Assessing the Role of Ancient and Active Geothermal Systems in Oil-Reservoir Evolution in the Eastern Basin and Range Province, Western USA

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ABSTRACT

Results of our research in progress on the oil fields of the Basin and Range province of the western USA continue to support the following concept: Convecting, moderate-temperature geothermal systems in this region have fostered and in some cases critically influenced the generation, migration, and entrapment of oil. At one Basin-Range field (Grant Canyon), for example, oil-bearing and aqueous fluid inclusions in late-stage hydrothermal quartz were entrapped at temperatures comparable to those now prevailing at reservoir depths (120-130°C); apparent salinities of the aqueous varieties match closely the actual salinity of the modern, dilute oil-field waters. The inclusion-bearing quartz has the oxygen-isotopic signature expected for precipitation of the mineral at contemporary temperatures from modern reservoir waters. Measured and fluid-inclusion temperatures define near-coincident isothermal profiles through the oil-reservoir interval, a phenomenon suggesting ongoing heat and mass transfer. These findings are consistent with a model whereby a still-active, convectively-circulating, meteoric-hydrothermal system: (1) enhanced porosity in the reservoir rock through dissolution of carbonate; (2) hydrothermally sealed reservoir margins; (3) transported oil to the reservoirs from a deep source of unknown size and configuration; and (4) possibly accelerated source-rock maturation through an increase in the local thermal budget. Grant Canyon and other Basin-Range oil fields are strikingly similar in many ways to the oil-bearing, Carlin-type, sediment-hosted, disseminated gold deposits of the nearby Alligator Ridge district, the focus for the next phase of our research. The oil fields could represent either weakly mineralized analogues of these deposits, or perhaps an incipient phase in their evolution.

INTRODUCTION

The Basin and Range physiographic province of northeastern and east-central Nevada is famous not only for the State's eleven productive oil reservoirs (Fig. 1), but also for its dense concentration of Carlin-type, sediment-hosted, disseminated precious-metal deposits. Results of our OBES-sponsored research-in-progress in the region have begun to reveal distinct parallels between these seemingly disparate occurrences. Many of the oil reservoirs are hot, and actually appear to have formed in moderate-temperature hydrothermal systems. Several of the clearly paleohydrothermal Carlin-type deposits (like those of the Alligator Ridge mining district; Fig. 1) contain considerable liquid hydrocarbon, and may have evolved under physical/chemical conditions quite similar to those presently prevailing at the thermally active oil fields.

Figure 1. Location map, showing productive oil fields of Nevada and the Yankee gold mine in the Alligator Ridge mining district.

GEOHERMAL INFLUENCES IN OIL-RESERVOIR EVOLUTION IN RAILROAD VALLEY

Our research to date has focused on the thermally active oil fields at Grant Canyon and Bacon Flat in eastern Nevada's Railroad Valley (Fig. 1). Ongoing lithologic, structural, stratigraphic, fluid-inclusion, hydrothermal-alteration and stable-isotope studies here have been coupled with hydrogeochemical investigations being conducted by Fraser Goff of Los Alamos National Laboratory (e.g. Goff et al., 1993) to yield an ever more convincing picture of these two hot fields as essentially oil-concentrating, active geothermal systems. Grant Canyon has produced nearly 19,000,000 barrels of oil to date since its discovery in 1983, making it the state's premier oil field (Montgomery, 1988; Nevada Department of Minerals bi-monthly production statistics). The adjacent Bacon Flat field produced about 340,000 barrels of oil before being shut-in 1987 (Montgomery, 1988), then was rejuvenated in 1992 by a successful step-out well; the field had produced about 400,000 barrels of oil as of March 1993. A 1993 Cenex Corporation discovery, Sans Spring field (Fig. 1) about 4 miles west of Bacon Flat, has produced as much as 1200 barrels of oil per day (Nevada Department of Minerals).

Both Grant Canyon and Bacon Flat fields, hosted by highly porous (locally cavernous), hydrothermally leached Devonian dolostone breccias beneath a Plio-Pleistocene valley-fill alluvial sequence, have long been recognized as thermally anomalous (Bortz, 1989; Veal et al, 1988; Read and Zogg, 1988; Duey, 1983) -- Bacon Flat reservoir temperature is probably between 125 and 135°C; Grant Canyon about 121°C (Fig. 2; Hulen et al., 1993a; Veal et al., 1988), corresponding to a simple geothermal gradient (thermal conductivity assumed constant) of about 90°C/km. This value is about three times the global norm (Kruger and Otte, 1973) and more than four times the value cited by Duey (1983) as typical for Railroad Valley overall. Only one published equilibrium-temperature log exists for wells in the two fields (Fig. 2), so our concept of the modern subsurface thermal regime is based upon drill-stem-test (DST) measurements -- these closely match the actual measured temperatures ($\pm 10^{\circ}\text{C}$) at the same depths in two

* Kleinhampl and Ziony (1985)

† Veal et al., 1988

** Typical Railroad Valley geothermal gradient reported by Duey, 1983

†† Approximate global "normal" geothermal gradient (Kruger and Otte, 1973)

*k = Thermal conductivity

**Moderate temperature, non-boiling

Figure 2. Composite temperature vs depth profile for Grant Canyon and Bacon Flat oil fields and vicinity, Railroad Valley, Nevada. The profile is formed by linking a static-temperature log for well 4-GC with the locus of temperatures measured during drill-stem tests (DST) of five productive and six non-productive oil wells. Shown for reference, and underscoring the heat anomaly at the oil fields, are typical geothermal gradients for Railroad Valley (Duey, 1983) and the world (Kruger and Otte, 1973), as well as a DST temperature at comparable depth for nearby dry hole 1-CH. Note that the composite thermal profile for the two oil fields closely matches that theoretically predicted for a convectively-upwelling, moderate-temperature geothermal plume beneath a conductively heated caprock (inset). Such a plume, we contend, was instrumental here in oil-reservoir evolution.

wells recently temperature-logged by the USGS (C. Williams, pers. comm., 1992). Note that the DST temperatures for the two fields and immediate vicinity vary little regardless of depth over an interval of nearly 800 m (a DST temperature for a dry hole four miles north is shown for comparison). We contend that this profile reflects an isothermally upwelling geothermal plume -- one which, moreover, critically influenced oil-reservoir evolution. Above the plume, as signalled by the 4-GC temperature log, a conductive thermal regime corresponds to the fields' tightly sealed caprocks, which in part have been formed by deposition of secondary minerals like quartz and kaolin at the top of the Grant Canyon geothermal plume.

Modern reservoir waters coexisting with oil at Grant Canyon and Bacon Flat are dilute, meteoric, $\text{Na-HCO}_3\text{-Cl}$ fluids reminiscent of those circulating in many well-studied, moderate-temperature geothermal systems -- they are, for example, enriched in SiO_2 , B, Br, Li, Cs, and Rb (Goff et al., 1993; Hulen et al., 1993a). They do not, however, display a large "oxygen shift", or enrichment in $\delta^{18}\text{O}$ relative to modern or older (based on tritium analyses) cool meteoric fluids sailed from springs, shallow wells, and a creek in Railroad Valley and its foothills (Fig. 3). Mathematical modeling of the reservoir waters' exceedingly low tritium content (<1 tritium unit; Goff et al., 1993) suggests that they were recharged in pre-Holocene time (>10,000 yr ago; Goff et al., 1993). An array of chemical and isotopic geothermometers (e.g. chalcedony; Na-K-Ca with Mg correction; Fournier, 1981) suggest that the reservoir waters may never have been much hotter than the modern measured temperature range.

The Grant Canyon and Bacon Flat oil-field waters have a measured concentration (4500 ppm total dissolved solids; Goff et al., 1993) virtually identical to the apparent salinity (0.35-0.53 wt.% NaCl equiv.) of primary aqueous fluid inclusion co-existing with oil inclusions in late-stage secondary quartz at both fields. Homogenization temperatures of these inclusions are close to modern reservoir temperatures (Fig. 4) -- for the aqueous inclusions virtually identical when an appropriate, slight pressure correction

Figure 3. Plot of $\delta^{18}O$ vs δD for thermal oil-field waters from Grant Canyon oil field vs other thermal and non-thermal waters collected from Railroad Valley and flanking mountain ranges. Note that the Grant Canyon oil-field waters are considerably depleted in both isotopes relative to cold meteoric waters from the ranges, ruling out reservoir recharge from modern precipitation. Note also that the oil-field waters have not become significantly enriched in $\delta^{18}O$ with respect to the cooler meteoric waters, and thus have apparently interacted minimally with the rocks through which they have circulated.

Figure 4. Plots of homogenization temperatures (T_h) vs frequency for aqueous and oil-bearing fluid inclusions in cores and cuttings spanning the elevation interval 80.8-331.9 m in productive wells 1-GC, 4-GC, and 7-GC at reservoir depths in Grant Canyon oil field. T_h data for these wells are similar regardless of elevation and are grouped here for clarity. A -- Plot for all inclusions analyzed, showing a prominent T_h maximum in the range 110-115 $^{\circ}\text{C}$. B -- Plot for unambiguous primary inclusions only. Two populations are apparent on this plot. One population corresponds to the T_h maximum observed in A, and includes only quartz-hosted primary oil, aqueous, and mixed oil/aqueous inclusions; the other corresponds exclusively with "saddle" dolomite-hosted, primary brine inclusions. Note that the lower T_h maximum is very close to the modern measured reservoir temperature of about 121 $^{\circ}\text{C}$.

(Potter, 1977) corresponding to contemporary reservoir pressure is added (Hulen et al., 1993a). The T_h values are the same regardless of elevation at reservoir depths or below -- duplicating the modern-day composition of the quartz ($\delta^{18}O = 5.24\text{‰}$; Hulen et al., 1993a) is consistent with its precipitation from modern oil-reservoir waters at present-day temperatures. These relationships strongly suggest that oil was transported to the Grant Canyon and Bacon Flat traps in an isothermally upwelling plume of dilute geothermal water much like the one apparently still in existence.

The oil-bearing quartz discussed above occurs not only abundantly in the Grant Canyon and Bacon Flat oil reservoirs, but also sparingly in the overlying caprocks, where along with chalcedony, kaolin, and calcite it helps provide an effective reservoir seal. In view of the quartz-hosted fluid-inclusion systematics summarized above, this suggests that formation of the oil reservoirs did not commence until Railroad Valley was filled with alluvial and lacustrine sediments to essentially modern levels. The fields would appear to be very young features indeed. This contention is supported by consideration of age-dated durations for many active and fossil geothermal systems (e.g. White, 1979; Silberman, 1983; Browne, 1984): few persist longer than 1 m.y., and the longest-lived dated system, Steamboat Springs, has been intermittently active for only 3 m.y. (White, 1979).

In summary, converging evidence from fluid-inclusion, hydrogeochemical, isotopic, and hydrothermal-alteration studies strongly indicates that the Grant Canyon and Bacon Flat oil reservoirs developed in the geologically recent past in a still-active, moderate-temperature, meteoric-hydrothermal system (Fig. 5). The system apparently created critical secondary porosity through hydrothermal carbonate-dissolution, helped seal reservoir margins by depositing a variety of secondary minerals, transported oil to the structural traps, and possibly helped generate oil from otherwise submature source rocks by significantly increasing the local thermal budget relative to the regional norm.

Figure 5. Conceptual model for geothermal evolution of the Grant Canyon and Bacon Flat oil fields. The key element of the model is a convectively upwelling, moderate-temperature plume, which heats the rocks at modern reservoir elevations to temperatures normally prevailing three km deeper. Hot waters in the plume help seal the overlying caprock by depositing silica and clay. More importantly, the plume enhances upward migration of oil from deeper and probably more basinward hydrocarbon source rocks or oil reservoirs.

THE OIL-RICH PRECIOUS-METAL DEPOSITS OF THE ALLIGATOR RIDGE MINING DISTRICT

Possible paleohydrothermal analogues of the oil-bearing Grant Canyon/Bacon Flat geothermal systems have been exposed by open-pit mining in the Alligator ridge mining district, about midway between the oil-field clusters of Railroad and Pine Valleys (including Blackburn field) in eastern Nevada (Fig. 1). Like the oil fields, the Alligator Ridge district occurs in Nevada oil "fairway", within which potential Paleozoic source rocks are regionally "trembling on the brink" of oil generation (Poole et al., 1983; Bortz, 1983). Three Carlin-type, low-grade, disseminated, sediment-hosted precious-metal deposits in the district -- Casino, Winrock, and Yankee -- contain considerable quantities of oil, either freely-flowing as at Yankee (Hulen et al., 1993b; Pinnell et al., 1991) or as abundant, oil-rich fluid inclusions, found at all three deposits. The Carlin-type deposits as a class all contain hydrocarbons in one form or another (e.g. Ballantyne, 1988), and numerous workers (e.g. Nelson, 1991) have suggested that many of these orebodies actually formed in pre-existing petroleum reservoirs. However, in most of the Carlin-type deposits, the hydrocarbons are "burned out", that is, tarry to graphitic residues. By contrast, the hydrocarbons in the three above-mentioned deposits are dominantly "live", theoretically once-producible oil, apparently transported and entrapped at unusually low temperatures for epigenetic ore deposits. Results of our work to date at Alligator Ridge strongly suggest that here the oils were transported and entrapped in moderate-temperature hydrothermal systems remarkably similar to those still circulating at the nearby Grant Canyon, Bacon Flat, and Blackburn fields (e.g. Hulen et al., 1993b).

The gold ores of the Alligator Ridge district are hosted by Paleozoic carbonate and carbonate-rich siliciclastic rocks. In the high-grade centers of the deposits, these have been massively decalcified, silicified, and sulfidized (e.g. Hulen et al., 1993b; Ilchik, 1991). Partially encircling the orebodies are gold- and arsenic-rich calcite-vein stockworks, within which the calcites

have isotopic signatures distinctly different than post-ore varieties (Fig. 6). At the Yankee mine, the calcite-stockwork zone (where unoxidized) hosts conspicuous and abundant concentrations of freely-flowing oil -- and the calcite itself contains large, abundant, primary oil-bearing fluid inclusions trapped at unusually low temperatures.

Figure 7 (from Hulen et al., 1993b) portrays fluid-inclusion T_h systematics for oil-bearing and coexisting aqueous fluid inclusions in the ore-stage Yankee calcites. Note that none homogenized above 150°C, and that the oil-bearing varieties have a mean T_h of about 95°C -- even though the calcites were collected less than 10 m from >0.05 oz/T gold ore. T_h here is believed on textural and stratigraphic evidence to approximate closely actual entrapment temperatures. We conclude that at Yankee, oil was transported and entrapped in the same hydrothermal system responsible for gold mineralization, and moreover at temperatures far lower than typical for the Carlin-type deposits as a class (190-250°C; Percival et al., 1988).

The Yankee mineralization temperature, however, is very similar to both the modern reservoir temperature and to that recorded by late-stage fluid-inclusion T_h at the Grant Canyon and Bacon Flat oil fields. Other similarities between the two types of occurrences, besides the obvious presence of oil, include: porosity formation by massive carbonate dissolution; a distinctive trace-element suite including As, Sb, Hg, and Au (only traces of the latter, however, at Grant Canyon/Bacon Flat); and the distinctive alteration/mineralization assemblage quartz-kaolin-barite-pyrite-marcasite (Table 1; Figure 8). The similarities between the thermally active oil fields and the Alligator Ridge deposits extend even to geochemical signatures. The oil fields and their caprocks are by no means mineable Carlin-type precious-metal orebodies, but all are enriched in the gold-associated pathfinder-element suite Hg-As-Sb-Tl. We have obtained gold values as high as 50 ppb (background 2 ppb) for oil-reservoir dolomite breccias in some Blackburn wells, and the silicified caprock penetrated in well Blackburn-16 (Figure 9) contains up to 20 ppb Au. The role (if

Figure 6. Plot of $\delta^{13}\text{C}$ vs $\delta^{18}\text{O}$ for calcites from the Yankee and Vantage Carlin-type precious metal deposits in the Alligator Ridge mining district, Nevada. The Yankee calcites, which contain large, primary, oil-bearing fluid inclusions, plot within the field for calcites occurring in prominent halos around gold mineralization at Vantage. We conclude from this finding and from field relationships at the Yankee mine free oil occurrence that the oils were probably transported and entrapped in the same hydrothermal system responsible for precious-metal mineralization.

Figure 7. Plot of T_h vs frequency for 188 calcite- and barite-hosted fluid inclusions from the basal Pilot Shale limestone hosting freely-flowing live oil in the Yankee gold mine. The delicate epithermal textures of the host crystals, along with stratigraphic reconstructions, suggest that these T_h are very close to the true fluid-entrapment temperatures. The mean T_h for the oil-bearing, calcite-hosted inclusions, about 95°C, is in the same range as the modern reservoir temperature (121°C) for the oil-transporting geothermal system now circulating at Grant Canyon field.

Table 1. Comparison of Carlin-type gold deposits of the Alligator Ridge district with the thermally active Blackburn and Grant Canyon oilfields

	ALLIGATOR RIDGE CARLIN- TYPE GOLD DEPOSITS ¹	BLACKBURN OIL FIELD ²	GRANT CANYON OIL FIELD ³
<u>Host Rocks</u>	Paleozoic carbonate and carbonaceous calcareous/dolomitic clastic strata	Paleozoic carbonate and carbonaceous calcareous/dolomitic clastic strata; minor ignimbrite	Paleozoic dolomite
<u>Traps</u>	Gentle anticlines; possibly now-eroded upthrown fault blocks	Upthrown fault block	Upthrown fault block
<u>Seals or Caprocks</u>	Paleozoic shales; locally silicified and argillized Tertiary tuffs and epiclastic sandstones; fault gouge	Silicified and argillized Paleozoic shales, siltstones, and sandstones; argillized Tertiary tuffs and epiclastic sandstones; fault gouge	Silicified and argillized tuffaceous sandstones and conglomerates; fault gouge
<u>Temperature</u>	Yankee: ~90°C (?) (fluid inclusions) Vantage: 200-230°C (pyrolysis and fluid inclusions) Others: unknown	~120°C (measured)	~120°C (measured) 114-123°C (fluid inclusions)
<u>Ground Preparation</u>	Fracturing, hydrothermal (?) brecciation, solution brecciation, carbonate dissolution	Fracturing, hydrothermal brecciation, carbonate dissolution	Fracturing, brecciation (origin?), carbonate dissolution
<u>Secondary Mineralogy</u>	Quartz, kaolin, barite, calcite, pyrite, marcasite, stibnite, orpiment, realgar, gold, alunite, jarosite, iron oxides	Quartz, kaolin, barite, dolomite, pyrite, marcasite, sphalerite ⁴ , galena ⁴	Quartz, kaolin, barite, dolomite, pyrite, marcasite
<u>Live oil present?</u>	Yankee: yes Vantage: no Casino: yes Others: unknown	Yes	Yes
<u>Geothermal System?</u>	Yes (fossil)	Yes	Yes
<u>Geochemical Enrichments</u>	Au, As, Sb, Hg, Ti, SiO ₂	Au, As, Sb, Hg, Ti, SiO ₂	Au, As, Sb, Hg, Ti, SiO ₂

1-data from Pinnell et al., 1991; Ilchik, 1991; Klessig: 1984; Cox and Lamborn, 1991a, 1991b; Hulen et al., unpubl. research results

2-data from Hulen et al., 1990a; Scott and Chamberlain, 1988; Hulen et al., unpubl. research results

3-data from Hulen et al., 1991a, 1992b; Veal et al., 1988; Read and Zogg, 1988; Hulen et al., unpubl. research results

4-pre-oil (probably Cretaceous mineralization)

Figure 8. Downhole distributions of selected rock-forming and alteration/vein minerals above and within the Blackburn oil reservoir as penetrated in well Blackburn-16. Silica enrichment in the lower half of the Chainman Shale reflects silicification and quartz veining -- The rock is essentially a jasperoid. Intense smectite alteration is confined to basal Oligocene tuffs and sandstones, and is probably of diagenetic origin. The occurrence of kaolin, by contrast, spans the tuffs, the Chainman, and the brecciated Devonian dolomite reservoir rock. This clay was probably deposited by acidic, moderate-temperature geothermal fluids.

Figure 9. Downhole distributions of gold and selected "pathfinder" elements above and within the Blackburn oil reservoir in well Blackburn-16 (see also Figure 21). Partially in the altered Chainman Shale but also in the uppermost reservoir, these elements are conspicuously enriched above background levels. This enrichment and: (1) corresponding alteration mineralogy; (2) the geologic setting; and (3) the presence of hydrocarbons are highly reminiscent of Carlin-type, sediment-hosted gold deposits.

any) of organics in actual precious-metal mineralization at Alligator Ridge remains to be determined, but it is clear from our preliminary work in the district that oil was transported and entrapped in the same hydrothermal systems which deposited gold.

We would suggest further that the many similarities between the thermally active Basin-Range oil fields and the Alligator Ridge Carlin-type deposits warrant the working hypothesis that the former are either weakly mineralized analogues of the latter, or that the oil fields represent in some cases an incipient stage in the evolution of the gold deposits.

PROJECT BIBLIOGRAPHY TO DATE (as of July 15, 1993)

Papers

Hulen, J.B., D.L. Nielson, M.L. Pinnell, and J.W. Cox, 1993, The Yankee mine oil occurrence, Alligator Ridge district, Nevada -- An exhumed and oxidized, paleogeothermal oil reservoir: Nevada Petroleum Society, Great Basin Oil Field Volume, in review.

Goff, F., J.B. Hulen, A.I. Adams, P.E. Trujillo, D. Counce, and W.C. Evans, 1993, Geothermal characteristics of some oil-field waters in the Great Basin, Nevada: Nevada Petroleum Society, Great Basin Oil Field Volume, in review.

Hulen, J.B., F. Goff, S.R. Bereskin, and L.C. Bortz, 1993, Geology and geothermal origin of Grant Canyon and Bacon Flat oil fields, Railroad Valley, Nevada: AAPG Bulletin, in revision.

Hulen, J.B., L.C. Bortz, and S.R. Bereskin, 1991, Geothermal processes in evolution of the Grant Canyon and Bacon Flat oil reservoirs, Railroad Valley, Nye County, Nevada: Nevada Petroleum Society, 1991 Fieldtrip Guidebook, p. 47-54.

Pinnell, M.L., J.G. Blake, and J.B. Hulen, 1991, Oil seep in Nevada gold mine holds intrigue for more exploration: Oil and Gas Journal, July 15, p. 74-79.

Hulen, J.B., S.R. Bereskin, and L.C. Bortz, 1990, High-temperature hydrothermal origin for fractured carbonate reservoirs in the Blackburn oil field, Nevada: AAPG Bulletin, v. 74, p. 1262-1272.

Abstracts (each accompanying presentation at a scientific symposium or general conference)

Hulen, J.B., S.R. Bereskin, and L.C. Bortz, 1990, High-temperature, natural hydraulic fracturing as a reservoir control in the Blackburn oil field, Nevada -- Implications for petroleum exploration in the Basin and Range province: AAPG Bulletin, v. 74, p. 679.

Allison, M.L., and J.B. Hulen, 1990, Oil and igneous intrusions in Nevada: AAPG Bulletin, v. 74, p. 1313.

Hulen, J.B., Bereskin, S.R., and Allison, M.L., 1991, Volcanic and intrusive centers as petroleum exploration targets in the Basin and Range province western USA (invited): Geological Society of America, Rocky Mountain Section Meeting, Abstracts with Programs, p. 35.

Hulen, J.B., L.C. Bortz, and S.R. Bereskin, 1991, The role of active and ancient geothermal systems in evolution of the Grant Canyon oil field, Railroad Valley, Nevada: AAPG Bulletin, v. 75, p. 1128.

Goff, F., J.B. Hulen, and A.I. Adams, 1992, Geochemistry and geothermal implications of oil-field waters in the eastern Basin and Range: EOS, v. 73, p. 547.

Hulen, J.B., F. Goff, L.C. Bortz, and S.R. Bereskin, 1992, An active geothermal system and its role in evolution of the Grant Canyon and Bacon Flat oil fields, Railroad Valley, Nevada: EOS, v. 73, p. 547.

Hulen, J.B., J.W. Cox, D.L. Nielson, and J.C. Lamborn, 1993, Oil in Carlin-type, sediment-hosted gold deposits -- Significance for petroleum exploration: AAPG Bulletin, v. 77 (April).

French, D.E., and J.B. Hulen, 1993, Origin and nature of the hydrocarbon seal in Railroad Valley, Nevada: AAPG Bulletin, v. 77, in press.

Green, D.J., and J.B. Hulen, 1993, Hydrothermal speleogenesis in the eastern Basin and Range province -- Implications for petroleum and precious-metal exploration: AAPG Bulletin, v. 77, in press.

Hulen, J.B., and D.L. Nielson, 1993, Hydrothermal systematics, alteration, and mineralization in the Grant Canyon, Bacon Flat, and Blackburn oil fields, Nevada -- Intriguing parallels with the Carlin-type gold deposits (invited): AAPG Bulletin, v. 77, in press.

Pinnell, M.L., J.B. Hulen, and J.W. Cox, 1993, Results of deep exploratory drilling between Long and Newark Valleys, Nevada -- Implications for oil migration in the nearby Yankee gold mine paleohydrothermal system (invited): AAPG Bulletin, v. 77, in press.

REFERENCES

Ballantyne, J.M., 1988, Shallow hydrocarbon accumulations, magmatic intrusions, and the genesis of Carlin-type, sediment-hosted gold deposits: Vancouver, BC, Society of Mining Engineers, American Association of Mining Engineers, 2nd International Conference on Gold Mining, Proceedings, p. 48-57.

Bortz, L.C., 1983, Hydrocarbons in the northern Basin and Range, Nevada and Utah: Geothermal Resources Council, Special Report 13, p. 179-197.

Bortz, L.C., 1989, Oil and gas potential of the Basin and Range province in Petroleum potential of the Basin and Range province (N. Foster, L. Bortz, H. Duey, A. Chamberlain, and S. Veal, eds.): 28th International Geological Congress, Fieldtrip T-113 Guidebook (July 3-7, 1989), p. 1-12.

Browne, P.R.L., 1984, Lectures on geothermal geology and petrology: Reykjavik, Iceland, United Nations University, Geothermal Training Program, Course Handbook, 92 p.

Cox, J.W., and J.C. Lamborn, 1991a, Geology and mineralization of the Casino deposit, White Pine County, Nevada in Geology and ore deposits of the Great Basin -- Fieldtrip guidebook compendium (R.H. Buffa and A.R. Coyner, eds.): Reno, Nevada, Geological Society of Nevada, p. 113-115.

Cox, J.W., and J.C. Lamborn, 1991b, Geology and mineralization of the Winrock project, White Pine County, Nevada in Geology and ore deposits of the Great Basin -- Fieldtrip guidebook compendium (R.H. Buffa and A.R. Coyner, eds.): Reno, Nevada, Geological Society of Nevada, p. 116-118.

Duey, H.D., 1983, Oil generation and entrapment in Railroad Valley, Nye County, Nevada: Geothermal Resources Council, Special Report 13, p. 199-205.

Fournier, R.O., 1981, Application of water chemistry to geothermal exploration and reservoir engineering in Geothermal systems -- Principles and case histories (L. Rybach and L.J.P. Muffler, eds.): New York, John Wiley, p. 109-143.

Goff, F., Hulen, J.B., Adams, A.I., Trujillo, P.E., Counce, D., and Evans, W.C., 1993, Geothermal characteristics of some oil-field waters in the Great Basin, Nevada: Nevada Petroleum Society, Great Basin Oil Field Volume, in review.

Hulen, J.B., Goff, F., Bereskin, S.R., and Bortz, L.C., 1993a, Geology and geothermal origin of Grant Canyon and Bacon Flat oil fields, Railroad Valley, Nevada: Nevada Petroleum Society, Great Basin Oil Field Volume, in revision.

Hulen, J.B., Nielson, D.L., Pinnell, M.L., and Cox, J.W., 1993b, The Yankee gold mine oil occurrence, Alligator Ridge district, Nevada -- An exhumed and oxidized, paleogeothermal oil reservoir: Nevada Petroleum Society, Great Basin Oil Field Volume, in review.

Ilchik, R.P., 1991, Geology and geochemistry of the Vantage gold deposits, Alligator Ridge-Bald Mountain mining district, Nevada: Economic Geology, v. 85, p. 50-75.

Kleinhampl, F.J., and Ziony, J.I., 1985, Geology of northern Nye County, Nevada: Nevada Bureau of Mines and Geology, Bulletin 99-A, 172 p.

Klessig, P.J., 1984, History and geology of the Alligator Ridge gold mine, White Pine County, Nevada: Arizona Geological Society Digest, v. 15, p. 9-19.

Kruger, P. and Otte, C., 1973, Geothermal energy -- Resources, production, stimulation: Stanford, California, Stanford University Press, 360 p.

Montgomery, S.L., 1988, Nevada: The next great awakening? -- Pt. 2: Field summaries and exploration considerations: Petroleum Frontiers, v. 5, pt. 2, 64 p.

Nelson, C.E., 1991, Metalliferous marine black shales and fossil petroleum reservoirs -- Source rocks and host environment for Carlin-type gold deposits in Geology and ore deposits of the Great Basin (G.L. Raines, R.E. Lisle, R.W. Schafer, and W.W. Wilkinson, eds.): Reno, Nevada, Geological Society of Nevada, Symposium Proceedings, p. 249-254.

Percival, T.J., W.C. Bagby, and A.S. Radtke, 1988, Physical and chemical features of precious-metal deposits hosted by sedimentary rocks in the western United States in Bulk-mineable precious-metal deposits of the western United States: Reno, Nevada, Geological Society of Nevada, Symposium Proceedings, p. 11-34.

Pinnell, M.L., J.G. Blake, and J.B. Hulen, 1991, Active oil seep at Nevada gold mine holds intrigue for more exploration: Oil and Gas Journal (July 15), p. 74-79.

Poole, F.G., G.E. Claypool, and T.D. Fouch, 1983, Major episodes of petroleum generation in part of the northern Great Basin: Geothermal Resources Council, Special Report 13, p. 207-213.

Potter, R.W., II, 1977, Pressure corrections for fluid-inclusion homogenization temperatures based on the volumetric properties of the system NaCl-H₂O: USGS Journal of Research, v. 5, p. 603-607.

Read, D.L., and W.D. Zogg, 1988, Description and origin of the Devonian dolomite oil reservoir, Grant Canyon field, Nye County, Nevada in Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists Guidebook, p. 229-240.

Scott, S., and A.K. Chamberlain, 1988, Blackburn oil field, Nevada -- A case history in Occurrence and petrophysical properties of carbonate reservoirs in the Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists Guidebook, p. 241-250.

Silberman, M.L., 1983, Geochronology of hydrothermal alteration and mineralization -- Tertiary epithermal precious-metal deposits in the Great Basin: Geothermal Resources Council, Special Report 13, p. 287-303.

Veal, H.K., Duey, H.D., Bortz, L.C., and Foster, N.H., 1988, Grant Canyon and Bacon Flat oil fields, Railroad Valley, Nevada: The Mountain Geologist, v. 25, p. 193-209.

White, D.E., 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from ages of spatially associated volcanic rocks: USGS Professional Paper 458-D, 13 p.