Narrative Progress Report
PRF # 58015 -DNI8
Conodont Thermochronology: Expanding the Utility of the (U-Th)/He Method to Marine Carbonates and Shales

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Report period: 09/01/2017 - 08/31/2018

Research problem

(U-Th)/He thermochronometry is a powerful hydrocarbon exploration tool that can provide important constraints on the burial/exhumation histories of source rocks, reservoir rocks, and structural traps and seals. Although the technique can be applied to a wide range of lithologies, marine carbonates and shales present a challenge because they lack the required accessory minerals, limiting opportunities for sampling and for acquiring complete thermal histories. Conodonts have emerged as a novel solution for the application of the method in carbonate-dominated successions; however, additional study is needed. These tooth-like fossils are made of hydroxyapatite with U and Th concentrations similar to magmatic apatite. These microfossils are ubiquitous in Cambrian through Triassic marine successions and are already routinely used for biostratigraphic control and as geothermometers via the conodont color alteration index (CAI). The objective of this study is to test the viability of conodonts as a (U-Th)/He thermochronometer at two different calibration sites. Site 1 focuses on conodonts extracted from outcrops located in footwalls of two major Miocene low-angle normal faults in eastern Nevada and western Utah. Zircon and apatite (U-Th)/He data from the study area, as well as published thermochronology data from the region provide relatively tight constraints on the thermal history of these faults, allowing for direct comparisons with conodont (U-Th)/He results. Site 2 focuses on two core-holes in western Kansas that penetrate relatively continuous sections of Paleozoic carbonates that are well studied in terms of their stratigraphy, paleontology, and geochemistry, but lack needed thermochronometric constraints.

Hypotheses to be tested

This study tests two specific hypotheses. (1) We explore the role of conodont microstructure and CAI on parent isotope distributions and (U-Th)/He dates. Our hypothesis is that hyaline tissue, which varies as a proportion of a whole conodont element, is more prone to parent isotope mobility and results in dispersed and anomalously old (U-Th)/He dates. This tissue type effect may be enhanced with increasing CAI. (2) This study also aims to constrain potential impacts of acid-based rock digestion procedures on geochemical data derived from conodonts. Our hypothesis is that these procedures can affect isotopic concentrations on the margins of the conodont, where parent isotopes may be enriched, and that this effect is enhanced with increasing thermal alteration or CAI.

Research efforts

Our efforts in year 1 have focused on Site 1, completing our analysis of conodonts extracted from carbonate outcrops in the footwalls of low-angle normal faults in the Mormon Mountains, Tule Spring Hills, and Beaver Dam Mountains, the results of which were published in a recent paper in *Chemical Geology* (Bidgoli et al., 2018). The main activity was interpretation and integration of (U-Th)/He dates, laser ablation-inductively coupled plasma mass spectrometry depth profiles of rare earth and trace elements, and images (microCT-based tomography and scanning electron microscopy) of conodont specimens with color alteration indices of 1.5–3. Resulting conodont (U-Th)/He dates are dispersed, but for the most part, younger that the depositional age of the units, consistent with thermal resetting of samples. However, conodonts with CAIs of 3 produced ages that are 2–6x older than the depositional age of our samples. Depth profiles also reveal that U, Th, and rare earth element concentrations depend on conodont tissue type (albid versus hyaline) and range from <10 to 100s of ppm. Parent isotopes and rare earth elements are also enriched on the margins of elements, 5–10x, relative to grain interiors. Overall, concentrations and margin enrichment are substantially lower in higher CAI conodonts. An inverse relationship between parent isotope concentrations and dates was also recognized in samples. SEM imaging suggests that the orientations of microcrystallites changes with increasing CAI, from perpendicular to parallel to the major axes of the conodont elements. SEM imaging also shows evidence of corrosion and recrystallization features in higher CAI conodonts. Together, the results suggest that microstructural changes associated with increasing CAI may be the cause of anomalously old CHe dates and data dispersion. Such thermal alteration associated with the early, prograde history of the samples, reflected as surface recrystallization and corrosion, may make conodont elements susceptible to late-stage parent isotope loss. The loss may occur in situ or in the laboratory during whole-rock digestion.

We have also initiated work on our Kansas sites. Samples have been collected from outcrops in the eastern part of the state for batch experiments that will explore the role of laboratory whole-rock digestion procedures on geochemical data derived from conodonts. Sample digestion is underway and once separated, conodonts processed using different digestion solutions and times will be analyzed for trace and rare earth element concentrations. To evaluate tissue type heterogeneity, we are using the U-Pb system as a proxy for (U-Th)/He dating (McNay et al., 2017, Jennings et al., 2018). We will date large (~1 mm in size) epoxy-mounted and polished conodonts from existing collections, a collaboration with K. McLeod and R. Ethington (Univ. of Missouri), to evaluate interior to margin variability and susceptibility to parent loss.

Additional efforts have focused on describing and collecting core samples from the western Kansas corehole sites. To date, 27 samples have been collected from the Rebecca K. Bounds corehole and another 7 samples from the Cutter KGS #1. Mineral separation is underway on the clastic samples. Whole-rock digestion of carbonates and carbonaceous shales will initiate once results are in-hand from batch experiments. Both the clastic apatite and conodont bioapatite will be dated using the (U-Th)/He method in the Spring of 2019.

Professional impact

Funding provided by the Petroleum Research Fund has allowed me to support analytical costs for two graduate students (one M.S. and one Ph.D. candidate), one of whom is also receiving graduate stipend and tuition support. The ability to fund graduate students and their research is critical to professional advancement in a tenure-track faculty position.

Publications (*student advisee supported by grant)

Bidgoli, T.S., Tyrrell, J.P., Möller, A., Walker, J.D., and Stockli, D.F., 2018, Conodont thermochronology of exhumed footwalls of low-angle normal faults: A pilot study in the Mormon Mountains, Tule Spring Hills, and Beaver Dam Mountains, southeastern Nevada and southwestern Utah: Chemical Geology, v. 495, p. 1-17, doi: 10.1016/j.chemgeo.2018.06.026.

Mcnay, H., *Jennings, D.L., Möller, A., **Bidgoli, T.S.** and Walker, J.D., 2018, Testing the viability of conodonts as a U-Pb geochronometer using Kansas core and outcrop samples: Geological Society of America Abstracts with Programs. v. 50, n. 4 , doi: 10.1130/abs/2018NC-312425.

*Jennings, D., **Bidgoli, T.S.**, Möller, A., and Walker, J.D., 2018, Assessing uranium heterogeneity and U-Pb geochronology viability in conodont elements using Kansas outcrop samples: Geological Society of America Abstracts with Programs, v. 50, n. 6, doi: 10.1130/abs/2018AM-323364.