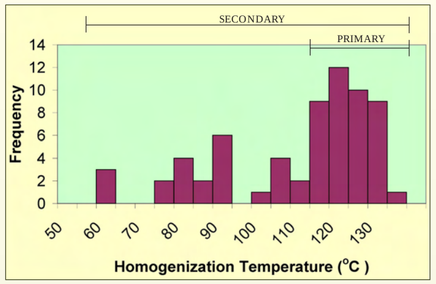
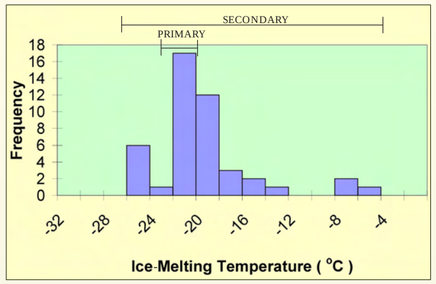
Fluid Inclusions

Fluid inclusions trapped in calcite, quartz and dolomite were studied from three wells, B-63, D-616 and D-816. All inclusions were classified as either primary or secondary. Primary inclusions are trapped at the time of mineral growth; secondary inclusions are trapped along healed fractures. All of the inclusions observed contained either 1 or 2 fluid phases at room temperature. Inclusions containing brine and vapor are the most common, but single phase aqueous inclusions, gas-rich inclusions and inclusions consisting of oil and vapor are present.

Heating and freezing measurements were made on doubly polished thick sections and hand picked crystals using a Linkham THSMG 600 freezing and heating stage. The precision of the measurements is estimated to be + 0.1°C at 0.0°C and + 3°C at 374°C. Homogenization and ice-melting temperatures were measured. Homogenization temperatures are minimum trapping temperatures. Ice-melting temperatures provide a measure of the fluid salinity. Salinities of inclusions with ice melting temperatures <-21.2°C displayed eutectic (first melting) temperatures of <-45°C, indicating the presence of divalent ions (most likely Ca and Mg). These inclusions had ice-melting temperatures as low as ~-27°C. As a first approximation, assuming that only Ca, Na and water are present in the inclusions, the salinities would be in the range of 25-30 weight percent NaCl-$CaCl_2$ equivalent.



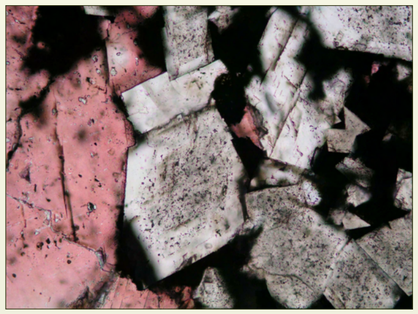


Homogenization and ice-melting temperatures of quartz-hosted aqueous inclusions. (From 8,356 ft in well D-616.)

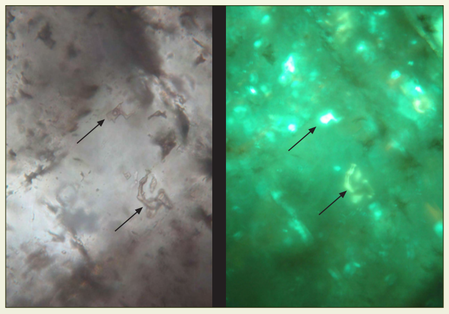
Fluid Inclusions in Dolomite

Dolomite replaces early calcite and fills voids. The dolomites analyzed were rhombic dolomite which is typically fine-grained; and later saddle dolomite which is coarser grained. Small fluid inclusions, most of which are less than a few micrometers in length, are common in both types of dolomite. These inclusions define growth zones, and consequently are interpreted as being primary in origin. Coarse-grained saddle dolomite frequently contains cloudy cores and clear rims.

Only aqueous inclusions were observed in the fine-grained rhombic dolomite. Saddle dolomite contains both aqueous and oil inclusions. Although many of the aqueous inclusions appear to contain only a single liquid phase, aqueous inclusions with variable liquid to vapor ratios are not uncommon. Fluid inclusions trapped during mineral growth at temperatures >70°C will typically contain a vapor bubble. The common absence of a vapor bubble in primary inclusions suggests that: 1) the dolomite formed at temperatures of less than ~50°C (Goldstein and Reynolds, 1994); 2) some fluid inclusions have re-

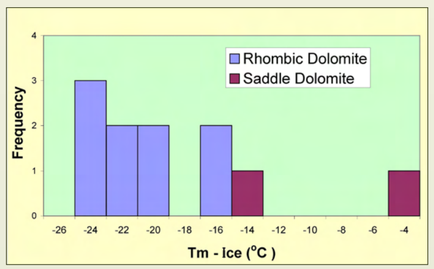


Dolomite (colorless) and calcite (red). The cloudy appearance of the dolomite is due to the presence of abundant fluid inclusions. Saddle dolomites (center of photo) typically have cloudy cores and clear rims. (From 10,004 ft in well



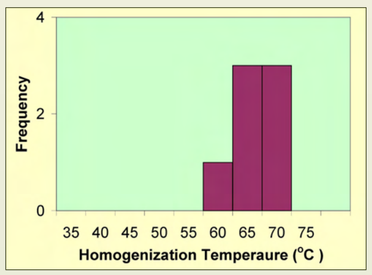
Oil inclusions in saddle dolomite. Arrows point to two of the inclusions; others are apparent in the right panel taken under fluorescent light. (From 9,939 ft in well B-63. Height of images is 0.3 mm.)

Aqueous Inclusions



Ice-melting temperatures of dolomite-hosted fluid inclusions. (Samples of rhombic dolomites from 8,372 ft in well D-616 and 8,444 ft in well D-816. Data from clear rim of saddle dolomite from 9,939 ft in well B-63.)

Oil Inclusions

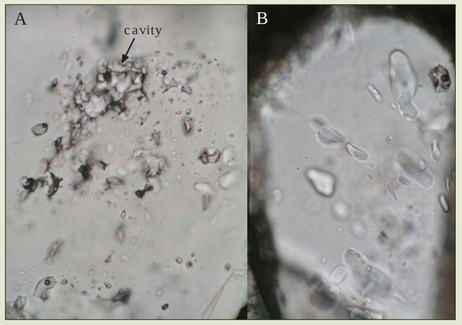


Homogenization temperatures of oil inclusions trapped in saddle dolomite from 9,939 ft in well B-63.

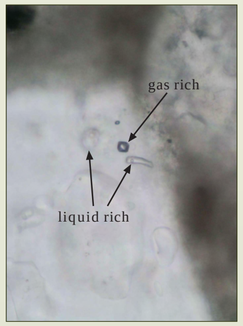
Fluid Inclusions in Quartz

Quartz occurs as fine- to medium-grained, euhedral crystals that postdate the dolomites. The quartz crystals contain numerous two phase aqueous inclusions; rarely, gas-rich and single phase liquid-rich inclusions are present. The gas is probably CH_4-rich.

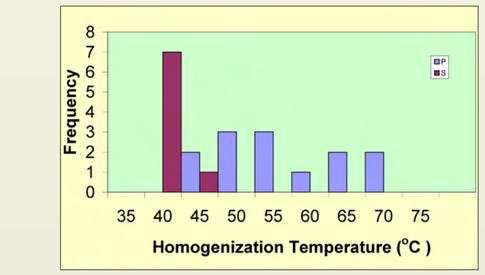
The presence of coexisting gas- and liquid-rich inclusions is significant because this suggests that the homogenization temperatures closely approximate the true trapping temperatures (Goldstein and Reynolds, 1994). The quartz-hosted inclusions provide the best direct measure of the temperatures reached.



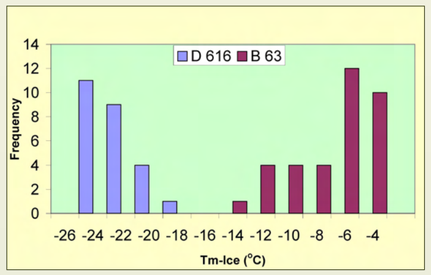
Liquid-rich inclusions in quartz. A) Inclusions of undetermined origin. The cavity originally contained anhydrite. B) Primary liquid-rich inclusion. Solid irregular shaped inclusions are anhydrite. (From 8,356 ft in well D-616. Height of images is 0.3 mm.)



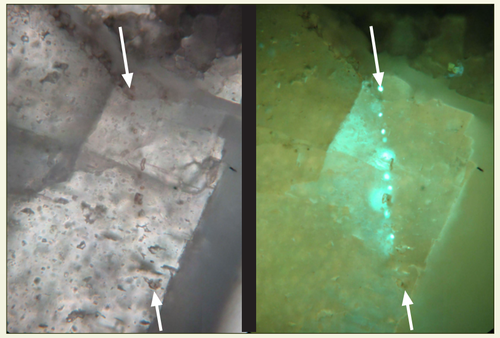
Coexisting primary liquid- and gas-rich inclusions in quartz. (From 8,356 ft in well D-616. Width of image is 0.3 mm.)



Comparison of homogenization temperatures of primary and secondary oil inclusions in late calcite.



Comparison of ice-melting temperatures of fluid inclusions in late calcite from wells D-616 and B-63. The ice-melting temperatures of fluid inclusions in late calcites from the D-616 well are indicative of fluids with much higher salinities than those fluids responsible for the B-63 late calcites.



Secondary oil inclusions in calcite filling a fracture (between arrows). The image on the right was taken under fluorescent light. Note the bluish green fluorescence color. (From 8,372 ft in well D-616. The height of each image is 0.3 mm.)

Fluid Inclusions in Late Calcite

Late calcite from depths of 9,936, 9,991, and 10,005 ft in well B-63 were analyzed. The calcite encapsulates dolomite and fills vugs. Secondary aqueous and oil inclusions occur in the late calcite. All of the aqueous inclusions display variable liquid to vapor ratios indicative of necking.

Late oil inclusions

Secondary inclusions trapped in late calcite from a depth of 9,936 ft in well B-63 provide unequivocal evidence of a mobile oil phase that postdates calcite deposition. These inclusions yielded consistent homogenization temperatures ranging from 39-43°C. For comparison, homogenization temperatures of primary oil inclusions are also shown below.

Conclusions from Fluid Inclusion Analysis

The results of this investigation have yielded the following conclusions:

1. Fluid inclusions in dolomite have re-equilibrated (stretched, necked, refilled) since trapping. The common presence of single phase aqueous inclusions suggests that the fine-grained rhombic dolomite and cores of coarse-grained saddle dolomite were deposited at temperatures <~50°C.

2. Euhedral quartz crystals (containing solid inclusions of anhydrite) contain primary fluid inclusions with homogenization temperatures that range from ~120-130°C. The presence of gas-rich inclusions in the quartz suggests these temperatures are close to the true trapping temperatures and possibly maximum burial temperatures.

3. The low ice-melting temperatures of quartz and late calcite-hosted inclusions from well D-616 suggest chemically complex Ca-Mg-bearing brines that have interacted with evaporite deposits, most likely the Pennsylvanian Paradox Formation. Late calcite from well B-63 trapped fluids with lower salinities.

4. The oil inclusions trapped in the saddle dolomite indicate that the temperature was at least 70°C during oil deposition. Oil trapped in the saddle dolomite must represent oil that was mobile at this time.

5. Oil was deposited in healed fractures within late pore filling calcite. These inclusions have homogenization temperatures of ~40°C. The lower temperatures of the secondary oil inclusions may reflect uplift or unroofing.