AAPG Search and Discovery Article #90012©2003 AAPG Hedberg Conference, Vail, Colorado, July 21-26, 2002 (2003).

AAPG HEDBERG CONFERENCE
"*Late Paleozoic Tectonics and Hydrocarbon Systems of Western North America – The Greater Ancestral Rocky Mountains*"
July 21-26, 2002, Vail, Colorado

Metals and Brines of the Paradox Basin, Colorado and Utah

C.A. Wallace, Consultant, 7294 Sourdough Dr., Morrison, CO 80465
Jon P. Thorson, Consultant, 5515 Nuthatch Rd., Parker, CO 80134
John V. Wright, Consultant, 50 Hoogstraat, 1381 VV VEESP, NETHERLANDS
John. W. Keller, Colorado Geological Survey, 1313 Sherman St., Denver, CO

Principles similar to those used for prediction of hydrocarbon generation are used to predict the time of generation and composition of metal-bearing brines in a subsiding basin. The data used for metal-brine predictions are similar to those used to predict the generation of hydrocarbons; thickness and descriptions of formations, relative porosity and permeability, subsidence history, sediment dewatering, and heat flow. The application of metal-brine modeling techniques allows us to predict the timing of metal-brine generation, its migration paths within the basin, and the location and character of the resulting mineral deposits

As a stratigraphic sequence subsides into a basin , sedimentary rocks are exposed to increasing temperature and pressure, which results in periodic release of pulses of water, first through compaction and then through stabilization of clay minerals by dehydration. Mechanical compaction causes water expulsion over the first 3000 ft. of burial, but temperatures are not high enough for optimum metal solution. The conversion of smectite to illite during burial is a gradual process that liberates large volumes of water between 6,000 and 10,000 ft. of burial (Powers, 1967). When temperatures in the sedimentary basin reach between 120ºF and 165ºF, liberation of uranium, vanadium, gold, PGE elements, copper and silver is initiated. Gradual conversion of illite to muscovite and chlorite liberates additional water at burial depths greater than 10,000 ft. and at temperatures above 200ºF (Hays and others, 1996). This temperature range is within the conversion window of kerogen to liquid hydrocarbons, and these conditions are optimum for solution of lead, zinc and silver. At temperatures above 400ºF illite is converted to muscovite and chlorite and a final episode of dewatering occurs (Hower and others, 1976), and these conditions are optimum for solution of copper, cobalt, and gold.

The aqueous fluids produced by clay-mineral dehydration may result in over pressure in shale-dominated sequences where permeability is low. Data on the tectonic history of the basin can be used to predict episodes of fluid release as faults tap overpressured fluid reservoirs. In extensional basins a combination of gravity, compaction, and overpressured zones can result in expulsion of fluids from the basin. In basins under compression, those forces for fluid expulsion may be assisted by tectonic pressures or hydrostatic drive.

The chemical composition of fluid produced by dehydration reactions is controlled by the initial composition of the connate fluid in the sediment and by mineral composition of the sediment. In marine rocks the initial fluid composition is likely to be sea water, or a brine formed by sea-water evaporation. In continental rocks the initial fluid may have been much less saline than sea water. Diagenetic reactions between those initial fluids and the minerals of source rocks, or of aquifers through which the fluids travel, results in fluid compositions that change with time. These evolving fluids commonly contain dissolved organic acids, chlorine, or sulfur compounds that leach metals from rocks through which they pass.

Rocks that react with the evolving aqueous fluid are characterized as either reduced or oxidized. Reduced metal-source rocks usually contain organic material and sulfides, and produce aqueous fluids with high concentrations of organic acids and reduced sulfur compounds. In reduced source rocks metals are generally attached to clay minerals, incorporated in organic material as metal-organic complexes, or fixed by reduced sulfur as metal sulfides. Oxidized metal-source rocks are characterized by iron-oxides that hold loosely bound metals. In reduced or oxidized immature rocks such as greywacke or arkose, the metals may still be bound in the lattice structure of original silicate or oxide sediment grains, but metals are released through diagenetic reactions. The net result of diagenetic maturation of the aqueous fluid is a warm metal-bearing brine.

Maturation of organic material into liquid and gaseous hydrocarbons in the oil window has a parallel maturation of the metal-bearing brine as metals are dissolved in the basin's aqueous fluids in a sequence of thermochemically controlled metal-maturity windows. The metals are released from their source rocks in a progressive sequence determined by ion concentrations and degree of association of ion complexes (Helgeson, 1969), so metals of similar ionic strengths and ionic diameters are released together. The temperatures at which these metal suites are released overlap, but the release follows a consistent pattern with increasing burial depth and rising temperature:

Metal maturity window	T(°C)	T(°F)
U-V-(Th)	35-100	120-240
Au-PGE	60-110	165-255
Cu-Ag	60-120	165-275
Pb-Zn	70-180	200-380
Au-Co-Cu	175-275	375-550

The analysis of metallogenesis of the Paradox Basin demonstrates the predictive power of applying the concept of metal-maturity windows to the evolution of sedimentary basins. The Paradox Basin is a NWSE-trending extensional, half-graben basin, of Pennsylvanian and Permian age, which had an active, syndepositional fault on the NE side, and a hinged carbonate platform margin on the SW side. In Pennsylvanian time black and gray, reduced-facies shales and siltstones were deposited with interbedded dolomite and evaporites in cyclical events during rapid subsidence. During Late Pennsylvanian and Permian time as much as 8000 feet of first cycle, immature arkose was deposited as the basin filled. During Triassic and Jurassic time the basin was dominated by continental fluvial and eolian sedimentation and subsided more slowly. In the Cretaceous rapid subsidence resumed during the marine incursion of the Interior Seaway. The Pennsylvanian evaporite beds were deformed into a series of NWSE-elongate salt anticlines that began growing in the Permian and continued periodic growth into Tertiary time, and perhaps continue today.

Studies of basin subsidence and petroleum generation by Nuccio and Condon (1996) and by us show that petroleum generation from lower Pennsylvanian petroleum source rocks was a progressive event that swept from NE to SW across the basin. In the NE part of the basin at the Humble Oil Uravan #1 Govt well, where early basin subsidence was rapid, petroleum generation may have begun as early as 270 Ma in Late Permian time, but certainly began by Triassic time. To the SW at Lisbon Valley, where the basin is shallower and subsidence was less, the first oil generation was about 156 Ma in Late Jurassic time. Farther to the southwest on the carbonate platform margin of the basin at Bluff, oil generation did not start until 77 Ma in Cretaceous time.

Two major episodes of fluid flow occurred in the basin. An early episode of fluid flow expelled large volumes of chemically reducing, acid brines that were associated with mobile hydrocarbons. The record of this event is found in large volumes of bleached rocks from Permian through Jurassic age in which hematite has been converted to pyrite. A second episode of fluid flow was characterized by a smaller volume of oxidized metal-rich brine in which carbonate and sulfate were stable, and also accompanied by hydrocarbons. This second fluid episode post-dates the deposition of the Cretaceous marine shale and may be as late as Tertiary.

Two widespread, but temporally different, episodes of metal-brine migration have effected large parts of the basin and deposited: (1) the Colorado Plateau U-V mineral deposits; and (2) epigenetic stratabound Cu-Ag mineral deposits. The U-V mineral deposits occur in Permian through Jurassic rocks, but are concentrated in the Triassic Shinarump Member of the Chinle Formation and Jurassic Saltwash Member of the Morrison Formation. The stratabound Cu-Ag minerals were deposited throughout the section of Pennsylvanian through Jurassic rocks and extend higher in the section into the lower Cretaceous Dakota Formation. The Cu-Ag stratabound deposits are preferentially concentrated in porous formations that were bleached and reduced by the earlier episode of brine migration.

REFERENCES

Hays, P.D., Walling, S.D., and Tieh, T.T., 1996, Organic and authigenic mineral geochemistry of the Permian Delaware Mountain Group, West Texas—Implications for the chemical evolution of pore fluids: *in* Crossey, L.J., Loucks, Robert, and Totten, M. W., Siliciclastic diagenesis and fluid flow—Concepts and applications, SEMP Special Publication 55, p. 163-186

Helgeson, H.C., 1969, Thermodynamics of hydrothermal systems at elevated temperatures: Journal of Science, v 267, p. 729-804.

Hower, John, Eslinger, E.V., However, M.E., and Perry, E.A., 1976, Mechanism of burial metamorphism of argillaceous sediment—1. Mineralogical and chemical evidence: Geological Society of America Bulletin, v. 87, p. 725-737.

Nuccio, V.F. and Condon, S.M., 1996, Burial and thermal history of the Paradox Basin, Utah and Colorado, and petroleum potential of the Middle Pennsylvanian Paradox Formation: US Geological Survey Bulletin 2000-O, 41p.

Powers, M.C., 1967, Fluid-release mechanisms in compacting marine mudrocks and their importance in oil exploration: American Association of Petroleum Geologists Bulletin, v. 51, p. 1240-1254.