Hydrothermal Oil

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Studies of hydrothermal dolomite (HTD)-hosted, Trenton-Black River type, gas fields of the Appalachian Basin (Keith and others, 2002) have led to an integrative hydrothermal oil model that may explain the generation, transport, and deposition of anomalous amounts of Mg and hydrocarbon that characterize HTD and closely analogous Mississippi Valley Type zinc deposits (MVT) deposits. These deposit types may be produced from previously unrecognized, major hydrocarbon sources in the peridotitic basement.

The new model agrees with experimental data (Berndt and others, 1996; Horita and Berndt, 1999; Horita and others, 2001). It also agrees with empirically constrained, mass-balance calculations that add new constraints to the previously enigmatic, HTD gas problem, as well as basin-centered gas. The reaction sequence below utilizes constraints derived from fluid fractionation modeling, transcurrent shear-zone kinematics, geochemistry, and basement structural data.

The reaction sequence (in reduced crust) is: Stage 1--generation of methane-hydrocarbon- stable metagenic fluids from serpentinization of peridotite in intracratonic failed rifts or collisional sutures in the basement when triggered by compressive, convergent orogenesis and subsequent ascension through probable transpressive conduit systems; Stage 2--initial, low temperature 'passive' dolomitization of the first replaceable shelf carbonate in the overlying cratonic cover sequence; Stage 3A--early saddle dolomitization at or near depositional site; Stage 3B--late saddle dolomitization, anhydrite formation, carbon dioxide effervescence, hydrogen loss and methane unmixing; Stage 4--sulfide and hydrocarbon deposition; and Stage 5--deposition of late calcite at depositional site and illite/smectite/kaolinite clays in and marginal to depositional site. Gas-charged fluids may continue to ascend to higher levels, where they deposit gas charge in higher level sandstone reservoirs. The new hydrothermal hydrocarbon model views basin petroleum resources from the 'bottom-up', especially where that bottom is peridotitic basement.

The above conceptual model was empirically tested at a specific site at the Glodes Corner HTD gas field in Steuben County, New York (Keith and others, 2002). Surface soil geochemical samples taken at Glodes Corner, NY, 8000 feet above a HTD-hosted gas field have produced a precise definitional tool that defines the overall gas field and also delineates the internal conduit features related to the hydrocarbon charge.

The field is within a seismically defined sag feature or collapse caused by the formation of HTD at the Trenton-Black River level. Soil geochemical patterns are strongly consistent with and specific to the above outlined fluid fractionation model within the context of a transcurrent shear-system kinematic model.

Significant lateral chemical zonation includes well-developed east to west asymmetrical patterns in $CO_2:O_2$ and ferric:ferrous ratios, hydrocarbon gases, and Na-As-Zn-K-V-Mg The east end of the field is characterized by lower oxidation state assemblages, such as higher $CO_2:O_2$ ratios, lower ferric:ferrous ratios, and greater abundances of C1 and C2 hydrocarbons with respect to C5 and C6 hydrocarbons. The east end of the field appears to be closer to a primary, northwest-striking, conduit system that was operating in left slip during fluid introduction. Fluids ascended through this conduit system, entered the field from the east, and became more oxidized as they migrated westward into east-west-striking Riedel-tensile fractures. The within-reservoir, Riedel-tensile, conduit architecture of permeability and dolomite plugging can be identified by interpretation of hydrocarbon gas distribution (C1-C2 high in conduits and trace metals, C5 and

C6 gases away from the conduits). A possible southerly conduit that may have additional production potential was also defined.

The above patterns, which display strong laterality, appear to be specifically predicted by the HTD hydrothermal oil model. The predominance of reduced species gases along with elevated CO_2 in the east end of the field is consistent with early Stage 3A and Stage 3B saddle dolomitization, carbon dioxide effervescence, hydrogen loss and methane mixing. The elevated base metal and hydrocarbon anomalies in the profile within the middle of the field are consistent with Stage 3B and Stage 4 base metal sulfide and hydrocarbon deposition in a later, more fractionated part of the paragenesis in the middle of the field. In the inferred more distal part of the field, high C-number gases and more oxidized geochemical signatures in the westerly geochemical profile are consistent with Stage 5 deposition of late calcite and illitic smectitic clays in the middle to western part of the Glodes Corner field.

The above pattern is consistent with cooling of an initially hot, reduced fluid that entered the field from the east, utilizing a Riedel-tensile conduit system that splayed off a more northwesterly striking conduit system. This conduit system was operating in left slip during what is inferred to be Acadian orogeny (approximately 350-400 Ma) within an inferred east-northeast to east-west-oriented, far-field maximum principal stress regime operant during the 'hard crunch' Acadian continental (Avalon-North America) assembly event. The northwest- trending primary conduit system may have been linked to a peridotitic source in the basement expressed by a coincident magnetic high and gravity low feature that occupies most of Steuben County. The foregoing geophysical signature is further interpreted to be linked with mafic sources within the Rome trough, a failed rift system of mid- to late Cambrian age.

The inferred peridotitic source in central Steuben County may be one example of a consistent linkage between HTD hosted hydrothermal oil and gas occurrences and peridotitic sources in failed rifts or orogenic sutures. Other similar examples may be the Arbuckle formation in the Ardmore-Anadarko basins of Oklahoma, the Williston basin of North Dakota, the Albion-Scipio field in southern Michigan, many fields in the Appalachian basin, the well-known Wabamun Group HTD-hosted oil and gas fields of Alberta, the Great Valley of California, Railroad Valley in Nevada, and the largest known oil field in the world - the Ghawar field of the Persian Gulf.

The provocative possibility also exists that oil and gas resources hosted in more conventional stratigraphic and structural traps (such as sandstone-hosted anticlinal traps) at higher levels in the above basins may also represent more oxidized, fractionated, leakage anomalies above the hydrothermal deposits, which typically reside near the bottoms of the above basins within close proximity to the basement.

If the hydrothermal point of view summarized above is viable, it has revolutionary implications for petroleum geology in general:

1) A significant amount of the world's oil may be derived from abiogenic sources in the basement.

2) Migration and trapping may be accompanied by abiogenic depositional reactions and transport mechanisms.

3) The oil window can be entered from high temperature/high pressure conditions via cooling and decompression of hot, hydrothermal fluids.

4) In common with many hydrothermal metal deposits (such as gold, tin and MVT deposits where smaller amounts of hydrothermal hydrocarbon material have been documented) that are derived from reduced sources, the oil and gas are formed as part of the reaction sequence associated with depositional events (mainly dolomite) that accompany cooling and depressurization of the hydrothermal fluid. This concept contrasts with current models where the reservoir environment is made by hydrothermal processes, and the oil generation and migration event occur much later.

5) A significant amount of the world's oil and gas may owe its origin to fractionation of and deposition from hydrothermal fluids (especially as a function of saddle dolomitization under reduced conditions), in common with metals deposited in hydrothermal metal deposits, which constitute most of the world's metallic mineral resources.

6) A significant amount of biogenic, basin-sourced hydrocarbons may be reworked and incorporated into hydrothermal hydrocarbon plumes originally sourced in reduced, deep basement rocks (especially peridotites).

7) Compared to metallic hydrothermal deposits, HTD deposits were formed from much larger hydrothermal plumes (about ten times the average MVT deposit and about one hundred times the average porphyry metal system).

8) Given that peridotite may be an important source of basement-sourced hydrothermal hydrocarbon systems, the ultimate source of the hydrocarbon is the mantle, as has been suggested by other workers (Gold, 1993; Kravtsov, 1985; Kropotkin, 1985; Kroptkin and Valyaev, 1976; Kropotkin and Valyaev, 1984; Kudryavtsev, 1959; and Chekaliuk, 1976). We have developed a geologically reasonable mechanism of reworking a peridotitic source via serpentinization under reduced abiogenic conditions to generate hydrocarbons out of metagenically derived basement fluids to transport them into overlying basement cover sequences.

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