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J. M. Cains

University of Arkansas, Fayetteville, jmcains@uark.edu

A. Potra

University of Arkansas, Fayetteville

E. D. Pollock

University of Arkansas, Fayetteville

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Lower Mississippian Chert Development, Southern Midcontinent Region

J.M. Cains*, A. Potra, and E.D. Pollock

Department of Geosciences, University of Arkansas, Fayetteville, AR 72701

*Correspondence: jmcains@uark.edu

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Abstract

The Lower Mississippian Boone Formation is a chert-bearing, fossiliferous limestone typically 100-115m. thick forming the Springfield Plateau across the tri-state region of northwestern Arkansas, southwestern Missouri, and northeastern Oklahoma. The Boone represents the maximum flooding, highstand, and regressive intervals of a single, third order transgressive-regressive carbonate cycle bounded by regional unconformities. Two types of chert occur in this formation, and provide the basis for subdivision of the Boone into informal lower and upper members in northern Arkansas. The lower Boone represents early Osagean maximum flooding conditions and consists of calcisiltites with interbedded dark, nodular chert. This chert exhibits compaction phenomena and shrinkage fractures, indicating a penecontemporaneous origin from reorganization of silica immediately below the sediment water interface prior to lithification of the carbonate sediments (Manger et al. 1988a). The upper Boone represents late Osagean highstand and regression and consists primarily of carbonate grainstones and packstones (Shelby 1986). This interval contains white, later diagenetic chert, interpreted as a groundwater phenomenon in which silica has replaced lithified carbonate along its bedding planes, replicating the fabric of the limestone (Manger and Shelby 2000). This later diagenetic chert replacement favors the finer grained intervals and replicates the fabric of the limestone being replaced.

Previous studies have shown that the penecontemporaneous chert typically comprises 40-50% of the lower Boone interval, while the later diagenetic chert contribution to the upper Boone ranges from 30-95% (Liner 1979). Understanding chert development is unsettled, and has been the subject of debate, primarily involving the source of the silica producing the chert, and the mode of formation of the chert-bearing intervals. Geochemical analyses suggest a volcanic rather than biogenic source for the silica in the Boone Formation.

Introduction

The Lower Mississippian Boone Formation is a succession of chert-bearing limestones deposited on a carbonate platform called the Burlington Shelf (Lane 1978). This succession in northern Arkansas reflects production of carbonates within effective wave base and subsequent transportation and deposition of excess sediment down ramp. There are two types of chert development in the Boone Formation that can be easily identified in outcrop and hand sample—penecontemporaneous and later diagenetic chert. Historically, Boone chert development has been attributed to a biogenic source (Hesse 1990). This study suggests that the primary silica source for the chert is more likely volcanogenic.

Geologic Setting

The geology of the southern midcontinent is dominated by the Ozark Dome, a broad, asymmetrical cratonic uplift (Manger et al. 1988b). A sedimentary section of Cambrian through Pennsylvanian units dips radially away from the Precambrian core (Manger et al. 1988b). Northeastern Oklahoma and northern Arkansas make up the south and west flanks of the dome, where beds are regionally dipping less than one degree (Chinn and Konig 1973). A series of major *en echelon* normal faults trends northeast-southwest, and are downthrown on the southeast (Manger et al. 1988b).

Three broad plateau surfaces are developed away from the center of the Ozark Dome, and include the Salem, Springfield, and Boston Mountains Plateaus. The Salem Plateau consists of Ordovician rocks, primarily limestones, dolomites, and orthoquartzitic sandstones exposed across much of southern Missouri and adjacent northern Arkansas. The Springfield Plateau comprises a thin and sporadic Silurian and Devonian section, succeeded by a thick, pervasive Lower Mississippian section at its top. The Boston Mountains Plateau includes Upper Mississippian through Middle Pennsylvanian strata (Manger et al. 1988b).

Lithostratigraphy

Differences in lithostratigraphic nomenclature exist within the tri-state area of northwestern Arkansas, northeastern Oklahoma, and southwestern Missouri. The term Boone is the oldest valid designation for the chert-bearing limestone in the southern midcontinent, the name being credited to J.C. Branner in 1891 for Boone County, Arkansas. Arkansas is the only state to formally use the name Boone, whereas the equivalent chert-bearing carbonate interval in Missouri is divided into three formations (ascending order): Reeds Spring, Elsey, and Burlington-Keokuk (Manger and Thompson 1982). In Oklahoma, this interval is designated the Reeds Spring and overlying Keokuk Formation (Huffman 1958). Recently proposed revisions in Oklahoma promote use of the names Reeds Spring and overlying Bentonville Formation, presumably separated by an unconformity (Mazzullo et al. 2013). The Boone Formation in northern Arkansas is subdivided informally into lower and upper members primarily based on chert content, but the transition from lower to upper Boone is also marked by a change to coarser-grained lithologies (Shelby 1986).

Fig. 1. Penecontemporaneous chert (dark blue-gray) within limestone (light gray) in the Boone Formation near Hindsville, Arkansas.

Penecontemporaneous chert in the lower Boone is dark, nodular, and poorly bedded. It disrupts the bedding of the limestone and exhibits compaction features and shrinkage fractures, indicating it was deposited prior to lithification of the limestone (Manger et al. 1988a). This type of chert is exclusive to the lower Boone, which represents the maximum flooding interval of a third order, eustatic cycle and consists of fine-grained calcisiltites (Shelby 1986). The chert is associated with deeper water settings during the maximum flooding interval, and understanding its

formation involves understanding the transition of opaline silica to cryptocrystalline/ microcrystalline quartz. Through evidence recovered by the Deep Sea Drilling Project, it is known that silica experiences the following diagenetic maturation sequence: opal-A (A = amorphous) (siliceous ooze) → opal-CT (CT = cristobalite and tridymite) (porcelainite) → chalcedony (micro-fibrous quartz) → cryptocrystalline/ microcrystalline quartz (chert) (Kastner et al. 1977).

Fig. 2. Upper Boone later diagenetic chert (white) replacing crinzoan packstones/wackestones (dark gray) near Fayetteville, Arkansas.

Later diagenetic chert in the upper Boone interval is white to light-gray, fossiliferous, and follows limestone bedding planes (Fig. 2)(Manger et al. 1988a). This chert results from groundwater replacement of carbonate lithologies by silica, favoring the finer grained intervals due to greater surface area, and maintaining the fabric of the limestone (Manger et al. 1988a). Larger grains and bioclasts remain unaltered for the most part, with silicification fronts visible in thin section showing that replacement is incomplete (Manger et al. 1988a).

The idea of a volcanic silica source for chert is not a new one—it was cited by W. A. Tarr in 1926, among others. Goldstein (1959) stated that extrusive volcanism is the only sufficient source for the large amounts of silica present. Other previous explanations involve the remobilization of hard parts of siliceous micro-organisms, particularly sponge spicules (Hesse 1990), or aeolian deposition of siliceous sediments based on correlation between episodes of paleoaridity and chert occurrences (Cecil 2015). Tarr (1926) attributed silica in marine environments to input from continental weathering and transportation by rivers and streams.

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Methods

A total of 40 chert samples were collected at 1.52 m. (five-foot) intervals from Boone roadcut exposures in Bella Vista, Arkansas; Pineville, Missouri; and Elkins, Arkansas. Chips were collected from samples and photographed under a Scanning Electron Microscope. Energy dispersive x-ray (EDX) was used to determine the surface elemental composition.

Seven samples were selected for trace element geochemical analyses. Each sample was cut into slabs, washed with deionized water, wrapped, and broken into pieces so that innermost, unaltered chips could be finely powdered using a shatter box. Samples were dissolved via a MARS 5 microwave digestions system from CEM Corporation using the sand digestion method utilizing HF, HCl, and HNO₃, under extremely high temperatures. A boric acid solution was used to neutralize the acids, and each was diluted by 10x. Finally, each sample was analyzed using the iCAP Quadrupole Inductively Coupled Plasma Mass Spectrometer (Q-ICP-MS).

Kelemen et al. (2004) published a comprehensive review of subduction-related magmatic arc geochemistry by compiling data from multiple sources. Included in these data are the specific trace element and rare earth element (REE) values associated with different arc types. Trace element and REE concentrations of the chert in the Boone Formation were compared to show whether there is a relationship between certain arc types and this chert. Trace element and REE data collected from the Q-ICP-MS were normalized to the compositional values of average primitive arc andesites for four different arc types: continental, intra-oceanic (Aleutian), boninites, and oceanic. Normalized values were plotted for each sample for each arc type on a log scale. Elements plotting near a value of one indicate similar concentrations.

Results and Discussion

Samples analyzed with EDX consistently showed the elevated presence of both aluminum and potassium in the chert, indicating possible volcanic input. Fig. 3 displays trace element concentrations normalized to average continental arc concentrations of the corresponding elements. For both continental arcs (Fig. 3) and intra-oceanic arcs (Fig. 4), ratios vary slightly, but ultimately plot near one, indicating volcanic input. The oceanic arc plot is not considered due to lack of

comparable data points. The similarity of the concentrations of these elements within the Boone chert and volcanic arcs strongly suggests a relationship between the two. These data point to volcanism as a silica source for the chert.

Fig. 3. Trace elements in Boone chert normalized to average continental arc values. B2, B5, and B7 are penecontemporaneous chert. B8, B9, B10, and B11 are diagenetic chert.

Fig. 4. Boone chert trace elements normalized to average intra-oceanic (Aleutian) arc composition.

Similar elemental compositions between the penecontemporaneous chert of the lower Boone and later diagenetic chert of the upper Boone indicate these two chert types likely share the same silica source. Penecontemporaneous chert likely formed from the mobilization and reprecipitation of silica derived from volcanic ash. This ash would have fallen through the water column and subsequently was reorganized to form amorphous silica below the sediment-water interface prior to carbonate lithification. Since the

diagenetic chert is a replacement phenomenon, it is unlikely to have been derived from a biogenic source or direct silica precipitation. More likely this chert is a reflection of ash being dissolved and incorporated into groundwater, allowing replacement of the finer-grained carbonates by silica to occur.

Conclusions

Trace element concentrations clearly indicate that a subduction-related, extrusive volcanic source was involved in generating the chert in the Boone Formation (see also Philbrick et al., this volume). The ratios of trace elements between the chert samples and average arc values are highly comparable. Since the ratios plot near one for each arc type, there are not enough data to draw a conclusion on which specific arc type sourced the silica in the Boone Formation. The magmatic arc producing this ash likely formed from the collision of Laurasia and Gondwana that caused the Ouachita Orogeny. Increased volcanism associated with this orogeny would certainly be capable of producing the necessary amount of silica to account for the chert in the Boone Formation.

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