SEDIMENTOLOGY AND PALEOENVIRONMENTAL CONDITIONS OF ORIGIN OF CONCRETIONS IN SITIA REGION, E. CRETE

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ABSTRACT

This work deals with the description and interpretation of the mode of origin and paleogeographic implications of spherical and highly-elongated concretions found in non-marine sandstones of Sykia and Lithinais area respectively, in Sitia district, E. Crete. The studied concretions must have grown after deposition of the host rock, presumably by precipitation of calcite from groundwater actively moving in the direction of the regional subsurface drainage. In addition, concretions are confined to specific horizons within sequences deposited under low or moderate sedimentation rates.

KEY WORDS: Sitia district, sedimentary facies analysis, concretions

1. INTRODUCTION

Sykia section is located along the road from Sykia village to Maronia village, in Sitia district, E. Crete (Fig.1). This section, which is 70 m thick, represents a transgressive sequence of facies ranging upwards from non-marine through marine low energy shoreline sediments to fully marine deposits (Skopi Formation sensu GRADSTEIN, 1973, Tortonian age). Concretionary structures are common in the lowest part of the sequence being dominantly calcitic. The sediments unconformably overlie pre-Neogene limestones and flyschoid rocks of the Mangassa series (GRADSTEIN, 1973, PETERS, 1985).

The aims of this work are 1) to describe and interpret the sedimentological features of Sykia section in Sitia district and 2) to describe and discuss the mode of origin of concretions found at the basal part of this section. In addition, this paper documents the presence of highly-elongated concretions in non-marine sandstones and examines the paleogeographic implications of their preferred orientations.

2. SEDIMENTARY FACIES ANALYSIS

A preliminary study of the Sykia section has been performed by DERMITZAKIS & DRINIA (1996). The studied section (Fig. 2) has been divided into six lithofacies, each one identified by its field aspect, physical and biological structures, grain size and lithology. The order in which these are described is in the typical upward trend seen in the section.

A. Braided -stream conglomerates: This facies can be described as a small-scale, fining-upward sequence (1-2m), consisting of a composite unit of conglomerate overlain by pebbly sandstone. These conglomerates rest directly on the basal unconformity of the Alpine basement. The beds are tabular, flat-based and laterally continuous.They are crudely stratified, clast-supported, with sub-angular to sub-rounded clasts, and commonly well-sorted and graded. The pebbly sandstones which occur at the top of the conglomerates, sometimes display an erosive base.

The sandstones are horizontally to cross-stratified and normally graded and vary in thickness from 30 to 40 cm. The texture and stratification of the clast-supported conglomerates strongly suggest a stream-flow origin. Evidence for streamflow processes in the conglomerate includes framework support and the

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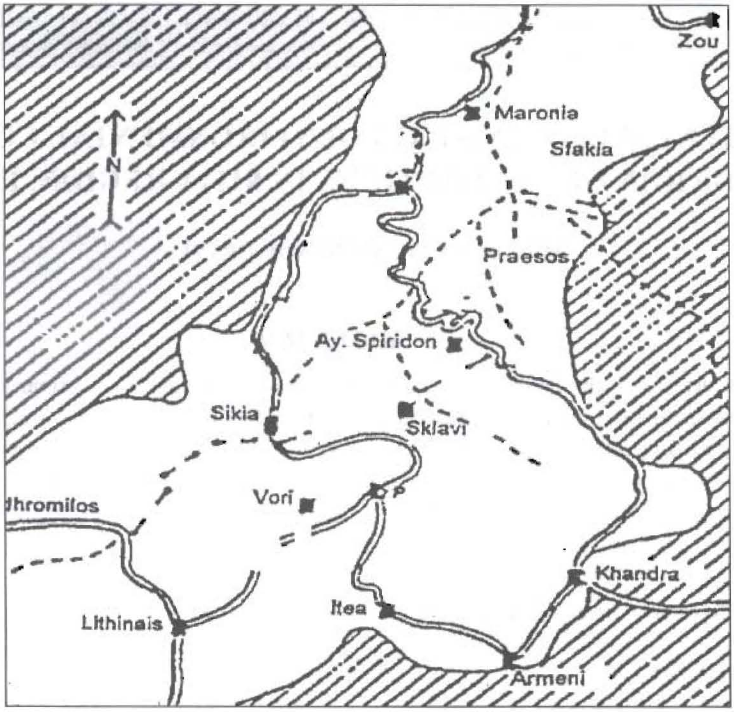

Fig. 1: The study area around Sykia section.

crude fining upward trends of individual units. The pebbly sandstones were probably deposited during waning flood stages.

B. Transitional to marine facies: This facies consists almost entirely of light brownish grey, fine-grained, lithic sandstones which are pebbly in places. The sediments are partly unconsolidated except where they have been cemented by calcite. Beds are tabular to wedge shaped and quite thick; scour and fill structures are rare. Trough-cross stratification and horizontal lamination are the main sedimentary structures but ripple-laminated beds are also present. A braided stream environment has been deduced for this facies. The most remarkable feature of this facies is the presence of spherical to oval or oblong and slightly flattened parallel to the bedding concretions, which range in size from 10 cm to approximately 50 cm along the longest diameter Fig. 3). The concretions are usually composed of carbonate. However, they are occasionally argillaceous or siliceous. They range in colour from brown to gray, are usually dense and hard, and they have a distinct petroliferous odor when freshly broken. The bedding in the sandstone bends or "flows" around the concretion both above and below.

C. Shoreface sandstones: This facies is characterized by thick (generally >1 m), massive and commonly bioturbated sandstone units. The sands are poorly to moderately-sorted, containing gravel pockets and lenses, plant debris and lignite fragments. Thin units of wave ripples are partly intercalated. This facies is interlayered with laminated, well sorted very fine sand, which contains abundant mollusc fossil fragments. Massive sandstones can be formed either by rapid deposition from suspension, penecontemporaneous deformation or by bioturbation. Pebble trains indicate tractional process, whereas lignite fragments suggest slow suspension sedimentation. The shallow marine-type mollusc fossils, wave ripples and lignite fragments indicate that deposition occurred near river mouth draining to shallow-marine environments.

D. Shelf deposits: This facies consists of blueish grey silts and marls which yield mollusc fauna. Fragments and well preserved fossils of oysters, bivalves, echinoderms, gastropods and foraminifers have been found.

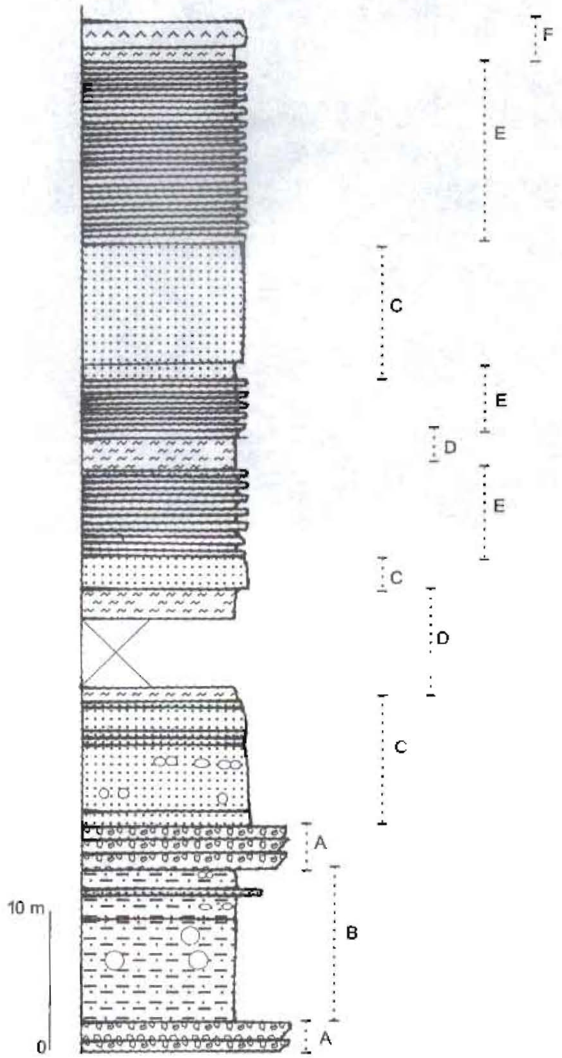

Fig. 2: Lithostratigraphical column of Sykia section showing the vertical facies distribution (explanation of the facies characteristics in text).

Partly, there are sharp-based sandstone beds which are normally graded and completely bioturbated. Based on its fine grained, bioturbated and fossiliferous character, this facies is interpreted as offshore marine deposits formed on the low energy parts of a shallow shelf.

E. Storm influenced shelf: This facies is represented by intensely bioturbated silty sands and sandy silts. They contain some shallow marine molluscan shells. Interbedded sands contain parallel lamination and current and/or wave ripple cross lamination. Some medium bedded sands have a convex up, lenticular geometry and contain trough cross lamination and minor hummocky cross stratification. Moderate to intense bioturbation is common. Intense bioturbated silty sands and sandy silts are common in a shelf environment influenced by storm events.

F. Heterostegina sands: This facies is found capping the section and constitutes a special interval within the shallow marine deposits. Within these *Heterostegina* sands there are scattered Echinoids (*Clypeaster*) and Pectinidae. According to KIDWELL (1989, 1991) and BANERJEE & KIDWELL (1991), these kind of

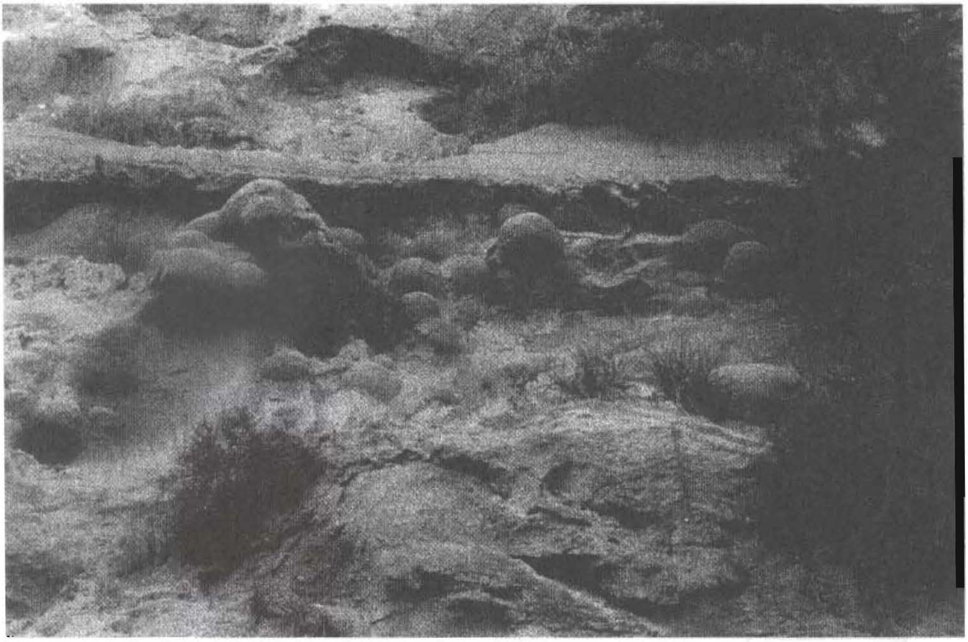

Fig. 3: The concretionary fluvial sandstone of Sykia section.

deposits represents high rates in shell production. These assemblages are formed during low sedimentation rates and have been reworked during repeated storm events.

3. TIME OF CONCRETION DEVELOPMENT

It appears that the concretions formed by intermittent precipitation of calcite in roughly concentric layers around a nucleus.

Concretions are made up of detrital material surrounded by authigenic microcrystalline and/or sparry carbonate, with the crystal size of the carbonate commonly reflecting the grain size of the host sediment (GAUTIER & CLAYPOOL, 1984). The conventional model for concretion zonation and precipitation is concentric, in which carbonate is progressively added to the outer edge of the growing concretion; consequently early zones are at the center and late zones near the outer edge.

A number of recent studies, however, indicate that concretion structure and growth may not exclusively follow the conventional concentric model discussed above (HENNESSY & KNAUTH, 1985; HOUNSLOW, 1988; FEISTNER, 1989; MOZLEY, 1989, 1996; TAYLOR, 1989; MOZLEY & HOERNLE, 1990; HART *et al.*, 1992; JORDAN *et al.*, *1992;* MOZLEY & CAROTHERS, 1992; HUGGETT, 1994). These workers suggest that late-stage and early-stage cements precipitated throughout the concretion, indicating that early cementation was incomplete, and that significant porosity and permeability remained to allow precipitation of late-stage cements in the concretion interior.

In our case, complex zonation has not been noted. There are two possible explanations for this observation: 1) complex zonation does not exist in sandstone concretions, or 2) complex zonation exists, but has not been noted because only a few detailed studies of sandstone concretions have been carried out (e.g. MCBRIDE, 1988). In addition, deflection of laminae within and around the studied sandstone concretions suggests that the central portions of the concretions were cemented before the exterior portions (Fig. 10, e.g. NEWBERRY, 1873; TOMKEIEFF, 1927; CLIFTON, 1957; RAISWELL, 1971; CRISS *et al.*, 1988).

As far as the very widespread and abundant occurrence of concretions in sandstones is concerned, there seems to be little doubt of a syngenetic or early diagenetic origin. According to TARR (1921), the physical relationship of the containing sandstones to the concretions is clearly one of envelopment during deposition or while the sediments were still in a very plastic state. He points out that it would be impossible after lithification of the sandstones to aggregate the calcareous material into a concretion, or to obtain the very distinctive physical relationships that exist between the sands and the concretions.

The manner in which the sandy strata "flow" around the concretions also indicates early concretion development, and subsequent compaction of the soft fluid-bearing muds around them.

Sedimentation rate appears to have a strong control on the growth of the concretions (SCOTCHMAN, 1989). According to SCOTCHMAN (1991) concretions are confined to specific horizons within sequences deposited under low or moderate sedimentation rates. In particular, the concretions occur commonly as distinct horizons where the bed thicknesses indicate a relatively low sedimentation rate. Otherwise in the sequence, where deposition was under high sedimentation rates, concretions are relatively rare.

4. THE ORIENTED CONCRETIONS OF LITHINAIS AREA

Highly elongated sandy concretions are found into loose sandy deposits along the trackroad in Lithinais valley (Fig. 4). Sands are fine to medium grained and cross-stratified. Scattered subrounded to rounded pebbles are forming lenses and pockets. In the basal part of the outcrop there is 25-30 cm of clast-supported stream-flow conglomerate similar with the one observed in Sykia section.

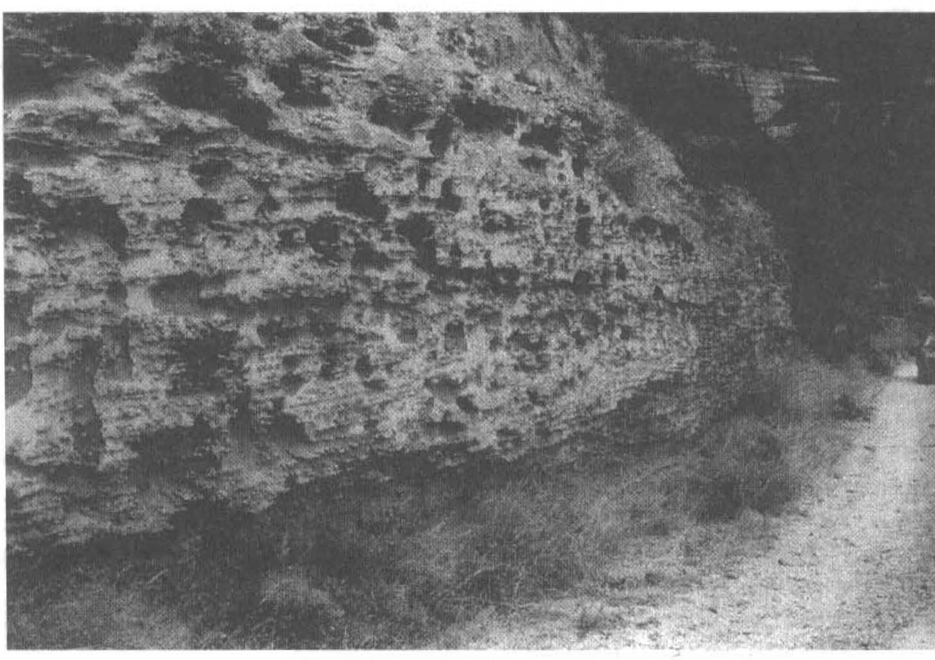

Fig: 4. Highly-elongated concretions in Lithinais area.

The highly elongated concretions are shaped like rods and thin blades. All concretions have slightly tapered and rounded exposed ends. Presumably, the rounded ends represent the natural ends of the concretions, but the concretions are friable and their ends may have been modified by wind erosion. The concretions are fragile. They project several cm from outcrops that have been eroded by wind and gravity. Concretions excavated and removed from outcrop have lengths of up to 30 cm. There is no evidence of the nucleation sites of concretions. Concretions have remarkably uniform orientations.

This type of elongated concretions in sandstones is very rare and of controversial origin. The presence of aligned concretions in beds with different types of stratification (parallel lamination, cross-beds) indicates that sedimentary structures do not control orientation of the concretions. Deviations from spherical shapes have been explained as the result of different growth rates in different directions because of permeability anisotropy (e.g. DEEGAN, 1971; GLUYAS, 1984) or inhomogeneous primary distribution of carbonate where cementation occurs by diffusive processes (BJORKUM & WALDERHAUG, 1990). Many researchers tried to explain the origin of the elongation of these concretions (SCHULTZ, 1941, PIRRIE, 1987, JOHNSON, 1989, REILLE & HOULEZ, 1977, THEAKSTONE, 1981, MCBRIDE *et al.*, 1994).Most of them agree the concretions developed their elongation by growth parallel with the direction of groundwater flow.

5. CONCLUSION

Spherical to oval concretions in Sykia section and highly elongated concretions in Lithinais area, are found into fluvial sandstones.

The concretions in the study area must have grown after deposition of the host rock, presumably by precipitation of calcite from groundwater actively moving in the direction of the regional subsurface drainage.

In particular, the highly oriented concretions present in fluvial sandstones could constitute a useful tool for reliably inferring the regional paleoslope and paleo-groundwater flow directions.

LITERATURE

BANERJEE, I. & S.M. KIDWELL, 1991. Significance of molluscan shell beds in sequence stratigraphy: an example from the Lower Cretaceous Mannville Group of Canada. *Sedimentology*, 38, 913-934.

BJORKUM, P.A. & WALDERHAUG, O., 1990. Geometrical arrangement of calcite cementation within shallow marine sandstones. *Earth-Science reviews*, 29, 145-161.

CLIFTON, H.E., 1957. The carbonate concretions of the Ohio Shale, Ohio. *J.Sci.*, 57, 114-124.

CRISS, R.E., COOKE, G.A. & DAY, S.D., 1988. An organic origin for the carbonate concretions of the Ohio Shale. *U.S. Geol. Surv.Bull.*, 1836, 1-21.

DEEGAN, C.E., 1971. The mode of origin of some late diagenetic sandstone concretions from the Scottish Carboniferous. *Scottish Journal of Geology*, 7, 357-365.

DERMITZAKIS, M.D. & H. DRINIA, 1996. Concretions, "geological creations of the nature" and legends, in the eastern Crete. *8th International Cretological Congress*, Heraklion, 9-14 September 1996, *in press*.

FEISTNER, K.W.A., 1989. Petrographic examination and re-interpretation of concretionary carbonate horizons from the Kimmeridge Clay, Dorset. *J. Geol. Soc. London*, 146, 345-350.

GAUTIER, D.L. & CLAYPOOL, G.E., 1984. Interpretation of methanic diagenesis in ancient sediments by analogy with processes in modern diagenetic environments. In: D.A. McDonald 7 R.C. Surdam (Eds), *Clastic Diagenesis. Am. Assoc. Pet. Geol. Mem.*, 37, 111-123.

GLUYAS, J.G., 1984. Early carbonate diagenesis within Phanerozoic shales and sandstones of the NW European shelf. *Clay minerals*, 19, 309-321.

GRADSTEIN, F., 1973. The Neogene and Quaternary deposits in the Sitia district of eastern Crete. *Ann. Geol. Pays Hell.*, 24, 527-572.

HART, B.S., LONGSTAFFE, F.J. & PLINT, A.G., 1992. Evidence for relative sea level change from isotopic and elemental composition of siderite in the Cardium Formation, Rocky Mountain foothills. *Bull. Can.Petrol.Geol.*, 40, 52-59.

HENNESSY, J. & KNAUTH, L.P., 1985. Isotopic variations in dolomite concretions from the Monterey Formation, California. *J. Sedim. Petrol.*, 55, 120-130.

HOUNSLOW, M.W., 1988. Siderite crystallographic fabrics in siderite concretions from the Carboniferous and Lower Jurassic. *27th Annual Meeting of the British Sedimentological Research Group*, unpaginated.

HUGGETT, J.M., 1994. Diagenesis of mudrocks and concretions from the London Clay Formation in the London basin. *Clay Miner.*, 29, 693-707.

JOHNSON, M.R., 1989. Paleogeographic significance of oriented calcareous concretions in the Triassic Katberg Formation, South Africa. *J. Sediment. Petrol.*, 59, 1008-1010.

JORDAN , M.M., CURTIS, C.D., APLIN, A.C. & COLEMAN, M.L., 1992. Access of pore waters to carbonate precipitation sites during concretion growth. In: Kharaka and Maest (Eds), *Water-Rock Interaction*, Rotterdam, Balkema, 1239-1242.

KIDWELL, S.M., 1989. Stratigraphic condensation of marine transgressive records: origin of major shell deposits in the Miocene of Maryland. *J. Geol.*, 97, 1-24.

KIDWELL, S.M., 1991. Condensed deposits in siliciclastic sequences: expected and observed features. In: Seilacher, D & G. Eisner (Eds), *Cycles and Events in Stratigraphy*, 682-695.

MCBRIDE, E.F., 1988. Contrasting diagenetic histories of concretions and host rock, Lion Mountain Sandstone (Cambrian), Texas. *Geol. Soc. Am. Bull.*, 100, 1803-1810.

MCBRIDE, E.F., DANE PICARD, M. & R.L. FOLK, 1994. Oriented concretions, Ionian Coast, Italy: Evidence of groundwater flow direction. *J. Sediment. Research*, A64, 535-540.

MOZLEY, P.S., 1989. Relation between depositional environment and the elemental composition of early diagenetic siderite. *Geology*, 17, 704-706.

MOZLEY, P.S., 1996. The internal structure of carbonate concretions in mudrocks: a critical evaluation of the conventional concentric model of concretion growth. *Sedimentary Geology*, 103, 85-91.

MOZLEY, P.S. & CAROTHERS, W.W., 1992. Elemental and isotopic composition of siderite in the Kuparuk Formation, Alaska: effect of microbial activity and water/sediment interaction on early pore-water chemistry. *J. Sediment. Petrol.*, 62, 681-692.

MOZLEY, P.S. & HOERNLE, K., 1990. Geochemistry of carbonate cements in the Sag River and Shublik Formations (Triassic/Jurassic), North Slope, Alaska: implications for the geochemical evolution of formtions waters. *Sedimentology*, 37, 817-836.

NEWBERRY, J.S., 1873. Geological structure of Ohio-Devonian system. *Ohio Geol. Surv. Rep.*, 1, 140-167.

PETERS, J.M., 1985. Neogene and Quaternary vertical tectonics in the South Hellenic Arc and their effect on concurrent sedimentation processes. *CUA Papers of Geology*, Series 1, No 23, 247p.

PIRRIE, D., 1987. Orientated calcareous concretions from James Ross Island, Antarctica. *Br. Antarct. Surv. Bull.*, 75, 41-50.

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

REILLE, J.-L. & HOULEZ, F., 1977. Diagenese et hydrologie souterraine: mise en evidence d' un paleoecoulement phreatique oriente dans un formation sableuse pliocene, "Sable des Montpellier'. *Academie des Sciences* (Paris), *Compte-Rendus*, 285, Ser. D, 505-508.

SCHULTZ, C.B., 1941. The pipy concretions of the Arikaree. *University of Nebraska State Museum Bulletin*, 2, 69-82.

SCOTCHMAN, I.C., 1989. Diagenesis of the Kimmeridge Clay Formation, Onshore UK. *J. Geol. Soc. London.*, 146, 285-303.

SCOTCHMAN, I.C., 1991. The geochemistry of concretions from the Kimmeridge Clay Formation of southern and eastern England. *Sedimentology*, 38, 79-106.

TARR, W.A., 1921. Syngenetic origin of concretions in shale. *Geol.Soc. America Bull.*, 32, 373-384.

TAYLOR, K.G., 1989. Complex siderite and trace elements geochemistry in siderite concretions from the non-marine Wealden sediments of south-east England. *28th Annual Meeting of the British Sedimentological Research Group*, unpaginated.

THEAKSTONE, W.H., 1981. Concretions in glacial sediments at Seglavatnet, Norway. *Journal of Sedim. Petrol.*, 51, 191-196.

TOMKEIEFF, S.I., 1927. On the mode and origin of certain kaolinite-bearing nodules in the Coal Measures. *Proc. Geol. Assoc.*, 38, 518-547.