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Middle Jurassic concretions from Częstochowa (Poland) as indicators of sedimentation rates

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ABSTRACT:

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The Częstochowa Clay from south-central Poland contains numerous carbonate (sideritic and calcitic) concretions. Their sedimentary and diagenetic features allowed determination of the relative progress of diagenesis during their formation. Four categories of concretions are identified using such characteristics as: mineral composition, shape, presence of septarian structures, presence and preservation of macrofossils, evidence of bioerosion and benthic colonization. The concretion types recognized are: (1) early-diagenetic calcite concretions with evidence of reworking (hiatus concretions), (2) early-diagenetic fossiliferous calcite-concretions, (3) early-diagenetic siderite-concretions with septaria, and (4) later early-diagenetic massive siderite-concretions. The reconstruction of early diagenetic environments is based on such factors as: the dynamics of compaction, isolation from oxygenated sea-water, and availability of carbonate ions. All these factors are attributed to changes in the rate of sedimentation. According to the proposed hypothetical mechanisms, the early-diagenetic concretions formed during periods of generally slower sedimentation than the later early-diagenetic bodies.

Key words: Middle Jurassic, Central Poland, Sideritic concretions, sedimentation rate.

INTRODUCTION

Many authors have discussed the chemical conditions required for the precipitation of carbonates during diagenesis (see COLEMAN 1985). It is not the author's intention to discuss detailed geochemistry, but to present an analysis based on field observations of sedimentary and diagenetic structures. Nevertheless, basic geochemical processes, taking place during the formation of carbonate concretions, are discussed below.

It is necessary to emphasize that the processes discussed here occur under specific setting of clay-rich sediments. The clay acts not only as a major source of iron ions, but also as an environment favorable for hosting large amounts of organic matter. Within this environment, the mineralogy of diagenetic carbonate is generally governed by effective isolation from seawater, which restricts access of free oxygen and sulfate ions (Factor 1). On the other hand, the abundance and character of concretions is controlled by abundance of organic matter within the sediment, which may determine amount of carbonate ions (Factor 2), and the state of compaction during precipitation (Factor 3).

Isolation from oxygenated sea water (Factor 1) is understood to be a process whereby the chemistry of pore water is largely unaffected by marine water. The complete absence of pore-water circulation is not required to satisfy this condition. Furthermore, the migration of pore fluid within the sediment must be possible in order to transport and concentrate dissolved ions (RAISWELL 1971, SELLWOOD 1971, COLEMAN & RAISWELL 1995). Within the organic-rich clay-sediments, deficiency of free oxygen and sulfate ions, caused by isolation from sea water, allows the reduction of ferric ions to ferrous ions, which in carbonate supersaturated solution and deficiency of sulfide ions leads to precipitation of iron-rich calcite and siderite. On the other hand, in the situation where there is a free access of marine waters carrying free oxygen and sulfate ions, the precipitation of calcium carbonates and pyrite is likely to occur in the successive reduction zones according to the COLEMAN's (1985) scheme.

The amount of organic matter (Factor 2) trapped within clay-rich sediment depends on the duration of its exposure to oxygen-rich sea-water. In other words, it depends on rate of sedimentation. The faster the rate of sedimentation and shorter the exposure of organic matter to oxygenated sea-water, the more organic matter may be trapped and protected within the sediment. The availability of organic matter limits microbiotic activity (COLEMAN 1985, 1993; PYE & *al*. 1990), and its significance for diagenetic geochemical-processes is widely recognized (COLEMAN 1993). It seems that bacteria are involved in all the major processes leading to the precipitation of either calcite or siderite. They play an important role in the degradation of organic matter, reduction of iron and sulfates, as well as creating microenvironments favorable to precipitation.

The organic matter (Factor 2) seems to be also important in production of carbonate ions, as well as associated with them hydro-carbonate ions, and carbon dioxide. The carbonate ions occur in sea water but their main source for pore waters is the sediment itself. They may be derived from dissolution of skeletal elements and/or from the degradation of organic matter. Isotopic analyses of the carbonates of concretions, conducted among others by IRVIN & *al*. (1977), HUDSON (1978), COLEMAN (1993), COLEMAN & RAISWELL (1995), and to a lesser extent those reviewed by RAISWELL & FISCHER (2000) suggest that both the organic and mineral source of carbon should be taken into consideration. For many of the examined concretions, the reported moderate (~ -15‰) (^{13}C values seem indicate that the ratio of organically derived carbonate (^{13}C ~ -25‰)) to mineral in origin, which usually exhibits close to zero carbon isotopic ratios, is approximately one to one. Going one step further, the organic matter degraded by microorganisms may not only provide carbon dioxide, hydro-carbonate, and carbonate ions but may also lower the pH, which causes dissolution of mineral calcium carbonates dispersed within the sediment. Therefore, the organic matter should be also treated as a trigger activating the carbonate ions of mineral origin.

The principal factor responsible for the morphology of concretions is the state of compaction during precipitation (Factor 3). The most rapid pore-space reduction within clays occurs during the accumulation of the first 10 m of overlying sediment (RAISWELL 1971). During this period, the porosity decreases from 80 to 55%. It finally reaches about 30% after burial by 300-500m of sediment. The compaction not only decreases the porosity but also effects the arrangement of clay minerals, which in turn results in the mostly horizontal migration of pore fluids. This variable permeability of the sediment causes the ellipsoidal shape of concretions, in contrast to spherical concretions, which are developed at the earliest stages (RAISWELL 1971, COLEMAN & RAISWELL 1995). Septarian structures appear to occur only within nodules developed in sediment of relatively high porosity (RAISWELL 1971). The degree of compaction, which took place before the formation of the concretions, also determines the preservation of fossils and all sedimentary structures (SELLWOOD 1971).

Hiatus concretions are often associated with hardgrounds or erosional surfaces, which may suggest a similarity in their genesis (KENNEDY & KLINGER 1972). All these structures may be the only indicators of substantial change in the depositional regime, if they occur in monotonous fine-grain sediment (BAIRD 1976, HESSELBO & PALMER 1992). Hiatus concretions may develop from coprolites, lithified burrows, diagenetic concretions, and other relatively resistant sedimentary components, which were eroded and exposed on a sea floor due to bottom currents or storm events (BAIRD 1976). They may be colonized by suspension feeders; mainly serpulids, pelecypods (including oysters and borers), crinoids, and corals (KENNEDY & *al*. 1977). A subsequent renewal of depositional processes may bury the incrusted objects and develop conditions favorable for carbonate-cement precipitation. Occasionally, numerous reburials may follow stages of erosion, and complicated multi-generation hiatus-concretion (VOIGT 1968) may develop.

CARBONATE CONCRETIONS IN THE ENVIRONS OF CZĘSTOCHOWA

Location and methods

The following description includes data collected at ten sites located in Częstochowa-Bugaj, Gnaszyn, and Grodzisko (Text-fig.1). The Gnaszyn area was the most significant for the present investigation. Its eight outcrops provided an approximately 60 m thick cumulative section (Text-fig. 2), which was divided into two parts based on lithologic differences, including abundance, chemical composition, and the structure of concretions.

The fieldwork was completed in 1995 and 1996, as part of a Master's Thesis in the Department Geology of the University of Warsaw. A description of specific sections was conducted in outcrops and included lithological

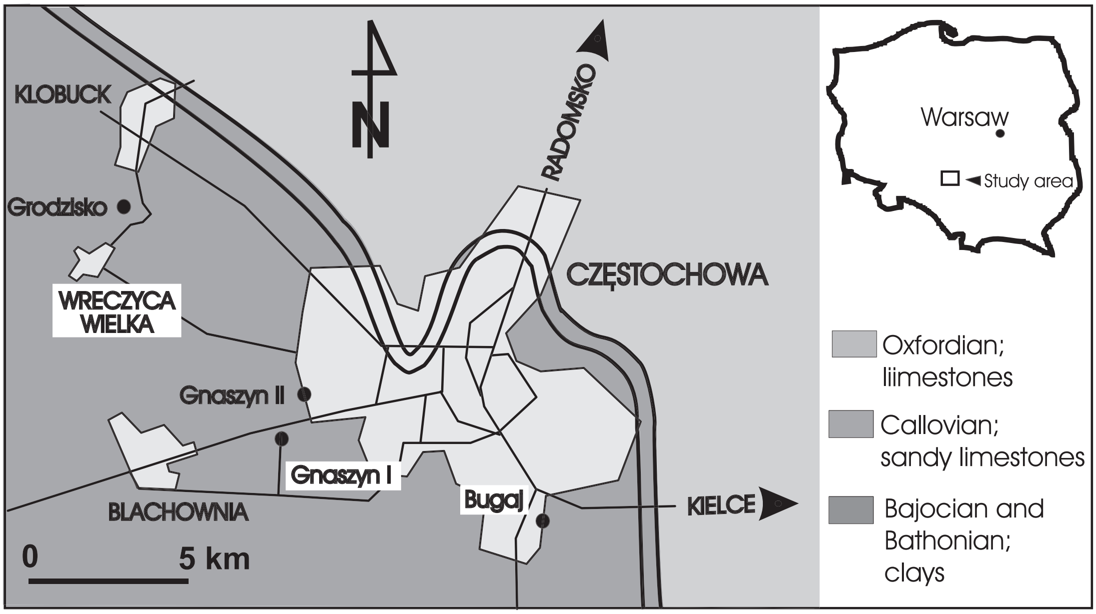

Fig. 1. Outcrops of the Middle Jurassic clays in the environs of Częstochowa; the schematic geological map shows the Jurassic bedrock only

variations, arrangement and forms of concretions, as well as associated sedimentary structures. Selected rock samples and fossils were collected and analyzed after the fieldwork had been completed. The most important group of samples consisted of over 500 ammonites, mostly of known stratigraphical position within the sections. Their state of preservation was affected by both sedimentary environments and diagenetic history. The composition of concretions was determined during fieldwork by determination of specific gravity and applying the hydrochloric-acid test. The general correlation of stratigraphical sections in the Gnaszyn area was based on the ammonite collections and the stratigraphical subdivision proposed by HAHN & *al*. (1990). The final detailed correlation was developed by a comparison of the arrangement of concretion layers within the particular sections.

Description

The Gnaszyn area

Within the older sediments of the Upper Bajocian and the lower part of the Lower Bathonian (Gnaszyn I; Text-figs1-2), massive continuous siderite horizons up to twenty centimeters in thickness dominate, and they are more frequent than concretion layers in the upper sections (Gnaszyn II; Text-figs 1-2). Plume structures are widely developed within the siderite bodies. The position of the siderite layers does not seem to be related to any lithological variations within the host sediment. Nevertheless, the host sediment contains numerous burrows in the form of small tubes filled by sediment that is occasionally rich in pyrite. Only a few of the ammonite shells are cracked by the growth of concretions. Some calcite concretions up to 15 cm thick and 35 cm long were also collected. They contain an abundant and variable fauna and include ammonites, mollusks, and crustaceans with well-preserved skeletons. This contrasts with the badly crushed shells, which can occur at the edges of the same concretions. No septaria occur inside the calcite concretions.

In the clays of the Middle and the Upper Bathonian age (Gnaszyn II; Text-figs 1-2) and from Grodzisko (Text-fig. 1), trace fossils are noticeably less common than within the underlying strata. Spheroidal, ellipsoidal, or irregular concretions are exclusively sideritic. In most cases, these are arranged in sparse layers but occasionally form discrete objects. Septarian structures of various shapes are common. Some of the concretions are clearly associated with layers enriched in skeletal fossils, but in most cases they do not seem to be related to lithological variations within the host sediment. Shells of ammonites are usually cracked by the growth of concretions inside the living chambers. The ratio of total crack width to the shell circumference ranges from 10 to 25 %. However, this ratio does not co-vary stratigraphically or among the various shell shapes. In two specimens, two stages of expansion of the concretion can be recognized. The ammonite fragmocones remain unfilled and, if unprotected by solid concretions, they are completely crushed. Numerous large ammonite shells exhibit evidence of incrusting by bivalves and serpulids. Faunal communities within the host sediment seem to be similar to those from lower part of the section. Fossilized wood, occasionally up to 50 cm long is also present.

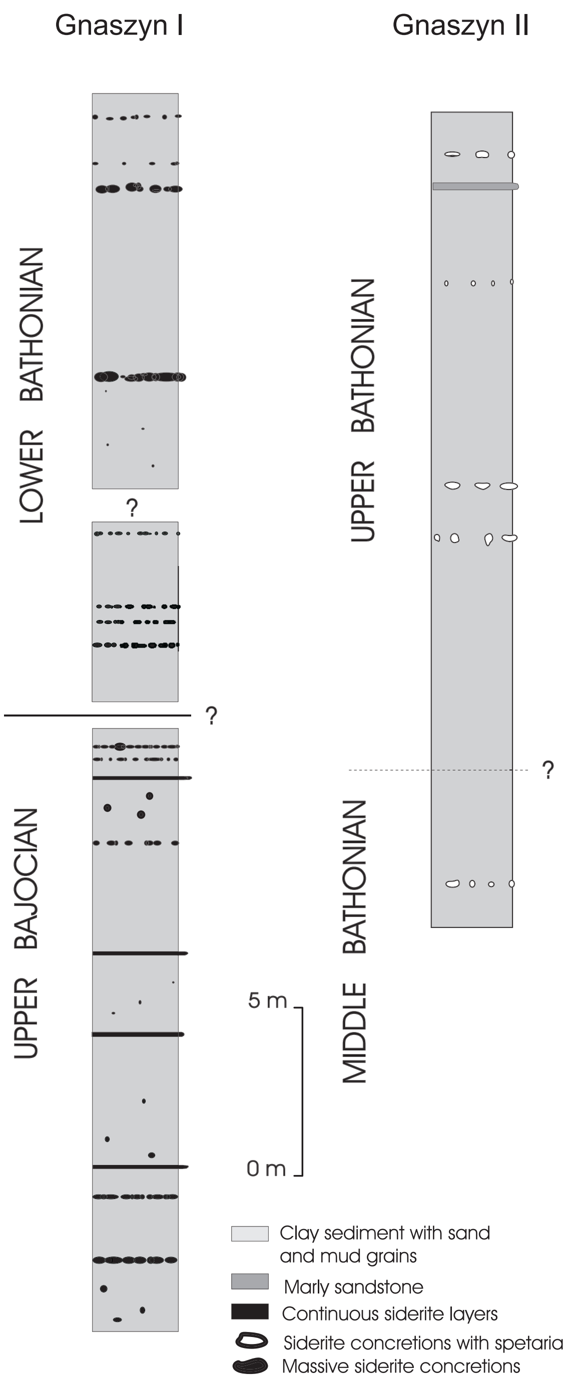

Fig. 2. Lithological sections of the Bajocian and Bathonian in the Gnaszyn area, Poland

In general, the relevant properties of the upper part of the Lower Bathonian (Gnaszyn I; Text-figs 1-2) sediments are intermediate with respect to both types of sediment described above. Calcite concretions with numerous, partly crushed shells are also present.

Częstochowa-Bugaj

This eight-meter thick section (Text-fig. 1) contains only three layers of concretions. Septaria and massive siderite concretions up to fifteen centimeters thick are not related to lithological variations within the host sediment. Some hiatus concretions were also collected. Unfortunately, these probably occur at a horizon below the depth of recent quarry excavation. All the specimens of hiatus concretions collected are calcitic, up to fifteen centimeters long, and without any septaria. They are rounded or ellipsoidal in cross-section, but their planar shapes are rather irregular. The hiatus concretions do not contain macrofossils but they are covered by remnants of colonization fauna. The encrusting organisms include: bryozoans, serpulids, solitary corals, and small oysters, all well cemented to the concretion surfaces. Two generations of bivalve borings are present. The older borings are 10 mm in length whereas the younger 5 mm.

Interpretation

Classification of the concretions from Częstochowa

The concretions have been grouped into four categories based on mineral composition and relative stage of compaction during their development. These types are:

— early-diagenetic calcite concretions with evidence of reworking (hiatus concretions). These include a few specimens from Częstochowa-Bugaj, which were collected at the base of the quarry excavation. Their shape seems to indicate that they were formed under a cover of sediment. Although they do not contain septaria, their rounded cross-sections suggest rather shallow burial and low compaction pressure during cementation. This corresponds to beginnings of early diagenesis. The diverse encrustating fauna indicates exhumation of these concretions at the sea floor of the Middle Jurassic basin.

— early-diagenetic fossiliferous calcite-concretions. These include only a few layers (possibly two) of concretions from the Upper Bajocian and Lower Bathonian part of the section. Their precise stratigraphic position is unknown. The shapes of concretions and presence of well-preserved and uncrushed fossils indicates development during a beginning of early diagenesis. The absence of septaria seems to be related to the mineral composition since it can be observed among all the calcitic concretions from Częstochowa-Bugaj and the Upper Bajocian of Gnaszyn, even though they are clearly early-diagenetic.

The stage of origination of the Lower Bathonian calcitic concretions is problematic. They do not contain septaria and their fossils are usually flattened but not completely crushed, which suggests a late origin but still within early diagenesis. On the other hand, an absence of siderite may indicate precipitation of these calcitic concretions within the zone penetrated by sea waters, which indicates a development at the beginning of early diagenesis.

— early-diagenetic siderite-concretions with septaria. They occur within the entire Middle and Upper Bathonian part of the section. The common occurrence of septaria and swollen shells suggest origination during the beginning of early diagenesis. In numerous cases, this was verified by the shape of concretions, which also preserved uncrushed but still empty fragmocones of ammonites.

— later early-diagenetic massive siderite-concretions. These commonly occur within the Upper Bajocian and Lower Bathonian section. The absence of septaria, their predominantly ellipsoidal shape, and the presence of ammonites with completely crushed fragmocones, point to a relatively late origin; however, still within early-diagenesis.

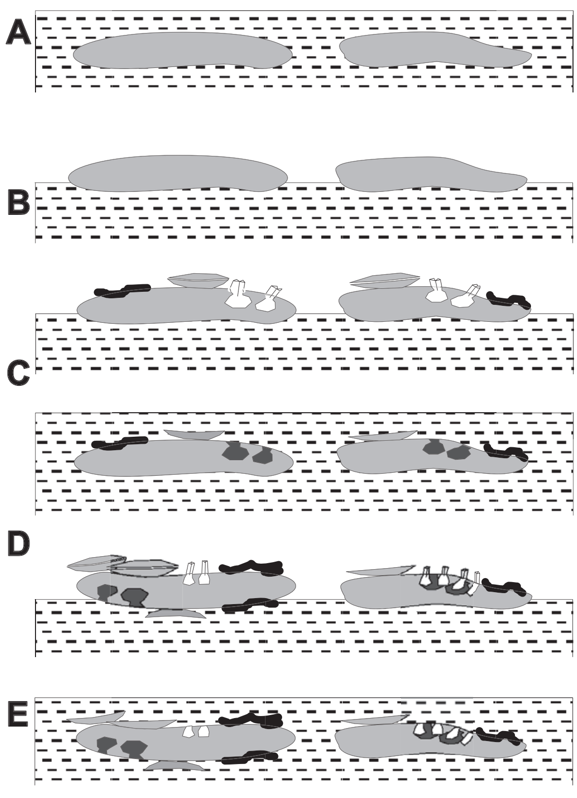

Fig. 3. Development of the hiatus concretions from Częstochowa-Bugaj, Poland; A – precipitation of calcite cements close to the sea floor during decrease in deposition rate; B – first stage of erosion and exhumation of concretions; C – benthonic colonization; D – renewal of sedimentation and precipitation of cements inside bivalve hollows; E – second stage of erosion, exhumation in some cases rotation, and repetition of benthonic colonization; F – second renewal of sedimentation and final burial

General assumptions

An attempt to present hypothetical circumstances of the development of the four types of concretions is described below. The following assumptions for further discussion were established:

– the presence of an unlimited reservoir of Fe^{+3} ions; since they are significant components of clay minerals (SELLWOOD 1971),

– the amounts of Fe^{+2} are governed by the availability of organic matter, which is required for both chemical and microbiotic reduction of ferric ions (SELLWOOD 1971, COLEMAN 1985),

– the amounts of $CO_3^{=}$ is also governed by the availability of organic matter, since carbonate ions, hydro-carbonate ions, and carbon dioxide are produced during decomposition of organic matter followed by dissolution of calcium-carbonate shells buried in the sediment,

– relative homogeneity of clastic sedimentation within the entire section; which is not completely the case since some minor discontinuous layers of silty clay occur.

Early-diagenetic hiatus concretions from Częstochowa-Bugaj

The development of diagenetic calcite concretions was probably the result of a substantial decrease in the sedimentation rate. Their genesis may be similar, although not identical, to the development of fossiliferous calcitic concretions in the Gnaszyn area (Text-fig. 4), which is discussed in details in the next section.

The suggested decrease in the sedimentation rate was followed by erosion, as indicated by evidence of reworking of the same calcite concretions. Probably, they produced the horizon of intraformational conglomerate described by DECZKOWSKI (1976). Only local recognition of this layer may indicate relatively limited removal of soft sediment. However, the erosion was quite intensive as indicated by the benthic colonization of all sides of concretions exhumed during this hiatus. The development of these hiatus concretions included at least two separate stages of erosion, which is expressed by the presence of small borings cutting cements precipitated inside older and larger hollows (Text-fig. 3).

The reason for the erosion events is not apparent. The two usually considered mechanisms, i.e., storm events or bottom currents, cannot be explicitly verified because of a lack of direct evidence. Nevertheless, the significant eastward shallowing of the Middle Jurassic basin in this area is clearly indicated by the presence of increasing amounts of sand and by the reduction in the thickness of clay-rich sediment reported by DECZKOWSKI (1976). The same bathymetric trend was recently confirmed by the palaeontological study, which indicated an eastward decrease in the number of large ammonites. The diverse ammonite assemblages from the Gnaszyn area, which is located ~ 10 km to the northwest (Text-fig. 1), are morphologically and taxonomically similar to the forms from Lechstedt (Middle Jurassic, Germany), where WESTERMANN (1996) deduced a bathymetric estimation based on the morphology of ammonite shells. For his location, WESTERMANN postulated a basin depth of 100 meters. Therefore, in Częstochowa-Bugaj, where large ammonites are totally absent and small shells are rare, the water depth was probably substantially shallower than the 100 m.

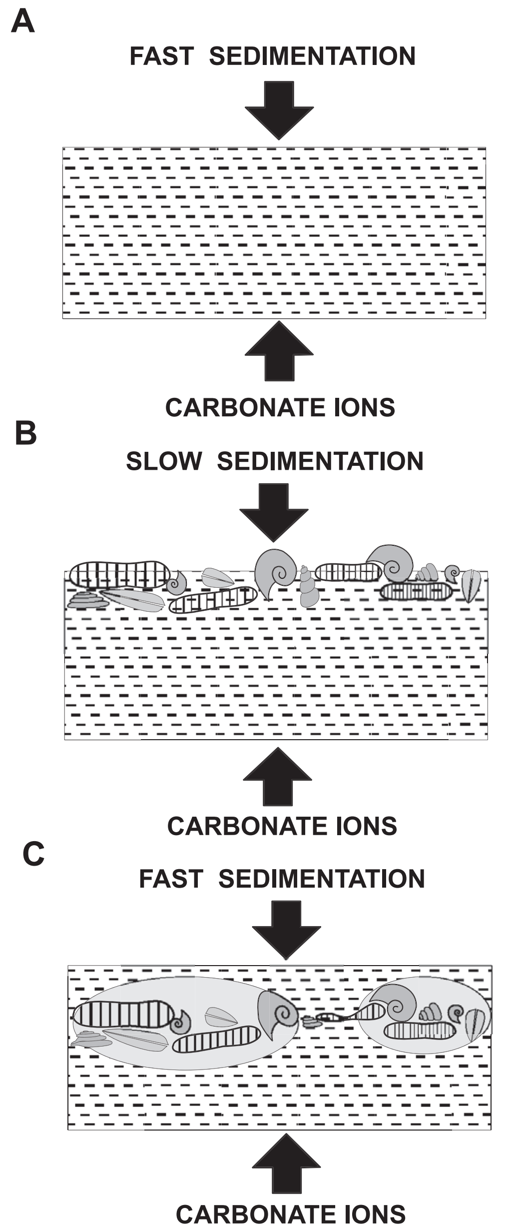

Fig. 4. Development of fossiliferous calcite-concretions; A – relatively fast deposition of sediment enriched in organic matter and establishing of a "pore-water flux" rich in carbonate ions; B – reduction of deposition rate and accumulation of shells; C – precipitation of calcite cements in a zone penetrated by sea water and under strong influence of "pore-water flux", followed by renewal of relatively rapid sedimentation

The position of the Częstochowa-Bugaj location within the shallow part of the Middle Jurassic basin may suggest that the dramatic changes in the deposition rate could result from extraordinary storms. These might affect some areas directly by removing part of the sediment, or indirectly by generating local debris flows, which eroded areas below the wave base. On the other hand, the hiatus concretions seem to be formed in the zone of rather permanent water-circulation, which caused exposure of the concretions for long enough to allow their benthic colonization.

Early-diagenetic fossiliferous calcite-concretions from the Gnaszyn area

Within the Middle Jurassic clays of Częstochowa, calcitic concretions are rare and were probably related to some extraordinary events during deposition. The great number and variety of fossils, found within these concretions, suggests either sudden deposition of the shells or relative reduction in rate of the background clastic-sedimentation. Both these reasons would have caused the relative concentration of fossils. There is a substantial difference in the driving force for carbonate precipitation between these two situations.

The rapid accumulation of 10-15 cm thick fossiliferous horizon may not cause any significant changes in a state of surrounding host-sediment that may induce the precipitation of calcium carbonate. Therefore, it seems that the exclusive reason for the precipitation of carbonates might be the presence of the shell-rich layer itself. Its concentrated organic matter and carbonate shells, which may be a substantial factor in production of carbonate ions, might become the reason for development of concretions. However, the presence of numerous shells does not seem to be the only cause for the development of calcite concretions in the area of Gnaszyn. After all, there are numerous fossiliferous layers which did not undergo cementation.

The second potential cause of fossil accumulation is the reduction of clastic sedimentation. In such case, the shell-rich horizon is not the reason for cementation but the result of an independent phenomenon that was directly responsible for the development of calcitic concretions. In this scenario, the origination of most of the carbonate ions could take place rather in the surrounding sediment than in the precipitation zone itself. The continuous carbonate ion generation together with increasing compaction could produce a consequent upward and/or lateral "flux" of pore waters rich in carbonate ions. In fact, the strength of such "flux" may have been very variable and in the case of the discussed sediment it is probably a rather exaggerated use of this term.

Nevertheless, this last scenario, involving episodic reduction of sedimentary rates, assumes that the near-surface zone of the sediment was penetrated by sea water carrying free oxygen and sulfate ions. Therefore, the ferrous ions were eliminated from the pore waters either by oxidation in the oxic (OX) zone or precipitation as pyrite in the zone of sulfate reduction (SR). Moreover, the carbonate ions were derived not only from the shell-rich layer but also by the continuous "pore-water flux" from the host sediment. The precipitation took place close to the sea floor, therefore, compaction was minimal.

The main advantage of the later approach is that it does not necessarily require the presence of an organic rich layer to produce calcitic concretions. This point seems to be critical for the explanation of the genesis of the calcite concretions from Częstochowa-Bugaj, which are not enriched in macrofossils. Why the other fossil-rich layers did not undergo cementation processes remains an enigma. Perhaps, their genesis was not associated with the reduction of sedimentation rates.

The deformation of ammonites from the lower part of the Lower Bathonian also cannot be easily explained. The scale of ammonite flattening is in many cases significant but often affects only their fragmocones. This shell deformation, as long as it took place after the secretion of cement, can be explained by an insufficient rate of calcite precipitation or too short period of the precipitation-zone stability. Both these factors might result in the incomplete filling of sediment pores inside and outside of the shells. A progressing compaction of the still-soft concretions containing ammonites could lead to deformation of their partly-filled living chambers and complete crushing of the empty fragmocones.

Early-diagenetic siderite-concretions with septaria from the Gnaszyn area

The mechanically and/or biogenetically destroyed ammonite shells, which temporarily remained uncovered on the sea floor, suggest a slow rate of sedimentation of the Middle and Upper Bathonian clays. Its final effect was probably a low organic matter content within the sediment and slow increase in compaction pressure, which could both result in the distribution and structure of the diagenetic concretions (Text-fig. 5).

The long exposure to sea water could prolong oxygenation of organic matter and decrease its amount preserved within the sediment. It could result in a relative deficiency in carbonate ions within the sediment, as the organic matter appears to be vital for carbonate-ion production when a supply of sea water is cut off. The relatively sparse arrangement of separate siderite-concretions (Gnaszyn II, Text-fig. 2) as well as the absence of calcitic concretions seems to be the direct result of this carbonate-ion depletion. The slow but continuous deposition could eventually cause isolation from oxygen-rich sea waters carrying sulfate ions. This isolation could make possible reduction of ferric ions to ferrous ions and make

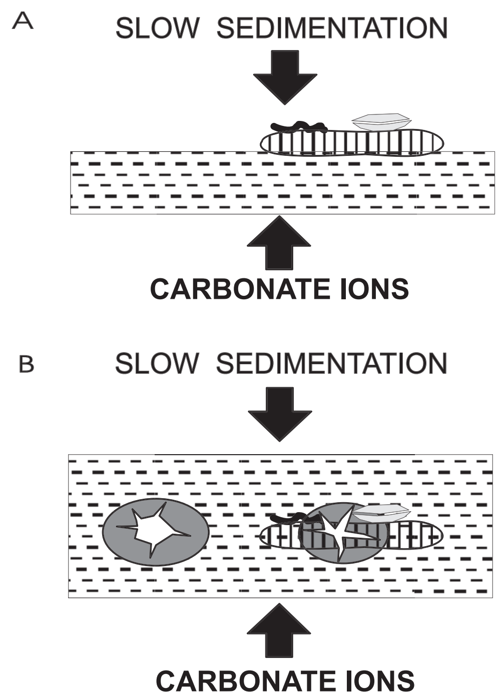

Fig. 5. Development of the sideritic concretions with septaria; A – slow sedimentation and development of a "pore-water flux" relatively depleted in carbonate ions, incrustation of uncovered shells; B – slow sedimentation continues, resulting in low compaction and growth of sparse siderite concretions with septaria

them available for the carbonate precipitation. Moreover, the postponed compaction could permit the formation of numerous septaria and some concretions containing ammonite shells with uncrushed fragmocones.

The low pressure of the surrounding sediment made possible an expansion of the developing concretions. Some ammonites were cracked by the growth of concretions inside their shells. In two specimens, two stages of expansion of the concretion took place, which may indicate variations in the rate of precipitation of siderite or the presence of episodic erosion of the overlying sediment.

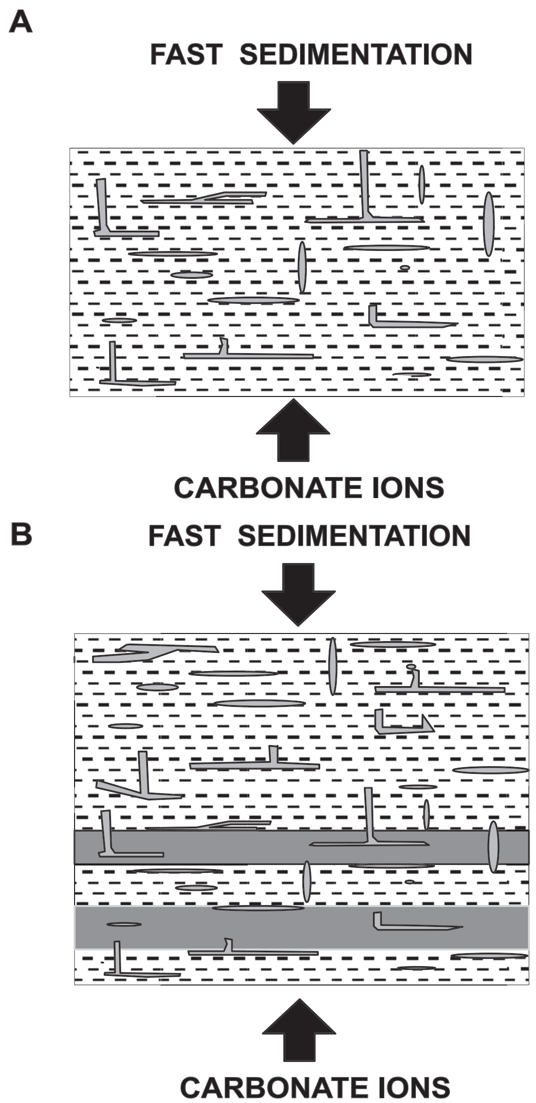

Fig. 6. Development of continuous, massive siderite layers; A – relatively fast deposition and colonization of the organically-enriched sediment by mud feeders, establishment of a "pore-water flux" rich in carbonate ions; B – continuation of the relatively rapid deposition, increase in compaction and extensive precipitation of siderite cements

Later early-diagenetic massive siderite-concretions from the Gnaszyn area

There is no direct evidence for the rate of sedimentation in the Upper Bajocian and the Lower Bathonian part of the section. However, a much greater abundance of diagenetic concretions than in other parts of the Middle Jurassic clays (Text-fig. 2), according to the assumptions presented above, may suggest broader availability of carbonate ions during the precipitation of cements. Going further, it may suggest that more organic matter was trapped within the sediment, which fact is perhaps confirmed by the presence of numerous fossil burrows exclusively within this part of the section. The proposed high abundance of organic mater within the host sediment may indicate that the deposition rates of this portion of the Middle Jurassic clays were relatively fast, which reduced the period of organic-matter oxygenation due to its isolation from the influence of sea water.

As argued above, the relatively rapid sedimentation could mean the broad availability of carbonate ions and extensive carbonate-cement precipitation. If the access of oxygenated sea water was truly cut off, anoxia could develop, which causing reduction of Fe^{+3} to Fe^{+2}. The presence of ferrous ions together with the access of carbonate ions made possible precipitation of the siderite. Because of fast deposition, the formation of the numerous sideritic horizons could occur under relatively strong compaction pressure, which prevented the development of septaria and expanded shells (Text-fig. 6).

SUMMARY AND CONCLUSIONS

The main factors affecting mineral composition, abundance, and the structure of the diagenetic concretions within clay-rich sediment are: effectiveness of isolation from oxygen and sulfate ions carried by sea water (A), abundance of organic matter within sediment as an important factor in production of carbonate ions (B), as well as the state of compaction during precipitation (C). The development of the concretions from the Częstochowa area and the associated sedimentary structures suggest that all the factors listed above may result from a single phenomenon, which is the rate of sedimentation.

In the particular setting of the environs of Częstochowa, a general decrease in the rate of sedimentation over time took place. Episodic oscillation of sedimentary input also occurred. The occurrence of hiatus concretions and the absence of large ammonites in the area of Częstochowa-Bugaj are consistent with suggestions, which point to an eastward shallowing of the Middle Jurassic basin.

The calcite concretions of the Gnaszyn area were formed at shallow depth below the sediment-water interface, probably during brief periods of reduced sedimentation, when the “pore-water flux” bearing carbonate ions intersected the near-floor zone. The septaria could be formed when the rate of sedimentation was relatively slow, which ultimately caused a slow increase in compaction and a deficiency in carbonate ions. Finally, the continuous and massive siderite-layers from the lower part of the section were probably formed synchronously with comparatively fast deposition, when compaction pressure increased relatively rapidly with time, isolation from oxygenated sea water was efficient, and the pore waters were relatively rich in carbonate ions.

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REFERENCES

BAIRD G.C. 1976. Coral encrusted concretions: A key to recognition of a ‘shale on shale’ erosion surface. *Lethaia*, **9**, 293-302. Oslo.

COLEMAN M.L. 1985. Geochemistry of diagenetic non-silicate minerals: kinetic considerations. *Philosophical Transactions of the Royal Society of London*, **315A**, 39-56. London.

— 1993. Microbial processes: Controls on the shape and composition of carbonate concretions. *Marine Geology*, **113**, 127-140. Amsterdam.

COLEMAN M.L. & RAISWELL R. 1995. Source of carbonate and origin of zonation in pyritiferous carbonate concretions: evolution of a dynamic model. *American Journal of Science*, **295** (3), 282-308. New Haven.

DECZKOWSKI Z. 1960. Charakterystyka doggeru częstochowsko-wieluńskiego. *Przegląd Geologiczny*, **8** (8), 412-415. Warszawa.

HAHN W., WESTERMANN G.E.G. & JORDAN R. 1990. Ammonite fauna of the upper Bathonium hodsoni Zone (middle Jurassic) at Lechstedt near Hildesheim, northwest Germany. *Geologisches Jahrbuch*, **A121**, 21-63. Hannover.

HESSELBO S.P. & PALMER T.J. 1992. Reworked early diagenetic concretions and the bioerosional origin of a regional discontinuity within British Jurassic marine mudstones. *Sedimentology*, **39**, 1045-1065. Amsterdam.

HUDSON J.D. 1978. Concretions, isotopes, and the diagenetic history of the Oxford Clay (Jurassic) of central England. *Sedimentology*, **25** (3), 339-367. Amsterdam.

IRVIN H., CURTIS C., & COLEMAN M. 1977. Isotopic evidence for source of diagenetic carbonates formed during burial of organic-rich sediments. *Nature*, **269**, 209-213. London.

KENNEDY W.J., LINDHOLM R.C., HELMOLD K.P. & HANCOCK J.M. 1977. Genesis and diagenesis of hiatus- and breccia-concretions from the mid-Cretaceous of Texas and northern Mexico. *Sedimentology*, **24**, 833-844. Amsterdam.

KENNEDY W.J. & KLINGER H.C. 1972. Hiatus concretions and hardgrounds in the Cretaceous in Zululand. *Palaeontology*, **15**, 539-549. London.

PYE K., DICKSON J.A.D., SCHIAVON N., COLEMAN M.L. & COX M. 1990. Formation of siderite-Mg-calcite-iron sulphide concretions in intertidal marsh and sandflat sediments, north Norfolk, England. *Sedimentalogy*, **37**, 325-243. Amsterdam.

RAISWELL, R. 1971. The growth of Cambrian and Liasic concretions. *Sedimentology*, **17**, 147-171. Amsterdam.

RAISWELL R. & FISCHER J.Q. 2000. Mudrock-hosted carbonate concretions: a review of growth mechanisms and their influence on chemical and isotopic composition. *Journal of the Geological Society of London*, **157**, 239-251. London.

SELLWEOOD B.W. 1971. The genesis of some sideritic beds in the Yorkshire Lias. *Journal of Sedimentary Petrology*, **41**, 854-858. Menasha, Wisconsin.

VOIGT E. 1968. Über Hiatus-Konkretionen (dargestellt am Beispielen aus dem Lias). *Geologische Rundschau*, **58**, 281-296. Stuttgart.

WESTERMANN G. 1996. Ammonoid life and habitat. *In*: N.H. LANDMAN & *al.* (*Eds*), Ammonoid paleobiology. Plenum Press. *Topics in Geobiology*, **13**, 608-710. New York, London.

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