PROCEEDINGS, Twenty-fourth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 25-27, 1999
SGP-TR-162

OILS IN THE DIXIE VALLEY AND KYLE HOT SPRINGS GEOTHERMAL SYSTEMS, NEVADA --- POTENTIALLY SENSITIVE INDICATORS OF NATURAL AND INDUCED RESERVOIR PROCESSES

Jeffrey B. Hulen[1], James W. Collister[1], Stuart D. Johnson[2], and Rick Allis[1]

1. Energy & Geoscience Institute, University of Utah, Salt Lake City, Utah
2. Oxbow Power Services, Inc., Reno, Nevada

ABSTRACT

Low-maturity oil is present in the Kyle Hot Springs and Dixie Valley geothermal systems in the Basin and Range of western Nevada. The Kyle oil is exclusively free-flowing (500 barrels produced accidentally with warm water at 80°C). The oil at Dixie occurs with produced geothermal water (initially 250°C) in a wellhead "bleed", and in calcite-aragonite-saponite scales deposited on hangdown strings in the upper 1500 m of at least four production wells. Organic geochemical analysis of the oils from both sites reveals that they were derived from Tertiary lacustrine hydrocarbon source rocks which are regionally submature -- incapable of generating liquid hydrocarbon unless hydrothermally heated. Biomarker transformation ratios of the oils indicate that they were (1) generated early in the "oil window" at temperatures near 100°C; and (2) not appreciably affected thereafter even by the elevated temperatures prevalent in the Dixie Valley system. The Dixie oils had to have entered the wellbores below casing at about 2600 m depth, so their preservation at reservoir temperature can only be explained by brief residence time in the hydrothermal system. Preliminary thermal modeling with optimally favorable geologic and kinetic parameters indicates an absolute maximum of 5000 yr. A more realistic appraisal suggests that the oils may have been drawn in by a production-induced "pressure sink" in a matter of months to years. In support of this contention is the magnesium-rich saponite associated with the scale-hosted oils. Magnesium is nearly absent from the natural geothermal fluid, but abundant in surrounding cooler basinal fluids, with which the oil may have gained access to the heart of the geothermal system. These findings are preliminary. Should they withstand further scrutiny, however, they could provide powerful new contraints on the Dixie Valley system's hydrothermal history as well as its production-influenced reservoir performance.

INTRODUCTION

The Kyle Hot Springs and Dixie Valley geothermal areas (**Fig. 1**) are among many concentrated within and just outside the southwestern "arm" of the regionally broad Battle Mountain heat-flow high (>100 mW/m^2; Lachenbruch and Sass, 1976) in the northern Basin and Range physiographic province. The Dixie Valley occurrence is a deeply drilled, richly productive (65 MW$_e$), and high-temperature (250°C) hydrothermal system; the one at Kyle Hot Springs yields warm waters (80-90°C) from a few shallow oil- and mineral-exploration boreholes. The two are linked, however, in (1) lacking direct evidence for an igneous heat source; (2) occurring along range-front fault zones; and (3), most surprisingly, containing natural oil. In both areas, the oil occurs mainly as a freely-flowing liquid associated with thermal waters; at Dixie Valley, it is also encapsulated in geothermal scale.

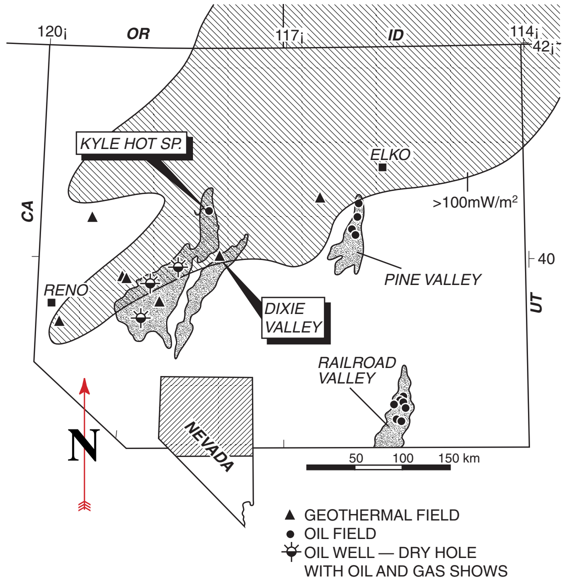

Figure 1. Location map, showing proximity of the Kyle Hot Springs and Dixie Valley geothermal areas in the western Basin and Range of Nevada. Shaded area on the full-size map is the "Battle Mountain (heat-flow) high" of Lachenbruch and Sass (1976). Stippled, irregular areas are selected, deeply-alluviated, fault block valleys, from left to right: Carson Sink/Buena Vista Valley, Dixie Valley, Pine Valley, Railroad Valley.

The presence of the oil leads naturally to several questions. What is its source? Is it pregeothermal, simply remobilized by the Dixie and Kyle systems, or was it hydrothermally generated from otherwise submature source rocks? Of whatever origin, how long has it survived in either system? Can the oil tell us anything about production-induced reservoir processes? Perhaps most importantly, can it be used as a natural tracer to help constrain fluid-flow rates and mechanisms? We have addressed these issues in preliminary fashion through the synthesis of geology, reservoir engineering, and organic geochemistry. The conclusions and speculations, we believe, could be germane to geothermal and petroleum exploration and development throughout the western Basin and Range.

GEOLOGIC SETTING

The western Basin and Range province characteristically comprises elongate, fault-block mountains separated by similarly-trending, deeply sedimented structural troughs. The ranges and valley floors consist of structurally juxtaposed metasedimentary and metavolcanic rocks of Cambrian through Triassic age, folded and broken by late Paleozoic to Triassic overthrusts, and intruded by Jurassic and Cretaceous mafic to felsic plutonic bodies. These older rocks are beveled and surmounted by Oligocene to Pliocene volcanic and sedimentary rocks, and all are dissected by moderate- to high-angle, Miocene to Recent, Basin-and-Range normal faults. The unmistakable valley-and-range topography of the province is the result of regional extension and concomitant crustal thinning (e.g. Lachenbruch and Sass, 1978; Parsons, 1995), processes which together favor elevated heat flow and creation of convective geothermal systems.

The Dixie Valley geothermal resource (**Figs. 1 and 2**) is an ideal, active example of these "deep- circulation", apparently amagmatic (no modern igneous intrusions have been identified) geothermal systems. Numerous others are warm (like Kyle Hot Springs) to extinct, but evidence of their past potency is preserved by hydrothermal alteration and siliceous sinter. These distinctive hot-spring deposits are found along the range-front fault systems at both Dixie Valley and Kyle. They are gold-anomalous, and one several km south of the Dixie Valley geothermal system supported bulk-tonnage gold mining at the Dixie Comstock mine (Vikre, 1994).

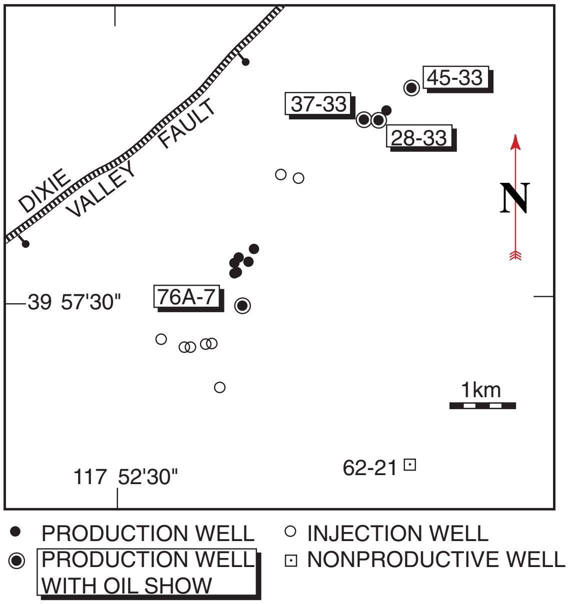

Figure 2. Well map of the Dixie Valley geothermal field, with the surface trace of the Dixie Valley fault zone.

A carbonate-replacement gold deposit beneath the Kyle siliceous sinter was the target concept leading to a shallow, angled, exploration borehole completed in 1993 by Independence Mining Company (Schalla et al., 1994; Neumann, 1994). A few metres above total depth (327 m), this hole, KHS-1, encountered vuggy, silicified, fault-brecciated limestone which yielded a copious flow of warm water mingled with minor oil.

The Dixie Valley oil shows are more modest. They comprise free oil from one production well, and oil encapsulated in geothermal scale from three others. No surface shows have been reported.

Discovery of the Kyle Hot Springs oil late in 1993 rekindled interest in western Nevada petroleum exploration. Evans-Barton, Inc., has since completed two additional encouraging exploration boreholes within 2 km of the original hole, KHS-1. Discovery of the Dixie Valley oil shows would seem equally favorable for petroleum exploration in that deep basin.

Important to any petroleum exploration program is the identity of the hydrocarbon source rock. Prior to 1979, interest in this part of the province was focused on Triassic marine source rocks. Nichols and Silberling (1977; cited in Bortz, 1983) noted that the 200 m-thick Fossil Hill member of the Triassic Favret Formation locally (e.g. in the range directly between the Kyle and Dixie oil shows; **Fig. 1**) contains ammonites filled with liquid hydrocarbon. Hastings

(1979) was the first to point out the source-rock viability of locally thick Tertiary lacustrine sedimentary sequences.

THE OILS

Kyle Hot Springs (summarized from Schalla et al., 1994) -- The artesian aquifer which yielded the oil in borehole KHS-1 is believed to be a hydrothermally altered fracture zone, and the probable fossil feeder for overlying siliceous sinter. When penetrated, it produced about 1500 l/m of warm (80°C) water bearing about 2% crude oil. Despite the best efforts of Independence and Halliburton Services, stopping the flow took more than four days, during which time approximately 500 barrels of oil escaped down an ephemeral stream channel. The oil quickly congealed to a highly viscous liquid upon exposure to surface-ambient temperatures. A sample was collected and set aside for this investigation shortly after some of the oil had accumulated in a relatively deep pool in the "oil stream".

Dixie Valley -- Free oil: Geothermal production well 37-33 (**Figs. 2 and 3**) yielded a small quantity of oil at the wellhead from wing valves in the flowing system. Temperature at the wellhead is 170°C. The well is cased to a depth of 2604 m, with thermal-fluid production (and oil) coming from near the Dixie Valley fault zone in an open-hole section extending to a depth of 2816 m (**Fig. 3**). Temperature in the production zone is 246°C. The only lithologies present in the open-hole section are Jurassic quartzite, Jurassic diorite and gabbro (of the Humboldt igneous complex; Lutz, 1998), and Cretaceous granite, none of which is a potential hydrocarbon source rock. Overlying the diorite/gabbro, however, is a sequence of Miocene lacustrine sediments which are locally dark-colored, ostracod-bearing, and possibly carbonaceous (S. Lutz, personal communication, 1999).

Oil in Geothermal Scale: Hangdown strings installed to administer minute amounts of scale inhibitor in the Dixie Valley wells nonetheless accumulate these deposits above the thermal-fluid flash point (e.g. **Fig. 3**), nominally at a depth of 1150 m and temperature of 230-240°C. Scale samples scraped from three recovered hangdown strings -- from wells 28-33, 45-33, and 76A-7 (**Fig. 2**) were examined in a separate effort to understand reservoir conditions imposed by production. The scales are distinctly banded, consisting mainly of calcite, aragonite, and saponite, with trace to minor amounts of magnetite and traces of electrum (?) at the pipe-scale interface. When viewed under ultraviolet (UV) light, portions of the scales fluoresce yellow-green. Geochemical analysis confirms that the fluorescence is due to included oil.

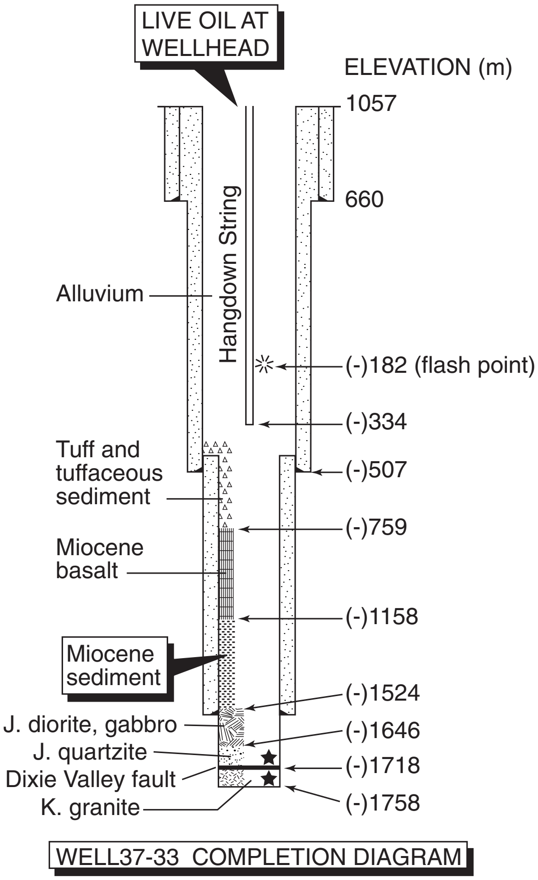

Figure 3. Completion diagram of Dixie Valley production well 37-33, showing location of the potentially carbonaceous Miocene sedimentary sequence relative to the bottom of casing and the open-hole section through which live oil at the wellhead had to have entered the wellbore (at a temperature of about 246°C).

Calcite and aragonite were expected in the scale – they commonly precipitate from boiling hydrothermal fluids. The saponite and oil were a surprise. Saponite is a trioctahedral smectite, a swelling clay. This particular smectite, analyzed by Fraser Goff of Los Alamos Laboratory, is typical in containing abundant MgO (about 25%), but unusual for its high Fe_2O_3 content (9.1%). The clay may be a hybrid between pure saponite and iron-rich nontronite, another trioctahedral smectite. In any event, a magnesium-rich precipitate would seem at odds with high-temperature geothermal water, in which magnesium is typically present in vanishingly small amounts. We will show that the presence of this magnesium can be linked with that of the oil to infer certain conditions imposed upon the reservoir by production.

Oil in the scale occurs as <5 micron fluid inclusions (liquid oil plus a vapor bubble) and as films -- "veils" -- along healed fractures. It is also present as a brownish impregnation in the saponite, imparting to that clay a bright yellow-green UV-fluorescence. Coexisting aqueous inclusions in the scale from well 76A-7 yielded homogenization temperatures of about 200°C (Lutz et al., 1998), suggesting, based on a flowing-temperature profile, that the scale accumulated at a depth of about 550 m.

ORGANIC GEOCHEMISTRY

Analytical Methods -- The free oils from Kyle Hot Springs KHS-1 and Dixie Valley 37-33, and the scale-hosted oils from the three other Dixie Valley wells, were analyzed utilizing liquid-column chromatography, gas chromatography-flame ionization detection (GC-FID), and gas chromatography-mass spectrometry (GC-MS). The scales were first powdered to <100 mesh, and the oil was extracted in a Sohxlet apparatus with dichloromethane. Liquid-column chromatography was performed using a stationary phase of silica gel (100-200 mesh activated at 100°C for 12 hr), and mobile phases of n-hexane (saturate fraction), toluene (aromatic fraction), and methanol (NSO fraction). GC-FID was completed using a Hewlett-Packard (HP) 6890 gas chromatograph equipped with a flame ionization detector. Split injection (50:1) was employed at 300°C (detector temperature 350°C) onto a non-polar Restek column (30m X 0.25mm X 0.25 microns). The GC column temperature was programmed from 35°C to 310°C at 4°C/min., with a final hold time of 29.25 min. Data were collected and processed using HP ChemStation software. The HP 6890 instrument with Restek column was also utilized for GC-MS. In this case the oven was programmed from 35°C to 310°C at 4°/min with a final hold time of 70.5 min, and a total run time of 210 min. Surrogate standards were added to the samples before separation into saturate and aromatic fractions by liquid-column chromatography as summarized above. Data were collected and processed using the ChemStation software.

Complete analytical results from the foregoing procedures, summarized in this paper, are available upon request from James W. Collister or Nicolas F. Dahdah at the Energy and Geoscience Institute Organic Geochemical Laboratory.

GC-FID Results – Patterns from GC-FID analysis for free oil from Kyle Hot Springs KHS-1 and Dixie Valley production well 37-33 (**Figs. 4A and 4B**) and for scale-hosted oil from well 45-33 (**Fig. 4C**) reveal features indicative of secondary alteration. The Kyle crude oil is devoid of gasoline-range compounds and low molecular-weight *n*-alkanes, suggesting it has been severely devolatilized and slightly biodegraded (see also Wavrek, 1997). The 37-33 free oil has been intensely biodegraded; acyclic isoprenoids and n-alkanes have been completely removed, making it rank 4 on the Peters and Moldowan (1993) scale. The scale-hosted oils, exemplified by the sample from well 45-33 (**Fig. 4C**), are less biodegraded, retaining variable amounts of long-chain -alkanes. This suggests that the

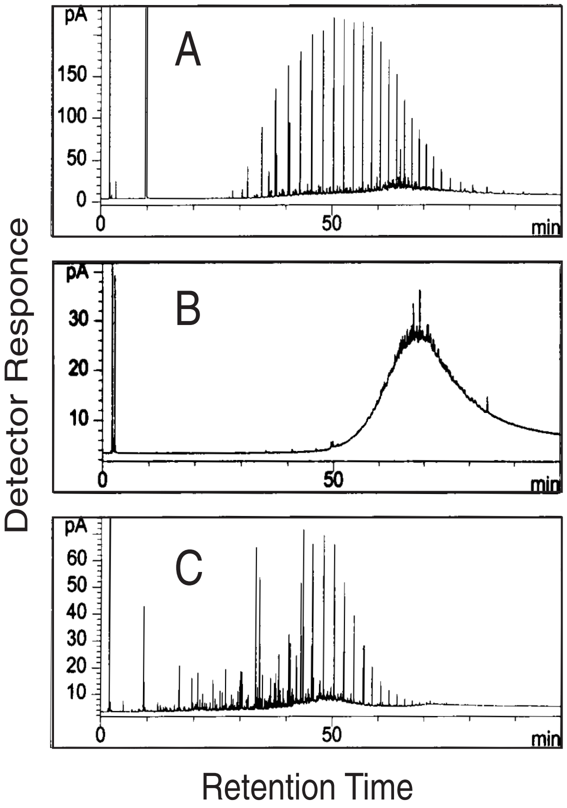

Figure 4. GC-FID traces for (A) Kyle Hot Springs oil, collected from the surface during uncontrolled flow from mineral-exploration borehole KHS-1; (B) Oil from a wellhead-bleed, production well 37-33, Dixie Valley geothermal system; (C) Occluded oil in a calcite-aragonite-saponite scale collected from the hangdown string in the upper portion of production well 45-33.

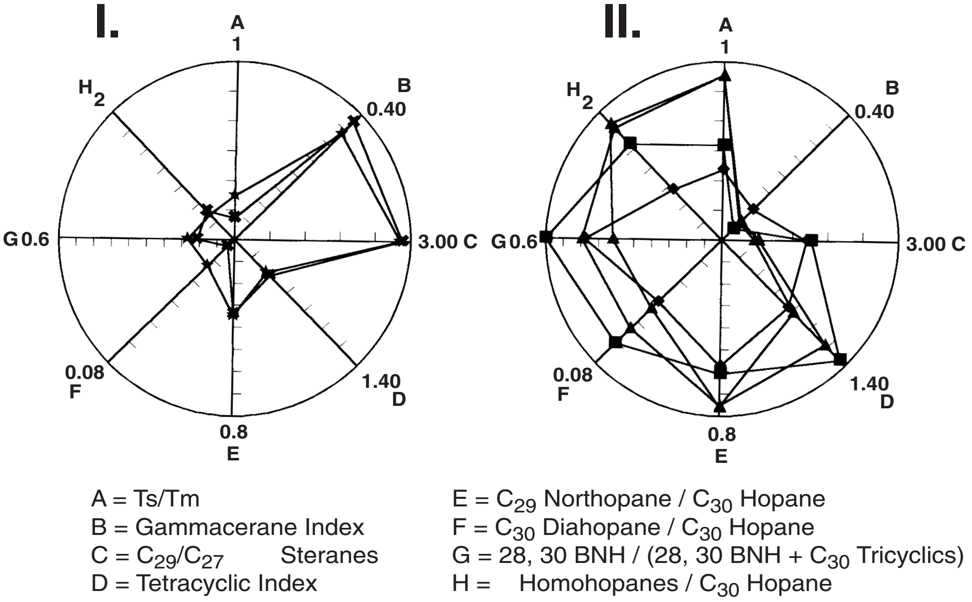

Figure 5. Star diagrams showing GC-MS correlation parameters for: I – Kyle Hot Springs free oils (surface accumulation and from 327 m depth in a mineral-exploration borehole; and II – Dixie Valley free and scale-hosted oils. The strongly divergent patterns for the two regions indicate regionally distinct petroleum systems.

oil was armored from microbial access by encapsulation in carbonate.

GC-MS Results – Terpane fractions of the oil samples (**Fig. 5**) indicate the presence of regionally distinct petroleum systems in the basins hosting the Kyle Hot Springs and Dixie Valley geothermal systems. The terpane traces (m/z 191) of the oils from both sites are dominated by pentacyclic terpanes and contain low to moderate abundances of tricyclic terpanes. The extended hopanes (C_{31} to C_{35}) are present in relatively low abundances in the Kyle oils whereas elevated concentrations relative to the C_{30} hopanes are evident in the Dixie Valley samples. Diagnostic features of the Kyle oils include elevated gammacerane indices, moderate tetracyclic indices, norhopane to hopane ratios near 0.35, low abundances of rearranged hopanes (C_{29}Ts and C_{30} diahopane), Ts/Tm ratios near 0.5, and a dominance of the C_{28} steranes. The Kyle-oil biomarker suite is consistent with generation from a hypersaline lacustrine source facies at a vitrinite reflectance (VR) equivalent near $R_o = 0.7\%$.

By contrast, the Dixie Valley oils contain lower abundances of gammacerane and near-equal abundances of the C_{27} and C_{29} steranes. Of facies significance is the presence of 18 and 18 oleananes. These compounds indicate a significant component of terrestrial higher plant matter in the presumed lacustrine depositional setting. The complete isomerization of the steranes (**Fig. 6**) in some samples suggests generation in the early oil window (equivalent VR = 0.6 to 0.8% R_o)

For the oils from both sites, extreme thermal alteration of the oil subsequent to expulsion is not supported by the biomarker distributions. Specifically, low abundances of the tricyclic terpanes, low triaromatic cracking ratios, and relatively low abundances of the C_{27} rearranged steranes and rearranged hopanes (C_{29}Ts and C_{30} diahopane) argue against thermal resetting of the relevant biomarker transformation ratios.

DISCUSSION AND CONCLUSIONS

Hydrocarbon Source Rock – Biomarker characteristics of both the Kyle Hot Springs and Dixie Valley oils clearly indicate that they were derived from lacustrine source rocks. This by itself constrains the source-rock age as Tertiary, since only rocks of this vintage in western Nevada are both carbonaceous and lacustrine (e.g. Bortz, 1983; Poole and Claypool, 1984). The Tertiary age is supported for the Dixie Valley oils by the presence of biomarkers indicating a contribution from higher plant matter, specifically angiosperms, which are absent from the geologic record prior to Cretaceous time.

Oil-exploration wells drilled in the Carson Sink in the

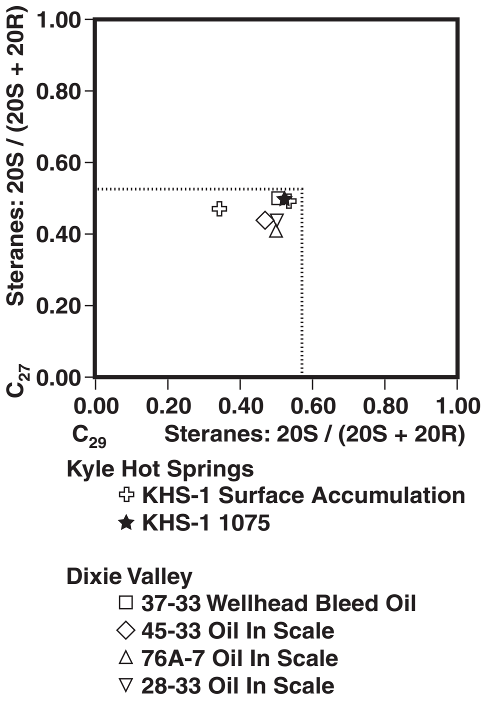

Figure 6. Crossplot showing degree of isomerization of the C27 and C29aaa steranes in oils from Dixie Valley and Kyle Hot Springs. Dashed lines represent equilibrium values for the ratios of isomers at equivalent vitrinite-reflectance values near 0.7 to 0.8% Ro.

mid-1970's (**Fig. 1**) encountered a Tertiary volcanic and lacustrine sedimentary sequence up to at least 2.5 km thick (Hastings, 1979). More than a km of this sequence was carbonaceous, with total organic carbon values as high as 4.5%. All but the very deepest portion of the sequence, however, was found to be submature, with thermal-alteration indices less than 2.5 (equivalent VR of about 0.7% R_o). Nonetheless, in one well at a depth of 2500 m, free oil was encountered in vugs in calcite-cemented basalt breccia. Similar low maturities were documented by Barker (1994) for these Tertiary rocks in wells in other parts of the region.

The most likely source rock for the Dixie Valley oils is a sequence of post-Oligocene, pre-Miocene-basalt lacustrine sedimentary rocks with an apparent thickness ranging from 100 to 420 m (Waibel, 1987; Plank, 1998). These were penetrated in many of the production wells, and include "dark gray siltstone", the color of which permissibly could be due to included organic material (S. Lutz, personal communication, 1999). Confirmation of this supposition, however, must await organic-geochemical analysis.

Hydrocarbon Thermal-Maturity Evaluation -- The State of Nevada is rich in potential hydrocarbon source rocks and both active and fossil hydrothermal systems (Bortz, 1983; Coyner and Fahey, 1996). It is no surprise, then, that introduced hydrocarbons are quite common in these systems, whether ancient or modern (e.g. Nelson, 1991; Hulen et al., 1994); even so, still-liquid oil is quite rare. The typical hydrocarbon in these systems is solid pyrobitumen, a dense, black substance produced by thermal devolatilization of the oil – the light fraction is liberated, and heavy sludge is left behind. The widespread presence of pyrobitumen in the fossil systems is believed to be the result of intense, high-temperature (>200°C, over hundreds of thousands of years), hydrothermal degradation of oil either initially in place or transported into the system at an early stage in its evolution (e.g. Christensen, 1993).

Finding oil in an active or extinct geothermal system, then, means either that the hydrocarbon has not experienced particularly high temperatures, or that it has done so, but too briefly for significant thermal degradation. The first case coud apply to the Kyle Hot Springs oil; the second to that of the Dixie valley system.

The maximum recorded modern subsurface temperature at Kyle Hot Springs is about 90°C, measured in a 1-km-deep exploration well completed about a kilometer to the west (D.H. Evans, personal communication, 1997). The "discovery" borehole KHS-1 yielded oil-bearing waters at a temperature of 80°C (Schalla et al., 1994). Both of these temperatures fall short of the minimum required for oil generation (variable with time, but typically cited as about 85-95°C; e.g. Tissot and Welte, 1984). Based on biomarker transformation ratios, the KHS-1 oil has a thermal maturity, expressed as equivalent VR, of about 0.7% Ro. This, in turn, is empirically equivalent to a peak paleotemperature, attained during "short-duration" (10^5 yr) hydrothermal heating, of roughly 110-115°C (Barker and Pawlewicz, 1994). Therefore, we can surmise that the oil was generated either (1) in a hotter part of the modern geothermal system; (2) when the system was higher temperature in the past; or (3) independent of the system in a deep-burial setting, from which it was later remobilized in an upwelling hydrothermal plume.

Only the third of these options can be ruled out. Biomarkers clearly indicate that the Kyle oil was generated from a Tertiary lacustrine source rock, all but the very deepest of which in western Nevada are submature (Hastings, 1979; Schalla et al., 1994). Generation of petroleum from these rocks requires hydrothermal heating. Temperatures deep in the Kyle system are clearly much hotter than those measured in the boreholes, and more than sufficient for this process. Silica and Na-K-Ca geothermometry of the hot-spring waters indicates a deep equilibration temperature range of 171-194°C (Garside and Schilling, 1979), well above the oil window.

More difficult to explain is the existence and preservation of low-maturity oil in the heart of the high-temperature Dixie Valley geothermal field. Reservoir temperatures in the field average about 250°C, and even well-head temperatures are near 170°C. Yet the well-head free oil from borehole 37- 33 and the scale-hosted oil from three other production wells all have biomarker-based thermal maturities equivalent to a VR of only 0.6-0.8% R_o. This is equivalent to only 95-132°C even if attained through "short-duration" hydrothermal heating (Barker and Pawlewicz, 1994). It seems very likely from these relationships that the production-well oil has had relatively brief residency in the Dixie Valley system.

A first-approximation, upper limit for the oil's residence time can be calculated by assuming that the cracking of oil to gas (and pyrobitumen): (1) follows a simple Arrhenius relationship (Burnham and Sweeney, 1991); and (2) can be modeled with a single activation energy (54 kcal/mole) and frequency factor ($10^{12}s^{-1}$). These values are typical of those used in proprietary thermal modeling codes such as Basinmod (Platte River Associates, Denver, Colorado). The oil is also assumed for the analysis to have been generated prior to establishment of the geothermal system, then instantaneously heated to a range of temperatures between 175°C and 300°C. The results (**Fig. 7**) show that at Dixie Valley reservoir temperatures (nominally 250°C), 50% of the oil will have been cracked to gas and pyrobitumen within approximately 800 years, and virtually all of the oil will have been destroyed within 5000 yr.

Large, high-temperature hydrothermal systems like Dixie Valley are thought to persist for hundreds of thousands of years (e.g. Silberman, 1983), or two orders of magnitude longer than required by the thermal modeling to fully crack an oil at 250°C. From this we can surmise that any oil generated within the system likely would have been long since destroyed. It is probable, however, that source rocks distal to the system have continued to generate oil, at temperatures ideal for maturation but sufficiently cool for preservation of the newly generated liquid hydrocarbon.

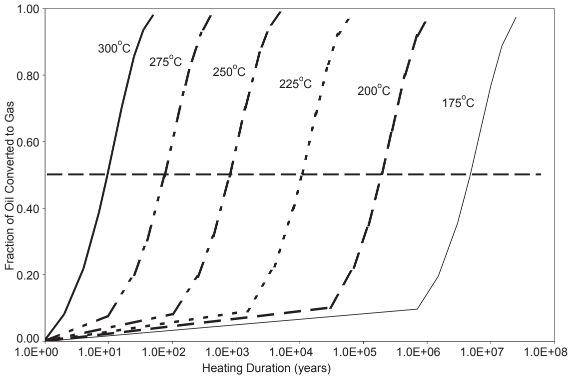

Figure 7. Arrhenius plot from the proprietary thermal-modeling program Basinmod (Platte River Associates, Denver, CO), showing the theoretical fraction of oil converted to gas for various heating durations and temperatures. The plot shows that at the Dixie Valley reservoir temperature, about 250°C, oil would be completely destroyed in about 5,000 yr. It is likely that in the process, the residual oil would also acquire an elevated thermal-maturity signature. Oil at Dixie Valley is distinctly low-maturity, and therefore has probably been resident in the system far more briefly than the modeled, kinetically optimal preservation limit.

Based on the foregoing arguments, we consider it unlikely that the low-maturity Dixie Valley oils have existed for long in the high-temperature geothermal reservoir. We suspect (though cannot document at this point) that liquid oil left as a long-term cracking residue at 250°C would have achieved a higher, biomarker-indicated thermal maturity than the scant 0.6-0.8% R_o actually measured.

Perhaps a more plausible explanation for the presence of the oils is that they were drawn into the system recently in response to a production-induced "pressure sink". We suspect, in fact, that the oils may have been resident for only months to years rather than the hundreds to thousands of years permitted by the most favorable geologic and kinetic constraints.

In support of this contention is the abundant presence of magnesium-rich saponite associated with oil in geothermal scales coating the hangdown strings of several production wells. Magnesium is a vanishingly small component of natural, high-temperature, dilute-chloride geothermal fluids; the Dixie Valley fluid measures about about 30 ppb; Bruton et al., 1997). However, the element is expected to be more abundant in the cooler fluids surrounding the geothermal system (e.g. 3200 ppb in a nearby [?] groundwater well; Bruton et al., 1997). We suggest that such externally-derived magnesium may have accompanied the oil into the lower-pressure realm of the geothermal system, where both were deposited in response to production-induced flashing of the now-mixed reservoir fluid.

Rose et al. (1998) have shown that tracers introduced into the Dixie Valley system through injection wells arrive at production wells 2 kilometers distant as soon as 40 days but generally about 100 days afterward. The latter flow rate is three to four orders of magnitude greater than that believed to prevail naturally – about 7000 km vs. 0.1-3 km per 1000 yr (Cathles, 1975; Elder, 1981). Assuming comparable flow channels from distal portions of the system, oil could be drawn at this rate from, say, a source 7 km away in about a year. Even if stressed at 250°C for the full trip, the oil's thermal-maturity signatures would remain largely unaffected.

These conclusions must be considered preliminary at this stage of our investigation. However, if they withstand more detailed geochemical, geological, and numerical scrutiny, they could provide natural new constraints on production-influenced reservoir performance in the Dixie Valley geothermal system.

ACKNOWLEDGMENTS

This research is being supported by the U.S. Department of Energy, Office of Geothermal Technologies, Contract No. DE-AC07-90ID12929. Said support does not necessarily constitute an endorsement of the views expressed in this publication. We thank Oxbow Power Services for access to the Dixie Valley field and accompanying reservoir information, unique geologic insight, and permission to publish this paper. Sue Lutz freely shared her extensive knowledge of the Dixie Valley system. Gabe Plank kindly permitted us to reference his excellent draft M.S. thesis on the area. Without Ron Wilson's artistic and efficiently produced illustrations, this paper could not have been finished in time for the conference (many thanks, Ron).

REFERENCES

Barker, C.E., and Pawlewicz, M.J., 1994, Calculation of vitrinite reflectance from thermal histories and peak temperaturs in Vitrinite reflectance as a maturity parameter (P.K. Mukhopadhyay and W.G. Dow, editors): American Chemical Society, Symposium Series, no. 570, p. 216-229.

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

Bruton, C.J., Counce, D., Bergfeld, D., Goff, F., Johnson, S.D., Moore, J.N., and Nimz, G., 1997, Preliminary investigation of scale formation and fluid chemistry at the Dixie Valley geothermal field, Nevada: Geothermal Resources Council, Transactions, v. 21, p. 157-164.

Burnham, A.K., and Sweeney, J.J., 1991, Modeling the maturation and migration of petroleum *in* Source and migration processes and evaluation techniques (R.K. Merrill, editor): Tulsa, Oklahoma, AAPG Treatise on Petroleum Geology, p. 55-64.

Cathles, L.W., 1981, Fluid flow and genesis of hydrothermal ore deposits *in* Economic Geology, 75th anniversary volume (B.J. Skinner, editor): El Paso, Texas, Economic Geology Publishing Company, p. 424-456.

Christensen, O.D., 1993, Carlin trend geologic overview in Gold deposits of the Carlin trend, Nevada (O.D. Christensen, editor): Society of Economic Geologists, Guidebook Series, v. 18, p. 12-26.

Coyner, A.R., and Fahey, P.L. (Editors), 1996, Geology and ore deposits of the American cordillera: Geological Society of Nevada, USGS, and Sociedad Geologica de Chile, Symposium Proceedings (April 10-13, 1996), 1747 p.

Elder, J.W., 1981, Geothermal systems: New York, Academic Press, 632 p.

Garside, L.J., and Schilling, J.H., 1979, Thermal waters of Nevada: Reno, Nevada Bureau of Mines and Geology, Bulletin 91, p. 163.

Hastings, D.D., 1979, Results of exploratory drilling in northern Fallon basin, western Nevada *in* 1979 Basin and Range symposium (G.W. Neumann and H.D. Goode, editors): Rocky Mountain Association of Geologists and Utah Geological Association Guidebook, p. 515-522.Par

Hulen, J.B., Goff, F., Ross, J.R., Bortz, L.C., and Bereskin, S.R., 1994, Geology and geothermal origin of Grant Canyon and Bacon Flat oil fields, Nevada: American Association of Petroleum Geologists

Bulletin, v. 78, p. 596-623.

Lachenbruch, A.H., and Sass, J.H., Models of an extending lithosphere and heat flow in the Basin and Range province in Cenozoic tectonics and regional geophysics of the western cordillera (R.B. Smith and G.P. Eaton, editors): Geological Society of America, Memoir 152, p. 209-250.

Lutz, S.J., Moore, J.N., and Benoit, D., 1998, Integrated alteration mineralogy and fluid-inclusion study at the Dixie Valley geothermal field, Nevada: Stanford University, Twenty-third Workshop on Geothermal Reservoir Engineering, preprint, 8 p.

Neumann, W.H., 1994, Oil shows in a mineral exploration hole at Kyle Hot Springs, Buena Vista Valley, Nevada: Reno, Nevada Petroleum Society Newsletter, March, 1994.

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.H. Wilkinson, editors): Reno, Geological Society of Nevada and USGS, Symposium Proceedings, p. 249-254.

Nichols, K.M., and Silberling, N.J., 1977, Stratigraphy and depositional history of the Star Peak group (Triassic), northwestern Nevada: Geological Society of America, Special Paper 178.

Parsons, T., 1995, The Basin and Range province *in* Continental rifts – evolution, structure, tectonics (K.H. Olsen, editor): Amsterdam, Elsevier, p. 277-324.

Peters, K.E., and Moldowan, J.M., 1993, The biomarker guide – Interpreting molecular fossils in petroleum and ancient sediments: New Jersey, Prentice-Hall, 363 p.

Plank, G.L., 1998, Structure, stratigraphy, and tectonics of a part of the stillwater escarpment – Implications for the Dixie Valley geothermal system: Reno, University of Nevada, M.S. Thesis, in prep.

Poole, F.G., and Claypool, G.E., 1984, Petroleum source-rock potential and crude-oil correlation in the Great Basin *in* Hydrocarbon source rocks of the greater Rocky Mountain region: Denver, Colorado, Rocky Mountain Association of Geologists, p. 179-229.

Rose, P.E., Benoit, W.R., and Adams, M.C., 1998, Tracer testing at Dixie Valley, Nevada, using pyrene tetrasulfonate, amino-G, and fluorescein: Geothermal Resources Council, Transactions, v. 22, p. 583-587.

Sass, J.H., et al., 1976, Heat flow near Kyle Hot Springs, Buena Visa Valley, Nevada: USGS Open-File Report 76-862.

Schalla, R.A., Barker, C.E., and Neumann, W.H., 1994, Hot water and oil from a shallow exploratory borehole, Buena Vista Valley, Pershing County, Nevada *in* Oil fields of the Great Basin (R.A. Schalla and E.H. Johnson, editors): Reno, Nevada Petroleum Society, p. 127-130.

Tissot, B.P., and Welte, D.H., 1984, Petroleum formation and occurrence: New York, Springer-Verlag, 699 p.

Waibel, A.F., 1987, An overview of the secondary mineralogy of the high-temperature geothermal system in Dixie Valley, Nevada: Geothermal Resources Council, Transactions, v. 11.

Wavrek, D.A., 1997, Hydrocarbons associated with hydrothermal water, Kyle Hot Springs, Buena Vista Valley, Nevada, USA – A reconnaissance program: Energy & Geoscience Institute, University of Utah, Report 97-GCSP(2), 30 p.