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Depositional Processes and Facies of the Early Mississippian Joana Limestone: An Example of Encrinite Formation within a Foreland Basin Setting, Western United States

Phelps, William T., and Mary L. Droser. Department of Earth Sciences, University of California, Riverside, Riverside, CA 92521. E-mail: phelps@citrus.ucr.edu

The Early Mississippian Joana Limestone crops out across much of eastern Nevada and western Utah, but is best represented by outcrops in southern and central Nevada, and west-central Utah where depositional sequences are thickest. The Joana represents limestone formation in a carbonate shelf and slope environment, with deposition influenced by the eastward migration of the forebulge axis associated with the Antler foreland basin (Goebel, 1991). As a result of the facies changes associated with this tectonism, the Joana can be divided into lower and upper members. The lower Joana is a set of regionally continuous deposits characterized primarily by massive cliff-forming limestones composed chiefly of crinoid debris (encrinites). This unit is generally interpreted as having formed in relatively shallow settings (Goebel, 1991) that represent deposition in a shelf or shoal environment (Sandberg, 1982). The upper Joana is characterized by a mix of slope and ledge forming facies indicative of outer shelf, slope and perhaps basin margin deposits. Although the differences in facies types between the lower and upper Joana are considerable, the bulk of the material that forms both of these units is crinoidal in origin.

In general, encrinites are rocks consisting of 50% or more pelmatozoan (usually crinoid) debris by volume. Encrinites occur in Ordovician through Jurassic strata, but they appear to be particularly abundant in Carboniferous limestones (Ausich, 1997). Around the globe in limestones of this age, packages of laterally extensive crinoidal sands, called regional encrinites are common. These deposits are greater than 5-10 meters in thickness and extend for at least 500 km^2 (Ausich, 1997). In addition, they are generally composed of nearly 100% pelmatozoan material and many form known hydrocarbon reservoirs. However, contrary to most generalizations about their mode of deposition, encrinites actually exhibit a wide array of stratigraphic expressions and may occur in abundance in all depositional settings across the shelf making them a unique biogenic lithofacies that spans a variety of environments and energies.

Encrinites of Mississippian age are particularly common in North America, and compose the bulk of the sediments forming the Burlington and Keokuk limestones in the eastern U.S. and the Lodgepole, and Joana limestones of the western U.S. This study examines the Joana Limestone because it is composed of sediments representing deposition across the shelf and slope environment with which are associated a wide variety of encrinite forms. Thus, analysis of this formation provides insight into the modes of formation and internal characteristics of both small-scale and regional encrinites, an understanding of which is important for reservoir characterization and a better understanding of depositional processes.

The Joana Limestone is informally divided into two units, the upper and lower (Goebel, 1991), which are distinguished by a rapid facies change at the top of the lower Joana. The lower member is represented by two main facies: a basal thin (< 5 m) argillaceous, wavy-bedded, wackestone, and an overlying massive to cross-bedded crinoidal packstone/grainstone. The argillaceous facies contains abundant crinoids, echinoids, and brachiopods, and less abundant gastropods, ostracods, trilobites, and rugose corals. The dominant fossils are the crinoids and echinoids, which compose millimeter thick encrinites that are pavements of disarticulated echinoderm debris. This type of encrinite is extremely common throughout the argillaceous facies and forms discontinuous pavements of crinoid ossicles and echinoid plates that show very little evidence of transport or disturbance by bioturbating organisms. Due to the regional extent (over 100's of km), fine grain size, diversity of normal marine organisms, and general lack of major sediment modification by currents, this facies is interpreted as a quiet water normal marine deposit that was likely deposited below storm wave base on the distal shelf.

The overlying packstone/grainstone facies is nearly 100% crinoidal debris ranging from less than 1/2 mm to over 2 cm in diameter with articulated stem segments up to 20 cm. Other fossils are rare but a few brachiopods and rugose corals are visible in outcrop. Bedding within this facies includes featureless massive beds in the lower part of the unit, and meter-scale cross bedding in the upper portion. Taken together, the coarse-grained nature of the sediments and large-scale sedimentary structures are indicative of a high-energy environment, where the crinoid debris acted as an episodically mobile substrate that produced cross-beds and buried some crinoid stems before disarticulation was complete. This entire facies is representative of a regional encrinite that is laterally traceable over at least 500 km^2, and forms beds up to 60 meters in thickness in the southern portion of the study area. At this time, further analysis is required to determine if these deposits represent shallow-water shoals, or deeper-water deposits influenced by storm activity.

Like the lower Joana Limestone, the upper Joana is divided into two main facies types: a slope-forming mudstone/wackestone facies, and a ledge-forming wackestone/packstone facies. These facies are interbedded throughout the upper Joana, and can be divided into discrete cycles of deposition (Goebel, 1991). The slope-forming facies is characterized by a fauna dominated by crinoids. However, some wackestones are dominated by brachiopods, gastropods, and rugose corals, with a subordinate fine-grained echinoderm or carbonate mud matrix. Laminated barren lime muds are also common with some showing minor to moderate bioturbation. Trace fossil in this material include *Zoophycos*, and *Chondrites*. Due to the dominance of generally fine-grained and often laminated beds, and the lower faunal diversity evident in these units, this facies is thought to represent a deeper water depositional environment, below storm wave base. Within this facies there is one type of encrinite, which is composed of coarse-grained (up to 1 cm in diameter) centimeter thick pods, lenses, and stringers of disarticulated crinoids. These coarse, laterally discontinuous encrinites likely represent lag deposits produced by the winnowing action of bottom currents.

Like the slope-forming facies, the interbedded ledge-forming facies also is dominated by crinoids, with subordinate brachiopods, gastropods, and rugose corals. However, this facies is dominated by wackestones and packstones and exhibits 3 types of encrinites: meter-scale fining upward coarse-grained encrinites; encrinites composed of very fine-grained (grains less than 1/2 mm in diameter) crinoidal sands, some of which display planar laminae; and wackestones which have over 50% of their material (allochems and/or matrix) composed of echinoderm debris. The meter-scale normally graded encrinites are composed of a range of grain sizes that include material between 1/2 and 15 mm. These deposits represent deposition by turbidite or storm currents transporting coarser-grained material in from the carbonate shoals further up the shelf. The second type of encrinite, composed of very fine-grained crinoidal sands that are laminated to massive, laterally continuous beds (at the outcrop scale), may represent a variety of depositional mechanisms such as sorting and winnowing by bottom currents, but most likely represent deposition by turbidite currents that have carried in the sand-sized fraction of small, broken and abraded grains from the encrinite shoals higher on the shelf. The last type of encrinite, characterized by crinoid dominated wackestones, may take several forms including beds that would normally be considered as dominated by another fauna (e.g. a brachiopod dominated bed) but which is actually a crinoid dominated bed when the matrix content is considered (which drives the overall echinoderm content to over 50% of the rock). Thus, this kind of encrinite may appear to be dominated by brachiopods, gastropods or rugose corals, but must be classified as an encrinite based on its whole rock composition. These encrinites exhibit little in terms of their sedimentary structure, but based on the other types of sediments present likely represent transported material.

Because these relatively thin (mostly meter-scale or less) deposits are interbedded with finer-grained sediments and because some beds exhibit primary sedimentary structures (e.g. fining upward sequences and planar laminae) associated with the initial deposition of the beds, these units are also thought to have formed in the deeper water conditions of the distal shelf or slope. However, if these encrinite types represent sediments transported by turbidity currents, then the facies of the upper Joana Limestone may be basin margin deposits, since turbidity currents are more likely to bypass the slope (Tucker and Wright, 1990).

In conclusion, within the Joana Limestone there are six main types of encrinites, which are loosely described as:
1. Millimeter thick encrinite pavements.
2. Encrinite pods, lenses and stringers.
3. Encrinite sands.
4. Normally graded coarse-grained encrinites.
5. Encrinite wackestones.
6. Regional encrinites.

Although there are certainly other forms of encrinites exhibited in other formations and associated with other depositional environments, within the scope of this study each of these encrinites has unique features separating it from the others and each can be associated with a particular facies. This work demonstrates that encrinites are not just crinoidal packstones or grainstones as is commonly recognized, but are a complex yet describable biogenic lithofacies that have many applications in sedimentology and stratigraphy and important implications for paleoecological studies.