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This volume is dedicated to Dr. Rainer Zangerl

Sedimentary Processes in *Rayonnoceras* Burial

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INTRODUCTION

The Mississippian Fayetteville Formation of northwestern Arkansas is chiefly black, clay-shale ranging from less than 40 to as much as 400 ft. thick and extending from the eastern part of Oklahoma (Braggs Mt. area) to east of Batesville, Arkansas, a distance of some 225 miles. Marine animal remains are quite abundant in some areas and plant remains occur occasionally. The marine fauna is notable for cephalopods. Some large, coiled nautiloids (Gordon, 1965, pp. 134-135), as well as orthocones as much as 9 ft. long (pl. 2, fig. 3), have been encountered. In addition, numberous goniatites of several genera occur in places.

The nautiloids in the shale are nearly all preserved with flattened living chambers; only those camerae filled with cameral deposits are undistorted. The large orthoconic nautiloid, *Rayonnoceras solidiforme* Croneis, 1926 (p. 343), may have flattened living chambers and partially flattened camerae. In life, *Rayonnoceras* deposited calcareous material ventrally in the septate portion of the shell to serve as ballast for the purpose of maintaining oriented buoyancy. As the individual grew in length and diameter (the body occupied approximately half the shell) the most posterior portion of the septate shell filled completely with calcareous deposits. Farther forward only the lower (ventral) part of the chambers was filled. As a result, the animals naturally floated dorsal side up in life. After death and burial the partially unfilled portions of the camerae became crushed. Croneis (1926, p. 345) assumed the filling was dorsal, not ventral, and that the siphuncle, though subcentral, was "conspicuously ventral." In addition to maintaining dorso-

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ventral orientation, the ballast most probably aided in horizontal orientation. Since the animals propelled themselves by jetting water through the hyponome, moving "backward," through the water and lacking any sort of "trim tabs," they may have been able to direct the shell upward or downward by altering body volume in some manner.

All the *Rayonnoceras* shells I have recovered from the Fayetteville shale (as many as 30-50) were oriented in response to the buoyancy of the shells, with the dorsal side up. A few were as much as 45° displaced to right or left but none were ventral side up. Zangerl et al. (1969, p. 113) reported a single specimen among 23 individuals ventral side up but did not mention the degree of completeness of the specimen. I saw a single fragment of conch, about 4 in. long, upside down. It appears that, in life, the animals lost sections of the nearly completely filled apical portion of the conch and these might sink to the sea floor in any orientation. Entire shells, however, are uniformly oriented with the dorsal side up.

More or less complete specimens of *Rayonnoceras* have been recovered that were oriented in the shale from vertical to horizontal. This relationship between conch and matrix was discussed by Zangerl et al. (1969, pp. 87-119) and the Fayetteville sediments and concretions described. These authors (p. 114) also suggested that the animals were buried suddenly by sinking in soft mud on the sea floor. Subsequent to burial, decay of bodies produced sufficient gas pressure to explode the living chambers and perhaps blow out to the surface of the enclosing mud.

My own observations lead to conclusions somewhat at variance with those of Zangerl et al. (1969). Whereas they assume the animals sank in mud already on the sea floor, it seems more probable that the animals sank to the sea floor and were subsequently engulfed by accumulations of clay in a thixotropic state (Kerr, 1963, pp. 132-142). The shells, as they are preserved, range from vertical to horizontal. Mostly, the non-horizontal ones are at an angle of 30 to 65° more or less. If the animals, in life, were essentially neutrally buoyant or approximately equal to the specific gravity of water they could not have sunk into any kind of bottom mud which must necessarily have a specific gravity much higher than water. A dead animal might float to the surface with the apex of the shell down, due to the ballast. As body gasses were lost it should sink gently to the sea floor resting initially on the apex of the shell. As decay proceeded, the shell would occupy a more and more horizontal position until it came to rest horizontally on the sea floor. As the body disappeared and sediment accumulated, the body chamber would fill with clay. The septate portion could not fill with clay. Eventually pressure would produce collapse of the septate portion but not necessarily of the living chamber. This condition is strikingly borne out in a black shale above the Fayetteville, the Imo Formation (Gordon, 1965, pp. 35-38; Quinn, 1966, p. 8). In this shale living chambers are most always intact and septate portions destroyed for both goniatites and nautiloids. Presumably, the shells were empty at the time of burial. There is also little indication of massive compression of the clay; this may indicate slow accumulation on the sea floor. The Fayetteville mud, insofar as fossils are concerned, was subjected to massive compaction of as much as 80 per cent in places.

Among the *Rayonnoceras* recovered from the Fayetteville strata, several were associated with "clusters" of goniatites. In cases where the shell was more or less vertically inclined, the goniatite cluster, contained in a pyritic concretionary mass or "halo" formed around the conch fairly parallel to the "bedding" of the shale. One such assemblage provides some information concerning the events involved in its production (pl. 1; pl. 2, figs. 1,2).

DESCRIPTION

The *Rayonnoceras* (UA 74-4-1) to be discussed here was collected by a former Geology undergraduate student of the University of Arkansas, Paul Thompson. I visited the site with Mr. Thompson. The conch had been entombed with the apex oriented to the south and dipping about 40° from the horizontal. The diameter of the "halo" is ±475 mm. The length of the conch below the halo is ±438 mm. Thickness of the halo is as much as 124 mm. The external configuration of the conch is not altered where it is enclosed within the halo and near the upper border is about 166 mm. in diameter.

The concretionary halo was sectioned to investigate its position with respect to the base of the living chamber. (The cutting was done at the University of Iowa by Dr. W. L. Manger.) From data acquired from other material (pl. 2, fig. 3) it appears that the septate portion of a conch about equals the living chamber in length. The rayonettes within the siphuncle on the last two or three septa tend to be partially developed, so that presence of these indicates within a centimeter or two the beginning of the siphuncle. Croneis

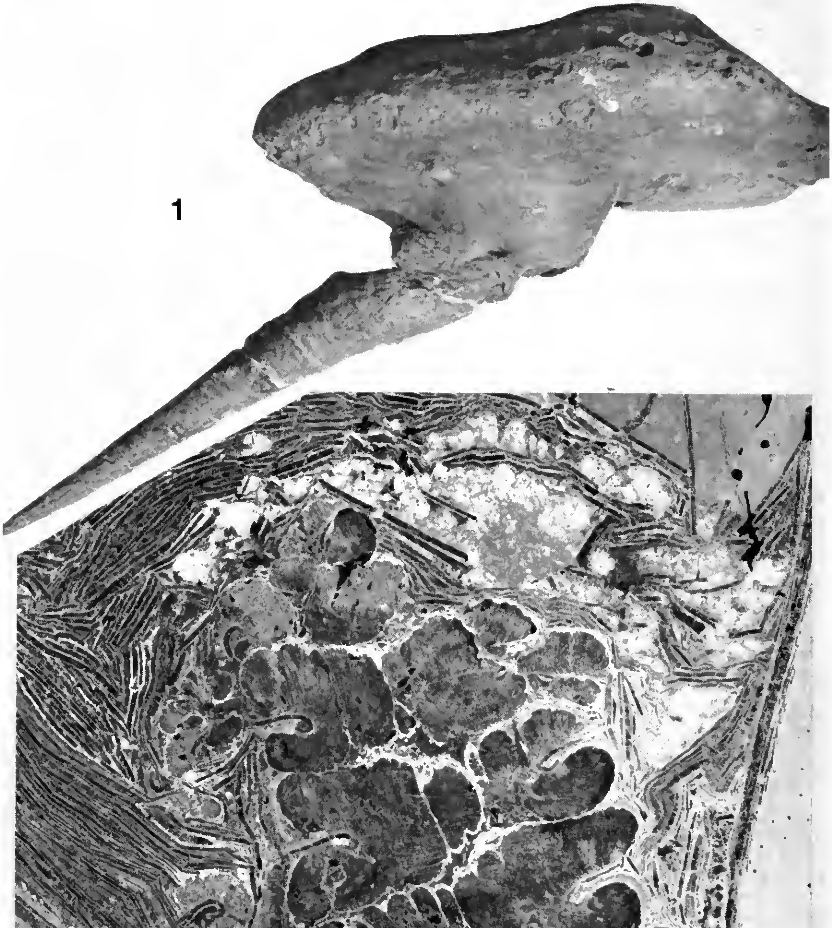

PLATE 1. *Rayonnoceras solidiforme*, Croneis 1926, Fayetteville Fm. westside of Hwy. 71 bypass, one-fourth mile south of Hwy. 62. 1, Conch and concretionary halo in burial position. (apex points nearly due south) (×.15 natural size). 2, Acetate peel of sectioned specimen. Crumpled plates are presumably septa. (×3.66)

1

2

3

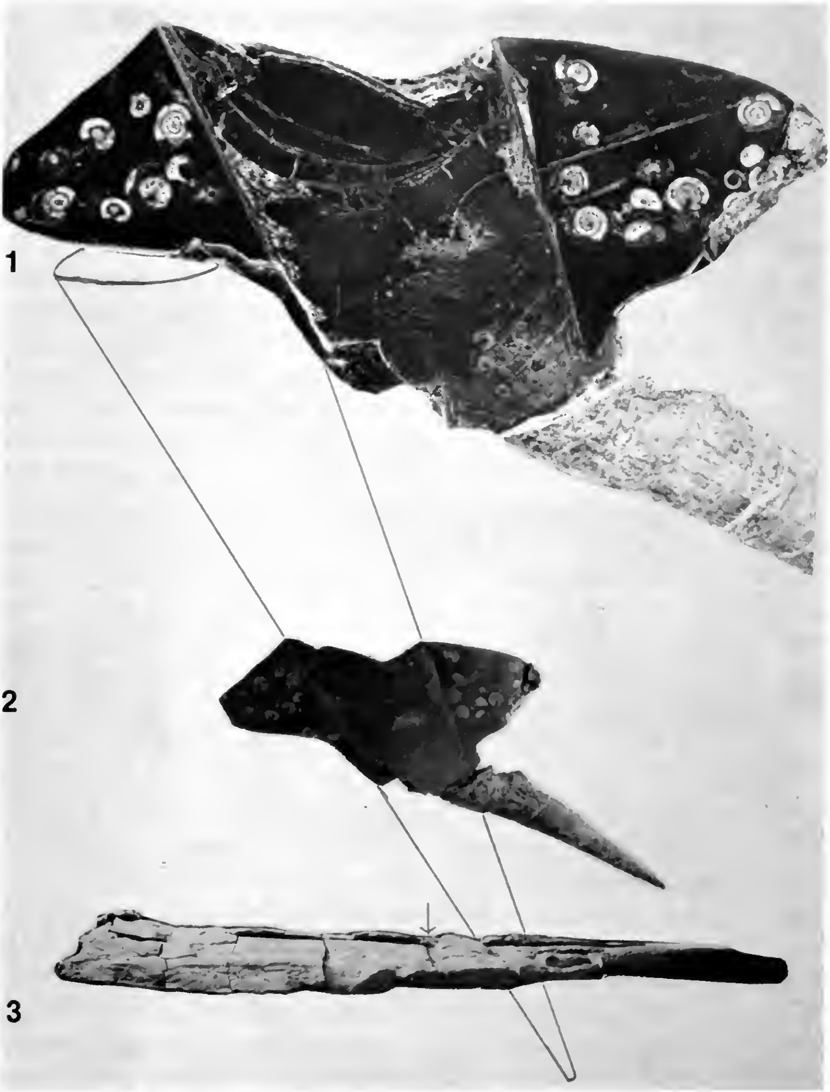

PLATE 2. Section of halo and projected shell restoration of *Rayonnoceras* of Plate 1. Nearly complete conch of large *Rayonnoceras*, Town Branch and Hwy. 265 about one-fourth mile west of Hwy. 71 S. in Fayetteville, Arkansas. 1, Polished section with goniatites and shell fragments in the halo. The enlarged area of Plate I, Figure 2 is in the lower right area of the cut section. (×.15). 2, Outline restoration of conch based on rate of taper and medial position of first septa (×.41). University of Arkansas 74-4-1. 3, Conch of large *Rayonnoceras* oblique view, arrow points to approximate position of beginning of siphuncle (×.09). University of Arkansas 63-26-1.

(1926, p. 347) suggested that the living chamber might be one-third as long as the septate portion. He also called attention to the uniform rate of shell expansion (p. 344), which he calculated to be 1 mm. in diameter for 6 mm. in length, indicating an apical angle of about 9°.

On this basis it is a simple matter to extend the conch boundary apically to the point where the two lines meet and adapically to an equal distance (pl. 2, fig. 2). This provides a total reconstructed conch length of about 1,300 mm. An enlarged acetate peel of the siphuncular area (pl. 1, fig. 2) shows the terminal rayonnettes displaced and a great deal of crumpled septal material. The restored outline of the shell (pl. 2, fig. 2) indicates that about one-third of the chambered portion of the shell has been telescoped into the base of the "halo," and has also been disturbed laterally due to compaction of the clay subsequent to burial of the shell.

The halo around the shell contains the remains of a number of goniatites as well as fragments of the living chamber. These are readily identificable because they are much thicker than the septa. Some fragments are resting at the base of the halo (not seen in this view). Some are intermingled with the goniatites in the halo surrounding the conch and some lie within the upper opening of the conch. If the living chamber is about 775 mm. long with an average diameter of 625 mm., there should be as much as 4,844 sq. cm. of surface of living chamber shell. There is probably no more than 10 per cent of the shell material of the living chamber preserved, indicating much loss.

Sedimentary Material:

The Fayetteville shale is a clay stone and has been described in detail by Zangerl et al. (1969, pp. 90-92). There is very little indication of bedding in unweathered shale. Weathered material is quite fissile and disintegrates to very small platelets in a few days. Pyrite concretions and pyritized fossils decompose rapidly near the surface. The "shale" becomes sticky, yellow clay in the soil profile. The pyrite mostly changes to melanteritic white powder. Fossils in trays in the laboratory disintegrate to "dust" in a few years. Small goniatites are distributed on bedding planes in places. A few bedding plane crinoids, brachiopods, and pelecypods also occur.

Problem of Burial:

The *Rayonnoceras* with a disc or halo of concretionary material initially resting at an angle of about 80° on the sea floor, or nearly vertical, had a conch length of more than 1,300 mm. To this must be added considerable length to cover the protruding portion of the body. In order to bury the animal completely, a layer of clay as much as 2,000 mm. deep would have been required. Burial must have taken place before decay of the body. This surely would require that the mud was already there and that the animal sank into it as suggested by Zangerl et al. or that the animal was in a nearly buoyant condition on the sea floor and subsequently engulfed in a "cloud" of clay-mud flowing down slope or settling from above.

The idea of mud flows or turbidity currents on the sea floor is widely recognized. There is seemingly a concomitant concept of turbulence associated with the term. If the mud flows of the Fayetteville strata involved thixotropic clays and no turbulence they are not properly turbidites in the accepted sense (Zumberge and Nelson, 1972, p. 290).

The *Rayonnoceras* conchs were not involved in undersea landslides or other turbulent movement because they nearly always are oriented in buoyant relationship to the sea floor.

A mud flow from near shore might well begin as a turbidity-type movement. If the material is all fine clay, the movement could maintain suspension and promote mixing of water with the clay. As the flowing material becomes more and more diluted it would tend to move more and more slowly. The flow would eventually cease. Some, if not all, fine clays have the property of behaving as a liquid if disturbed and as a solid otherwise (Kerr, 1963, pp. 132-142). The flow might be as much as, or more than, 50 per cent water. It could flow around a dead *Rayonnoceras* resting on the sea floor without disturbing its orientation beyond moving it forward and perhaps altering the direction of dip. Once the clay ceased to move it would become a solid with the peculiar attribute of reversion to liquid on disturbance.[1]

An empty shell buried under these conditions would have the living chamber filled with mud. Depending on the degree of dilution, post-depositional factors permit, or induce, settling or compaction

[1] I have suggested a solid—not a plastic—state since the clay is not responsive to gradually applied stress. In the lab we prepared a beaker of clay sufficiently liquid to pour readily when shaken. In about 30 min. the clay would become non-liquid if not disturbed. A steel rod the size of a pencil, inserted vertically in the clay would remain in that position. In water or a plastic it would, of course, become recumbent; abruptly in water, slowly in plastic material.

of the mud. Presumably a shell filled with highly diluted clay would be subject to as much compaction as the identical surrounding material. In some cases the degree of compaction appears as high as 80 per cent (3 to 4,000 mm. of the thixotropic clay may finally be reduced to no more than 50 mm. of thickness). In cases where the clay accumulates gradually on the sea floor, this magnitude of compaction or settling would not occur. Thus empty shells should not be crushed. In either case the shale rock resulting does not furnish macroscopic differences in appearance, only the condition of the fossil shells indicate the different mode of accumulation.

The largest *Rayonnoceras* from the Fayetteville Formation was discovered by R. H. Mapes, formerly a student at the University of Arkansas. This specimen has some 450 mm. of the apical end of the shell missing — lost before burial. The adapical portion is complete. The anterior border of the shell thins abruptly to a thin edge. The shell is flattened but not completely so. The beginning of the calcified siphuncle is expressed. Approximately half the shell is living chamber. This specimen (UA 63-26-1) (pl. 2, fig. 3) is nearly 2,840 mm. long as preserved. No cluster or concentration of goniatite shells was associated.

This combination of factors, some matrix within the living chamber, no goniatites, and the horizontal orientation of the shell, indicates that it was empty when buried but that it was buried by a thixotropic mud flow.

Most of the large *Rayonnoceras* recovered from the Fayetteville shale lack a living chamber or preserve only a portion. Many but not all portions of living chamber contain or are associated with clusters of goniatites. There is reason to suppose the goniatites had been ingested by the *Rayonnoceras* and the shells ejected or retained according to the means of destruction of living chambers (Zangerl et al., 1969, p. 114). Concerning the preservations with the disc or halo containing goniatites (fig. 1), it appears that the *Rayonnoceras* was deeply buried in the clay; the body decay subsequently generated enough gas to explode the living chamber, ejecting body content, fragments of living chamber, and goniatites upward. The shock and gas blow-out necessarily liquified the clay adjacent to the body of the animal. Many of the shell fragments of the body chamber and other material escaped upward to the sea above the clay body. Some of the material settled back to the bottom of the void produced by the explosion. Chemical exchange or reaction between organic and inorganic materials in the mud produced pyritization or mineralization within and around concentrations of organic material. After concretions were thus formed in the clay, compaction of major magnitude occurred, telescoping and disrupting portions of the shell not enclosed in the concretion.

SUMMARY

Conditions of preservation of *Rayonnoceras* and goniatites in the Fayetteville Formation indicates the introduction of thick blankets of clay highly charged with sea water onto the sea floor, capable of becoming "solid," with termination of movement and subject to reliquification if disturbed. Thus much of the accumulation of clay on the Fayetteville sea floor occurred in this manner.

It must also be assumed that *Rayonnoceras* preyed on goniatites as a staple food item. Because *Rayonnoceras* shells are oriented according to buoyancy, it is not feasible to assume they were overwhelmed by turbidity currents in the sense of turbulent sea-floor landslides. There is a question if the mud flows of the Fayetteville Formation should or should not be considered turbidity currents.

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