Ordovician Mid-Continent Epeiric Sea, USA: Year of Wisconsin Work

Featured Faculty Research

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Introduction

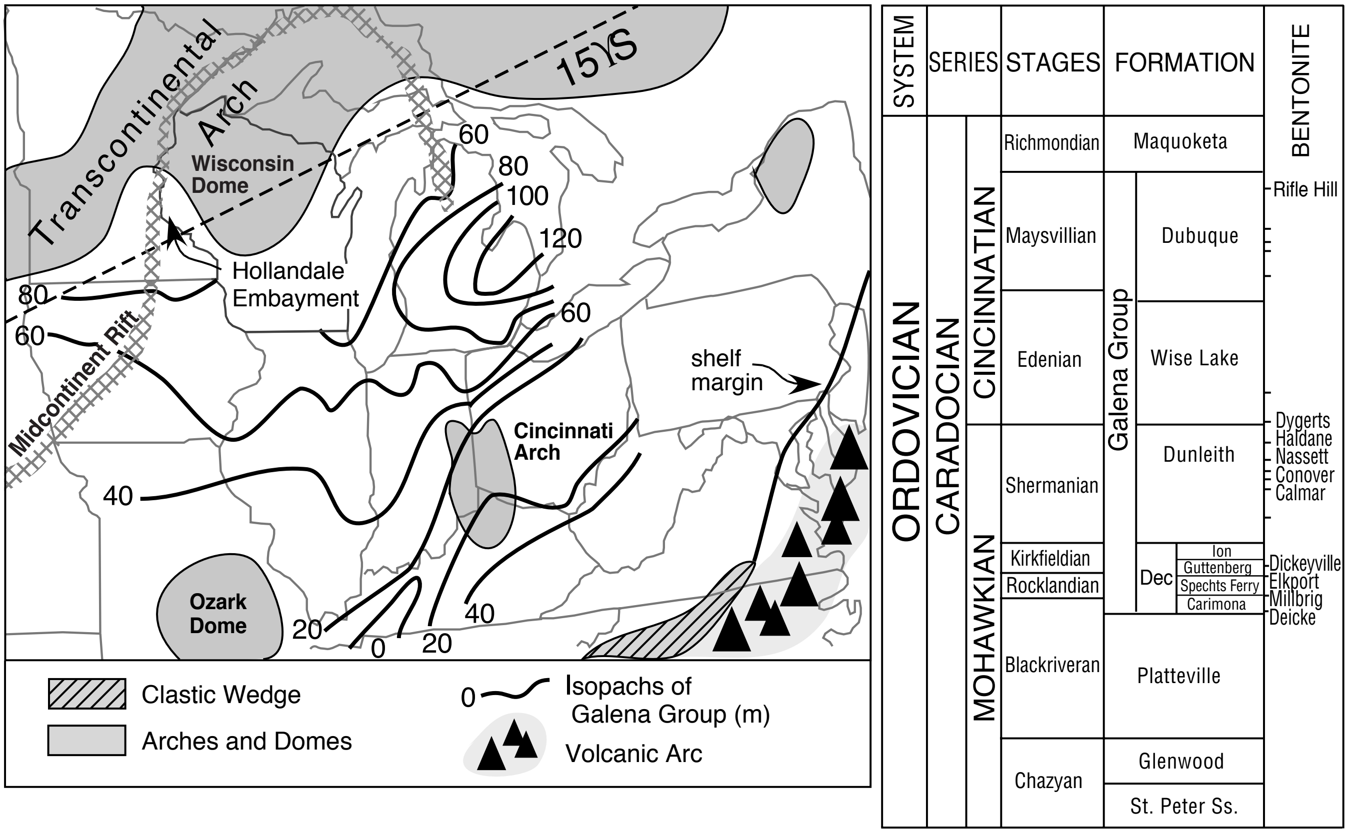
Ordovician carbonates and sandstones cover much of southern Wisconsin and large parts of the Upper Midwest. Geological surveys of different states have studied these rocks in great detail and subdivided the succession into stratigraphic units as thin as three feet and the stratigraphic lingo is rich in names that change from state to state.

Many Badgers have worked these rocks from the stratigraphic, sedimentologic and paleontologic point of views (see review of theses, following). Together with C.W. Byers and students (in specific Luke Choi, Norlene Emerson and Liz Leslie) we have revisited the geology of the entire Galena and in specific of the Decorah Formation integrating bentonite stratigraphy, paleontology, stable and radiogenic isotopes, and lithostratigraphy. Below is a summary of recent work in which we re-evaluate the Middle Ordovician stratigraphy of the upper midcontinent based on a new k-bentonite correlation within the Hollandale Embayment, (2) provide a comprehensive depositional model where inherited topography and run-off budget play major roles in the depositional history, and (3) review data supporting a complex oceanographic setting within the midcontinent epeiric sea.

Geologic and Stratigraphic Setting

During the Middle and Late Ordovician, the North America craton experienced one of the largest episodes of marine flooding which resulted in extensive carbonates being deposition across much of the continent (Witzke, 1980; Witzke and Kolata, 1988). The continent had a subequatorial position and contained numerous tectonic flexures that gave the Ordovician epeiric sea a complex structure (Fig. 1).

The stratigraphy of the Middle Ordovician in the midcontinent (Fig. 1) starts with a craton-wide karst unconformity (Dott et al., 1986) overlain by the St. Peter Sandstone. A shift to carbonate lithofacies occurred with the deposition



SYSTEM	SERIES		STAGES	FORMATION		BENTONITE
ORDOVICIAN	CARADOCIAN	CINCINNATIAN	Richmondian	Maquoketa		
			Maysvillian	Galena Group	Dubuque	Rifle Hill
			Edenian		Wise Lake	
		MOHAWKIAN	Shermanian		Dunleith	Dygerts Haldane Nassett Conover Calmar
			Kirkfieldian		Dec: Ion Guttenberg	Dickeyville Elkport
			Rocklandian		Dec: Spechts Ferry Carimona	Millbrig Deicke
			Blackriveran	Platteville		
			Chazyan	Glenwood St. Peter Ss.		

Fig. 1. Geologic setting for the midcontinent eastern U.S. showing major tectonic flexures, and depositional patterns for the Middle to Upper Ordovician Galena Group. Note positon of the Hollandale Empayment between the Transcontinental Arch and Wisconsin Dome coincident with the subsurface Proterozoic failed rift system (modified from Sims et al. 1993). Generalized isopachs of the Galena Group following Witzke and Kolata (1988), Kolata et al. (2001), and Hohman et al. (1998)). Chronostratigraphy following Templeton and Willman (1963). D-bentonites from Kolata et al. (1986).

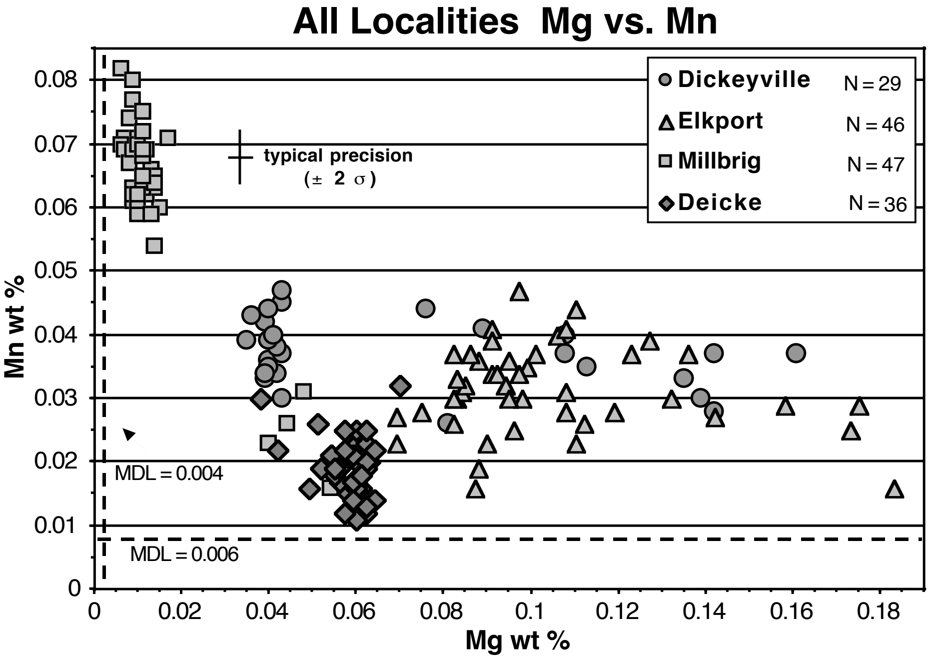


Fig. 2. Plot of Mg vs. Mn (elemental wt %) of all apatite grains analyzed using EMPA. MDL=minimum detection limits. Each data point represents probe values averaged from 3-5 points taken from a single grain. See Emerson, 2002 for sample locations and complete probe results for each grain.

of the Platteville Formation (Willman and Kolata, 1978; Leverson and Gerk, 1983; Delgado, 1983). The overlying lower portion of the Galena Group (Decorah Formation) is a mixed shale-carbonate unit while younger formations (Dunleith, Wise Lake and Dubuque) are composed of thin carbonates containing abundant hardgrounds and minor to no shale. The youngest Ordovician strata in the area correspond to the shales of the Maquoketa Formation.

We have focused our work in the Decorah Formation as it reflects the interplay between continental flooding and weathering of exposed land, is fossiliferous and contains a brachiopod disappearance involving 32 species, contains closely spaced k-bentonites that provide chronostratigraphic control and tight temporal correlation.

K-Bentonite Correlation

Four regionally widespread k-bentonite layers (Wilman and Kolata, 1978) are located within the Decorah Formation (Fig. 1). They were identified and correlated in the field based on their position and relationship within the surrounding strata (Emerson, 2002). Correlation was further supported by “fingerprinting” of the k-bentonites on the basis of the geochemical composition of apatite phenocrysts contained within the altered ash beds. Figure 2 shows the clear separation of the different k-bentonite apatite phenocrysts into four unique clusters and making them k-bentonites distinguishable time-horizons across the studied region.

Sedimentology and Sequence Stratigraphy

The Decorah Formation is bound below and above by sequence boundaries that mark abrupt major regional lithologic and environmental changes. The integration of the k-bentonite and lithologic correlations allows for the subdivision of the Decorah Formation into two major sedimentary wedges, a lower shale and an upper carbonate (Fig. 3). These two wedges have a compensating relationship with the shale thinning southeastward and the carbonate thinning northwestward. The shale facies occurs primarily within the Hollandale Embayment and thins against the Wisconsin Dome. The overlying carbonate facies extends more up-ramp onto the Wisconsin Dome and becomes thinner, less grainy and shalier northwestward (down-ramp) into the Hollandale Embayment. The inverse relationship occurs during deposition of the younger carbonate-rich wedge. This correlation (Fig. 3) is different from previous interpretations of interfingering between shales and carbonates (Kolata et al., 1987, 1998, 2001; Witzke 1988; Ludvigson et al., 1996).

Brachiopod Biostratigraphy

Brachiopod specimens collected and identified from the Decorah Formation reveal that most species have FADs (first appearance datum) and LADs (last appearance datum) within the Decorah Formation and do not have ranges that cross sequence boundaries (Emerson, 2002). SHE diversity analyses show that a rather stable community structure existed throughout deposition of the Decorah and that the most pronounced change occurred at the upper sequence boundary rather than within the sequence (Emerson, 2002). Multivariate statistical cluster analyses using Jaccard, Baroni-Urbani Buser, and Pearson similarity coefficients resulted in establishing two major clusters reflecting the shale- verses carbonate-rich lithofacies change (Emerson, 2002). These results were interpreted to indicate that both biofacies and lithofacies patterns reflect a close link between environmental shifts and faunal change.

Decorah Isotopic Record

$\delta^{13}C$ profiles of the Decorah Formation have been developed from numerous sites in NE Iowa (Hatch et al., 1987; Ludgivson et al., 1996; Ludgivson et al., 2000; Smith et al., 2000). The bulk stable isotope values from rocks deposited near the edge of the Wisconsin Dome show a positive $\delta^{13}C$ excursion of approximately 3‰ (Hatch et al., 1987; Ludgivson et al., 1996). The excursion appears to start below the Millbrig k-bentonite and peaks near the transition between the shale and carbonate wedges, near the position of the Elkport k-bentonite (Fig. 4). High TOC (up to 50%) and high concentrations of *G. prisca* occur above the Elkport k-bentonite after the increase in, and in part overlapping with, the $\delta^{13}C$ excursion (Jacobson et al., 1995; Pancost et al., 1998, 1999). The more expanded sections deposited in the Hollandale Embayment to the northwest corroborate that the $\delta^{13}C$ increase started between the Deicke and Millbrig k-bentonites and peaks near the Elkport k-bentonite position (Ludvigson, personal communication). These sections also show an interruption in the excursion with more negative $\delta^{13}C$ values within the interval with high concentrations of phosphate granules (Fig. 4). Within this interval visual estimates indicate little or no presence of *G. prisca* in the sections.

Decorah Depositional Model

The Decorah was deposited within a ramp environment (Ludvigson et al., 1996; Choi et al., 1999; Kolata et al., 2001) between the Wisconsin Dome and the Transcontinental Arch. Two depositional stages are identified. During an early stage the Transcontinental Arch was exposed and runoff from the land supplied clastic sediment that accumulated at depth within the Hollandale Embayment and thinned southeastward onto the Wisconsin Arch. Our interpretation is that freshwater runoff needed to bring the clays into the basin created a salinity-stratified water column in the epeiric sea. This led to times of dysoxic conditions.

Soon after deposition of the Elkport k-bentonite, relative flooding of the Transcontinental Arch greatly diminished the supply of both clastic sediments and freshwater. The salinity stratification broke down, oxygenating the sea floor, and permitted carbonates to form on the Wisconsin Dome. We hypothesize that the improved water clarity expanded the photic zone and increased primary productivity greatly allowing for the anomalous organic content and increased *G. prisca* deposition. It is possible that *G. prisca* behaved like modern phytoplankton with concentrations highest at the chlorophyll maximum (the maximum concentration of phytoplankton).

The oceanographic changes that allowed for the switch from shale to carbonate deposition increased the penetration of light at depth and accelerated photosynthesis, producing seasonal blooms of *G. prisca* and burial of organic matter. The favorable conditions for high phytoplankton productivity lasted during the lower part of the carbonate wedge (Figs. 3 and 4). It appears that conditions degraded as both the potential for preservation of organic matter diminished (as oxic sea floor conditions increased) and the carbonate production increased, diluting organic matter found in the carbonate sediment. These local conditions in the Hollandale Embayment coincide with the regional and probably global $\delta^{13}C$ excursion, but appears to be an independent event as there is a time lag between the two processes (Fig. 4).

Correlation of the Iowa $\delta^{13}C$ excursion with one observed in Pennsylvania (Patzkowsky et al., 1997) as well as the, ε_{Nd} values and Sm/Nd ratios recorded in conodont and

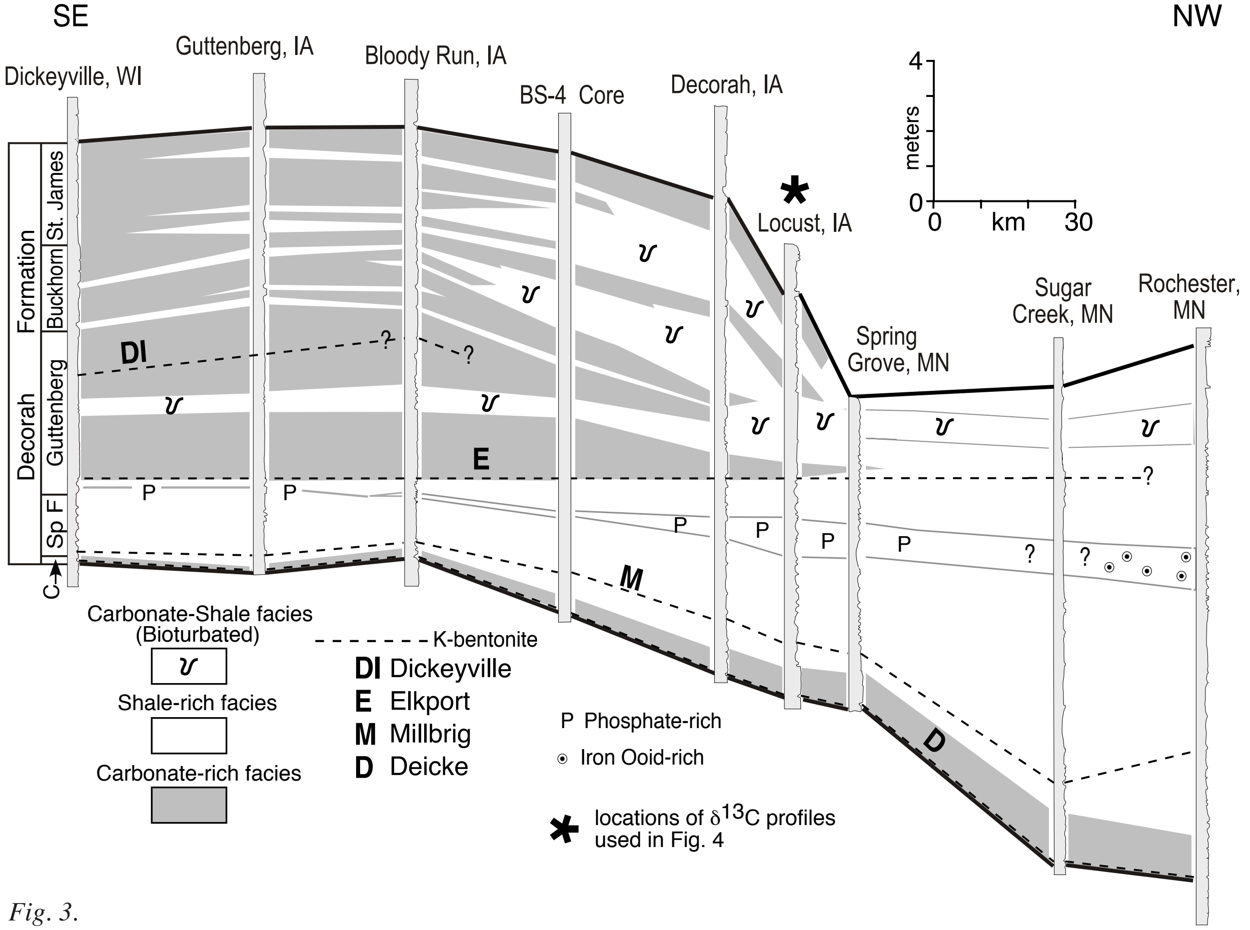


Fig. 3.

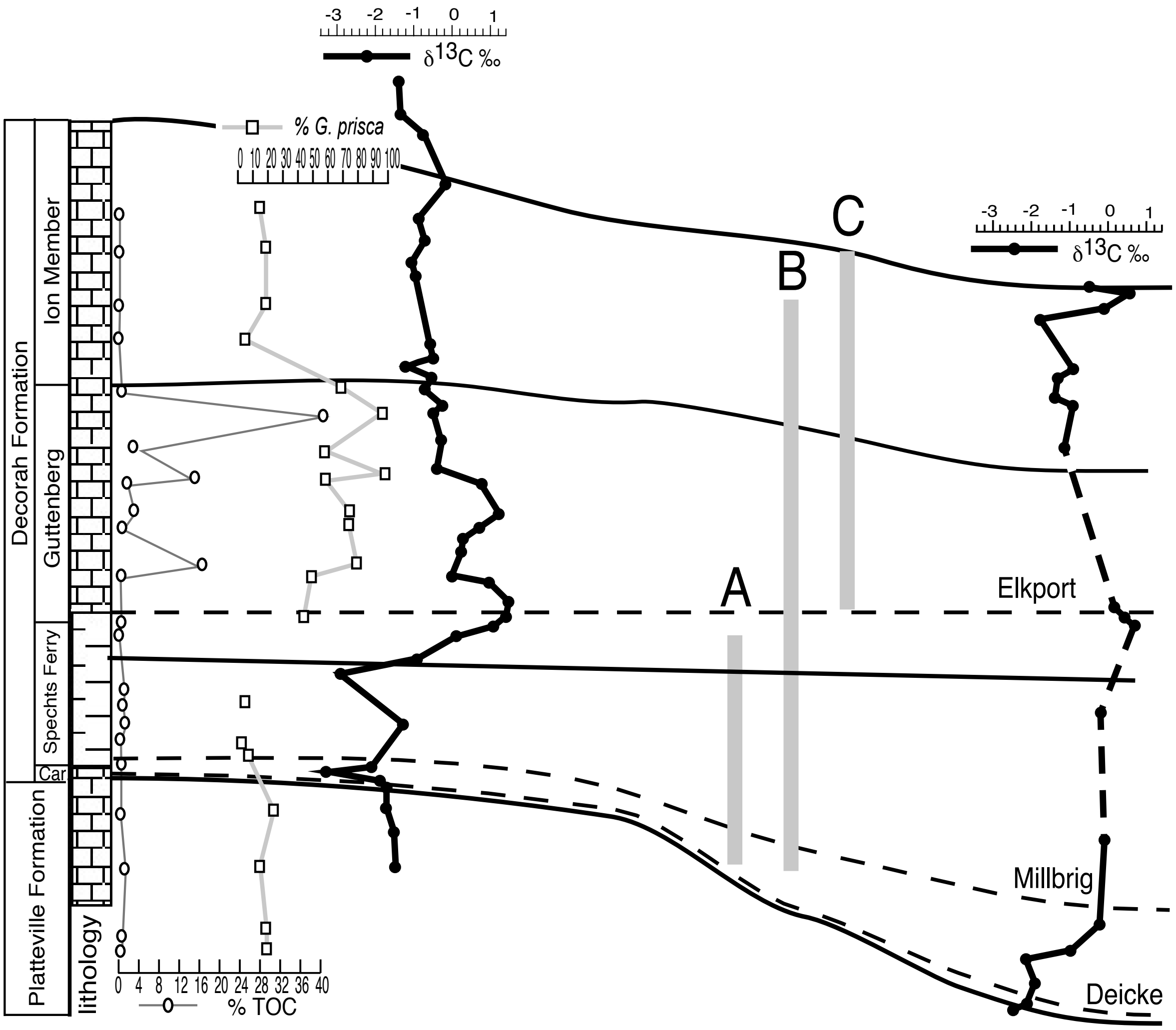


Fig. 4

carbonate samples collected throughout eastern and central North America between the Millbrig and Deicke k-bentonites (Holmden et al., 1998) suggest different water masses for the midcontinent and eastern North America. It is our interpretation that during deposition of the Decorah Formation, the Ozark and Cincinnati Domes were connected by a shallow sea that physically isolated the midcontinent cratonic interior epeiric sea from the eastern North America open shelf (which evolved into a foreland basin). This scenario indicates that the North America Ordovician epeiric sea was not necessarily a continuous sea but rather subtle topographic changes divided the flooded continent into different depositional areas with distinct physical, biological and chemical signatures. Subtle topography exerted important changes in that it modified storm currents and restricted circulation within the sea in such a way that small variations in runoff and evaporation may have drastically changed the water chemistry resulting in major facies and faunal changes.

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