FAULT-RELATED HYDROTHERMAL ALTERATION: AN IMPORTANT MODEL FOR CARBONATE RESERVOIR DIAGENESIS

Reservoir Characterization Group at the New York State Museum

Langhorne B. Smith Jr.,
New York State Museum, Albany, NY
Graham Davies
GDGC Ltd, Calgary, AB

Abstract

Most carbonate diagenesis is interpreted to have occurred very near the surface (meteoric, mixing zone, reflux models) or at depths of more than a kilometer (deep burial dolomitization, etc). Upon closer analysis, it appears that a significant amount of diagenesis previously attributed to those near-surface or deep models may have occurred due to high-temperature, high-pressure fluid flow up faults and into formations at relatively shallow depths of less than a kilometer (commonly less than 500 m).

These hydrothermal fluids are interpreted to flow up faults at very high rates (up to meters/second) when the faults were active. Carbonate solubility is affected by variations in composition, temperature, pressure, PCO2, pH, and salinity and all of these may fluctuate on very short time scales in fault-controlled hydrothermal systems. Diagenesis may be done solely by the fault-sourced fluids or by mixing with in situ fluids.

Reservoir-enhancing processes include dolomitization, leaching of limestone and dolomite, development of microporosity, brecciation and propping of open fractures with minerals. Reservoir-destroying processes include precipitation of pore and fracture filling dolomite, anhydrite, calcite, quartz, fluorite, barite, bitumen, authigenic clay minerals, sulfides and more.

Common structural settings for hydrothermal alteration include strike-slip, extensional and especially transtensional faults. Subtle faults with little vertical offset may be the best conduits. Fault-controlled hydrothermal diagenesis is most easily interpreted using a holistic approach involving field relations, structural geology, seismic interpretation, stratigraphy, geochemistry, fluid inclusions, petrography, hydrology, rock mechanics and more. A focus on only one of those disciplines may lead to erroneous interpretations.

Current Paradigms

Although it is not a new concept to the mining industry, the importance of fault-related diagenesis has only recently become clear to some in the world of carbonate geology. A better understanding of the processes and products of hydrothermal alteration is leading to several major paradigm shifts. Because the products of hydrothermal alteration are abundant in carbonate rocks, they have commonly been attributed to other models. **That is not to say that some diagenesis does not occur in these settings: it does**. Paradigms likely to be affected include:

Meteoric Karst Breccias

Many carbonate geologists immediately think of meteoric karst or possibly evaporite solution collapse when they see a carbonate breccia. Brecias do form immediately under exposure surfaces (surficial) and where caves have collapsed (penetrative) and **this will always be a possible interpretation for a brecciated carbonate** unit. Not all breccias are related to karst or evaporite solution collapse however. Breccias may also form around faults, especially in transtensional settings where space is created in the fault zone (see Poster 2). These breccias can be fairly easily distinguished from karst brecias with the proper criteria.

Exposure-Related Meteoric Leaching and Microporosity Development

Leaching of limestone and dolomite and the development of microporosity are commonly attributed to subaerial exposure and meteoric diagenesis. This may be the case for the first meter or two beneath unconformities, but in the absence of fractures, fluids percolating down through a limestone matrix will become supersaturated almost immediately rendering them unable to leach or create microporosity. Fault-derived fluids (and resultant mixed fluids) have the potential to leach and develop microporosity because of their transient pressure and temperature state and rapid emplacement within a formation that helps to overcome rock buffering.

"Deep Burial" Diagenesis

Many carbonate geologists have correctly interpreted leaching, dolomitization and other mineralization to occur at relatively high pressures and temperatures. Without the hydrothermal model, most of this diagenesis has been interpreted to have occurred at depths of several kilometers (i.e. depths where temperatures match fluid inclusion homogenization temperatures using a normal geothermal gradient). Hydrothermal or thermobaric fluid flow brings pressures and temperatures typcially associated with much greater burial depths to much shallower depths (see Poster 4).

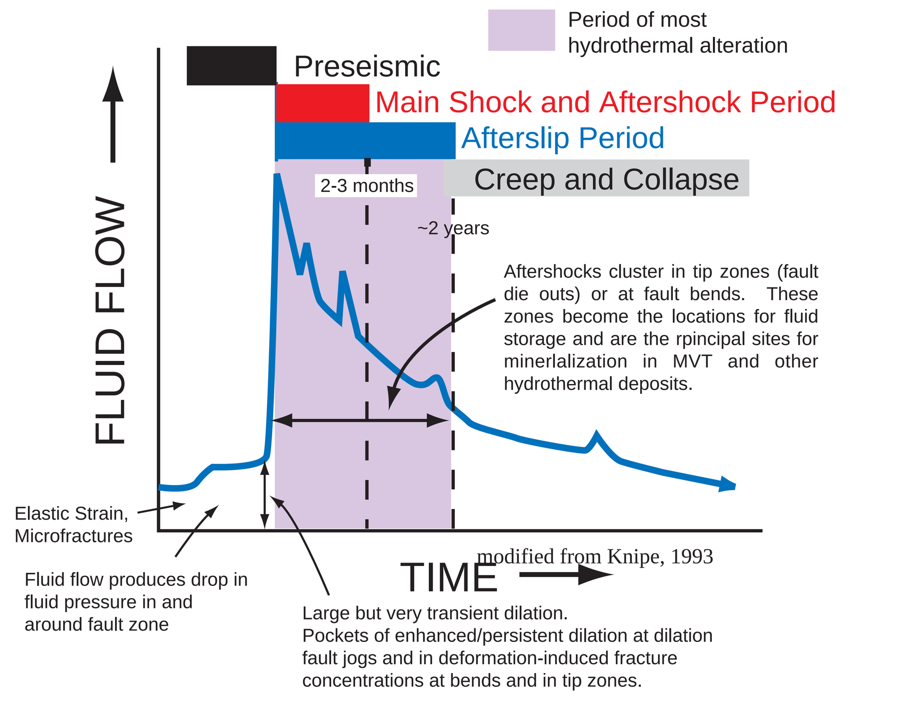
Mixing Zone Dolomitization

Light oxygen isotope values made this a popoular intepretation for many years but many of these dolomties probably formed in a hydrothermal setting.

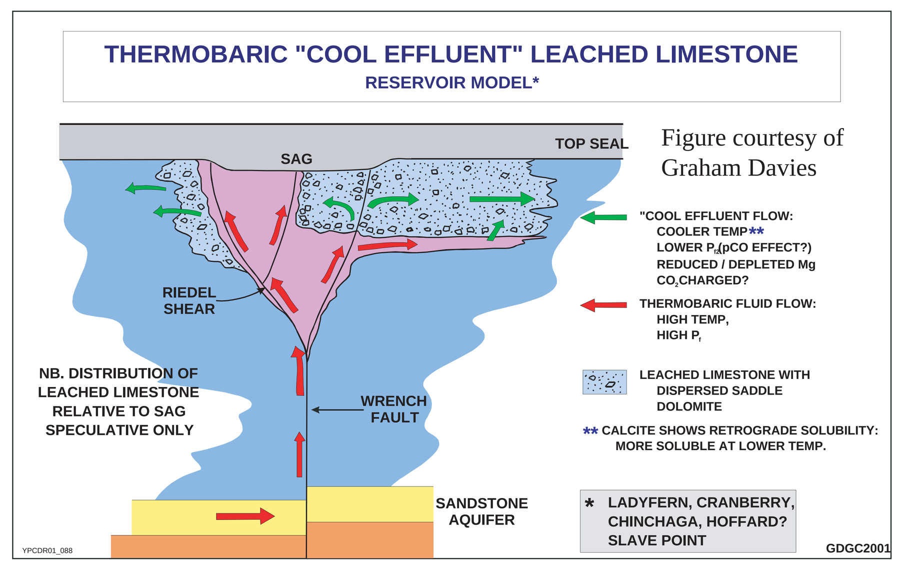
Impact Structures

At least one example of an interpreted impact structure is likely to be a fault related hydrothermal feature.

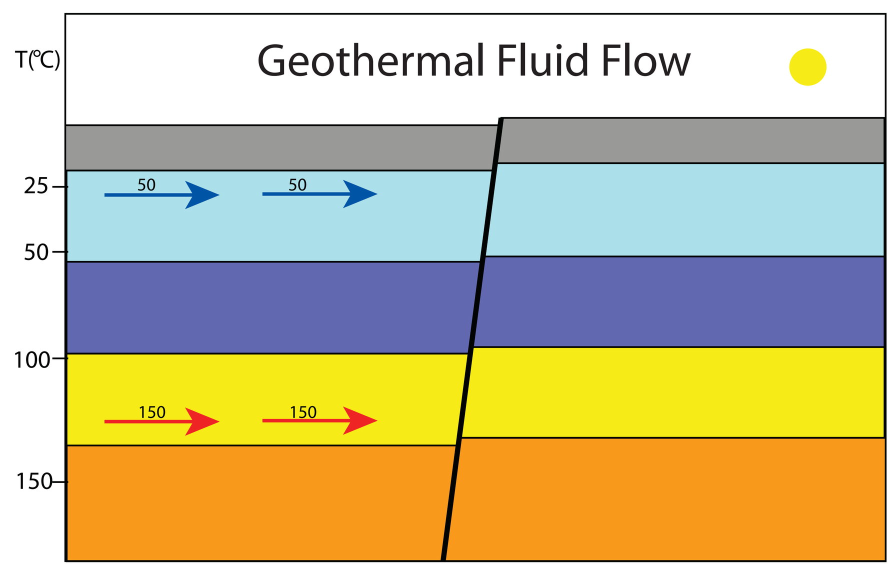
Fault Related Hydrothermal Alteration



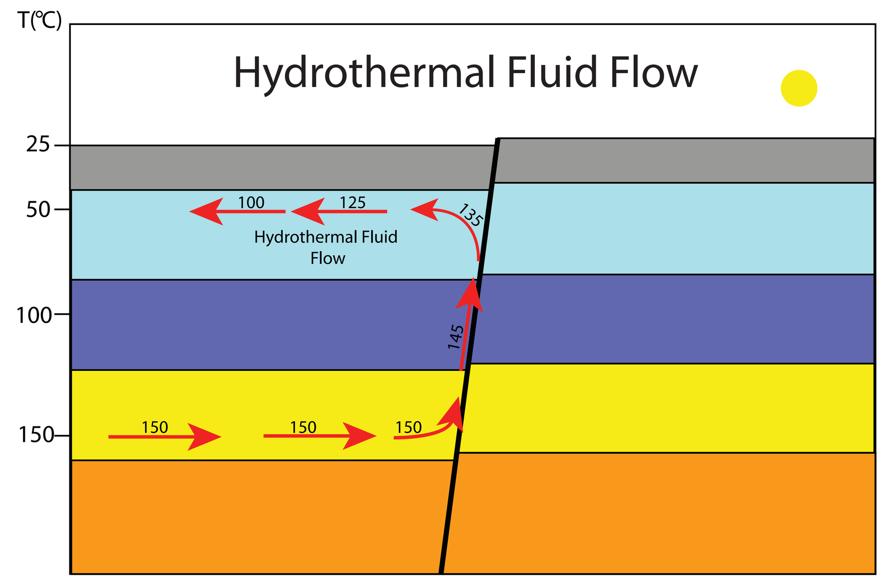
Hydrothermal alteration is here thought to occur when fluids flow up active faults to relatively shallow depths. Most fluid flow occurs just before and during periods of fault movement. Fluid flow rates could be meters/second.



Fluids will flow up faults until they hit a seal (typically shale, shaly limestone or evaporites) and then flow laterally through the uppermost permeable units. Near the fault, dolomitization may occur from hot superstaurated fluids experiencing a pressure drop. Farther from the fault, cooling fluids may leach limestone.

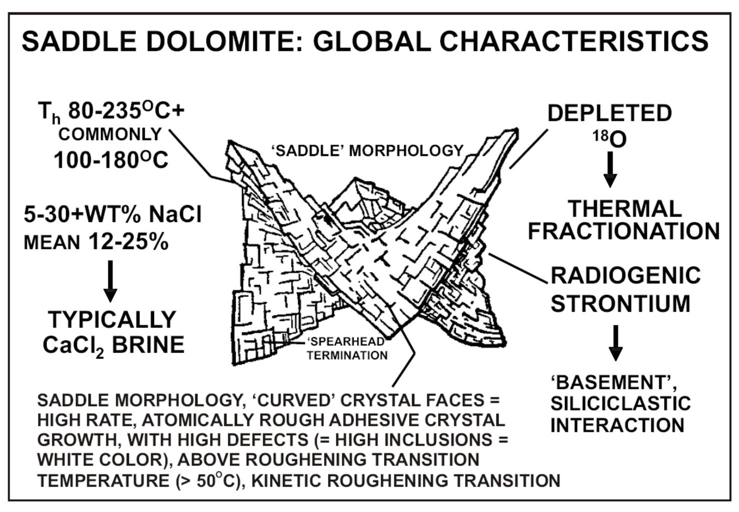


Geothermal fluid flow - fluids same temperature and pressure as ambient burial conditions - lack of contrast in pressure and temperature, low fluid flow rates and rock buffering of composition make these relatively weak diagenetic fluids

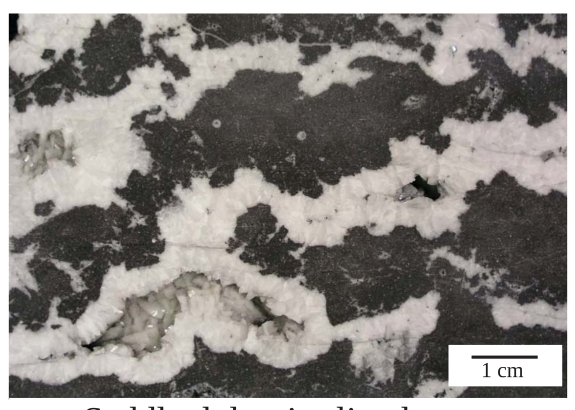


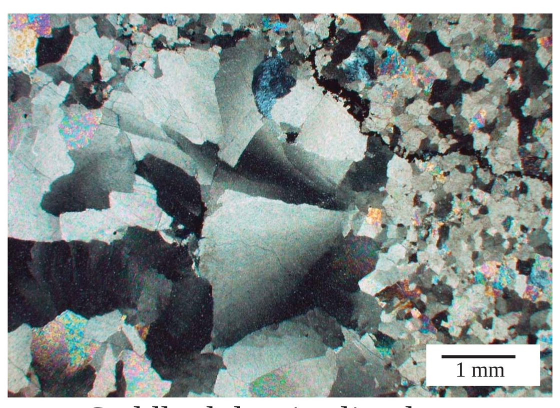
Hydrothermal fluid flow - pressure and temperature of fluids exceeds ambient pressure and temperature - faults required in most cases - contrast in pressure, temperature, composition, high fluid flow rates and potential for mixing makes these powerful diagenetic fluids

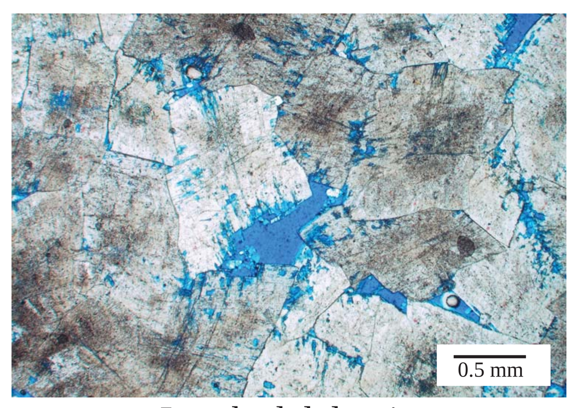
Common Products of Hydrothermal Alteration



Presence of abundant saddle dolomite is an indicator of hydrothermal alteration

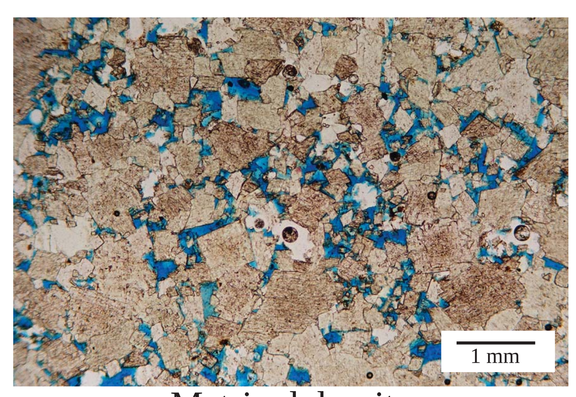

Saddle dolomite-lined vugs

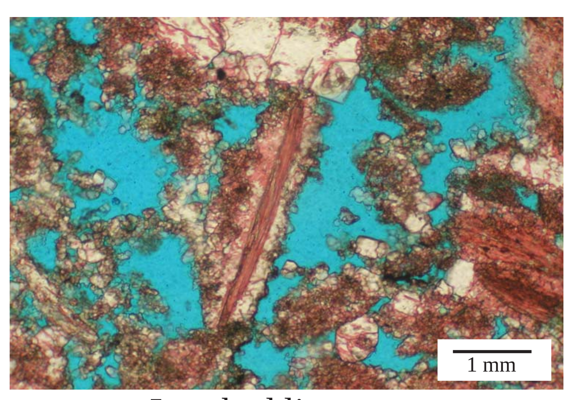

Saddle dolomite-lined vugs

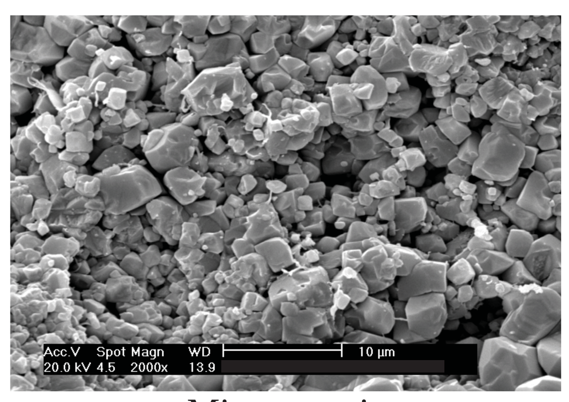

Leached dolomite

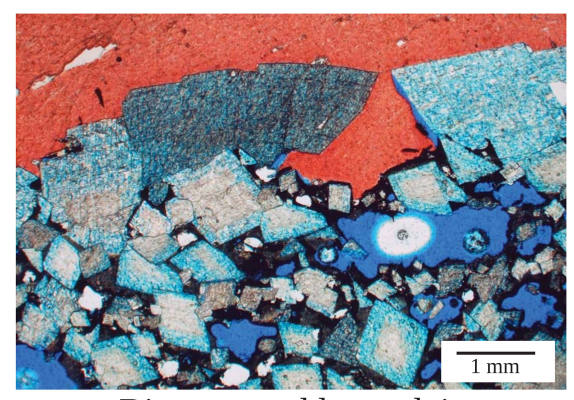

Saddle dolomite-cemented breccia

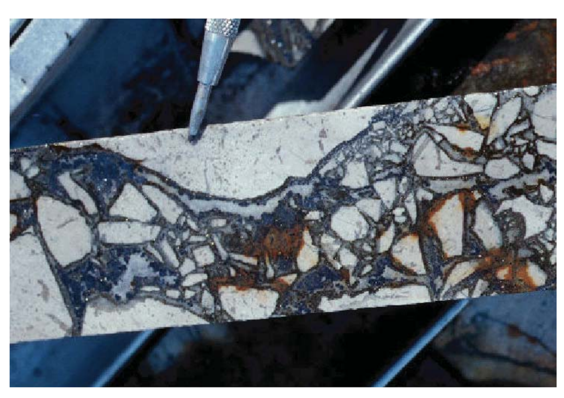

Zebra fabrics

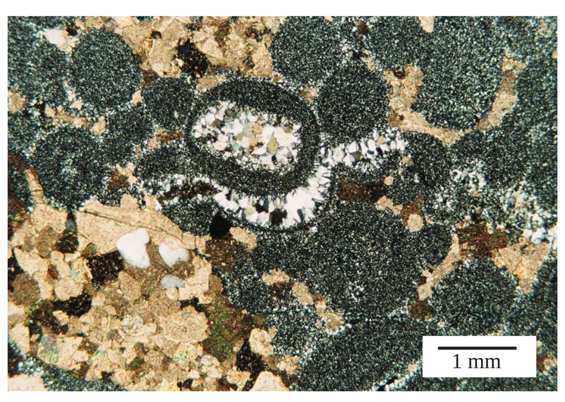

Matrix dolomite

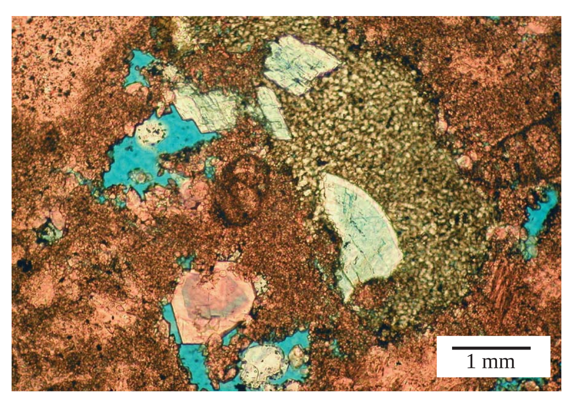

Leached limestone


Microporosity


Bitumen and late calcite


Sulfides


Late quartz cement and chert


Kaolinite and other clay minerals