TEMPERATURE OF FORMATION OF THE VACA MUERTA "BEEF" DETERMINED BY CLUMPED ISOTOPES

Ralf J. Weger, Donald F. McNeill, Sean Murray, Peter K. Swart,
Gregor P. Eberli, and the Vaca Muerta Team

PROJECT OBJECTIVE

- Determine the temperature and the lateral variation in temperature and fluid composition of the beef calcite using stable $\delta^{13}C$ and $\delta^{18}O$ values and the clumped isotope paleo-thermometer.

PROJECT RATIONALE

Many fissile mudstones around the world that are unconventional resource plays show abundant bedding-parallel calcite veins, often within the organic-rich, sometimes clay-rich matrix. Such bedding-parallel expansion seams were described by Sorby (1860) who originally coined the term "beef-in-shales." Other occurrences have been described as horizontal fractures or fibrous veins. In the Vaca Muerta, abundant beef calcite within organic-rich mudstone can be observed across all of our studied sections. In the sections from the Sierra de la Vaca Muerta, beef is generally limited to thin (<1-2 cm) features, restricted in lateral extent. In the more basinal facies in sections around Puerta Curaco (PC), beef occurrences are more dominant, both with respect to thickness and abundance, as well as with respect to lateral continuity. In addition, some beef occurrences are of such lateral persistence, that they clearly represent a feature able to provide in-field well-to-well correlation. Several publications associate bed-parallel expansion seams with high temperature and localized overpressure conditions that existed at the time of hydrocarbon generation and correlate to its thermal maturity (Cobbold et al., 2013; Rodrigues et al., 2009).

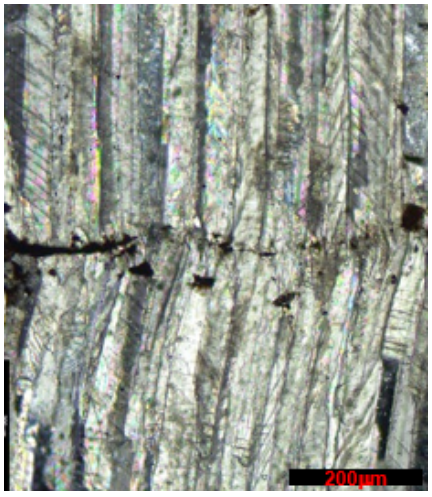

Figure 1. Photomicrograph of a PC Beef sample showing crystal termination along the central seam of the calcite crystals.

SCOPE OF WORK

As a first step, we used petrographic analysis as well as $\delta^{13}C$ and $\delta^{18}O$ values of Vaca Muerta beef in order to generate a vertical transect across a 6 cm thick sample to establish its internal growth symmetry (Fig. 1). Both carbon and oxygen isotopic values of Vaca Muerta beef were compared to a variety of other materials from the Puerta Curaco section of Vaca Muerta. The $\delta^{18}O$ values of the PC beef ranged between -9 and -11‰, the $\delta^{13}C$ values

varied between 0 and +2‰. In contrast, $\delta^{18}O$ values of the sampled concretion matrix material ranged between +1 and -3‰ with $\delta^{13}C$ values ranging from +5 to +10‰. All other sample material; fracture fill calcite from two concretions and the mudstones surrounding the sampled beef show $\delta^{18}O$ values substantially more negative (-7 to -9‰) than the sampled concretion matrix material. Both the $\delta^{13}C$ and $\delta^{18}O$ values of the background mudstone surrounding the beef sample are similar to those of the beef itself and the concretion fracture fill calcite. Assuming similar isotopic properties of the formation fluids, the more negative values of $\delta^{18}O$ would suggest significantly higher formation temperatures for the beef and the fracture fill calcite when compared to the concretion matrix material. Clumped isotope analysis suggest formation temperatures of Vaca Muerta beef to be approximately 110°C with formation fluid $\delta^{18}O$ values of 6 to 6.5‰, whereas the mudstones 50 cm above and below the beef show temperatures of approximately 100°C but formation fluid $\delta^{18}O$ values ranging from 6 to over 8‰.

In future work we intend to extend the clumped and C and O isotopic analyses over the entire lateral extent of the beef as well as examining other beef layers in the strata, and also the associated nodules and carbonate occurrences.

SIGNIFICANCE

Beef veins form symmetrically from the edge to the center, showing crystal terminations, oil or bitumen residue, and occasionally a central open void (Fig. 1). This pattern of formation suggests that overpressure may have produced the original opening and that hot fluids attempting to escape are responsible for the formation of beef. These results are consistent with the hypothesis put forward by Rodriques et al. (2009) that overpressure and horizontal compression was responsible for the Vaca Muerta beefs.

Clumped isotope measurements of Vaca Muerta beef indicate that the calcite in the beef was formed at a temperature of approximately 110°C in in concert with the burial depth of the Vaca Muerta Formation. If these calcite veins indeed represent the burial depth, the clumped isotope method would be an excellent tool to track the burial history of sedimentary basins and to assess at which depth burial diagenesis is most important.

REFERENCES

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