Research on freshwater invertebrate fossils from the Florissant Formation as evidence for Eocene-Oligocene climate change

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Summary

The Florissant Fossil Beds, in the Colorado Front Range, are protected within a National Monument because of the exceptional preservation of plant and insect fossils found in this region. These fossils are preserved in the sedimentary rocks that comprise the Florissant Formation, dated as 34.07 $\pm$ 0.10 million years old (latest Eocene Epoch). The sedimentary rocks represent a large lake system that was adjacent to a contemporaneously active volcanic field. The extensive fossil flora consisting of exquisitely preserved leaf, flower, fruit, pollen and wood is well described and has been used to construct both paleo-temperature and paleo-elevation models for this part of the Rocky Mountains during a time of the Eocene-Oligocene boundary. This epoch boundary marks a shift from a globally warm climate to much cooler average global temperatures and greatly expanded polar ice sheets.

The fossil lake bed sediments also preserved a unique diatom assemblage that has been described. Diatom blooms preserve within paper thin shale layers as extensive algal mats in which the fossils were trapped. Together with the land plants, a diversity of insects and arthropods and a few vertebrates were also trapped and preserved within these paper shales. This CESU supported study focused on the lacustrine mollusks. The mollusks have not been studied since their description in 1906. In this study a taxonomic revision of the three sphaeriid bivalves and two pulmonate gastropods is established. Taphonomic and assemblage reconstruction of the mollusks found no differences in population dynamics but critical difference in shell preservation. Only one stratigraphic unit of the Florissant Formation, the caprock conglomerate, yielded unaltered shells. In the other units the calcium carbonate of the shells had been replaced by silica as the mollusks were trapped within the diatom mats. Calcium carbonate shells were utilized for stable oxygen and carbon isotopic analyses as a proxy for paleo-temperature and paleo-productivity of the lake during this critical time of climatic change.

Results of the stable isotope analyses were not conclusive but point to seasonal fluctuating temperatures and productivity and an additional input to the water system of hydrothermal fluids from the adjacent Thirtynine Mile volcanic field.

Introduction

This study focused on the paleoecology of molluscan fossils from Florissant Fossil Beds National Monument, Teller County, Colorado. Fossil are preserved in the rocks that represent a late Eocene (34 million years old) lake that was dammed by volcanic debris from the adjacent and contemporaneous Thirtynine Mile volcanic field. The Florissant Fossil Beds National Monument was created to conserve the spectacular plant and insect fossils preserved in these rocks. Fossils include giant redwood tree stumps and a very high floral diversity represented by leaves, flowers, cones, fruit and seeds, and pollen. An equally high diversity of insects and arachnids has been found as well as a few vertebrate fossils including fish, three birds and some mammal bones. Collections of fossils from Florissant are housed in museums across the U.S., and within the Monument (Meyer and Smith, 2008; Meyer, 2013).

This report is based on the document attached which was submitted to the University of Washington in partial fulfillment of an M.S. degree by Bret Buskirk (2014). Page numbers, tables and figures from this document are noted throughout this current report and all references to prior studies are listed within the References sections, pages 23-27. This attached document is not an official Thesis; however it is currently being prepared for submission to a peer-review journal.

Geological Setting

The Florissant Formation consists of lake and river deposited mudstones, shales and conglomerate units with a total stratigraphic thickness of 74 m (see attached report and figure 2 within). The sediments are predominantly derived from volcaniclastic debris flows, ash falls and redeposited volcanic debris (Evanoff et al., 2001; Meyer and Smith, 2008). The main source of the volcanic sediments was the nearby Thirtynine Mile volcanic field.

The best preservation of plant and animal remains is within the paper shales from the middle units of the Florissant Formation. A recent study of diatoms here showed that each paper shales lamination (millimeters in thickness) consist of a couplet of a layer of smectite clay and a layer of silica from diatom blooms, i.e. an algal mat (Benson et al., 2012). Each diatom bloom secreted mucilaginous biofilm which trapped fallen leaves and insects that then sank to the bottom of the lake. The exquisitely preserved fossils lie within this siliceous layer, which was then covered by a very thin terriginous clay layer. Mollusks that lived on the lake bottom or attached to aqueous plants were extremely thin shelled, and were also very well preserved within these paper shales.

Mollusks were also collected from the upper capstone conglomerate of the Florissant Formation (see attached document figure 2). This unit has been interpreted as the deposit of a volcanic debris flow (a lahar). Clams and snails in the lake were picked up and mixed into the upper part of this flow but were neither crushed nor altered.

Radiometric dates obtained from volcanic sanadine crystals (mean single-crystal $^{40}Ar/^{39}Ar$) indicate that the rocks are 34.07 $\pm$ 0.10 million years old, which is immediately before the Eocene-Oligocene epoch boundary. This geologic time period is characterized by a rapid change from a globally very warm climate with wide tropical belts to an “icehouse” climate with narrow tropical belts and an average drop in global temperature of ~7^{o}C (De Conto and Pollard, 2003; Pearson et al., 2009). This major global climate perturbation was first described from changing floras in western North America. The Florissant flora has been used in many studies to determine the paleo-temperature and paleo-elevation of this region of the Rocky Mountains, as elevation will affect temperature as much as global climates. Different paleo-temperature models based on the Florissant flora have yielded mean annual temperatures of 10.7^{O}C to 18^{O}C, and elevations from 305 m to 4133 m above sea level (see attached document Table 1). The need for further studies into the environmental setting of the Florissant Formation motivated this current study that used the mollusks to a) stabilize the taxonomies, and b) to utilize the biogenetic calcite for stable isotopic analyses that may indicate environmental conditions of the lake

Materials and methods

Molluscan fossils for this study were collected from two localities, P-9 and P-39, in the middle shale unit and one locality, P-16, in the caprock conglomerate. The fauna consists of three species of lacustrine bivalves from the Family Sphaeroidea, and two gastropod genera and species from the Family Planorbidae. Collections methods and methods for geochemical analyses of the shells are described in the attached document, pages 7, 14 and 17. All specimens are retained in the collections of the Florissant Fossil Beds National Monument.

Results

a) Taxonomy

These mollusk species were described by Cockerell in 1906 and no other study has been published since. A review of the taxonomies, upgrading their higher level placements, and a more complete description and photographs are provided for each species (see attached document, pages 7-11 and figures 3-5). Cockerell (1906) placed these mollusks within extant genera. However recent phylogenetic studies indicate that correct identification requires both shell and soft part characteristics, and molecular studies have shown cryptic species and inconsistently characterized higher-level taxonomic units. Generally, thin-shelled fresh water mollusks have few unique shell features and species level placement is very difficult.

The two Florissant gastropod species, *Gyraulus florissantensis* (Cockerell, 1906) and *Lymnaea (Stagnicola) scudderi* (Cockerell, 1906), are described from paloelake Florssant in the attached report, pages 8 and 9, and figures 5a and 5b. In living gastropods, these genera were placed within the suborder Basammatophera which is polyphyletic, and they are now placed in the unranked higher clade Hydrophila (Bouchet and Rocroi, 2005).

The bivalves in this study were placed with the described species *Sphaerium florissantense* Cockerell, 1906, and two undefined new species *Sphaerium* species 1 and *Sphaerium (Musculium)* species 1 (see attached document pages 9-11 and figures 5c-5f).

b) Taphonomy

The very fine shell features of these thin-shelled mollusk is apparent in most specimens collected, and provided material for taphonomic studies across different units within the middle shale and caprock conglomerate rock layers (see attached document page 13-15 and figure 6). X-ray analyses of the shell microstructure confirmed the important results of this study: that all the shells from the middle shale unit were chemically replaced with silicate minerals, and none of the original biogenic calcium carbonate remained. These shells were trapped within the diatoms mats and subjected to the same diagenetic process that preserved the plant and insect fossils. Alternatively, the shells preserved within the caprock conglomerate remained as original calcite. X-ray diffraction methods used to determine these results are described in the attached document pages 15-16 and figure 7.

c) Isotope analyses

Oxygen and carbon isotope ratios (^{18}O:^{16}O, and^{13}C:^{12}C, recorded as δ notation) were analyzed from 40 bivalve and 8 gastropod shells from the caprock conglomerate unit, as well as four samples of a non-biogenic carbonate from a bedding-parallel, fibrous calcite layer within the caprock conglomerate for comparison. Results and discussion of this study are reported in the attached document pages 18-21 and figures 8-11. Shell carbonate yielded $\delta^{18}O$ values ranging from -4.792 to + 1.054, with a single outlier of -9.764 from a *Lymnaea scudderi* shell. $\Delta^{13}C$ values ranging from -4.243 to -0.147, with the same outlier shell at -11.931 (see attached document Table 2). The fibrous vein-calcite yielded an average $\delta^{13}C$ value of 4.6773, and $\delta^{18}O$ value of -14.448.

These results clearly differentiate the biogenic and non-biogenic origin of the carbonate signatures. The results indicate that 1) the shells from the caprock conglomerate were not chemically altered and isotope ratios reflect the true biotic interaction with the lake waters; 2) that the fibrous calcite was produced a subsequent diagenetic influx of ground water.

Discussion and conclusions

Variations of the $\delta^{18}O$ and $\delta^{13}C$ values (Figure 9) can be attributed to seasonal variations in lake water chemistry. Covariance of $\delta^{18}O$ and $\delta^{13}C$ values obtained from freshwater mollusks is generally associated with a closed lakes system (long water residence time, no effective surface outflow) versus an open system (short water residence time, strong inflow and outflow). Results from the carbon isotope values in this study indicate that paleo Lake Florissant was a closed system. This is supported by the geologic history of a lake that formed in a valley from a dammed river. (Buskirk reported (attached document page 18):

> As the basin filled with water, deposition and geochemical values would reflect a closed lake system, until either the dam was broken, or until water levels over-filled basin constraints and the lake would switch to an open system. While closed, evaporation would have the largest effect on the $\delta^{18}O$ values (Talbot, 1990; Leng et al., 2005), substantially depleting the lake water in ^{16}O, creating more positive values in $\delta^{18}O$.

The millimeter thin paper shales also indicate fluctuations conditions of the lake. Increased seasonal rain would have augmented silica input to the lake system. Spring-time diatom blooms utilized this silica and the increased photosynthesis depleted the $\delta^{13}C$ values of the total dissolved organic carbon in lake waters. During colder months without phytoplankton blooms the expected values of carbonate carbon would deplete $\delta^{13}C$.

Evaporation of surface water from a closed lake system is likely one of the primary influences of oxygen isotope signatures. However the results from this study do not confirm that for paleo Lake Florissant, and it is suggested that there is additional input of a heavy oxygen component $\delta^{18}O$ into this lake system. The hypothesized source of this was hydrothermal fluids originating from the Thirtynine Mile volcanic field leaching into the watershed of the lake (see attached document figures 10 and 11).

Comments on the original statement of work from task agreement, page 3

1. A collaborative study was completed with the University of Washington and the National Parks, entitled *Research on freshwater invertebrate fossils from the Florissant Formation as evidence for Eocene-Oligocene climate change.*
2. This report and the attached document are the work of a graduate student Bret Buskirk, who was in the Earth & Space Sciences Department under the supervision of the co-PIs of this project Elizabeth Nesbitt and Herbert Meyer. Additional members of Bret Buskirk' s M.S. committee were Jody Bourgeois and Roger Buick.
3. Molluscan fossils from Florissant Fossil Beds National Monument were utilized for this study, but the ostracods proved not to be applicable.
4. Taxonomic and taphonomic studies were conducted in the Paleontology Division of the Burke Museum, University of Washington
5. Stable isotope analyses were obtained from facilities in the Isotope Lab of the Earth and Space Sciences Department.
6. The results of this study were not compared with other contemporaneous lake deposits in the western U.S. as all the Florissant taxa are unique and none of the other sites have had comparable stable isotope studies. This will be a productive and valuable study that needs to be done in the future.
7. All fossils studied here have updated identifications, are housed in the Florissant National Monument collections, and entered into the associated database.
8. Material and ideas contributed to the new exhibits at Florissant Fossil Beds National Monument.
9. An extension of one year, from December 2013 to December 2014, was required to finish this project.