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A Preliminary Analysis of the Fluid History of a Normal Fault in the Keno Pit, Alligator Ridge Mining District, White Pine County, Nevada

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The flow of oil along faults is only poorly understood. In many cases a fault is the only means of transportation for the oil from its area of deposition to its current location. This assumption is reasonable due to chemical fingerprinting of oil. In some cases the oil in a reservoir and the oil in a fault zone have been analyzed chemically and found to be the same. The problem is this; early in a fault's history it produces a thin layer of fine-grained material between its fault surfaces. This condition is not conductive to fluid flow. Therefore another mechanism must have acted on the system to facilitate fluid flow. A likely mechanism is fluid pressure. A likely hypothesis is that when the fluid pressure in a system reaches a critical point, the fault surfaces are forced apart, and fluid can flow along the fault. This continues until the pressure drops below the critical point (due to the removal of the oil that has been removed from the system) and the fault closes. This allows the pressure to build up once again, and so oil flows along the fault in a cyclic fashion.

In the Alligator Ridge Mining District near the Ruby Mountains in White Pine County, Nevada there are several open pit mines. One of these, the Keno pit, has been reclaimed, and is available for study. This pit produced approximately 50,000 ounces of gold. The dominant lithology of the pit is the Devonian Pilot Shale, with minor outcrops of the Devonian Devil's Gate Limestone and Mississippian Chainman Shale. All research was conducted in the Pilot Shale. The Keno Pit is bisected by a north-south striking, east dipping normal fault with more then two hundred feet of vertical displacement. In the southern part of the pit in the footwall of the fault there are many calcite veins. Most of these are associated with subsidiary faults related to the previously mentioned normal fault. Throughout the pit, in the hanging-wall of the fault, there are several pockets of hydrocarbon-rich rocks. The likely source of these hydrocarbons is oil-rich fluid that moved along the fault zone. In order to test this hypothesis samples from the calcite veins were collected and analyzed using fluid inclusion analysis, x-ray diffraction, optical microscopy, and scanning laser confocal microscopy. The fluid inclusion analysis was of limited usefulness, but did indicate that the veins were deposited in temperatures less than or equal to $150^{\circ}C$. The samples were also analyzed using scanning laser confocal microscopy. In this technique small subsamples were prepared and analyzed. The laser used was a potassium-argon laser that emits light at three wavelengths. The wavelength of interest is 488nm. Light at this wavelength was found to excite oil and cause it to emit light at 515nm. In this manner images of the oil in the samples could be produced. It was later determined that the other materials in the samples, including but not limited to quartz and calcite, fluoresced at 520nm. The results of these analyses will be discussed by sample.

A1CV4

This vein has an average attitude of 169/73/NE, with a variable aperture of 0.5-5.0 cm. It exhibits a very atypical mineralogy, being composed of two distinct minerals. One is calcite, the other is an aluminum hydroxide, indicated by x-ray diffraction. Images derived from confocal microscopy indicate that one mineral is older than the other. The determination of which mineral is older is not yet possible due to further tests, particularly scanning electron microscopy, that are to be run on the samples before thin sections can be made. The oil is associated with the younger episode. One image of A1CV4 shows a grain of the older mineral surrounded by a rim of oil. A possible explanation of this is that when the older mineral was solid, and the younger liquid, the oil, which is hydrophobic, attached itself to the older particle. This is precisely what was observed during analysis of an oil collected from another sample. The oil, mixed with water, formed a halo around a sediment grain, when observed with confocal microscopy. Another explanation is that the older mineral is actually younger, and formed by filling on oil coated void. A problem with this is that the mineral may have had difficulty attaching itself to the void wall due to the oil coating. Optical microscopy will indicate which mineral is older, and therefore which hypothesis is correct.

A young vein cutting across part of the sample was also analyzed. The vein was very found to be very rich in oil, and during emplacement appeared to have torn pieces of material from the surrounding walls. This indicates that the vein was emplaced under high-pressure conditions. The oil did not significantly diffuse into the surrounding material indicating that the material was solid at the time of emplacement.

A1CV5

Vein A1CV5 has a maximum aperture of 10cm, and an orientation of 209/85/SE. It is one of the most noticeable veins in that area, but shows no signs of movement. It is composed of three different calcite areas. The oldest is composed of spelayan calcite, and is coarsely grained. The intermediate episode forms the matrix of a breccia, with the clasts composed of fault gouge. This area is rich in anhydrite, with it forming an estimated 30-50% of the matrix. The transition between the intermediate and oldest calcite episodes is gradational. There is no anhydrite in the oldest episode, but the calcite grains are meshed, becoming smaller as the intermediate calcite is approached. The contact between the intermediate and youngest calcite episodes is abrupt. Breccia clasts and veinlets in the intermediate episode are truncated. The youngest vein is composed of spelayan calcite, with a laminar fabric parallel to the contact with the intermediate vein.

The oldest episode was found to be moderately rich in oil. The oil was randomly distributed. This distribution carried over to the intermediate episode with the exception that this episode was very rich in oil. With that much oil existing in a sample, it is reasonable to expect some sort of pattern to be apparent. The fact that there is none indicates that this episode was deformed after deposition. A problem with this is the fact that the oldest episode shows only minor deformation, and the contact between the two is gradational. Perhaps this indicates the intermediate episode was subject to deformation contemporaneous to deposition. This deformation would have been intense enough to deform the not yet solidified intermediate episode while causing only minor deformation in the oldest episode.

There is a relatively small amount of oil in the youngest calcite episode, and that oil occurs in veins. The analyzed vein showed an internal structure that has not yet been explained. There are definite grains, with random orientations, inside the vein. This texture does not continue into the surrounding material. The oil in the vein diffuses significantly into the country material on one side of the vein, while it only minorly diffuses on the other. This image was produced before it was determined that the other minerals in the sample could be made to fluoresce, and so the structure of the calcite is not apparent. In any case, it is apparent that one side of the vein was more permeable than the other at the time of the emplacement of the oil.

A2CV12/13

This vein has an average orientation of 209/86/NW, and a maximum aperture of 10+ cm. There is no evidence of movement along the vein. This vein is composed of one major episode of calcite emplacement. This calcite forms the matrix of a breccia in places, but commonly occurs as a solid mass on the surface of the vein.

Analysis of the calcite forming the matrix of the breccia indicates two major periods of fluid flow. The first was oil-rich, while the second was oil-poor. The oil in the older episode occurs as wavy laminae with an anastomosing texture. There are areas of high oil concentration in the younger episode, but the oil in them appears to have been derived from the older episode. This is hypothesized because the deposits occur in a roughly linear distribution parallel to the laminae in the older episode.

Analysis of the calcite outside of the breccia also indicates two episodes of fluid flow. In the earliest episode the oil is deposited in laminae. This laminae alternate between oil-rich and oil-poor members. It is possible that a couplet consisting of one of each represents one minor episode of fluid flow. This observation is based on two observations. The first is that oil is immiscible in water, and the second is that oil is less dense than water. Therefore it stands to reason that if an oil-rich fluid were deposited it would separate into oil-rich and oil-poor members, with the oil-rich layer overlying the denser oil-poor layer. There are two problems with this hypothesis. The first is the unknown role of temperature. At high temperatures it is possible that the solubility of oil in water would increase. The other problem is the unknown composition of the oil. The lighter an oil is, the higher its solubility. Therefore it is possible that each laminae represents an episode of minor fluid flow, with oil-rich laminae representing an oil-rich fluid and vice-versa.

The older episode is again cut by a younger oil-poor episode. There are minor amounts of oil in this episode, but this oil falls in a line with the laminae of the older episode. The laminae are wavy, indicating that they were likely deformed after deposition.

A2CV18

The attitude of A2CV18 is highly variable. An average attitude is 270/75/N. This vein is relatively thin, with a maximum aperture of 3cm. However, the calcite grains in this sample are vary coarse, averaging 0.5cm. The calcite overlies a breccia whose clasts are derived from an earlier breccia. This phenomenon was relatively common, and indicates multiple episodes of movement along the fault from which the breccia was derived.

The most noticeable image collected from A2CV18 is that of a possible chevron fold. The fold is composed of laminae similar to those observed in A2CV12/13. This fold is overlain by a discontinuous but linear relatively oil-rich fabric. This fabric is undeformed, and therefore younger than the chevron fold. Another explanation of the possible fold is that it shows growth along a crystal face. This seems unlikely due to the nature of the laminae in the interior of the fold. They are more strongly deformed than the outlying laminae and do not exhibit the chevron-like shape. If this fold were actually due to crystal growth, it seems unlikely that the outer laminae would be so linear if they grew on top of such a deformed mass. It therefore seems more likely that the observed shape is a chevron fold due to deformation after the laminae were originally deposited in a flat manner.

The other image collected from A2CV18 is that of a contact between the massive calcite and the breccia. The oil does not penetrate the breccia at all, indicating that it is very impermeable. This reinforces the idea discussed at the beginning of the paper: the fine-grained material developed early in a fault's history is impermeable.

This study is not yet complete. The next step is to analyze the samples that were examined by confocal microscopy using scanning electron microscopy. From this elemental distributions of the samples will be determined, and further information about the history of fluid flow along the fault derived. Also, this technique may yield information about any gold-rich fluids that may have moved along the fault zone. After the SEM analysis is completed thin sections of the samples will be made. It is not possible to make these thin section before hand because the oil in the samples is destroyed during preparation. Chemical fingerprinting of the oil in the samples will also be determined.

What is apparent from this study is the episodic nature of the oil flow in this fault zone. This is indicated by the laminae of oil as well as the larger major episodes that were occasionally observed. This is in agreement with the hypothesis that oil flow along a fault zone is a cyclic process that is dominated by fluid pressure. When complete this study will yield information about how oil moves from its area of deposition to its reservoir. This information will be of use to the petroleum industry, which is always trying to better understand the processes behind the deposition of oil.