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

Petroleum Systems Related to Source Rocks in the Mississippian Antler Foredeep of Eastern Nevada and Western Utah

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Emphasis on Source Rocks, Oil Generation, Migration, Entrapment and Timing

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Organic-rich shaley and phosphatic rocks present in the infill section of the Mississippian Antler foredeep basin of eastern Nevada and western Utah constitute one of the thickest and most widespread source rock sections in North America. This paper will describe the distribution of the source rocks, their generation history, and known and probable petroleum systems related to them. Much of the data to be presented is a synthesis of specific and semi-regional information presented by previous investigators that I have incorporated into a broader regional scheme.

During the Mississippian-age Antler Orogeny (Kinderhookian?, Osagean through Chesterian), an area of uplift was formed that extended in a north-south direction across central Nevada. The east side of the uplift was bounded by the east-vergent Roberts Mountain Thrust. A large foredeep basin was formed east of the uplifted area in eastern Nevada and western Utah. The infill section of the basin may be simplistically described as being deposited in the following lithofacies packages:

1) A thick (up to 10,000 ft) easterly prograding and thinning wedge of coarse clastic rocks eroded from the adjacent Antler uplift was deposited in a narrow trough on the west side of the Antler Basin (the "Diamond Peak" facies).
2) The eastern cratonic side of the Basin was filled by a westerly prograding carbonate shelf facies that reached a thickness of 5000 ft. (the Deseret Limestone, Humbug Formation and Big Blue Limestone).
3) A thin (up to 60 ft) phosphatic "starved basin facies" unit (Delle Member of the Deseret) was deposited at the lower slope and basin floor of the lower Limestone shelf margin. It was overridden by the prograding Deseret shelf and extended for some distance westward beyond the shelf margin toward the center of the basin as a basal unit of the infill section.
4) The area between the Diamond Peak facies on the west and the carbonate shelf margin on the east was characterized by deposition of a relatively thin (5000 to <2000 ft) section of shaley sediments (the "Chainman" facies") that interfingered with coarse clastics in the Diamond Peak and formed the toe and basinal equivalent of the upper Big Blue part of the carbonate shelf margin

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A reasonably extensive database of organic geochemical analysis involving Antler Basin rocks is available in the public domain. Although the database contains some subsurface information from wells, most of the data has been obtained from surface outcrop samples that may be affected by weathering. As a whole, the clastic and phosphatic facies of Antler Basin are characterized by rather organic-rich sediments, although the amount of contained total organic carbon (TOC) and the nature of its kerogen are rather variable both laterally and vertically. Significant variations in analytical values may be caused by a) weathering alteration in surface samples, b) different degrees of subsurface thermal alteration ("maturity") and c) primary depositional content. Analyzed TOC ranges from <0.1 to 5.04% in the Diamond Peak facies and is characterized by mixtures of sapropellic oil-generation-prone marine type II, gas-generation-prone humic type III, and non-generative degraded type IV kerogens. TOC in the Chainman shaley facies ranges from <0.1to 10.6% and generally has somewhat higher values in immature samples than those of comparable maturity in the Diamond peak facies. While the range of Chainman samples indicates a of a variety of mixed type II, III and IV kerogen types, many of the samples are typical of relatively pure type II. TOC in the phosphatic Delle facies ranges from .019 to 4.97% and is presumably dominated by type II kerogen.

Antler rocks were subjected to several post depositional periods of burial, tectonic disturbance and erosion. Major events include:

1) Substantial and variable burial occurred during Permo-Pennsylvanian time. This was followed by shallow Triassic burial and a long period of non-deposition during the Jurassic and Lower-Middle Cretaceous.
2) Compressional folding, and faulting occurred during the Upper Cretaceous Sevier Orogeny accompanied or followed by variable erosion of the Paleozoic section.
3) Scattered relatively thin Lower Tertiary lacustrine basin deposition was followed by a period of extrusive Oligocene volcanism.
4) A period of extensional rifting and faulting occurred during the Mio-Pliocene-Recent Basin-and-Range Orogeny. Antler-age rocks were uplifted and eroded in mountain ranges, and were buried beneath variable amounts of fill sediments in adjacent basins.

Reconstructions of the hydrocarbon generation history of Mississippian-age organic-rich potential hydrocarbon source rocks show that they have undergone several distinct periods of generation based on depths of burial, average temperature gradients and type II kerogen thermal reaction kinetics. Burial history modeling yields maturity values that closely match measured outcrop and subsurface data.

A major period of generation was created prior to the Upper Cretaceous Sevier/Laramide Orogeny as a result of Permo-Pennsylvanian burial and mid-Mesozoic non-deposition. Significant generation occurred during this time period in most of the potential source rock area, with more-advanced maturity present in areas where the Permo-Pennsylvanian section was thickest. Burial depths of over 30,000 feet in the Oquirh Basin of northwestern Utah were responsible for placing source rocks in the wet gas and condensate generation/stability window.

A second major period of generation took place between the end of the Upper Cretaceous-Lower Tertiary Sevier and the Miocene Basin-and-Range Orogenies. During this period, Mississippian rocks were both a) eroded over uplifted Sevier Laramide anticlinal folds and b) maintained at nearly the same depth as they were at the end of Permian time in Sevier synclines. In areas of uplift where depths and temperatures become less than those required for active generation, no additional generation took place even if source rocks had previously been placed in the maturity window, and no generation took place in areas of previous immaturity. In areas of preserved burial depth, such as in the synclinal Butte Trough of central eastern Nevada, the effects of time on generation kinetics produced additional increments of maturity, reaching stages of wet gas/condensate and dry gas generation and stability.

Much of the area occupied by Mississippian source rocks generated large amounts of oil and gas prior to the Basin-and-Range Orogeny, and petroleum accumulations containing large volumes of generated products were undoubtedly created. Most, if not all, of the accumulations created prior to Miocene time were probably destroyed during either the Sevier or Basin-and- Range Orogenies. The large tar sand deposits in Permian and Triassic rocks exposed along the Colorado River Canyon in southern Utah are believed by some workers to represent fossil accumulations related to one of these early periods of generation. This would seem to indicate a fair distance of migration eastward from the nearest mature Antler-age source rock in the Delle phosphatic unit. Based on the presence of favorable rock types, a pre-Tertiary migration path through Pennsylvanian, Permian and Triassic rocks seems feasible.

The preponderance of global evidence indicates that it is very difficult to preserve large quantities of hydrocarbons through later periods of major structural dislocation and erosion. One of the basic premises involved in the concept of petroleum systems is that they are both created and destroyed and therefore have a limited geologic time period for their existence. It would seem more probable that significant hydrocarbon accumulation would occur in situations where generation and migration is contemporaneous with, or closely follows, the creation of current structural fabric and hydrocarbon trap formation. This seems to be the case for the only productive oil accumulations that have been conclusively tied to Antler-age source rocks. Accumulations in Pine Valley and Railroad Valley Basins in central-eastern Nevada are related to depths and temperatures achieved during burial of immature Chainman facies source rocks beneath Mio-Pliocene age basin fill deposited during the Basin-and-Range Orogeny. Migration paths are vertical and lateral from basin-bottom areas of source rock maturity to subcrop and geomorphic unconformity traps formed beneath a top seal at the base of the Upper Tertiary basin fill. Productive reservoirs are present in any porous and permeable rock present beneath the top seal unconformity. These include Silurian, Devonian and Pennsylvanian carbonates, Mississippian Antler-age sandstones, Eocene sandstones and carbonates and Oligocene volcanics.