) and phosphorus (ca. 0.1 wt. % P₂O₅). No traces of Se and Fe were detected by electron microprobe in pearly layer of shells which contain a little silica.

Microscope examination of the substance filling aragonitic ammonite shells have shown the dominance of carbonate-clayey mass in them, embedding single quartz, feldspar and mica grains. Quartz and feldspar crystals are sharp-edged and well developed what suggests short transport. Micas are represented mainly by well preserved muscovite flakes and considerably weathered biotite. Single pyrite grains or their concentrations are embedded in the groundmass. Larger concentrations of this mineral usually occur at the contact of shells with surrounding rock. Mineral composition of the filling mass was determined more precisely by X-ray study. In the obtained pattern we observe distinct dominance of calcite accompanied by subordinate amounts of quartz, feldspars, micas and kaolinite. Diffuse reflection $d_{hkl} = 2.79 \text{ \AA}$ suggests the presence of poorly crystallized apatite, confirmed by chemical analysis (3.05 and 2.75 wt. % P₂O₅ respectively) of two samples examined, containing also 0.53–0.60 wt. % Mg. Small amount of clay minerals indicates that the mass in question is represented by weakly diagenesized slightly arenaceous marl, containing variable amounts of organic matter.

SUMMARY

1. Ammonite shells from Łuków were found to be aragonitic, showing typical layered structure.
2. Two varieties of CaCO₃ were distinguished in the shells studied:
 - a) crystalline one forming layers of parallel oriented prismatic aragonite crystals, and
 - b) cryptocrystalline non-oriented calcitic forming thin laminae cementing aragonitic layers.
3. Two systems of channels were observed in shells:
 - a) a system of short ones, circular in section, occurring within aragonite layers and oriented perpendicularly to the surface of shells, and

b) a system of longer and oriented parallel to those surfaces, observed within cryptocrystalline calcite laminae.

4. Organic substances is fairly common in these shells, being either uniformly distributed or forming characteristic "atolic" structures.

5. Pyrite occurs commonly in the shells studied. On their surfaces it forms thin laminae whereas in inner zones occurs as single grains or their aggregates. Frambooidal structure of pyrite suggests its bacterial origin.

6. The substance filling well preserved ammonite shells consists predominantly of calcite and subordinate amounts of quartz, micas, kaolinite, pyrite and apatite (increased P₂O₅ content). The mass is saturated with organic matter.

The obtained results and very widespread occurrence of organic matter both in ammonitic tests and in their moulds, are consistent with the opinion of Kennedy and Hall (1967) that screening of individual aragonite crystals by organic membranes is responsible for the preservation of this metastable variety of calcium carbonate.

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ARAGONIT MUSZLI AMONITÓW JURAJSKICH Z ŁUKOWA (POLSKA)

Streszczenie

Muszle amonitów pochodzą z cegielni Łapiguz w Łukowie, położonej kilkudziesiąt kilometrów na wschód od Warszawy. Średnice muszli dochodzą niekiedy do kilkunastu centymetrów, a dobrze zachowane skorupy mają grubość do 5 mm i perłowy połysk. Zebrany materiał poddano badaniom mikroskopowym (mikroskopia optyczna i skaningowa), rentgenograficznym i spektroskopowym w podczerwieni. Potwierdzono aragonitową budowę muszli. Warstewki krystalicznego aragonitu (o jednakowej orientacji kryształów) cementowane są cienkimi wkładkami skrytokrystalicznego węglanu wapnia stanowiącego mieszaninę aragonitu i kalcytu. Opisano formy występowania substancji organicznej oraz framboidalny piryt pochodzenia bakteryjnego. Na podstawie uzyskanych wyników badań autorzy przychylają się do poglądu, że istotnym czynnikiem powodującym zachowanie się aragonitu w niektórych muszach amonitów jest efekt ekranowania organicznymi błonkami pojedynczych krystalitów tej nietrwałe odmiany polimorficznej CaCO_3 .

OBJAŚNIENIA FOTOGRAFII

PLANSZA I

- Fot. 1. Amonit z Łukowa – *Quenstedtoceras rybinskinianum* (Nikitin) – w stadium gerontycznym, z muszłą aragonitową szczególnie zachowaną na ostatnim skręcie. 1×
- Fot. 2. Amonit z Łukowa – *Quenstedtoceras carinatum* (Eichwald) – część wewnętrznego skrętu z zachowaną cienką muszlą aragonitową. 1×

PLANSZA II

- Fot. 3. Obraz mikroskopowy muszli amonita w przekroju prostopadłym do powierzchni. Pomiędzy warstwkami jawnokrystalicznego aragonitu biegą wąskie strefy skrytokrystalicznych.
- Fot. 4. Obraz mikroskopowy muszli w przekroju równoległym. Atolowe skupienia substancji organicznej (czarne). W starym tle aragonitu widoczne są krótkie kanaliki. Nik. 1, pow. 120×

PLANSZA III

- Fot. 5. Obraz mikroskopowy muszli w przekroju równoległym. Skupienia substancji organicznej (czarne) podobne są do skupień pirytu zamieszczonych na fot. 6. Nik. 1, pow. 120×
- Fot. 6. Obraz mikroskopowy muszli w przekroju równoległym z licznymi skupieniami pirytu pochodzenia bakteryjnego (frambody). Nik. 1, pow. 120×

PLANSZA IV

- Fot. 7. Obraz perłowej powierzchni muszli amonita widoczny w skaningowym mikroskopie elektronowym. Pow. 4600×
- Fot. 8. Powierzchnia muszli amonita ustawiona nieco ukośnie. Widoczne są nakładające się warstewki aragonitowe oraz wyloty kanalików (koliste w przekroju). Skaningowy mikroskop elektronowy, pow. 5200×

PLANSZA V

- Fot. 9. Przekrój prostopadły do powierzchni muszli widoczny w obrazie skaningowego mikroskopu elektronowego. Pow. 5200×
- Fot. 10. Przekrój muszli jak na fot. 9, w dwukrotnie większym powiększeniu. Skaningowy mikroskop elektronowy. Pow. 10 500×

PLANSZA VI

- Fot. 11. W przekrojach prostopadłych do powierzchni muszli amonita widoczne są kanaly, których wyloty pokazano na fot. 8. Skaningowy mikroskop elektronowy. Pow. 1200×
- Fot. 12. Pojedyncze kryształy pirytu w aragonitowej muszli amonita. Skaningowy mikroskop elektronowy. Pow. 1000×

PLANSZA VII

- Fot. 13. Framboidy pirytu pochodzenia bakteryjnego rozmieszczone na powierzchni muszli. Skaningowy mikroskop elektronowy. Pow. 4500×
- Fot. 14. Inny przykład framboiów pirytu. Skaningowy mikroskop elektronowy. Pow. 4500×

OBJAŚNIENIA FIGUR

- Fig. 1. Dyfraktogramy rentgenowskie aragonitu budującego muszle amonitów z Łukowa:
A – dyfraktogram uzyskany z powierzchni perłowej muszli (wyraźnie zaznacza się efekt orientacji aragonitu), *B* – dyfraktogram aragonitu z muszli, próbka sproszkowana
- Fig. 2. Dyfraktogramy rentgenowskie:
I – piryt wyseparowany z aragonitowych muszli (Pr – piryt, Q – kwarc), 2 – ośrodek – materiał wypełniający wnętrze muszli (Ms – miki, hydromiki, K – kaolinit, Q – kwarc, C – kalcyt, Ap – apatyty)
- Fig. 3. Widmo absorpcyjne w podczerwieni aragonitu budującego muszle amonitów z Łukowa

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АРАГОНИТ РАКОВИН ЙУРАЙСКИХ АММОНИТОВ ИЗ ЛУКОВА (ПОЛЬША)

Резюме

Раковины аммонитов были найдены в районе кирпичного завода в Лукове, расположеннымным несколькими десятками километров к востоку от Варшавы. Диаметр раковин иногда достигает более десяти сантиметров, а хорошо сохранившиеся раковины имеют толщину до 5 мм и перламутровый блеск. Собранный материал подвержен был микроскопическим (оптическая и сканирующая микроскопия), рентгенографическим и ИК-спектрометрическим исследованиям. Констатировано арагонитовое строение раковины. Слои кристаллического арагонита (с одинаковой ориентировкой кристаллов) цементируются тонкими прослойками криптокристаллического карбоната кальция, представляющего собой смесь арагонита и кальцита. Описываются

формы присутствующего органического вещества, а также фрамбоидальные формы пирита бактериального происхождения. На основании полученных результатов исследований авторы склоняются к мнению, что существенным фактором, обуславливающим сохранение арагонита в некоторых раковинах аммонитов, является эффект экранирования органическими пленками единичных кристаллов этой неустойчивой полиморфной модификации CaCO_3 .

ОБЪЯСНЕНИЯ К ФИГУРАМ

Фиг. 1. Рентгеновские дифрактограммы арагонита, слагающего раковины аммонитов из Лукова
А — дифрактограмма, полученная из перламутровой поверхности раковины (четко отмечается эффект ориентировки арагонита), В — дифрактограмма арагонита из раковины, измельченный образец

Фиг. 2. Рентгеновские дифрактограммы
1 — пирит, выделенный из арагонитовой раковины (Pr — пирит, Q — кварц), 2 — внутреннее ядро, материал, выполняющий внутреннюю часть раковины (Ms — слюды, гидрослюды, K — каолинит, Q — кварц, С — кальцит, Ap — апатит)

Фиг. 3. ИК-спектр поглощения арагонита, слагающего раковины аммонитов из Лукова

ОБЪЯСНЕНИЯ К ФОТОГРАФИЯМ

ТАБЛИЦА I

Фото 1. Аммонит из Лукова — *Quenstedtoceras rybinskinianum* (Nikitin) — в старческой стадии, с арагонитовой раковиной, особенно сохраненной на последнем обороте, 1×
Фото 2. Аммонит из Лукова — *Quenstedtoceras carinatum* (Eichwald) — часть внутреннего обертона с сохраненной тонкой арагонитовой раковиной, 1×

ТАБЛИЦА II

Фото 3. Микроскопическая картина раковины аммонита в поперечном разрезе. Между прослойками явно кристаллического арагонита простираются узкие зоны криптокристаллических карбонатов (кальцит, арагонит) и конхиолина (?). Один николь, увел. 120×
Фото 4. Микроскопическая картина раковины в продольном разрезе. Атолловидные скопления органического вещества (черное). На сером фоне арагонита заметны короткие канальцы. Один николь, увел. 120×

ТАБЛИЦА III

Фото 5. Микроскопическая картина раковины в продольном разрезе. Скопления органического вещества (черное) похожи на скопления пирита, показанные на фото 6. Один николь, увел. 120×
Фото 6. Микроскопическая картина раковины в продольном разрезе с многочисленными скоплениями пирита бактериального происхождения (фрамбоиды). Один николь, увел. 120×

ТАБЛИЦА IV

Фото 7. Изображение перламутровой поверхности раковины аммонита. СЭМ, увел. 4600×
Фото 8. Поверхность раковины аммонита немного косо расположенная. Заметны накладывающиеся арагонитовые слои, а также устья канальцев (круглого сечения). СЭМ, увел. 5200×

ТАБЛИЦА V

Фото 9. Разрез перпендикулярный к поверхности раковины. СЭМ, увел. 5200×
Фото 10. Разрез раковины как на фото 9, вдвое увеличенный. СЭМ, увел. 10 500×

ТАБЛИЦА VI

Фото 11. В разрезах перпендикулярных к поверхности раковины аммонита заметны канальцы, устья которых показаны на фото 8. СЭМ, увел. 1200×

Фото 12. Единичные кристаллы пирита в арагонитовой раковине аммонита. СЭМ, увел. 1200×

ТАБЛИЦА VII

Фото 13. Фрамбоиды пирита бактериального происхождения, расположенные на поверхности раковины. СЭМ, увел. 4500×

Фото 14. Другой пример фрамбоидов пирита. СЭМ, увел. 4500×

EXPLANATIONS OF PHOTOGRAPHS

PLATE I

Phot. 1. Ammonite from Łuków — *Quenstedtoceras rybinskinianum* (Nikitin) in gerontic stage with aragonitic shell, particularly well preserved is the last whorl. Natural size.
Phot. 2. Ammonite from Łuków — *Quenstedtoceras carinatum* (Eichwald) — fragment of inner whorl with preserved thin aragonitic test. Natural size.

PLATE II

Phot. 3. Thin section of ammonite shell cut perpendicular to its surface. Between layers consisting of crystalline aragonite we observe thin zones of cryptocrystalline carbonates (calcite, aragonite) and conchiolines (?). One polar, 120×
Phot. 4. Thin section of ammonitic shell cut parallel to its surface. Atollic concentrations of organic matter (black). Short channels are observed within gray aragonitic groundmass. One polar, 120×.

PLATE III

Phot. 5. Microscopic image of shell in parallel section. Organic matter concentrations (black) resemble pyrite concentrations presented in phot. 6. One polar, 120×
Phot. 6. Microscope image of shell in parallel section with numerous frambooidal pyrite aggregates of bacterial origin. One polar, 120×

PLATE IV

Phot. 7. Scanning electron microscope image of pearly surface of ammonite shell. 4600×
Phot. 8. Slightly obliquely oriented ammonite shell surface. We observe superposing aragonite laminae and outlets of small channels (circular in section). Scanning microscope image. 5200×

PLATE V

Phot. 9. Scanning microscope image of a section cut perpendicularly to the surface of shell. 5200×
Phot. 10. The same section as in Phot. 9 but taken at magnification, 10 500×

PLATE VI

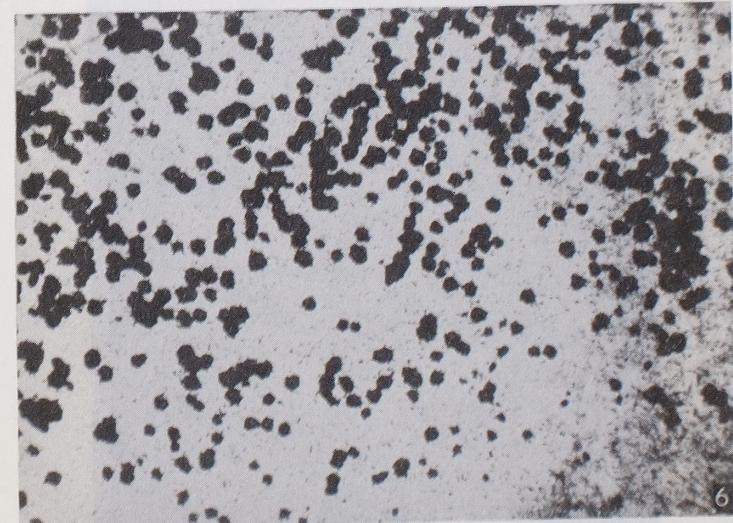
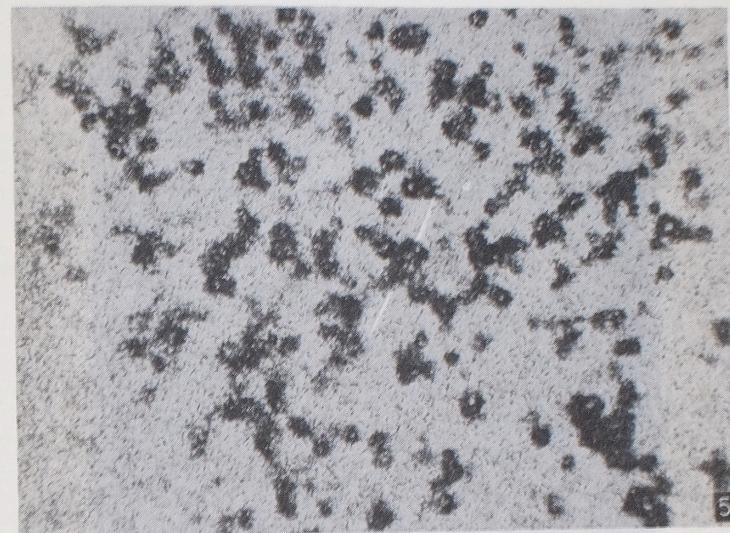
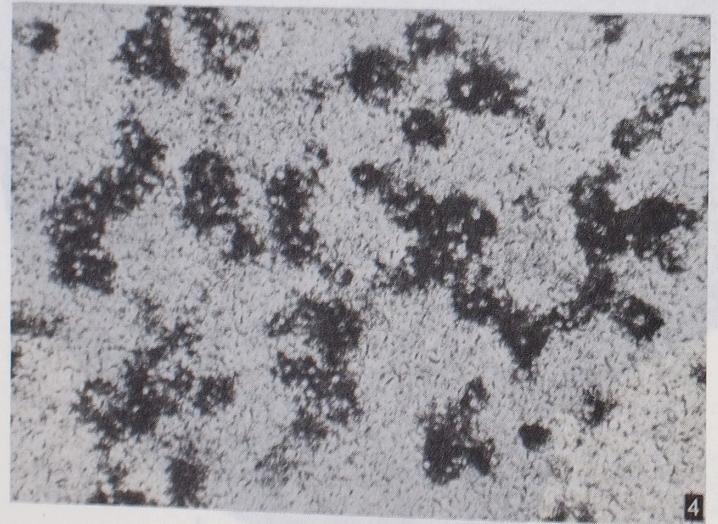
Phot. 11. Scanning microscope image of shell section cut perpendicularly to its surface showing channels, the outlets of which are presented in Phot. 8. 1200×
Phot. 12. Scanning microscope image of individual pyrite crystals embedded in aragonitic mass of ammonite shell. 1000×

PLATE VII

Phot. 13. Pyritic frambooids of bacterial origin distributed at the surface of a shell. Scanning microscope image. 4500×
Phot. 14. Other pyritic frambooids in scanning microscope image, 4500×

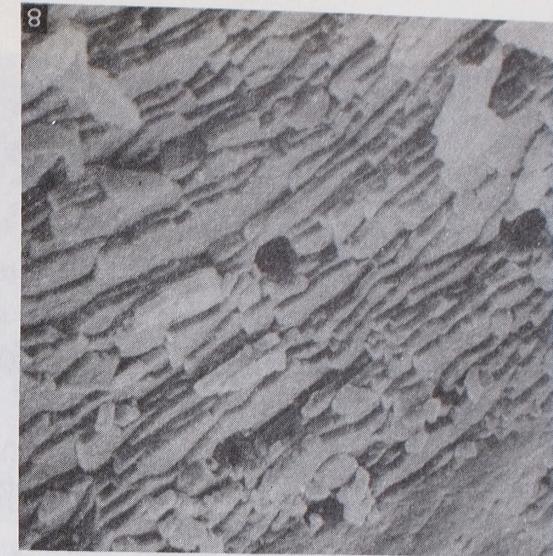
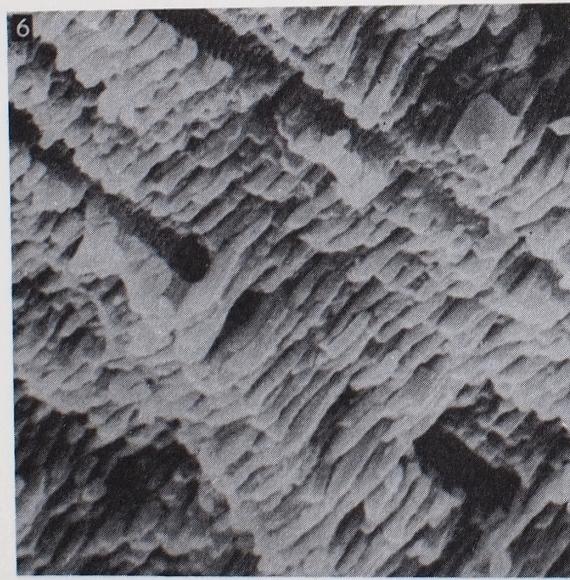
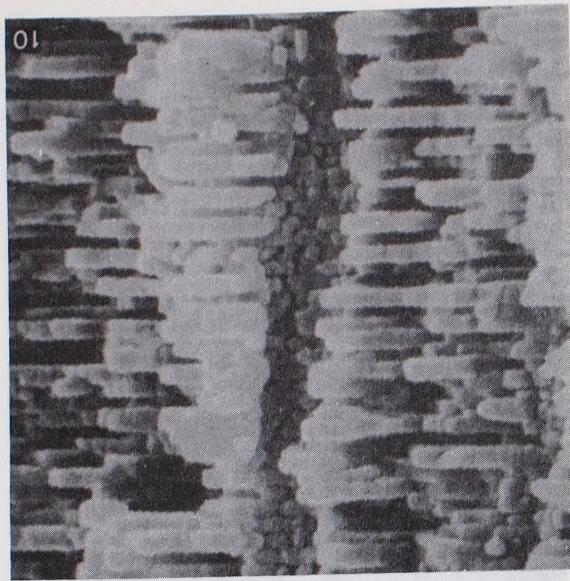


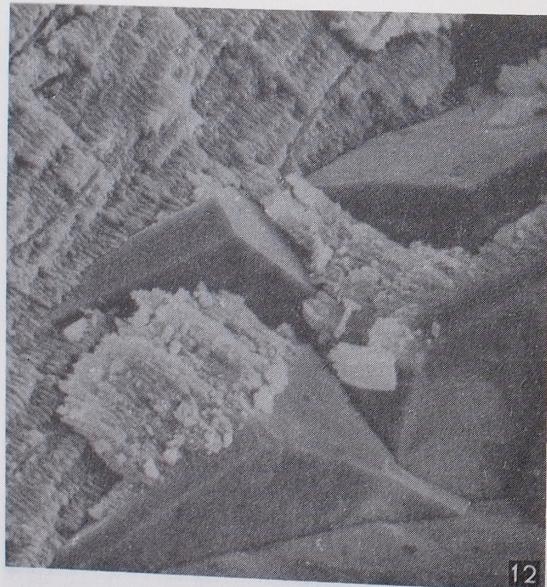
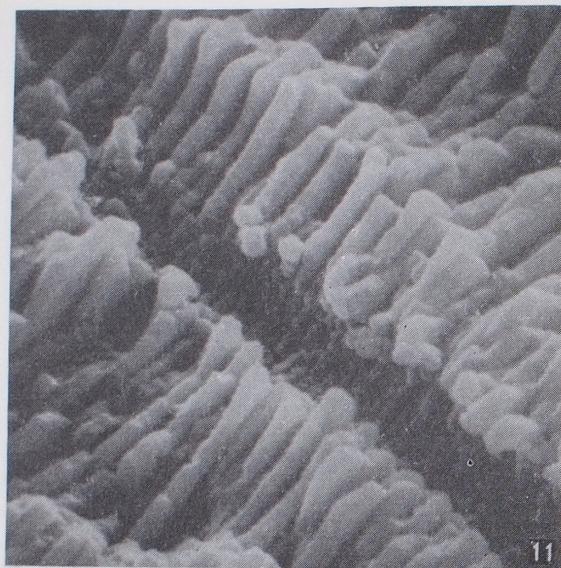
Andrzej MANECKI, Radosław TARKOWSKI – Aragonite of Jurassic ammonite shells from Łuków
(Poland)



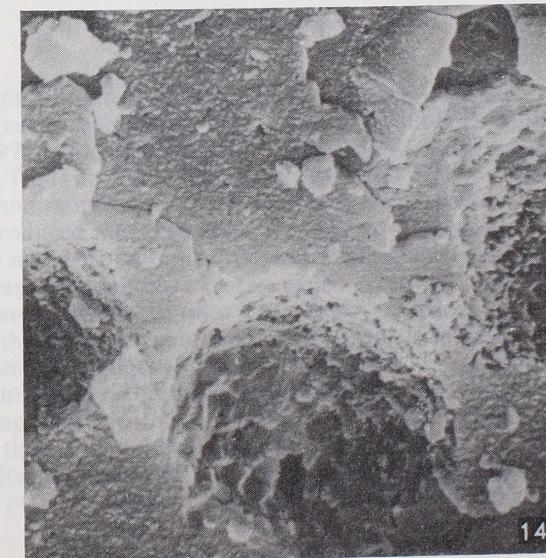
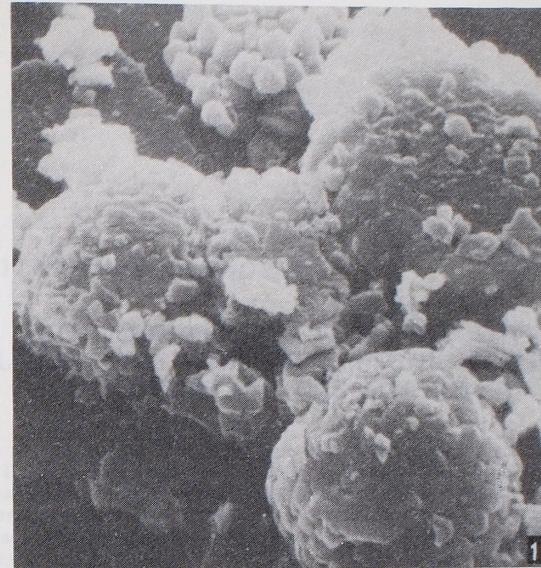
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