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EACan “Volcanic Tephra Fall” Replace “Sea Level Transgression” as the Dominant Driver for Organically Enriched Rock Formation and Their Cyclic Deposition at the Well-Studied Cenomanian-Turonian Boundary (OAE2; 93-94 Ma)?*

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Abstract

“The presence of volcaniclastic sediments within the OAE2 interval in the subtropical North Atlantic is consistent with a major phase of explosive volcanic activity in the Caribbean and other regions.” (Huber et al., 1999). “Major periods of volcanism {in western North America—DMP} peaked in the Cenomanian.” (Christiansen et al., 1994). Bentonite deposits are recognized at the C/T Boundary at Black Mesa, AZ and in the Mancos Shale. The USGS study of the Utah Mancos Shale concluded, “It is enriched in uranium, copper, silver, vanadium, mercury, arsenic and, to a certain extent, gold. The metals probably came in with the volcanic tuffs that compose much of the Mancos itself.” (Marlatt, 1991). The GSSP for the C/T Boundary is near Pueblo, Colorado. Glenister et al. (1985) compared the regressive facies to the transgressive facies and noted that the transgressive facies contained abundant volcanic ash, many more disconformities, and was more organically enriched. The Mowry Shale (part of the Greenhorn Cyclothem) has been commercially mined for bentonite in Montana. The Niobrara “cyclothem” contains hundreds of ash layers (Sonnenfeld et al., 2016). Therefore, at least two Cretaceous Seaway sea level cycles were times of large-scale ash deposition. The Eagle Ford was deposited at the same time as the Greenhorn Cyclothem. Eldrett et al. (2013) states, “The Eagle Ford Formation consists of a succession of calcite-rich mudstones (marls and limestones) and over 300 volcanic bentonite layers.” Frebourg et al. (2016) stated about the Eagle Ford/Boquillas system, “The co-occurrence of volcanic ash beds and globigerinid-rich sediments suggests that most nutrient input was associated with ash depositions. The cyclic alternations of globigerinid argillaceous wackestones and pelagic grainstone deposits thus appear to be primarily controlled by volcanogenic nutrient input instead of other climate or sea level–driven processes.” Volcanic ash fall as a mechanism for organically enriching rock is consistent with what we observe near the Cenomanian-Turonian Boundary worldwide, including the well-studied rocks of the Greenhorn Cyclothem.

Introduction

The Global Stratotype Section and Point (GSSP) for the Cenomanian-Turonian Boundary is the “Greenhorn Cyclothem” section near Pueblo, Colorado, in the western United States. It has traditionally been interpreted to represent one third-order cycle of sea level transgression and regression. The cause of the organic enrichment of the rocks in this stratigraphic section has been attributed to that sea level transgression. But some geoscientists now believe that volcanic ash fall, and not sea level change, is the mechanism by which organics are enriched and preserved in sedimentary rocks (Zimmerle, 1985; Parker, 2017; Lee et al., 2018).

Can volcanic ash fall be the organic enrichment mechanism for sediments near the Cenomanian-Turonian Boundary worldwide? Is volcanic ash fall consistent with observations at the much-studied Cenomanian-Turonian Boundary? Because the emplacement of Large Igneous Provinces (LIPs) is coincident with, and considered by many to be the trigger for Oceanic Anoxic Events (OAEs), is there a link between the volcaniclastic component of any known LIP and the organic enrichment of rocks at OAE2, the Cenomanian-Turonian Boundary (Bonarelli Event, OAE2; Late Cretaceous 93-94 Ma)?

Methods

A search of the published literature has identified data that supports the thesis that sizable, largely unrecognized volumes of volcanic ash has fallen episodically in earth’s history. This new paradigm better explains what is observed at times of Oceanic Anoxic Events than other existing theories, such as those including the upwelling of nutrient-rich water, reduced oceanic circulation causing anoxia, and increased seasonality causing enhanced primary productivity. This poster addresses whether this new paradigm applies to the OAE2 at the Cenomanian-Turonian geologic boundary, one of the most thoroughly studied of all the OAEs.

Results

The link between the OAE2 and the emplacement of three LIPs has been made. Kuroda et al. (2007) looked at organic carbon and lead isotope compositions within the Italian Bonarelli Black Shale (Livello Bonarelli black shale -- Marche-Umbrian Apennines of Italy). “These data suggest a rapid, substantial increase in the relative supply of silicate minerals from the two LIPs (Caribbean and Madagascar flood basalts). Massive subaerial volcanism associated with LIP formation provides an explanation for these two isotopic geochemical signals via release of a huge amount of carbon dioxide (~ 105 Gt CO_2) and particulate materials into the atmosphere, which resulted in a rapid negative shift of δ13C in seawater, and changes in Pb isotopic compositions in the silicate sediment fraction. We interpret that massive volcanism triggered significant climatic changes, inducing biotic crises and oceanic anoxia.” (Kuroda et al., 2007).

Possible LIP triggers for OAE2 include the Caribbean and Madagascar LIPs (documented by Kuroda, 2007; and Huber, 1999) and High Arctic Large Igneous Province (Schroder-Adams, et al., 2019).

There is evidence of volcanic sedimentation across the C/T Boundary in the Atlantic Ocean. “The presence of volcaniclastic sediments within the OAE2 interval in the subtropical North Atlantic is consistent with previous suggestions that the C/T Boundary was a time of anonymously high rates of CO_2 flux into the atmosphere and oceans during a major phase of explosive volcanic activity and large igneous province emplacement in the Caribbean and other regions worldwide." (Huber, 1999).

"Mafic volcaniclastics make up a significant fraction of Large Igneous Province eruptive volume, including in the Siberian (~251 Ma), Emeishan (~261 Ma), North Atlantic (60-55 Ma), Karoo (183 Ma), Ferrar (183 Ma), and Columbia River basalts (~17-14 Ma)." (Ukstins-Peate et al., 2009 – geologic ages inserted).

But volcanism across the C/T Boundary was not limited to oceanic plateau emplacement. Explosive volcanism was extensive in western North America. Western North America was east of a volcanic island arc at this time (Figure 1). The Mesozoic Era of the Western Interior of the United States was dominated by sedimentation in shallow marine and continental settings behind a magmatic arc developed along the western margin of the continent. After compiling the ages of rocks from different discrete ash beds, either analcime-rich or bentonitic mudstones, Christiansen et al. (1994) concluded that, "Major periods of volcanism occurred during the Late Triassic (about 225 Ma), during the Middle Jurassic (about 160 to 140 Ma), and during two periods in the Late Cretaceous, peaking in the Cenomanian (about 95 Ma) and again near the Campanian-Maastrichtian boundary (about 75 Ma)."

The position of North America east of a volcanic arc meant volcanic tephra deposition was aerially extensive at the Cenomanian-Turonian Boundary. Bentonite deposits are recognized at the C/T Boundary near Black Mesa, AZ. The Cenomanian/Turonian stage boundary occurs within the 54.6-meter thick lower Mancos Shale. The lower shale is composed of bioturbated, highly calcareous shales with numerous prominent bentonites, calcisilts, and several concretion horizons." (Kirkland, 1996).

The Utah Geologic and Mineral Survey contracted a study of metals in the Utah Mancos Shale and concluded, "During deposition it appears to have acted as a sink for various metals. It is enriched in uranium, copper, silver, vanadium, mercury, arsenic and, to a certain extent, gold. The metals were probably deposited contemporaneously with the shale, coming in with the volcanic tuffs that compose much of the Mancos itself." (Marlatt, 1991).

The Global Stratotype Section and Point (GSSP) for the Cenomanian-Turonian Boundary (C/T Boundary) is the Rock Canyon anticline sequence near Pueblo, Colorado. Its transgressive facies consist of the Muddy Sandstone, Mowry Shale, Graneros Shale, and the Greenhorn Formation through the Middle Bridge Creek Limestone Member. Glenister et al. (1985) compared the regressive facies to the transgressive facies and noted that the transgressive facies contained abundant volcanic ash, many more disconformities, and was more organically enriched.

The Mowry Shale (a part of the transgressive facies of the Greenhorn Cyclothem) has been commercially mined for bentonite in the "Hardin District" of Big Horn County, Montana. (District is mostly within the Crow Indian Reservation and includes Custer Battlefield National Monument).

The cyclothem overlying the Greenhorn Cyclothem, the Niobrara "cyclothem" including the Niobrara Formation, contains hundreds of ash layers identified by Sonnenfeld et al. (2016) when they looked at its mechanical properties. Therefore, at least two of the Cretaceous Interior Seaway transgressive sea level cycles were also cycles of large-scale volcanic ash deposition.

The Eagle Ford/Boquillas Formation of south Texas was deposited at the same time as the Greenhorn Cyclothem further north. Eldrett et al. (2013) state, "The Eagle Ford Formation consists of a succession of calcite-rich mudstones (marls and limestones) and over 300 volcanic bentonite layers." Ozkan et al. (2014) also recognized more than three hundred interbedded volcanic ash beds throughout the section in the Maverick Basin." Frebourg et al. (2016) stated in their discussion of the Eagle Ford/Boquillas system, "Although it is possible that some nutrients were delivered to the basin by non-volcanogenic processes, the co-occurrence of volcanic ash beds and globigerinid-rich sediments suggests that most nutrient input was associated with ash deposition. The cyclic alternations of globigerinid argillaceous wackestones and pelagic grainstone deposits thus appear to be primarily controlled by volcanogenic nutrient input instead of other climate or sea level–driven processes."

Lee (2018) described volcanic ash as a driver of enhanced organic carbon burial throughout the Cretaceous.

Discussion

The failure to appreciate the volume and significance of volcanic ash to organic enrichment, both within the Greenhorn Cyclothem and Boquillas/Eagle Ford, has likely contributed to the perception that sea level transgression causes the formation of organically enriched rocks.

In terms of sequence analysis, fine-grained, organic-rich facies do not always represent distal, quiet water deposition; nor do they represent deeper water deposition when they overlie sediments of dominantly carbonate composition. Instead, they more often represent episodic volcanic ash fall (and erosion-and-redeposition of altered ash from adjacent land masses) into the carbonate environment of the Cretaceous Seaway. The rise and fall of sea level must be re-evaluated and the conclusions about water depth determined only by those fossil assemblages diagnostic of sea level, and not by the relative coarseness of the clastic sediments or the relative carbonate richness of the sediments. Certainly, the layers of altered ash in a water body, in whatever volume it occurs, are not related to whether that water level is rising or falling.

Kauffman (1995) synthesizes available data to recognize that the C/T extinction event could better be described as a series of smaller events (Figure 2). Mr. Kauffman's contribution to examination of the Cenomanian-Turonian Boundary event is huge and is greatly appreciated.

The carbon isotope excursions, TOC variations, and "trace element enrichment levels" can be interpreted to oscillate more rapidly, beginning in the Late Cenomanian, with the onset of more frequent regional bentonite layers. Oscillations in these measurements are not likely to have a sea level trigger, as sea level is interpreted to be high throughout many Late Cenomanian and Early Turonian oscillations. These bentonites represent ash fall still found in layers. It is important to keep in mind Scudder's (2016) conclusion that much volcanic ash is not in layers but dispersed throughout the rock, and that dispersed ash is largely unrecognized and unquantified.

In discussing the relevance to today's climate change situation, Kauffman (1995) states, "In searching for a geological test case for the study of ancient global change with relevance to the modern Earth, the Cretaceous Period emerges as one of the best candidates. In particular, the Middle Cretaceous presents a unique opportunity to document and model dynamic changes in ocean-climate systems associated with a global mass extinction (Cenomanian-Turonian Boundary bioevent) in a greenhouse world, and then to compare these with the environmental and ecological crisis on the modern Earth as it potentially moves from an icehouse to a greenhouse state." Kauffman (1995) is therefore in agreement with most researchers in the scientific community.

This author believes there is something in the data Kauffman (1995) presents (see Figure 2) that makes the Cenomanian-Turonian, and all of the Cretaceous extinctions, significantly different and not good analogies to the earth's current climate situation. So far in earth's current climate change scenario, there has been no increase in local or regional volcanism, and no Large Igneous Province emplaced as a trigger for a corresponding oceanic anoxic event. The current increase in atmospheric CO2 is not a part of volcanic emissions that include global ash fall, and therefore that portion of the biotic extinctions that result from ash fall will not occur. The organic carbon burial of the Cretaceous, the key to hydrocarbon source rock creation (Zimmerle, 1985; Parker, 2017; Lee, 2018), also will not occur. Climate-ocean-atmospheric models which attempt to explain organic carbon burial and biotic extinctions without ash fall will likely be incorrect.

Conclusion

Volcanic ash fall as a mechanism for organically enriched rock formation is consistent with what we observe near the Cenomanian-Turonian Boundary worldwide, including the rocks of the GSSP for that boundary, those rocks of the Greenhorn Cyclothem.

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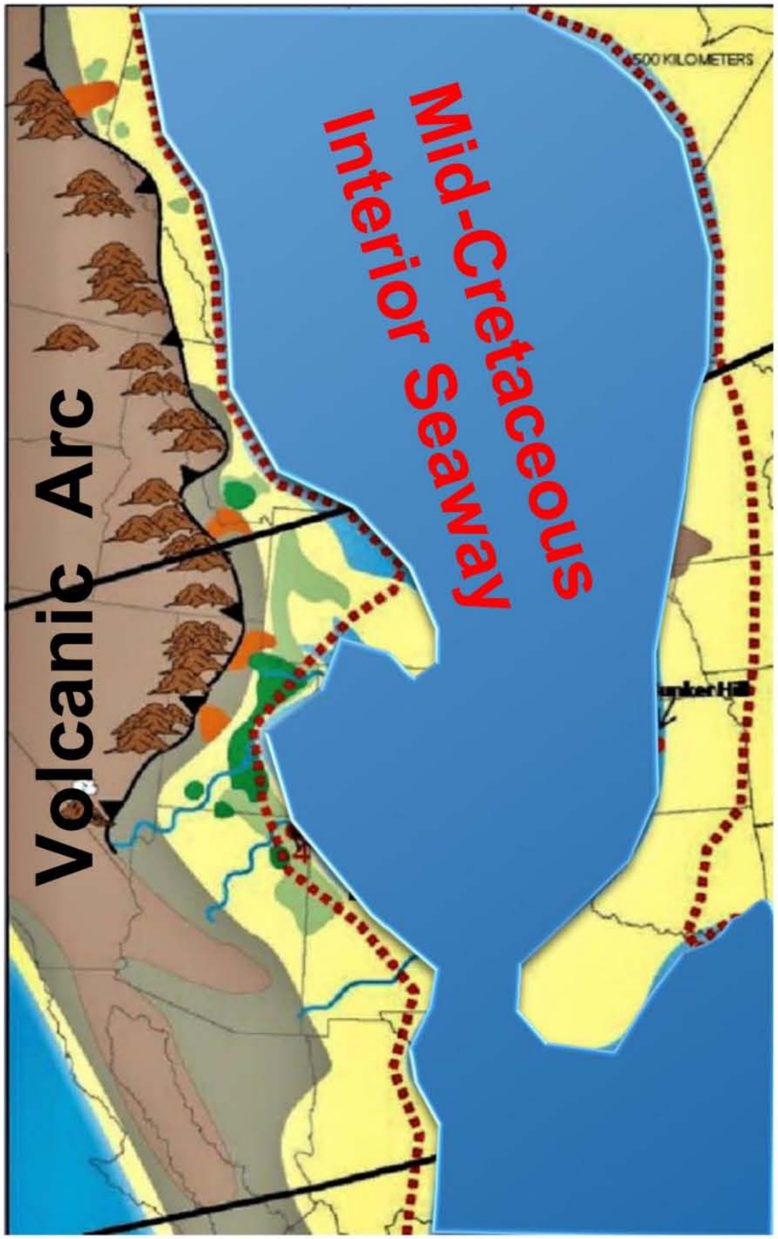

Figure 1. In North America, compounding the effects of global LIP volcaniclastics, was ash from an active volcanic arc west of the Interior Seaway. Volcanism extended from Triassic to Late Cretaceous peaking in the Cenomanian (95 Ma) and Campanian-Maastrician Boundary (75 Ma, Christianson et al., 1994). {Note: Volcanism episodically through the Oligocene - DMP}. Drawing Modified From: Shang, et al., 2018.

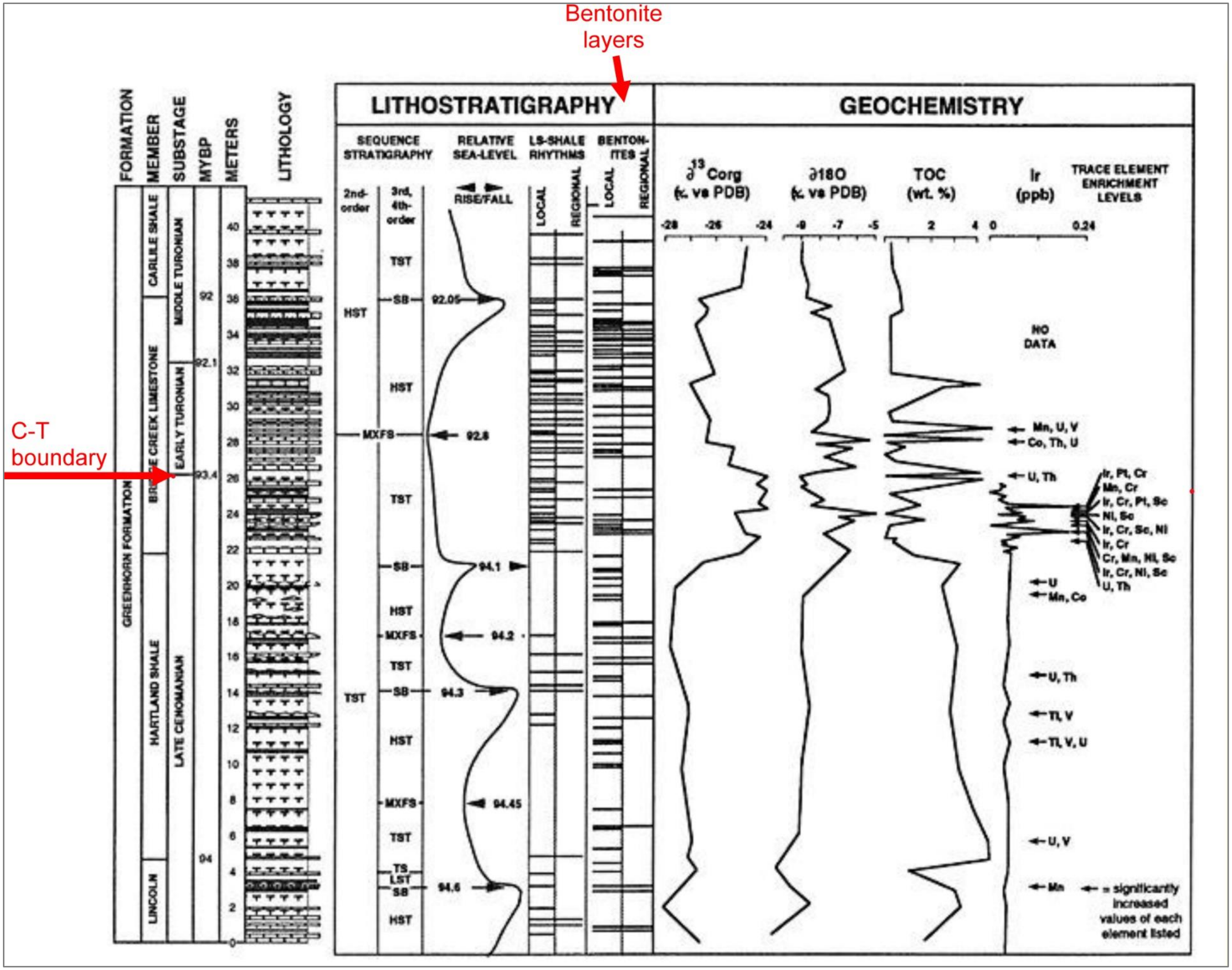

Figure 2. Sea level interpretation, bentonite layers, carbon isotope variation, TOC variation, and trace element enrichment levels across Cenomanian-Turonian Boundary, from Kauffman (1995).