In-Situ SIMS Oxygen Isotope Analyses Reveals a Continuous 300 Ma History of Carbonate Cementation and Dolomitization in the Middle Bakken

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ABSTRACT

Calcite and dolomite cements are the key control on the quality of Late Devonian, middle Bakken siltstones/sandstones, the major tight oil formation of the Williston Basin. Petrographic data show that calcite cement is an early phase, and combined with mineralogical data suggests that much of the dolomite replaces calcite. Dolomitization increased porosity slightly. BSEM and SEM-CL suggest several textural types of both calcite and dolomite, suggesting that reservoir quality is controlled by a potentially complex diagenetic history. Oxygen isotopes preserve important information about the temperature at which minerals form and the nature of the fluids from which they precipitate. However, most studies have been unable to separate and analyse individual phases, especially the finely-intergrown phases observed in the Bakken. Diagenetic histories are thus blurred or uncertain. In this study we have used 10 micron resolution, in situ Secondary Ion Mass Spectrometry to determine the oxygen isotopic composition of 230 individual, 10-50 micron-size crystals of dolomite and calcite across six samples. This amount of data places important constraints on the range of temperatures and times that carbonate cementation and replacement occurred. Over spatial scales of less than a centimetre, analyses of individual calcite crystals gave a range of 5‰ for the group of crystals, and for the group of individual dolomite crystals, 10‰ – a range as great as observed in studies of carbonate cements sampled over many metres. There was no relationship between dolomite texture and isotopic composition at this spatial scale, although microscale CL zoning is seen which cannot be resolved with a 10 micron spot size. Assuming, since it is an early cement, that calcite precipitated from seawater, the temperature range over which calcite precipitated was ca. 15-40 °C, mainly at the lower temperatures. Present-day formation waters in Devonian rocks in this region have oxygen isotope compositions of 7-8 ‰. Using these values as a likely dolomitizing fluid, we suggest that dolomitization, which resulted in a modest increase in porosity, occurred continuously from ca. 40 – 140 °C over 150 – 200 million years in a fluid with a high Mg/Ca ratio resulting from gypsum formation in local evaporites. The exceptionally slow rate of dolomitization was probably controlled by the rate of supply of Mg in a very sluggish flow regime; dolomitization is incomplete because of a limited supply of Mg.