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CONTENTS

	Page
INTRODUCTION.....	1
GEOLOGIC SETTING.....	2
THE HOT OIL FIELDS.....	7
THE GOLD POINT DEPOSITS.....	9
THE EXHUMED FOSSIL OIL RESERVOIRS OF THE SOUTHERN ALLIGATOR RIDGE DISTRICT.....	10
Geologic Setting of the Yankee-Group Deposits.....	11
Structural Controls.....	13
Alteration and Mineralization.....	18
Hydrocarbons.....	22
<i>Hydrocarbon Source Rock</i>	24
<i>Oils</i>	32
<i>Thermal-Stress Analysis; Thermal Maturity of the Oils</i>	37
<i>Thermal Maturity of Possible Hydrocarbon Source Rocks</i>	46
DISCUSSION.....	49
ACKNOWLEDGEMENTS.....	53
REFERENCES.....	54

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APPENDICES

Page

**Appendix 1. Publications and presentations supported by Grant
No. DE-FG02-ER14133 to the Principal Investigator.....A1**

List of publications.....A1a

Publications.....*reprints + abstracts removed*.....A1e

Appendix 2. Vitrinite-reflectance histograms (data by Jeffrey C. Quick).....A117

**Appendix 3. Rock-Extract data. Gas chromatography-flame
ionization detection; and gas-chromatography-
mass spectrometry (data by Nicolas F. Dahdah).....A129**

**Appendix 4. Crude oils and fluid-inclusion extract (oils). Gas
chromatography-flame ionization detection; and gas-
chromatography-mass spectrometry (data by Nicolas F. Dahdah)....A147**

ILLUSTRATIONS

Page

Figure 1. Location map, showing oil fields, high-temperature geothermal systems, the oil-bearing Gold Point mine, and the oil-bearing Carlin-type deposits of the Alligator Ridge district.....	2
Figure 2. Location map, showing oil fields, Carlin-type gold deposits, the Nevada "oil fairway", and the Alligator Ridge district.....	6
Figure 3. Geologic map of the Alligator Ridge mining district.....	12
Figure 4. Detailed geologic map of the southern half of the Yankee subdistrict of the Alligator Ridge mining district.....	14
Figure 5. Geologic section (transverse) through the Yankee subdistrict of the Alligator Ridge mining district	16
Figure 6. Geologic section (longitudinal) through the Yankee subdistrict of the Alligator Ridge mining district.....	17
Figure 7. Geologic, alteration, oil, and calcite-vein-distribution sections (detailed) through the southwestern lobe of the Yankee deposit.....	19
Figure 8. Carbon-oxygen isotopic compositions for calcite veins and calcareous host rocks from the Yankee, Saddle, and Rebel deposits in the Yankee area of the Alligator Ridge mining district.....	21
Figure 9. Calculated oxygen-isotopic compositions of calcite-depositing hydrothermal fluids for the oil-bearing Yankee and Saddle orebodies.....	23
Figure 10. Generalized stratigraphic column for the Alligator Ridge-Bald Mountain mining district, showing formations which host gold mineralization and those which are potential hydrocarbon source rocks.....	24
Figure 11. Cross-plot of total-generation potential vs total organic carbon for cuttings from various stratigraphic units penetrated by Pioneer Oil and Gas Co. well YMF-27-23X.....	25
Figure 12. Modified "Van Krevelen" diagram showing Rock-Eval pyrolysis data points for cuttings from YMF-27-23X.....	31

ILLUSTRATIONS, continued

Page

- Figure 13. Diagnostic Rock-Eval data for YMF-27-23X, plotted relative to stratigraphy, showing oil-generation capacity of potential hydrocarbon source rocks penetrated by the well.....33**
- Figure 14. Ternary diagram showing relative abundances of saturated and aromatic hydrocarbons vs NSO compounds in fluid-inclusion oils from the Yankee and Saddle mines. Shown for comparison are corresponding data for produced oils from Grant Canyon and Trap Spring oil fields.....35**
- Figure 15. Gas chromatography-flame ionization detection profile for oil from a Yankee mine calcite vein.....36**
- Figure 16. Gas chromatography-flame ionization detection patterns for fluid-inclusion oils extracted from Yankee and Saddle mine calcite veins.....38**
- Figure 17. Ternary diagrams showing normalized distributions of sterane carbon numbers for Yankee and Saddle mine fluid-inclusion oils.....40**
- Figure 18. Crossplot of two conventional organic molecular indices useful for assessing water oxicity.....41**
- Figure 19. Star diagram summarizing various molecular parameters for Yankee and Saddle mine fluid-inclusion oils. The diagram clearly shows that the Mississippian-Devonian Pilot Shale is the likely hydrocarbon source rock for these oils.....42**
- Figure 20. Biomarker transformation ratios and interpreted thermal maturities for Yankee and Saddle mine fluid-inclusion oils.....45**
- Figure 21. Vitrinite reflectance vs depth for organic-rich cuttings samples from YMF-27-23X.....48**

ILLUSTRATIONS, continued

Page

Table 1. Sample information and list of analyses performed on drill cuttings from YMF-27-23X, for fluid-inclusion oils from the Yankee and Saddle mines, and for produced oils from the Grant Canyon and Trap Springs oil fields.....	25
Table 2. Total organic carbon content and Rock-Eval pyrolysis data for cuttings from well YMF-27-23X.....	28
Table 3. Liquid column chromatography data for Soxhlet bitumen extracts from YMF-27-23X drill cuttings; for fluid-inclusion oils from the Yankee and Saddle mines; and for produced oils from the Grant Canyon and Trap Springs oil fields.....	34
Table 4. Summary of conventional molecular correlation parameters determined through analysis, by gas chromatography-mass spectrometry, of fluid-inclusion oils from the Yankee and Saddle mines as well as produced oils from the Grant Canyon and Bacon Flat oil fields.....	39
Table 5. Summary of molecular parameters used in maturity, or thermal-stress analysis, of Yankee, Saddle, Grant Canyon, and Trap Spring oils. Also shown are equivalent vitrinite reflectance values for the oils as determined using methods outlined in Peters and Moldowan (1993) and Wavrek et al. (1997).....	44

THE ROLE OF ACTIVE AND ANCIENT GEOTHERMAL SYSTEMS IN THE GENERATION, MIGRATION, AND ENTRAPMENT OF OIL IN THE NEVADA BASIN AND RANGE PROVINCE

Jeffrey B. Hulen, Principal Investigator

INTRODUCTION

The Basin and Range (B&R) physiographic province of the western USA (Fig. 1) is famous not only for its geothermal and precious-metal wealth, but also for its thirteen oil fields, small but in some cases highly productive. The Grant Canyon field in Railroad Valley, for example, for years boasted production of more than 6000 barrels of oil (BO) per day from just two wells (Montgomery, 1988); aggregate current production from the Blackburn field in Pine Valley (Fig. 1) commonly exceeds 1000 BO per day (Ehni, 1997). These two and several other Nevada oil fields are unusually hot at reservoir depth -- up to 130°C at depths as shallow as 1.1 km (Hulen et al., 1994b), up to three times the value expected from the prevailing regional geothermal gradient (e.g. Lachenbruch and Sass, 1978).

None of these hot oil fields are associated with a detectable magmatic heat source, so their shallow-crustal thermal anomalies must be due to convective heat transfer in an amagmatic, "deep-circulation" type geothermal system (e.g. Garside and

Schilling, 1979). The question remains, however: Did these geothermal systems have anything to do with the oil reservoirs harbored in their interiors? This question, a principal focus of this investigation, will be addressed at length in the following pages. The answer is of considerable interest to petroleum explorationists, for if the heated oils are of primary geothermal origin -- or even if they have been remobilized and reconcentrated by hydrothermal systems -- then geothermal search techniques could be usefully added to conventional petroleum exploration packages.

The hot B&R oil fields, not surprisingly in view of their geothermal affinities, show evidence of widespread and locally intense hydrothermal alteration (e.g. Hulen et al., 1994a; 1990). This alteration -- silicification, kaolinization, sulfidation, decarbonatization -- is not unlike that developed in the organic-rich, Carlin-type, disseminated gold deposits which share much of the same regional distribution (Fig.2; Seedorf, 1991). The oil fields contain only traces of gold, but like the Carlin-type deposits are also locally enriched in the non-metallic, moderately siderophile

Figure 1. Location map, showing near-surface heat flow (from Lachenbruch and Sass, 1978); oil fields; producing high-temperature geothermal systems; high-temperature geothermal prospects; the Kyle hot springs geothermal/oil discovery; and the oil-rich Carlin-type gold deposits of the Alligator Ridge mining district.

"pathfinder" elements arsenic, antimony, and tellurium (Oppliger et al., 1997; Hulen and Nielson, 1993). This relationship between the gold deposits and oil fields was sufficiently compelling to lead Hulen et al. (1994b) to suggest that the small, locally oil-bearing Carlin-type deposits of the Alligator Ridge mining district (Ilchik, 1991; Howald, 1994; Stout, 1994) were in effect also exhumed, fracture-controlled oil reservoirs which accumulated in amagmatic hydrothermal systems much like the one still active at Grant Canyon. Similarly, Castor and Hulen (1996a) showed that the hydrocarbon-rich Gold Point electrum deposits near Railroad Valley (Fig. 1) could also have formed in a Grant Canyon-type (albeit slightly hotter) meteoric-hydrothermal system.

Testing the suggested genetic affiliations among the B&R's sediment-hosted gold deposits, oil fields and geothermal systems, ancient as well as active, has involved detailed characterization of the oil-bearing Gold Point and Alligator Ridge paleohydrothermal systems as well as three of the hot oil fields -- Grant Canyon, Bacon Flat, and Blackburn. The oil fields have furnished valuable information about geothermal oil-reservoir evolution in progress, but their three-dimensional configurations are poorly constrained because of their deep concealment -- 1-2 km -- and their penetration only by widely-

spaced boreholes. On the other hand, the precious-metal deposits, although long-since cooled, are well-exposed by mining excavations; fossil fluid-flow paths, alteration zones, and hydrocarbon accumulations can be readily mapped and studied to yield a detailed picture of oil-reservoir evolution in the postulated causative paleohydrothermal systems.

Results of this integrated geothermal-oil-gold investigation are discussed, debated and cautiously interpreted in the text which follows. Much of the data and numerous interpretations for the hot oil fields and the oil-bearing Gold Point quartz-vein deposits have been published in the papers appended to this document (*Appendix I*). After a brief recapitulation, the focus here will be on results from the integrated study of the exhumed souther Alligator Ridge paleogeothermal oil reservoirs.

GEOLOGIC SETTING

The B&R is the northwestern sector of the Great Basin, a unique region of highly extended continental crust in the western United States. For a full analysis of B&R geologic history, the reader is referred to Parsons (1995) and Montgomery (1988), papers from which much of the following synopsis has been summarized.

B&R extension is currently manifested as a

series of narrow, northerly-trending fault-block mountain ranges separated by equally narrow, deeply alluviated valleys. The rocks of the ranges record a complex sedimentological, igneous, and structural evolution. A passive, west-of-craton continental margin developed in late Proterozoic and remained stable until late Ordovician, when subducting oceanic crust to the west resulted in formation of an island arc. The ensuing compression eventually caused the Antler orogeny, in turn resulting in deposition of the organic-rich, Devonian-Mississippian Pilot Shale and the slightly younger Mississippian Chainman Shale in the adjoining foreland basin, which covered much of eastern Nevada and western Utah; the Chainman is the B&R's premier hydrocarbon source rock (Poole and Claypool, 1984). A second compressional orogeny took place in Permo-Triassic, and formed the Golconda allochthon in (what is now) western Nevada. The Sevier orogeny persisted from mid-Jurassic to latest Cretaceous or early Tertiary time; its effects were concentrated principally east of Nevada, although local folds and thrusts as well as scattered igneous intrusions throughout the state have been linked to the event. The elongated high-angle fault-block mountains of the B&R are fairly recent in origin (Miocene and younger). The rugged fault-block topography preserves evidence of older Cenozoic extensional events of various durations and styles, including widespread,

low-angle, mid-Eocene to early Miocene low-angle detachment faulting. Extensive volcanism affected the region commencing at about 43 Ma, when voluminous calc-alkalic lavas and ignimbrites began to erupt principally in northern Nevada. This style of volcanism swept southward into southern Nevada until about 18 Ma, after which, until about 6Ma, low-volume bimodal rhyolite-basalt volcanism prevailed. Basalts as young as Holocene are locally present throughout the region.

Eight high-temperature geothermal fields and thirteen oil fields have now been discovered in Nevada (Fig. 1) -- most are still productive. Nevada is the second largest geothermal producer in the USA, behind only California. Since discovery of the Eagle Springs field in 1954, the Nevada fields have collectively produced slightly more than 40 million BO (Ehni, 1997). More than half that amount has come from the prolific, geothermally active Grant Canyon field (Hulen et al., 1994a), which at its peak was producing, from only two wells, oil valued at up to \$140,000 per day. The Grant Canyon success story continues to lure oil explorationists to the B&R in spite of its formidable geologic complexity.

Note that Grant Canyon and the other oil fields of Railroad Valley, several of which are hot, are nonetheless situated in a prominent heat-flow low (Fig. 1), the

"Eureka low" of Lachenbruch and Sass (1978). The fields of Pine Valley, to the north, are just off the edge of the "Battle Mountain high" (Fig. 1), a zone of elevated heat flow and high geothermal gradient (generally $>50^{\circ}\text{C}/\text{km}$) in or adjacent to which all the state's high-temperature geothermal systems occur (Fig. 1). The Eureka low is believed by John Sass (pers. comm., 1995) to be a relatively shallow feature produced by cool groundwater flow which masks the deeper heat-flow regime more characteristic of the region.

Except for Steamboat (Fig. 1), Nevada's high-temperature geothermal systems and prospects lack a detectable magmatic heat source. They are believed to be the result of deep and rapid circulation of meteoric fluids in this region of elevated heat flow (e.g. Flynn and Buchanan, 1990; Garside and Schilling, 1979). Ultimately, however, they all probably have a magmatic connection, since the high heat flow of the B&R is probably a consequence of crustal stretching and thinning with attendant asthenospheric upwelling and associated basaltic magmatism (e.g. Parsons, 1995).

Are these geothermal systems and oil fields related to the Carlin-type gold deposits with which they share the province (Fig. 2)? The association cannot be a modern one; the oil fields occur mostly south of the bulk of the Carlin deposits; the geothermal systems are

principally to the west. The Carlin-type deposits of the southern Alligator Ridge district (Fig. 1), however, occur almost exactly halfway between the two oil-producing valleys. Among the Carlin-type deposits, those at Alligator Ridge bear the strongest resemblance to the oil fields -- most notably in that several of the ore bodies actually contain substantial quantities of live oil (e.g. Pinnell et al., 1991; Hulen et al., 1994b). Obviously, the Alligator Ridge deposits are old relative to the active oil fields, none of which can be older than early Miocene (D. French, pers. comm., 1995). The probable Oligocene-age (Ilchik, 1991; see also Arehart, 1996) Alligator Ridge deposits did, however, probably form during an earlier period of B&R extension -- one dominated by low-angle faulting and by voluminous calc-alkaline volcanism during a time of higher regional heat flow than at present.

The oil-rich, electrum-bearing quartz veins at the Gold Point mine (Fig. 1) are not only closer spatially to the Grant Canyon oil field, they are even more similar geologically to this field than the gold deposits of Alligator Ridge (Castor and Hulen, 1996a). Fluid-inclusion, isotopic, and mineralogic evidence to be discussed in more detail later in this paper indicate that the mineralizing hydrothermal system at Gold Point differed from the one still circulating at Grant Canyon only in being slightly hotter (180 vs 130°C).

Figure 2. Location map showing relative positions of the Alligator Ridge mining district, with its considerable quantities of "live" oil; the invariably organic-rich (but generally oil-free) Carlin-type, low-grade, sediment-hosted gold deposits; and the oil fields of Railroad and Pine Valleys. Shown for reference is the famous Nevada "oil fairway", within which, in a general sense, potential Paleozoic hydrocarbon source rocks like the Mississippian Chainman Shale are at or near peak oil-generation capacity (Poole and Claypool, 1984; Montgomery, 1988).

Like Alligator Ridge, it occurs spatially associated with Oligocene calc-alkaline volcanic rocks, and is probably of similar age, though K-bearing secondary minerals which could prove this relationship remain to be found at either site.

The Gold Point deposits occur near an Oligocene stock, a potential heat source (Castor and Hulen, 1996a). For the deposits of the southern Alligator Ridge district, even such an ambiguous potential magmatic heat engine is lacking. The southern Alligator Ridge deposits appear to have formed in an amagmatic geothermal system perhaps not unlike (although larger than) those producing electrical power in the western part of the state. Moreover, this "deep-circulation" system almost certainly was instrumental in the migration and entrapment of a considerable quantity of oil -- in effect a small paleohydrothermal oil reservoir (Hulen et al., 1994). The mechanisms responsible for this oil-reservoir evolution have been clarified by our research. Details of the process remain to be elucidated, but it is clear that hydrothermal systems of a particular sort and temperature can efficiently lead to the formation of oil reservoirs. Moreover, ancillary hydrothermal effects like hydrothermal alteration and carbonate dissolution affect much greater rock volumes than the oil reservoirs (or mineral deposits) themselves, affording potentially useful additional

targeting parameters for B&R petroleum exploration.

THE HOT OIL FIELDS

Four oil fields in the B&R -- Grant Canyon, Bacon Flat, Sans Spring, and Blackburn (Fig. 1) -- are substantially hotter at reservoir depth than expected from the regional geothermal gradient. The effect is most pronounced for the first two fields, which are shallow and also occur in the "Eureka low". The Grant Canyon and Bacon Flat reservoir temperatures, 120-130°C, correspond to a geothermal gradient approaching 100°C/km (Hulen et al., 1994a); Blackburn field, with a similar temperature, is deeper and corresponds to a gradient of about 60°C/km (Hulen et al., 1990). Note that Blackburn is situated very near the southern margin of the Battle Mountain heat-flow high (Fig. 1), within which geothermal gradients commonly exceed 50°C/km (Lachenbruch and Sass, 1978). This regional thermal anomaly is defined on the basis of quite widely separated data points, and could extend southward to encompass the Blackburn field area.

The Blackburn field, now Nevada's top producer (Ehni, 1997), occurs in brecciated Devonian dolostone above a concealed Cretaceous granodiorite stock (Hulen et al., 1990; *Appendix 1, p. A101*). Fluid inclusions in ancient dolomite veins in the

oil-reservoir rock have trapping temperatures commonly in excess of 350°C, suggesting that the mineralizing fluids were expelled from or heated by the granodiorite intrusion. These high temperatures, coupled with distinctive breccia textures in the dolostone reservoir rock, led Hulen et al. (1990) to suggest that much of the porosity ultimately occupied by oil at Blackburn may have been created by high-temperature, magmatically-related, natural hydraulic fracturing. This Cretaceous paleohydrothermal system is wholly unrelated to the one now circulating beneath and around the oil reservoir. This younger geothermal system, however, may have been responsible for silicification and sulfidation of the oil-reservoir rock; for enrichment of this rock in the gold "pathfinder" elements"; and intense argillic alteration of overlying Mississippian shales and Oligocene ash-flow tuffs to create an effective top seal.

The Grant Canyon and Bacon Flat fields in Railroad Valley occur in an active geothermal system which has the same temperature at reservoir depth as the Blackburn field (120-130°C), but at much shallower depth (1.1-1.6 km)(Hulen et al., 1991, 1994a; *Appendix 1, pages A33 and A78*). Hulen et al. (1994a) applied a variety of proven and novel geological evaluation methods, including fluid-inclusion microthermometry; stable-isotope geochemistry of rocks, veins, and fluids;

hydrogeochemical analysis; and three-dimensional alteration and mineralization mapping to show that the coupled Grant Canyon and Bacon Flat oil reservoirs were formed in the geologically recent past (probably within the last 2 m.y.) in an amagmatic meteoric-hydrothermal system which has persisted relatively unchanged to the present day. Goff et al. (1994; *Appendix 1, page A73*) and Hulen et al. (1994) also demonstrated that the geothermal waters associated with (and which formed) the oil reservoirs here are of Pleistocene age (no detectable tritium), and probably entered the convecting geothermal system more than 10 ka ago.

We have not been able to determine unambiguously whether the oils now reservoirized in the Grant Canyon geothermal system were actually generated by that system or were simply remobilized from an older reservoir. Some other fields in Railroad Valley, most notably Trap Springs (Fig. 1), are actually cooler at reservoir depth than expected from the presumed regional geothermal gradient (D.E. French, pers. comm. and unpublished drill-stem-test data); they may have formed in the absence of a direct convective-geothermal influence. Geothermal heating would clearly abet the generation of oil from the Chainman Shale (or other appropriate source rock), but we cannot demonstrate that this actually took place at Grant Canyon. Analysis of

biomarker transformation ratios, however, shows that the Grant Canyon oil has not been heated above modern reservoir temperature (Wavrek et al., 1997).

There is little doubt that the modern Grant Canyon geothermal system was instrumental in concentrating the oil now being produced (Hulen et al., 1994a). Therefore, given (1) the vast volumes of favorable Chainman source rock present in the eastern Great Basin, and (2) the area's unusually high concentration, past and present, of convective hydrothermal systems (e.g. Garside and Schilling, 1979), it seems likely that additional geothermally generated or enhanced oil reservoirs still await discovery in the region.

Remaining to be investigated: The possible role of extinct hydrothermal systems in formation of oil reservoirs which are now cooler than, or equal to, the geotherm at reservoir depth. Hydrothermal systems are dynamic features with relatively short life spans (no more than a few million years, and commonly less), and so may have participated in oil-reservoir evolution even in the fields which are now "cold". It is also possible that these cool fields formed in the absence of a direct geothermal influence, since the Chainman Shale is locally buried deeply enough beneath Cenozoic valley-fill sediments to induce oil generation by traditional diagenetic means (Bortz, 1989).

THE GOLD POINT DEPOSITS

Very near oil-rich Railroad Valley are the hydrocarbon- and gold-bearing quartz veins of the Gold Point area in the Currant mining district (Castor and Hulen, 1996a, 1996b, 1994; Fig. 1; *Appendix 1, pages A17 and A83*). The veins contain visible electrum which is invariably associated with blebs of pyrobitumen. Castor and Hulen (1996a) demonstrated that the electrum probably formed initially by adsorption onto the pyrobitumen, which was acting much like the activated charcoal utilized to retrieve gold from cyanide-leach solutions throughout the western U.S. Many of the pyrobitumen blebs, or the interiors of hollow shells in quartz veins from which the organic drained, are coated with microspheres of electrum -- exactly the texture displayed by gold adsorbed on activated charcoal. Once nucleated, the electrum in many cases at Gold Point grew to megascopically visible size as fern-like masses as long as 3 mm.

More to the point, however, the gold-bearing Gold Point veins also contain abundant "live" oil inclusions (fluorescent under UV excitation) very similar to those in quartz of the Grant Canyon oil reservoir (Castor and Hulen, 1996a). The inclusions, of primary origin, as well as large, ovoid to spherical pyrobitumen masses in the veins (signifying transport as globules prior to bitumen solidification) clearly record oil transport in

the mineralizing hydrothermal solutions, demonstrating once again that circulating thermal waters can provide an efficient means for moving oil in the subsurface.

Stable isotopic analysis of the quartz entrapping the oil and pyrobitumen at Gold Point, coupled with primary fluid-inclusion trapping temperatures, shows that the mineralizing Gold Point waters were isotopically near-identical to those still circulating at Grant Canyon oil field (Castor and Hulen, 1996a) -- roughly -14 per mil $\delta^{18}\text{O}$. It is clear, however, that the Gold Point waters were much hotter, up to 200°C and averaging about 180°C. This may account for the fact that although enriched in the "pathfinder" elements, the Grant Canyon reservoir rock contains no more than a few tens of ppb (parts per billion) of the precious metal (Hulen and Nielson, 1993).

Organic geochemical analysis of the fluid-inclusion oil and pyrobitumen at Gold Point shows that the hydrocarbon source rock was, as at Grant Canyon, the Chainman Shale (Castor and Hulen, 1996a; D. Wavrek, pers. comm., 1997). This is not surprising since the mineral deposits are localized in a stratiform jasperoid (massive microcrystalline quartz) developed at the upper contact of the Chainman with the overlying Mississippian Joana Limestone. We do not know if the Gold Point system formed a Grant Canyon type oil reservoir -- too much material has

been eroded away from the former. The Gold Point deposits do, however, provide clear supporting evidence that circulating hydrothermal systems can mobilize and transport considerable quantities of liquid hydrocarbon.

THE EXHUMED FOSSIL OIL RESERVOIRS OF THE SOUTHERN ALLIGATOR RIDGE DISTRICT

The Alligator Ridge district, located midway between the oil fields of Pine and Railroad Valleys (Fig. 2), is at the southern end of two parallel belts of Carlin-type, low-grade, disseminated gold deposits (e.g. Ilchik, 1996; Percival et al., 1988; Seedorf, 1991) in northeastern Nevada. In common with all Carlin-type deposits, those at Alligator Ridge are associated with abundant organic matter, both indigenous and introduced (Percival et al., 1988; Ballantyne, 1988; Leventhal and Hofstra, 1990; Nelson, 1991; Ilchik, 1991). Unlike the rest of the Carlin-type deposits, however, many of the Alligator Ridge orebodies, most notably Yankee (Fig. 3) are prominently oil-bearing (Pinnell et al., 1991; Hulen et al., 1994; *Appendix 1, page A59*). The Yankee deposits were locally so oil-rich that Pinnell et al. (1991; *Appendix 1, page A95*) initially postulated that the oil might be actively seeping, a situation which clearly increased the area's oil-exploration potential (several deep wells were drilled here between 1993

and 1996, including Pioneer's 14-14 Grubstake Federal (Fig. 3), featured on the cover of this report). Hulen et al. (1994b), however, subsequently showed that the Yankee oil was a residuum, found only in scattered pods of unoxidized rock in a "sea" of otherwise deeply weathered and oxidized material. Even so, the "free" oil at Yankee was found to be associated with oil-bearing fluid inclusions, occurring within or adjacent to gold ore. This relationship was intriguing since intuitively it seemed likely that the high temperatures normally associated with Carlin-type mineralization (perhaps 180-240°C; e.g. Ilchik and Barton, 1996) would have "cooked" the oil to solid residues, and perhaps caused decrepitation of volatile-rich oil inclusions. Yet the oil had clearly survived. Either it survived at temperatures much higher than those of the favorable oil-generation "window" (perhaps 60-150°C; e.g. Tissot and Welte, 1984), or the Yankee mineralization temperatures were lower than typical for the Carlin-type deposits as a class. The present research project in part was aimed at determining which of these scenarios was the more likely. More importantly, however, the Yankee oil occurrence almost certainly constituted a once-sizable oil accumulation -- perhaps several million BO prior to exhumation and oxidation (Hulen et al., 1994b). If it could be shown that this oil accumulation was not only spatially associated with Carlin-type mineralization, but actually developed in the

causative, mineralizing hydrothermal system, then other "Carlin-type" oil reservoirs, still deeply concealed, might yet be found. Moreover, many aspects of the Yankee fossil oil reservoir were clearly similar to the geothermally active Grant Canyon-Bacon Flat and Blackburn oil reservoirs -- fractured carbonate and siliciclastic host rock; silicification, sulfidation, and argillization; massive carbonate dissolution.

Geologic Setting of the Yankee-Group Deposits -- The dozen small Carlin-type deposits of the Yankee group (Fig. 3) are separated from the premier deposits of the Alligator Ridge district -- the Vantage group (about 0.5M oz Au produced; Ilchik, 1991) - - by about 9 km. The deposits of both groups, however, are geologically similar. They are hosted principally by the Mississippian-Devonian Pilot Shale, which consists dominantly of dolomite- and calcite-rich siltstone. The orebodies occur mostly in the basal part of the Pilot, particularly those of the Yankee group, and occur within and above a stratiform jasperoid which spans the contact between the Pilot and the underlying Devonian Devils Gate Limestone, for the most part a massive micrite. The jasperoid, clearly of hydrothermal origin, is nonetheless far more extensive than the gold deposits with which it is associated; it covers literally square kilometers, whereas the orebodies are typically tens to hundreds of square meters in areal extent.

Figure 3. Geologic map of the Alligator Ridge mining district (modified from Hose and Blake, 1976; and Ilchik, 1991), showing relationship of the relatively large Vantage group of deposits (which yielded about 500,000 oz Au) to those of the smaller Yankee group to the south. The Yankee group deposits commonly contain "live" oil in fluid inclusions, along fractures, and in crystal-lined vugs in unoxidized basal Pilot Shale. Also shown are locations of oil wells completed within and near the district. Ddg -- Devonian Devils Gate Limestone. Mdp -- Mississippian-Devonian Pilot Shale. Mcj -- Mississippian Chainman Shale and overlying Joana Limestone, undivided. Md -- Mississippian Diamond Peak Formation. Pe -- Pennsylvanian Ely Limestone. Par -- Permian Arcturus Formation. Knc -- Tuffaceous, ostracod-bearing mudstones and siltstones, possibly correlative with the Cretaceous Newark Canyon Formation. Tj -- jasperoid. Tv -- Intermediate-composition flow rocks, debris-flow breccias, and subordinate fallout tuffs, probably Oligocene in age. Qal -- Quaternary surficial deposits. All oil well symbols indicate "show of oil in dry hole". Solid triangles -- gold deposit. DH-WSR-32 is the exploration drill hole from which Ilchik et al. (1986) obtained "background samples of the Pilot Shale for Rock-Eval pyrolysis."

The Pilot and Devils Gate are part of a thick Paleozoic carbonate and siliciclastic sequence which in the district ranges from Cambrian to Permian age (Fig. 3). This sequence has been deformed into a series of broad open folds of probable Mesozoic age, and is overlain locally by Oligocene intermediate-composition volcanics; above the Vantage group of ore deposits, tuffaceous shales contain Cretaceous ostracods (W. Howald, pers. comm., 1995) and are tentatively assigned to the Newark Canyon Formation. The presence of this formation here helps constrain burial- and thermal-history reconstructions for the district. Although Jurassic (155-158 Ma) granitoid stocks intrude the Paleozoic sequence about 30 km to the north (Hitchborn et al., 1996), there is no direct evidence of intrusive activity in either the Vantage or Yankee areas. The orebodies themselves are frequently cited as such evidence, but Ilchik (1991) makes a good case that they and other Carlin-type deposits might well have formed in amagmatic geothermal systems larger than but otherwise not unlike those currently circulating at the Grant Canyon oil field.

The small Carlin-type deposits of the Yankee group occur in the previously mentioned stratiform jasperoid and in overlying siltstones and a basal argillaceous limestone of the Pilot Shale. In and around the orebodies, the Pilot is highly fractured and

locally brecciated, and has been extensively modified by hydrothermal alteration (Stout, 1996; Howald, 1996; Hulen et al., 1994b). Silicification and decarbonatization are the most prominent alteration types; the gold ores are localized in each, with the highest grades associated with former limestone weakly silicified but decalcified to a residual-illite-rich "paste". The bulk of the economic mineralization is localized in more competent silica-rich material.

Figure 4 is a detailed geologic map of the south Yankee deposits, prepared by John Cox and others of USMX, Inc., the former owners of this part of the district (The entire Alligator Ridge-Bald Mountain district is now owned and operated by Placer Dome U.S., Inc.). The Yankee, Saddle, Spur, Crusher, Rebel, and Rifle deposits located on the figure are geologically identical to the Monitor deposit (shown on the cover of this report) and several others within two km to the north. The recently discovered Vicksburg deposit is immediately adjacent and similar in size to the northern portion of the Yankee open pit. All these deposits are hosted by the basal Pilot Shale and underlying stratiform, pre-ore jasperoid (Howald, 1994; Stout, 1994).

Structural Controls -- Serving as a microcosm for the entire Alligator Ridge-Bald Mountain district, the south Yankee area is disrupted by high-angle faults of an

Figure 4. Detailed geologic map of the southern half of the Yankee subdistrict at Alligator Ridge (please refer to Figure 3 for location). This map shows the location of gold deposits and/or open-pit gold mines (dotted and hachured lines, respectively) as well as major mapped faults, most of which are high-angle and most recently of normal displacement. Shown for reference is a postulated paleostain ellipse showing that most of the major faults can be placed into a divergent wrench fault regime (e.g. Christie-Blick and Biddle, 1985). The stress field at the time these faults were generated was clearly different than the modern east-westerly extension of the Basin and Range province. This latter regime is believed responsible for normal-displacement reactivation of the older faults and for development of the major northerly-trending faults which displace those of the older set. RLS -- Right-lateral shear. SS -- Synthetic shear. RF -- High-angle reverse faults (also the predicted trend for folds). NF -- minor extensional normal faults [of the older set]. U -- Upthrown blocks of faults where known.

older set trending principally NW, NE, and EW, and a younger set with a more northerly orientation (Fig. 4). The older faults now show principally normal displacement, but may in part represent reactivated structures of a strike-slip regime (Howald, 1994). A conceptual paleostrain ellipse (Fig. 4; from, for example, Christie-Blick and Biddle, 1985), shows that the northwesterly-trending faults could be right-lateral shears and synthetic shears; the northeast trending faults antithetic shears; and the short east-west faults high-angle reverse faults. The expected northerly-trending high-angle normal faults are probably masked by more recently developed, typical high-angle B&R-style normal faults (for example, the one at the western edge of the Yankee open pit.

The ore deposits of the Yankee group are clearly developed within and near faults of the older group (Fig. 4), which appear to have served as feeders for the mineralizing hydrothermal solutions. These fluids, as, we will see, also apparently transported the oils which accumulated to form the Yankee oil reservoir.

Cross sections through the south Yankee area are shown as Figures 5 and 6. Section A-A⁴ was chosen to intersect both the Yankee open-pit gold mine and, to the southwest, Pioneer Oil and Gas Company's exploration well Yankee Mine Federal (YMF)-27-23X. Two alternative cross

sections along A-A⁴ are illustrated -- the first employing rather simplified normal faults to reconcile the mapped geology with the stratigraphic sequence penetrated by the well; the second, from Pioneer, drawing upon proprietary seismic data. Regardless of which model is accepted, it is clear that the Mississippian Chainman Shale and Devonian-Mississippian Pilot Shale were penetrated in the Pioneer well at elevations significantly lower than the modern surface in the Yankee area, where the formations are widely exposed. If as we believe likely, this configuration or something like it prevailed during mineralization, then both the Chainman and Pilot were in appropriate structural position to serve as hydrocarbon source rocks for the Yankee oils.

Figure 6 is a longitudinal section, B-B², through the south Yankee area (see Fig. 4 for location), showing the relatively simple near-surface geology in relationship to the scattered, shallow, Carlin-type gold deposits (these particular deposits are sufficiently low-grade that they must be accessible by open-pit mining methods). This section clearly illustrates the "semi-regional" extent of the aforementioned stratiform jasperoid relative to the restricted occurrence of the orebodies. Also highlighted is a gentle anticline readily apparent even though dissected by normal faults. Recalling that folding is apparently even more pronounced in a direction orthogonal to this section (see

Figure 5. Alternative, interpretive geologic sections through the Yankee deposit and Pioneer Oil and Gas oil-exploration well YMF-27-23X. Both sections are consistent with mapped geology and with formation intercepts in the well. The top section explains the deep penetrations of units in the Pioneer well relative to their exposure at the surface in the Yankee area as simply having been downdropped along a series of simple normal faults. The bottom section, by Pioneer oil and Gas geologists, is based on proprietary seismic data, and shows a much more complex overthrust-backthrust-lithic fault model.

Figure 6. Northwest-southeast geologic section through the south Yankee area, showing position of the semi-regional stratiform jasperoid spanning the contact between the upper Devils Gate Limestone (Ddg) and overlying Pilot Shale (Mdp) and the much more restricted distribution of the area's small, locally oil-bearing, Carlin-type gold deposits. Note the gentle anticline apparent even though dissected by younger normal faults. This anticline (see also Figure 5) is believed to have served as a structural trap for a small oil reservoir, formed in the same hydrothermal system responsible for the gold mineralization (see also Hulen et al., 1994). Section based on data from numerous shallow gold-exploration drill holes completed by USMX, Inc. and Placer Dome U.S., Inc.

Fig. 5), the structural setting at south Yankee would appear to have offered the "four-way closure" favorable for accumulation of oil.

Alteration and Mineralization -- The geologic setting, hydrothermal alteration, vein mineralization, and location of oil "shows" in and around a typical south Yankee gold orebody are shown as Figure 7, section A²-A³, drawn longitudinally through the southwest extension of the namesake Yankee deposit. Note the characteristic substratiform configuration of the orebody, arbitrarily defined for this report as >1 ppm (about 0.03 ounces per ton) gold, as well as its localization within and above the more regionally extensive jasperoid at the contact of the Devils Gate Limestone and Pilot Shale. The orebody "balloons" variously downward and upward along this section, as is typical, in association with prominent dissolution breccias created by hydrothermal decarbonatization. These breccias were clearly a second-order control on ore mineralization because of the porosity and permeability enhancement caused by removal of large volumes of primary calcite and dolomite from the Pilot. The breccias do not appear to extend downward into the Devils Gate (Fig. 7) here or elsewhere in the Yankee area.

Decalcification and silicification are the principal hydrothermal alteration types (Fig.

7, middle). Most of the higher grade ore is associated with silicification, a massive, cryptocrystalline to microcrystalline replacement of the protolith. The silicification encompasses the cores of many of the dissolution breccias (Fig. 7), and also extends into Pilot strata either initially more permeable and porous, or made so through hydrothermal carbonate dissolution.

Hydrothermal fracture-filling, or veining, and related intraclast open-space filling in breccias is of two principal types -- quartz and calcite. The quartz veinlets are generally < 0.5 mm wide, microcrystalline (only slightly coarser crystals than the matrix silica), and occur in silicified rock with or without minor alunite, kaolinite, barite, and "limonite" (oxidized pyrite and marcasite).

Both older and younger calcite veins and veinlets are present in the Yankee deposits. By contrast with the quartz veinlets, the calcite veins may be quite thick and massive. Older calcite veinlets (e.g. Fig. 7, bottom), commonly contain oil inclusions and are light gray to dark brown depending on the concentration of these inclusions. These veins are up to 10 cm in width, are both concordant and high-angle discordant, and, in the lower Pilot argillaceous limestone (in which they are most common) locally coalesce to form ovoid or "potato-shaped" masses up to 30 cm in diameter. Based on cross-cutting relationships, they are of

Figure 7. Detailed lithologic/stratigraphic (top), alteration (middle), and calcite-vein-distribution cross sections through the southwestern lobe of the oil-bearing Yankee deposit, showing relationship of gold mineralization to these features and to the relatively restricted distribution of free oil in unoxidized basal Pilot limestone pods. Samples Y-69 and Y-85 are calcite vein samples with abundant oil inclusions; these were selected as representative for the organic geochemical analyses discussed later in this report.

several ages, some richer in oil inclusions, some relatively impoverished in oil. These calcite veins extend only partway into the silicified cores of many of the ore-bearing dissolution breccias. At the edges of their distributions around these silicified breccias, the calcite veins themselves have been extensively decalcified. These relationships demonstrate that they (the oil-bearing calcite veins) are older than the silicification and quartz veining. Nonetheless, we will present evidence that they were likely precipitated by a pre-gold phase of the mineralizing hydrothermal system.

Younger veins and masses of coarsely crystalline, snow-white calcite are truly impressive, locally forming pods up to several meters in diameter. They also occur as veins, up to a meter in width, which along with the pods are concentrated in the Devils Gate Limestone immediately beneath stratiform jasperoid. Some of the calcite pods were clearly precipitated in large irregular caverns, forming concentric bands of the carbonate partially to completely filling the initial open space. The younger calcite also occurs as smaller veins and encrustations in the stratiform jasperoid, and to a lesser extent in altered rocks of the overlying Pilot Shale. This calcite appears unrelated to mineralization, and we speculate that it might have formed in a much younger and lower-temperature, cavern-forming (and -filling) episode (see also Green, 1993).

The two types of vein calcite are clearly distinguished on a plot of $\delta^{13}\text{C}$ vs $\delta^{18}\text{O}$ (Ilchik, 1991; also Fig. 8, top). Essentially, the older veins are typified by isotopically heavier carbon; the younger veins are considerably "lighter" (Ilchik, 1991). Veins from the Yankee and Saddle deposits (see Fig. 4 for location) are for the most part isotopically similar to their counterparts at the large Vantage deposit to the north (Ilchik, 1991). Some calcite veins from the Rebel deposit have much heavier oxygen-isotopic values than their Yankee and Saddle counterparts. This apparent discrepancy could be due to the fact that by contrast with the large open-pit mine samples from Yankee and Saddle, those from Rebel were small-diameter drill cuttings -- they could conceivably represent slightly coarser-crystalline limestone host rock, which in all three of these gold deposits has roughly the same isotopic signature as apparently do the Rebel veins (compare Fig. 8 top and bottom).

The Rebel calcite veins (?) and the basal Pilot argillaceous limestone host rock for the Yankee area orebodies are similar in isotopic composition to the early, pre-gold (barren), hydrocarbon-bearing veins of the Carlin deposit (Fig. 8, top; Kuehn and Rose, 1995), for which the class is named. The Yankee and Saddle calcite veins are isotopically similar to both pre-ore regional and ore-stage veins at Carlin. None of the Alligator

Figure 8. Carbon-oxygen isotope systematics — $\delta^{13}C$ vs $\delta^{18}O$ — for oil-bearing calcite veins from the Yankee, Saddle, and Rebel deposits (top; see Figures 4 and 8 for locations) and for whole-rock calcites from these deposits as well as from the basal Pilot Shale siltstone as penetrated in Pioneer Oil and Gas Co. well YMF-27-23X. Shown for comparison are analogous values for the nearby Vantage deposits (Figure 3) and for the Carlin gold deposit a little more than 100 km to the north. See text for explanation.

Ridge calcite veins approximate isotopically the late ore-stage calcite veins at Carlin.

Utilizing fluid-inclusion trapping temperatures for the Yankee and Saddle oil-bearing calcite veins ($>100^{\circ}\text{C}$; $<150^{\circ}\text{C}$; Hulen et al., 1994b) and the isotopic compositions of the calcites discussed above, the presumed oxygen-isotopic compositions of the calcite mineralizing waters have been calculated and are plotted as Figure 9. Note that the presumed Yankee and Saddle vein-forming waters were very similar to those calculated for Vantage (adapted from Ilchik, 1991), and also overlap the main and late gold-stage calcite veins for the Carlin deposit. The early hydrocarbon-bearing veins at Carlin are isotopically distinct, though in terms of their contained oil (now pyrobitumen), they are, among all Carlin calcite veins, most similar to the oil-bearing calcite veins at Yankee and Saddle.

Hydrocarbons — Like all the Carlin-type deposits, those of the Alligator Ridge district contain abundant hydrocarbon. At the Vantage deposit, the hydrocarbon is principally pyrobitumen, formerly liquid but now a vitreous-appearing solid residue (Ilchik et al., 1986; Ilchik, 1991). It is a pre-ore phase at Vantage, and in this it is similar to the paragenetic stage for hydrocarbons in most Carlin-type deposits — the organics appear to have been in place prior to gold mineralization. Nelson (1991), in fact,

discussed the Carlin-type deposits, many of which occur in anticlinal traps with hydrocarbon, as mineralized fossil oil reservoirs.

Although in many ways very similar geologically to Vantage, the dozen or so deposits of the Yankee group contain very little pyrobitumen. The principal organic in and around the deposits is oil. The oil occurs both as fluid inclusions in the early calcite veins (see above), and, more rarely, as “live” oil coating fractures and lining or filling crystal-lined vugs in unoxidized basal Pilot limestone (Fig. 7; Hulen et al., 1994b; Pinnell et al., 1991).

The Yankee oil, although originally envisioned as actively seeping (from a deep, rich oil reservoir, it was hoped), has been shown through this research project to be a residuum, occurring only in scattered pods of unoxidized basal Pilot (Fig. 7). Most of the formation throughout the district is thoroughly weathered and oxidized to a depth of more than a hundred m (Hulen et al., 1994b), making a true seep quite unlikely.

The Yankee oil is much more widespread as oil inclusions in calcite veins, occurring throughout much of the Pilot Shale but certainly concentrated in the basal limestone which also hosts the relict “free” (fracture-

Figure 9. Calculated isotopic compositions of the fluids responsible for precipitating the oil-bearing calcite veins of the Yankee and Saddle deposits, compared to analogous fluid compositions for calcite-precipitating fluids at the Vantage and Carlin deposits.

controlled) oil. Since the oil inclusions and the free oil occur together in the unoxidized pods, it is likely that they shared the same distribution prior to deep oxidation, though this cannot be proven beyond doubt. If the relationship is valid, the Yankee free oils once may have filled or at least partially filled fractures in the anticlinal structure shown by Figures 5 and 6. This likelihood led Hulen et al. (1994b) to speculate that the Yankee deposits, prior to oxidation, coincided with an oil reservoir of at least several million barrels -- larger than many of the fields currently producing oil in Nevada. A test of this hypothesis has been one of the major thrusts of this investigation.

Hydrocarbon Source Rock -- The ideas outlined above depend in part on the presumed genetic relationship between the oil entrapped in fluid inclusions in calcite veins and the associated free oil in fractures and vugs. Establishing this relationship, in turn, depends on identification of the likely hydrocarbon source rock(s) for the oils. Fortunately, a suite of drill cuttings from Pioneer Oil and Gas Company's oil-exploration well 27-23X-YMF was available for this purpose. Organic geochemical analyses and complementary organic petrographic studies were completed for these cuttings, and for fluid-inclusion and free oils from the Yankee and Saddle mines, at the Energy and Geoscience Institute Organic Geochemical Laboratory (Wavrek et

al., 1997). The full list of samples analyzed for this study -- their locations and (for the well samples) depths -- is presented as Table 1.

The possible source rocks for the Yankee oils in this geologic setting are restricted to the Mississippian Diamond Peak Formation and Chainman Shale and the Pilot Shale, of Devonian to Mississippian age (Figs. 3,5, and 10). On the basis of Rock-Eval pyrolysis experiments, the Pilot Shale was dismissed as regionally overmature -- that is, not a viable hydrocarbon source rock -- in the Alligator Ridge district by Ilchik et al. (1986), who also presented evidence that no hydrocarbons were actually added to the Vantage-deposit host rocks prior to or during mineralization. The previously mentioned Vantage pyrobitumen, he felt, simply signalled redistribution of indigenous organic material in the Pilot. The Chainman Shale is the main source rock for the oil reservoirs of the B&R (Poole and Claypool, 1984). Based on this fact, and the presumed depleted state of the Pilot, Pinnell et al. (1991) and Hulen et al. (1994b) concluded that the Chainman must have sourced both the Yankee free and fluid-inclusion oils.

Analytical methods used to characterize the Pioneer cuttings, the Yankee area oils, and, for comparison, oil from Grant Canyon and Bacon Flat field included bulk methods (total organic carbon analysis, Rock-Eval

A

Sample	Well	Location *	Company	Depth	Formation	Age	TOC (a)	Rock Eval (a)	Soxhlet Extraction (b)	GC-FID (b)	GC-MS (b)	Vitrinite % Ro (b)
96002R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	1630 - 1640	Diamond Peak	Mississippian	Φ	Φ				Φ
96003R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	1640 - 1650	Diamond Peak	Mississippian	Φ	Φ	Φ	Φ	Φ	Φ
96004R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	1710 - 1720	Diamond Peak	Mississippian	Φ	Φ				Φ
96005R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	1760 - 1770	Diamond Peak	Mississippian	Φ	Φ	Φ	Φ	Φ	Φ
96006R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3000 - 3010	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	
96007R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3040 - 3050	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	
96008R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3090 - 3100	Chainman Shale	Mississippian	Φ	Φ				Φ
96009R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3120 - 3130	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	
96010R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3140 - 3150	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	
96011R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3160 - 3170	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	
96012R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3190 - 3200	Chainman Shale	Mississippian	Φ	Φ				Φ
96013R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3290 - 3300	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	Φ
96014R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3340 - 3350	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	Φ
96015R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3390 - 3400	Chainman Shale	Mississippian	Φ	Φ	Φ	Φ	Φ	Φ
96016R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3800 - 3810	Joana Limestone	Mississippian	Φ					
96017R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4100 - 4110	Pilot Shale	Miss - Devonian	Φ	Φ	Φ	Φ	Φ	
96018R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4040 - 4050	Pilot Shale	Miss - Devonian	Φ	Φ				
96019R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4060 - 4070	Pilot Shale	Miss - Devonian	Φ	Φ	Φ	Φ	Φ	
96020R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4080 - 4090	Pilot Shale	Miss - Devonian	Φ	Φ	Φ	Φ	Φ	Φ
96021R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4170 - 4180	Pilot Shale	Miss - Devonian	Φ	Φ				
96030R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	3870 - 3880	Pilot Shale	Miss - Devonian	Φ					
96031R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4020 - 4030	Pilot Shale	Miss - Devonian	Φ	Φ	Φ	Φ	Φ	
96032R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4140 - 4150	Pilot Shale	Miss - Devonian	Φ	Φ	Φ	Φ	Φ	
96033R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4150 - 4160	Pilot Shale	Miss - Devonian	Φ	Φ				
96034R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4160 - 4170	Pilot Shale	Miss - Devonian	Φ	Φ				
96035R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4180 - 4190	Pilot Shale	Miss - Devonian	Φ	Φ				
96036R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4490 - 4500	Pilot Shale	Miss - Devonian	Φ	Φ	Φ	Φ	Φ	
96037R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4570 - 4580	Devils Gate	Devonian	Φ					
96038R	YMF 27-23X	White Pine Co., NV	Pioneer Oil & Gas	4960 - 4970	Devils Gate	Devonian	Φ					

* 1837'FWL, 1898'FSL sec 27, T21N, R57E (MDBM)

a: Humble Instruments & Services

b: completed at EGI

B

ESRI Sample	Hulen Sample ID	Field Name	Comments	API Gravity (a)	GC-FID (a)	Asphaltene Precipitation (a)	Column Chrom. (a)	GC-MS (SIM)	
								Saturate (a)	Aromatic (a)
95002C	NV/OF93-56	Grant Canyon	crude oil	25.6	Φ	Φ	Φ	Φ	Φ
96001C	NV/OF91-17	Trap Springs	crude oil	X	Φ	Φ	Φ	Φ	Φ
96002C	NV/SA 68	Saddle Mine	fluid inclusion from calcite	X	Φ	Φ	Φ	Φ	Φ
96041C	NV/Y-69	Yankee Mine	oil bearing calcite veins	X	Φ	X	Φ	Φ	Φ
96043C	NV/Y-85	Yankee Mine	oil & gold bearing calcite-realger veins	X	Φ	X	Φ	Φ	Φ
96044C	NV/SA-66	Saddle Mine	oil bearing cacite veins	X	Φ	X	Φ	Φ	Φ
96045C	NV/SA-104	Saddle Mine	oil bearing calcite-realger veins, 5' from gold ore	X	Φ	X	Φ	Φ	Φ

a: Completed at EGI

X: Not performed due to insufficient sample

Table 1. Sample information and list of analyses performed on (A) drill cuttings from Pioneer Oil and Gas Co. well 27-23X-Yankee Mine Unit Federal (see Fig. 3 for location), and (B) crude oils from the Yankee and Saddle mines (Figs. 3 and 4) and, for comparison, produced oils from the Grant Canyon and Trap Springs oil fields in Railroad Valley (Fig. 1).

Figure 10. Generalized stratigraphic column for the Alligator Ridge-Bald Mountain mining district, showing formations which host gold deposits, and those which are organic-rich and thus potential hydrocarbon source rocks.

pyrolysis, and Soxhlet extraction), chromatographic analysis (liquid column chromatography, gas chromatography/flame ionization detection (GC-FID), gas chromatography-mass spectrometry (GC-MS), and optical methods (kerogen typing and vitrinite petrography and reflectance analysis (Wavrek et al., 1997). The following synopsis of the results of this study is adapted from Wavrek et al. (1997), to which the reader is referred for more detail. Supporting data generated for the study, as well as all relevant crossplots of these data (exemplified by the representative plots illustrated for this report) are available upon request from the Energy and Geoscience Institute.

Total organic carbon contents (TOC) for the analyzed Pioneer well cuttings show that the Diamond Peak Formation and the Chainman Shale have fair to excellent source potential (average TOC = 2.62% and 3.31%, respectively; Table 1), and that the Pilot Shale has poor to excellent source potential (average TOC = 1.23%; Table 1). The Devils Gate and Joana Limestone sample analyzed for comparison rank as non-sources. It should be borne in mind that the TOC values only indicate the abundance of the contained organic matter in these rocks, not their effectiveness as hydrocarbon sources.

Results of Rock-Eval pyrolysis analysis of

the cuttings provide additional information on source-rock potential. The Rock-Eval data are summarized in Table 2, but only for those samples with TOC values in excess of 0.5% (below this value, the Rock-Eval results are believed to have questionable reliability). The S1, S2, and S3 values (in equivalent kg of product per ton of analyzed rock) reported in the table correspond, respectively, to (1) indigenous hydrocarbons; (2) hydrocarbon-like compounds generated by the pyrolysis; and (3) oxygen-containing volatiles like water and carbon dioxide generated during the higher-temperature stages of the procedure, but short of the temperature at which, for example, carbon dioxide is produced by decrepitation of calcite or other carbonate phases. Tmax is the temperature corresponding to the maximum S2 production, and is a standard measure of source-rock thermal maturity (used, for example, by Ilchik et al., 1986, in their evaluation of hydrothermal organic-matter maturation at the Vantage deposits). The production index (PI), $S1/(S1+S2)$, gauges the amount of hydrocarbon already produced from the rock as compared to the amount of hydrocarbon which the rock theoretically could yield. The total generation potential (TGP) is simply the denominator of the production index. Finally, the reactive carbon index (RCI) is a parameter utilized to assess the proportion of the TOC which could actually yield hydrocarbons.

Sample	Formation	TOC	S1	S2	S3	Tmax	HI	OI	S1/TOC	S2/S3	PI	TGP	RCI
96002R	Diamond Peak	4.03	0.51	25.88	0.62	439	642	15	0.13	41.74	0.02	26.39	65.48
96003R	Diamond Peak	4.42	0.39	22.88	0.95	442	518	21	0.09	24.08	0.02	23.27	52.65
96004R	Diamond Peak	0.98	0.24	4.51	0.49	440	460	50	0.24	9.20	0.05	4.75	48.47
96005R	Diamond Peak	1.05	0.26	4.97	0.29	443	473	28	0.25	17.14	0.05	5.23	49.81
96006R	Chainman Shale	2.83	0.73	18.93	0.47	441	669	17	0.26	40.28	0.04	19.66	69.47
96007R	Chainman Shale	5.90	0.81	41.74	0.62	443	707	11	0.14	67.32	0.02	42.55	72.12
96008R	Chainman Shale	4.71	0.63	32.77	0.6	442	696	13	0.13	54.62	0.02	33.40	70.91
96009R	Chainman Shale	3.82	0.61	26.2	0.54	443	686	14	0.16	48.52	0.02	26.81	70.18
96010R	Chainman Shale	2.61	0.62	17.91	0.43	445	686	16	0.24	41.65	0.03	18.53	71.00
96011R	Chainman Shale	6.00	0.74	41.9	0.54	443	698	9	0.12	77.59	0.02	42.64	71.07
96012R	Chainman Shale	4.10	0.89	28.28	0.55	443	690	13	0.22	51.42	0.03	29.17	71.15
96013R	Chainman Shale	1.31	0.33	5.09	0.39	443	389	30	0.25	13.05	0.06	5.42	41.37
96014R	Chainman Shale	0.79	0.39	3.45	0.02	444	437	3	0.49	172.50	0.10	3.84	48.61
96015R	Chainman Shale	1.03	0.37	3.81	0.22	444	370	21	0.36	17.32	0.09	4.18	40.58
96016R	Joana Limestone	0.24											
96017R	Pilot Shale	1.16	0.53	5.1	0.46	444	440	40	0.46	11.09	0.09	5.63	48.53
96018R	Pilot Shale	0.97	0.43	4.42	0.35	443	456	36	0.44	12.63	0.09	4.85	50.00
96019R	Pilot Shale	1.72	0.39	6.1	0.45	447	355	26	0.23	13.56	0.06	6.49	37.73
96020R	Pilot Shale	3.51	0.38	15.73	0.35	440	448	10	0.11	44.84	0.02	16.11	45.80
96021R	Pilot Shale	0.52	0.17	0.62	0.33	444	119	63	0.33	1.88	0.22	0.79	15.19
96030R	Pilot Shale	0.40											
96031R	Pilot Shale	1.46	0.59	5.6	0.35	440	384	24	0.40	16.00	0.10	6.19	42.40
96032R	Pilot Shale	1.13	0.40	3.31	0.35	445	293	31	0.35	9.46	0.11	3.71	32.83
96033R	Pilot Shale	1.08	0.40	3.19	0.31	443	295	29	0.37	10.29	0.11	3.59	33.24
96034R	Pilot Shale	0.83	0.34	1.73	0.41	438	208	49	0.41	4.22	0.16	2.07	24.94
96035R	Pilot Shale	0.67	0.2	0.86	0.42	436	128	63	0.30	2.05	0.19	1.06	15.82
96036R	Pilot Shale	1.27	0.49	2.23	0.41	440	176	32	0.39	5.44	0.18	2.72	21.42
96037R	Devils Gate	0.40											
96038R	Devils Gate	0.24											

from Wavrek et al., 1997

$$\begin{aligned}
 HI &= S2 \cdot 100 / TOC \\
 OI &= S3 \cdot 100 / TOC \\
 PI &= S1 / (S1 + S2) \\
 TGP &= S1 + S2 \\
 RCI &= ((S1 + S2) \cdot 10) / TOC
 \end{aligned}$$

Table 2. Total organic carbon (TOC) and Rock-Eval pyrolysis data for cuttings from Pioneer Oil and Gas Co. well YMF-27-23X. Please refer to Table 1 for sample depths.

These source-rock quality indicators have been crossplotted to derive a subjective quality index with four categories ranging from poor to excellent. Figure 11 exemplifies these crossplots, showing, based on TGP vs TOC, that the Diamond Peak Formation and Chainman Shale penetrated in the Pioneer well still have fair to excellent source-rock potential, and that the Pilot Shale is a fair to good potential source rock. A plot of Tmax vs RCI (not illustrated) shows that all but two samples are "oil-prone" (these two, from the Pilot Shale) are prone to generate both oil and natural gas (Wavrek et al., 1997).

Figure 12 is a modified "Van Krevelen diagram" (e.g. Tissot and Welte, 1984), plotting the hydrogen indices (HI) vs oxygen indices (OI; Table 1) for the analyzed Pioneer-well samples. On such a diagram, the three principal types of kerogen and their generalized thermal maturation pathways can commonly be discerned. Type I kerogen is commonly of algal origin; type II is commonly derived from a mixture of marine phyto- and zooplankton as well as bacteria; and type III is formed primarily from terrestrial plant material (Tissot and Welte, 1984). As these kerogens thermally mature they tend to become more and more carbon rich along the "maturation pathways" designated on Figure 12. The ultimate residuum -- which would plot near the lower left hand corner of the diagram -- is in terms

of its petroleum generation capacity a useless "dead carbon". Figure 12 shows that values for some of the Pilot cuttings samples verge upon this "dead carbon" region, but the rest of the Pilot samples as well as those from the Diamond Peak Formation and (especially) the Chainman Shale are still quite capable of oil generation.

Figure 12 also shows the fields for "background" and "mineralized" Pilot from the Vantage area (from Ilchik et al., 1986). The background field, based on Rock-Eval analyses of cuttings from a shallow mineral-exploration drill hole (WSR-32; Fig. 3) near the Vantage open pits, encompasses several of the Pioneer-well Pilot samples. The mineralized Pilot field, which Ilchik et al. (1986) attributed to the effects of the mineralizing fluid upon the indigenous organic matter, we believe might also arise from the effects of supergene weathering and attendant oxidation of the organic matter; even though the analyzed Vantage samples were visually unoxidized "black siltstones", they were collected from large pods of unoxidized rock entirely surrounded by thoroughly oxidized material. It would seem possible that these blackish rocks could have been affected by oxidation without destruction of the carbonaceous material (or, for that matter, conversion of sulfides like pyrite to "limonite").

The results of our source-rock analysis are

- ◇ Diamond Peak Fm.
- △ Chainman Shale 1
- ⊕ Chainman Shale 2
- Joana Limestone
- Pilot Shale 1
- ⊗ Pilot Shale 2
- ▽ Devils Gate Limestone

Figure 11. Cross-plot of total-generation (TGP) vs total organic carbon (TOC) for cuttings from various stratigraphic units penetrated by Pioneer Oil and Gas Co. well YMF-27-23X. The Pilot and Chainman Shale samples are arbitrarily subdivided into those with good to excellent source-rock potential (Pilot and Chainman "1") and those with fair to poor potential (Pilot and Chainman "2"). The Joana and Devils Gate Limestone samples, with extremely low TOC, were omitted from the diagram for clarity. The descriptors poor, fair, good, and excellent refer to hydrocarbon source-rock quality (from Wavrek, 1997). Please refer to text for further explanation.

Figure 12. Modified "Van Krevelen" diagram plotting hydrogen index vs oxygen index, from Rock-Eval pyrolysis analysis, of cuttings from Pioneer Oil and Gas Co. Well YMF 27-23X vs (1) standard thermal-maturation pathways for kerogen types I, II, and III; (2) background Pilot Shale (cuttings from drill hole WSR-32; Figure 3) and corresponding gold-mineralized Pilot from the Vantage deposits (Ilchik et al., 1986).

summarized in Figure 13. It can be seen that all three potential source rocks for the Yankee mine oils -- the Diamond Peak, Chainman, and Pilot -- theoretically could have sourced the oils. The Chainman is certainly the most favorable source rock, but the Diamond Peak and the Pilot are also quite oil-prone where penetrated by the Pioneer well.

Oils -- Liquid chromatographic analysis of Soxhlet extracts of the Pioneer-well samples and of oils from the Yankee and Saddle mines (details in Wavrek et al., 1997) (Table 3) yield saturate, aromatic, and NSO (nitrogen-sulfur-oxygen) values fairly typical for worldwide crude oils (Fig. 14; see also Tissot and Welte, 1984). By contrast, oil clearly affiliated with high-temperature hydrothermal systems (as at oceanic spreading centers and, for example, at hot springs like Calcite Spring in Yellowstone National Park; Kvenvolden and Simoneit, 1990; Love and Good, 1970) are markedly enriched in aromatic hydrocarbons. The Yankee oils may well have been transported and entrapped by the causative, gold-mineralizing hydrothermal system (Hulen et al., 1994b), but if so that system, based on these normal-crude-oil signatures, must have been tepid compared to a typical Carlin-type system, in which temperatures commonly exceeded 250°C (e.g. Percival et al., 1988).

Figure 15 displays two GC-FID responses

for oil from a Yankee mine calcite vein, no. Y-85 (Fig. 7). This vein crosscut basal Pilot argillaceous limestone less than 10 m from 1 ppm (0.03 oz/T) gold ore. The surface of the vein was coated with live oil; the vein itself hosted so many oil-bearing fluid inclusions that it appeared brown in hand sample. In order to ascertain the relationship of the free oil on the vein surface to oil trapped in the vein-filling calcite, the sample was first "rinsed" in an organic solvent to remove the surficial hydrocarbon. This material was analyzed by GC-FID, then the vein sample was pulverized, and the fluid-inclusion oil extracted and similarly analyzed. The two traces show a similar "hump" or, more technically, a raised baseline indicative of "unresolved complex mixture", in turn a hallmark of biodegradation (Wavrek et al., 1997; Tissot and Welte, 1984). The surface oil sample has been severely biodegraded, and its GC-FID trace lacks all but trace indications of the more prominent typical n-alkane peaks shown for the fluid-inclusion oil trace. We believe it likely that the sample was riddled with natural microfractures. These conceptually would expose some of the fluid-inclusion oils to weathering, and would also permit infiltration and subsequent weathering and oxidation of small but detectable amounts of free oil. These relationships are not surprising, since the Yankee orebodies and their host rocks are deeply oxidized, locally to depths approaching 300 m (W. Howald and W.

Figure 13. Diagnostic Rock-Eval data for Pioneer Oil and Gas Co. well YMF 27-23X. The descriptors "good" and "excellent" on the the TOC column refer to potential source-rock quality. This diagram clearly shows that the Diamond Peak, Chainman, and Pilot formations are all potential source rocks for the oil occurring in association with gold in the Yankee and similar deposits of the southern Alligator Ridge district

Summary of Soxhlet Extraction and Liquid Column Chromatography Data

Sample	TOC wt %	a	b	c	mg Bitumen		Liquid Chromatography			
		Rock mass (g)	Bitumen mass (g)	Carbon mass (g)	g carbon	g Rock	saturate (%)	aromatic (%)	NSO (%)	non-recovered (%)
96003B	4.42	6.0862	0.0052	0.26901	19.33	0.85	13.7	31.4	45.1	9.8
96005B	1.05	5.7941	0.0048	0.0608	78.90	0.83	34.1	29.3	34.1	2.4
96006B	2.83	5.5939	0.0132	0.1583	83.38	2.36	27.7	39.2	21.5	11.5
96007B	5.90	6.3718	0.0175	0.3759	46.55	2.75	11.4	42.8	32.5	13.3
96009B	3.82	4.7423	0.0086	0.1812	47.47	1.81	21.1	31.6	34.2	13.2
96010B	2.61	5.5071	0.0092	0.1437	64.01	1.67	26.1	35.5	37.2	1.2
96011B	6.00	4.6263	0.0129	0.2776	46.47	2.79	18.0	36.0	32.4	13.5
96013B	1.31	7.0444	0.0059	0.0923	63.93	0.84	42.9	28.6	17.9	10.7
96014B	0.79	4.8630	0.0047	0.0384	122.34	0.97	41.9	31.0	24.1	3.0
96015B	1.03	4.8335	0.0061	0.0498	122.53	1.26	29.1	21.8	29.1	20.0
96017B	1.16	5.1492	0.0085	0.0597	142.31	1.65	32.4	24.3	25.7	17.6
96019B	1.72	8.4112	0.0076	0.1447	52.53	0.90	30.3	27.3	33.3	9.1
96020B	3.51	3.8672	0.0056	0.1357	41.26	1.45	9.8	33.3	39.2	17.6
96021B	0.52	3.7312	0.0013	0.0194	67.00	0.35	23.1	38.5	30.8	7.7
96031B	1.46	6.3046	0.0091	0.0920	98.86	1.44	42.4	31.8	20.0	5.9
96032B	1.13	3.2876	0.0018	0.0371	48.45	0.55	22.2	11.1	11.1	55.6
96036B	1.27	1.1524	0.0010	0.0146	68.33	0.87	33.3	44.4	22.2	0.0

a: grams rock extracted with solvent

b: grams bitumen obtained upon extraction of rock specimen

c: grams organic carbon in sample calculated from wt % TOC (Rock Mass*TOC/100)

from Wavrek et al., 1997

Summary of Column Chromatography Data

Sample	Topping Loss* (%)	Liquid Column Chromatography				
		saturate (%)	aromatic (%)	NSO (%)	Asphaltene (%)	non-recovered (%)
95002C	5.9	48.7	28.3	8.6	10.1	4.4
96001C	4.1	46.6	27.3	9.4	12.1	4.7
96002C	N/A	34.5	38.0	18.1	6.5	2.9
96041C	N/A	34.6	37.7	15.7	N/A	11.9
96043C	N/A	51.9	23.3	12.4	N/A	12.4
96044C	N/A	51.6	34.3	8.6	N/A	5.5
96045C	N/A	68.7	21.6	4.7	N/A	5.0

*weight percentage loss after topping at 60°C for 24 hours

N/A = not available due to limited sample volume

Table 3. Liquid column chromatography data for (A) Soxhlet bitumen extracts from Pioneer YMF-27-23X drill cuttings (please refer to Table 1 for sample depths and formations) and (B) crude oils from the Yankee and Saddle mines (bottom five samples in the table) and from Grant Canyon (first sample) and Trap Springs oil fields for comparison.

Figure 14. Relative abundances of saturated and aromatic hydrocarbons and NSO compounds of fluid-inclusion oils from the Yankee and Saddle gold deposits vs crude oil from the Grant Canyon and Trap Springs oil fields and vs bitumen extracts from cuttings from Pioneer YMF-27-23X. Shown for reference is the field for 636 global crude oils (from Tissot and Welte, 1984, Fig. I.V.1.4). Note that all of the fluid-inclusion oils fall well within the “normal” crude oil field, as do the produced oils. By contrast, oils generated at anomalously high temperatures (as at oceanic spreading centers and in hot springs such as Calcite Spring at Yellowstone National Park; Kvenvolden and Simoneit, 1990; Love and Good, 1970) are highly enriched in aromatic hydrocarbons. We conclude that the Yankee oils have never experienced such high temperatures, even though there is strong evidence that they were transported and entrapped in the same hydrothermal system (which must therefore have been a moderate-temperature one) which precipitated the gold ores.

From Wavrek, 1997

from Wavrek et al., 1997

Figure 15. Gas chromatography-flame ionization detection (GC-FID) profile for oil from a Yankee mine calcite vein. (A) Pattern for oil "rinsed" from the surfaces of coarsely ground chips of vein material. (B) Pattern for oil extracted from the same chips after pulverization. Note that both patterns show a "hump" characteristic of biodegraded oil (e.g. Peters and Moldowan, 1993). The "rinse" sample shows the most effects of biodegradation, for it shows few of the characteristic n-alkane peaks revealed by the powdered-sample extract. We interpret the extract-sample pattern as being a mixture of undegraded, crush-liberated fluid-inclusion oil and its weathered counterpart tightly trapped in microfractures which the "rinse" did not access.

Stout, Placer Dome U.S., Inc., pers. comm., 1995).

In Figure 16, the GC-FID trace for the partially biodegraded Yankee mine fluid-inclusion oil sample (bottom of figure) is contrasted with a fluid-inclusion oil extract from a similarly positioned (with respect to gold ore) calcite vein from the Saddle mine just south of Yankee (Fig. 4). The Saddle mine inclusion-oil pattern (top of figure) shows little of the biodegradation-related "hump" so prominent for the Yankee mine. In our view, this simply indicates that the Saddle mine sample has not been as intensely microcracked as its Yankee counterpart, so that the entrapped oils have largely escaped the ravages of weathering and attendant biodegradation.

The Yankee and Saddle fluid-inclusion oils were analyzed by GC-MS to yield a suite of conventional molecular correlation parameters (Table 4). These parameters, variously crossplotted (as exemplified by the sterane carbon-number ternary diagram of Figure 17; many additional such diagrams and their implications in Wavrek et al., 1997), reveal that the fluid-inclusion oils are very similar compositionally to the drill-cuttings bitumen extracts from the various formations penetrated in YMF-27-23X. Note on Figure 17 that the oil-field oil data match closely the Chainman Shale extracts from the Pioneer well cuttings. By contrast,

the fluid-inclusion oils match most closely -- in fact strikingly so -- the extracts from the Pilot Shale cuttings. These relationships would suggest that the Pilot itself, rather than the Chainman, as initially seemed likely, was the source of the fluid-inclusion oils in the Yankee and Saddle calcite veins.

Figure 18 crossplots two more organic molecular indices which are particularly useful for assessing the oxicity of the water column in which hydrocarbon source-rock sediments accumulated. As above, the data shown on this crossplot strongly point to the Pilot Shale as the source of the Yankee and Saddle fluid-inclusion oils. Figure 19 is a summary "star diagram" summarizing the parameters discussed above and clearly pointing to the Pilot Shale as the source of the Yankee and Saddle fluid-inclusion oils.

Thermal-Stress Analysis; Thermal Maturity of the Oils -- The Yankee and Saddle fluid-inclusion oils and the produced oils from Trap Springs and Grant Canyon fields were examined in detail to determine the extent of their thermal alteration. For the gold-mine oils, this assessment was viewed as one good test of the hypothesis tendered by Hulen et al. (1994b) that the oil-transporting hydrothermal system responsible for the gold mineralization was of only moderate temperature -- certainly no more than 150°C. The rationale was that if the gold-mine oils had experienced the

From Wavrek, 1997

from Wavrek et al., 1997

Figure 16. GC-FID patterns for fluid-inclusion oils extracted from calcite veins from the Saddle mine (A) and the Yankee mine (B), revealing different contributions of biodegraded and ungraded oils. The Saddle mine sample is relatively unaffected by biodegradation, but the Yankee mine sample is dominated by degraded components. This is almost certainly due to varying degrees of microfracturing which have disrupted the oil-bearing veins. The microfracturing will not only expose fluid-inclusion oils to weathering, it will also allow have allowed penetration by “free” oils, readily weathered upon contact with near-surface meteoric waters.

Sample	TERPANES												STERANES						PHEN			
	C35H	C19..C26t	Tri-cyclic	Tetra-cyclic	GA	GA	Sterane	C29*Ts	C29H	Ts	BNH	C30dH	%αββ m/z 218			αββ	αββ	αββ	Sterane	DBT	DBT	Phen
	C31..C35H	C29..C33H	Index	Index	Index	C31H (R&S)	Index	C29H	C30H	Tm	BNH + C30t	C30H	C27	C28	C29	C27	C28	C30	conc. (ppm)	Phen	conc (ppm)	conc (ppm)
95002C	0.07	1.33	0.37	0.29	0.07	0.11	1.16	0.37	0.50	1.34	0.15	0.09	33.6	20.9	45.5	1.35	0.46	0.12	3710	0.83	460	557
96001C	0.11	0.86	0.19	0.23	0.08	0.13	1.04	0.47	0.41	1.26	0.06	0.11	35.4	20.5	44.0	1.24	0.47	0.11	5732	0.36	198	553
96002C	0.10	0.13	0.18	0.49	0.07	0.09	0.36	0.56	0.37	2.15	0.12	0.08	27.0	19.0	54.0	2.00	0.35	0.05	4699	0.49	99	202
96041C	0.10	0.68	0.06	0.23	0.12	0.12	1.05	1.16	0.53	2.34	0.01	0.32	32.7	19.7	47.6	1.45	0.41	0.07	6166	0.24	5	19
96043C	0.11	0.23	0.15	0.42	0.12	0.13	0.58	0.91	0.47	2.50	0.12	0.21	27.8	20.1	52.1	1.88	0.39	0.08	6097	0.57	9	17
96044C	0.09	0.23	0.23	0.46	0.05	0.06	0.41	0.65	0.38	2.98	0.15	0.12	29.8	19.8	50.4	1.69	0.39	0.05	4243	0.56	46	83
96045C	0.15	0.38	0.34	0.44	0.10	0.10	0.57	1.53	0.40	5.57	0.09	0.32	30.8	21.8	47.4	1.54	0.46	0.05	2781	0.81	39	47

H = Hopane
T = Tetracyclic
t = Tricyclic
GA = Gammacerane
BNH = 29,30 Bishorhopane
dH = Diahopane
Tr = Compound present in trace concentration

$$\text{Tricyclic Index} = \frac{C19t + C20t}{C19t + C20t + C23t + C24t}$$

$$\text{Tetracyclic Index} = \frac{C24t}{C29t \text{ (R\&S)}}$$

$$\text{GA Index} = \frac{\text{Gammacerane}}{C30 \text{ Hopane}}$$

$$\text{Sterane Index} = \frac{\text{Steranes}}{\text{Steranes} + C29..C33H}$$

$$\text{Sterane conc.} = \frac{\text{Steranes} \cdot 400 \text{ ppm}}{5b \text{ Cholane}}$$

Structures: I = 5B,10B(CH3) Non-Rearranged
V = 5b(CH3),10B(H) Rearranged

DBT = Dibenzo[thiophene]
Phen = Phenanthrene
MA = Monosomatic

Table 4. Summary of conventional molecular correlation parameters determined through analysis, by gas chromatography-mass spectrometry (GC-MS), of fluid-inclusion oils from the Yankee area and produced oils from Grant Canyon and Trap Springs oil fields. For sample locations and affiliations, please refer to Table 1. A full description of all these parameters is beyond the scope of this report; the interested reader is referred to Wavrek (1997) and to Peters and Moldowan (1993).

Figure 17. Ternary diagram showing normalized distributions of sterane carbon numbers for fluid-inclusion oils extracted from Yankee mine and Saddle mine calcite veins compared to corresponding data for bitumen extracts from drill cuttings from Pioneer well YMF-27-23X. Characteristics of produced oils from the Grant Canyon and Trap Springs fields are shown for comparison. Note the close match of the produced oils with data points for the Chainman Shale extracts, supporting prior conclusions (Poole and Claypool, 1984) that the Chainman is the hydrocarbon source rock for the Grant Canyon and Trap Springs as well as most other Nevada fields. By contrast, the fluid-inclusion oils from Yankee and Saddle are compositionally very similar to extracts from the Pilot Shale, suggesting that this unit and not the Chainman is the source of the oil found in the Yankee area gold deposits.

Figure 18. Crossplot of two conventional organic molecular indices particularly useful for ascertaining oxicity of the water column in which hydrocarbon source-rock sediments accumulated. Plotted on the diagram are measurements of these parameters for fluid-inclusion oils from the Yankee and Saddle mines; produced oils from Grant Canyon and Trap Springs fields; and bitumen extracts from cuttings of various Paleozoic formations penetrated in Pioneer well YMF-27-23X. Note that the gold-mine fluid-inclusion oils are similar compositionally to bitumen extracts from Pilot shale cuttings, further evidence that the Pilot, and not the Chainman, is the likely hydrocarbon source rock.

Figure 19. Star diagram with its seven “rays” corresponding to various molecular parameters discussed previously in this report. Plotted on the diagram are values corresponding to bitumen extracts from the Chainman Shale and Pilot Shale penetrated by the Pioneer well; fluid-inclusion oils from the Yankee and Saddle open pit gold mines, and produced oils from Trap Springs and Grant Canyon oil fields. The values for each category represent the “average” for the entire group. It is clear from this diagram that the produced oils are compositionally affiliated with the bitumen extracts from the Chainman Shale (seemingly a remarkable correlation since the produced oils accumulated in Railroad Valley, about 160 km to the south (Fig. 1)). It is equally clear that the Yankee and Saddle fluid-inclusion oils were likely sourced from the nearby Pilot Shale.

higher temperatures typically associated with Carlin-type paleohydrothermal systems (perhaps 175-250°C; Percival et al., 1988; Kuehn and Rose, 1995), temperature-dependent biomarker transformations (methodology outlined, for example, by Peters and Moldowan, 1993) would faithfully record the effect of this heating. Implicit in this analysis is that the gold-mine oils were entrapped in fluid inclusions either prior to or during gold mineralization -- the free oil is clearly post-gold, but no unambiguously post-gold oil inclusions have been identified. It should also be borne in mind that interpretation of the biomarker transformation reactions requires particularly careful evaluation by an experienced investigator, since assigning equivalent thermal-maturity values to the affected oils requires integration of multiple transformations in light of the influence of source-rock facies on individual biomarker parameters. For a complete analysis of the oils evaluated for this study, the reader is referred to Wavrek et al. (1997).

Table 5 and Figure 20 summarize the molecular parameters and their values used in thermal-maturity analysis of the fluid-inclusion and produced oils, and also present the interpreted thermal maturities of the oils as based on these analyses. All the oils fall within a very narrow interpreted thermal maturity range, from 0.75 to 0.95% Ro. According to empirical vitrinite-reflectance

geothermometers developed by Barker and Pawlewicz (1994), this range corresponds to the following maximum paleotemperatures experienced by the fluid-inclusion oils: 113-132°C (so-called "normal" deep-burial-heating case) or 116-146°C (short-duration hydrothermal heating, as established in active geothermal systems).

Regardless of which of the above cases one selects, it would appear the Yankee and Saddle fluid-inclusion oils have *not* experienced the high temperatures typically associated with formation of the Carlin-type deposits (>175°C; Kuehn and Rose, 1995; Ilchik and Barton, 1996). Yet the oil-bearing calcite veins are not only hydrothermal in origin (see Figs. 8 and 9), they clearly pre-date the main stage of gold mineralization with which they are associated. The calcite veins were already in place when gold mineralization commenced. Had this mineralization taken place at typical Carlin-type temperatures, we contend that the effects of those temperature would have been faithfully imprinted on the fluid-inclusion oils. The conclusion: The gold-mineralizing fluids must have been of only moderate temperature.

Pinnell et al. (1991) collected a sufficient amount of free oil from the Yankee open pit, immediately after the oil show was breached by mining operations, for organic geochemical analysis similar in approach to

A

Sample	TERPANES				STERANES				AROMATIC STEROIDS			(28TA+29MA)	PHENANTHRENES	
	C31H	C32H	C30M	3R	29	27	29	27	LMW	C20	MPI-1		MPDF	
	22S	22S			20S	20S	$\alpha\beta\beta$	$\beta\alpha$						
	22S+22R	22S+22R	C30H + C30M	3R+5R	20S+20R	20S+20R	$\alpha\alpha\alpha + \alpha\beta\beta$	$\alpha\alpha\alpha + \beta\alpha$	LMW+HMW	C20+C28(R&S)				
95002C	0.62	0.57	0.10	0.42	0.48	0.54	0.55	0.35	0.40	0.31	0.79	0.49	0.52	
96001C	0.61	0.58	0.11	0.32	0.50	0.50	0.50	0.38	0.33	0.32	0.73	0.83	0.47	
96002S	0.61	0.57	0.10	0.05	0.52	0.48	0.50	0.43	0.20	0.16	0.81	0.81	0.48	
96041C	0.65	0.70	0.10	0.21	0.52	0.53	0.53	0.56	0.03	0.02	0.78	0.63	0.44	
96043C	0.56	0.57	0.08	0.08	0.52	0.49	0.52	0.52	0.18	0.18	0.73	0.89	0.47	
96044C	0.60	0.57	0.08	0.10	0.55	0.51	0.52	0.56	0.12	0.11	0.74	0.95	0.47	
96045C	0.59	0.57	0.08	0.14	0.52	0.46	0.53	0.77	0.70	0.77	0.77	0.95	0.48	

H = Hopane
M = Moretane
Nil = Norhopane

3R = Tricyclic terpanes (C19 - C24)
5R = Sum of C29, C33 Hopanes
Tr = present in trace amounts
LMW = C20 and C21 triaromatic steranes
HMW = C26, C28 triaromatic steranes (20S+20R)
MA = Monoaromatic steroid
TA = Triaromatic steroid

MPI-1 = Methylphenanthrene Index-1
 $1.5 \cdot (2MP+3MP)/(P+1MP+9MP)$
MPDF = Methylphenanthrene Distribution Factor
 $(2MP+3MP)/(2MP+3MP+1MP+9MP)$

from Wavrek et al., 1997

B

Sample	Field	%Ro _{eq}
95002C	Grant Canyon Field	0.90-0.95
96001C	Trap Springs Field	0.85-0.90
96002C	Saddle Pit Mine	0.80-0.85
96041C	Yankee Mine	0.75-0.80
96043C	Yankee Mine	0.80-0.85
96044C	Saddle Pit Mine	0.80-0.85
96045C	Saddle Pit Mine	0.90-0.95

Table 5. A -- Summary of molecular parameters used in maturity analysis of fluid-inclusion oils from the Saddle and Yankee mines, and of produced oils from the Grant Canyon and Trap Springs oil fields in Railroad Valley (Fig. 1). **B --** As interpreted from the molecular parameters listed at left, apparent thermal-maturity levels of these oils expressed as equivalent vitrinite reflectance (%Ro_{eq}).

Modified from Wavrek et al., 1997

BIOMARKER TRANSFORMATION

- A** $LMW/(LMW+HMW)$
- B** $TA28/(TA28+MA29)$
- C** $C27: \beta\alpha/(\beta\alpha+\alpha\alpha\alpha)$ steranes
- D** $C29: \alpha\beta\beta/(\alpha\beta\beta+\alpha\alpha\alpha)$ steranes
- E** $C29: 20S/(20S+20R)$ steranes
- F** $Ts/(Ts+Tm)$
- G** $3R/(3R+5R)$ terpanes
- H** $\beta\alpha/(\beta\alpha + \alpha\beta)$ C30 hopanes
- I** $22S/(22S+22R)$ C32 hopanes

Figure 20. Biomarker transformation ratios and interpreted equivalent thermal maturities for fluid-inclusion oils from the Yankee and Saddle gold mines (see also Table 5). Shown for reference are petroleum generation stages and corresponding paleotemperatures appropriate for normal burial heating and for shorter-duration hydrothermal heating (from Barker and Pawlewicz, 1994)

that outlined above for the fluid-inclusion oils. W.G. Dow, of DGSI, Inc., who completed this analysis for Pioneer Oil and Gas, reported that the free oil from Yankee had a thermal maturity equivalent to 0.70 to 0.80% Ro (Pinnell et al., 1991). This would correspond to a peak paleotemperature range of 107-118°C (deep burial) or 107-124°C (hydrothermal heating; Barker and Pawlewicz, 1994). There is some uncertainty in blending analyses and interpretations from two different laboratories, but assuming that all measurements are valid, then it would appear that the Yankee free oil, definitely of post-fluid-inclusion-oil age, was trapped at a slightly lower temperature. This relationship would be consistent with late-stage oil emplacement as the gold-mineralizing hydrothermal system cooled somewhat from its thermal maximum.

Thermal Maturity of Possible Hydrocarbon Source Rocks -- Kerogen in cuttings samples from YMF-27-23X with higher TOC were selected for petrographic and reflectance analysis by Jeffrey C. Quick, formerly with EGI and now with the Utah Geological Survey evaluating Cretaceous coals. All twelve of the Pioneer-well samples were examined as whole-rock specimens; five were additionally studied as kerogen concentrates. Details of sample preparation and analytical methods are outlined in Wavrek et al. (1997).

Table 6 lists the measured reflectances of vitrinite from the three potential hydrocarbon source rocks penetrated by the Pioneer well - the Diamond Peak Formation, the Chainman Shale, and the Pilot Shale -- along with previously reported maturation parameters from Rock-Eval pyrolysis of the same samples. The reflectances are plotted relative to depth on Figure 21. On this figure, the four upper samples correspond to the Diamond Peak; the middle samples to the Chainman, and the lower two samples to the Pilot. Two Chainman samples are characterized by perhydrous vitrinite, believed to yield anomalously low reflectance (J. Quick, pers. comm., 1996). On this basis, they were excluded for purposes of constructing a regression line through the vitrinite-reflectance data points. The regression line shows a uniformly increasing reflectance with depth, ranging from about 0.55% Ro in the Diamond Peak samples to about 1.00% Ro in the basal Pilot (Figure 20).

Paleotemperatures indicated by this regression line increase from about 88°C in the Diamond Peak to 136°C in the basal Pilot (deep burial case), or 76-152°C if hydrothermal heating is invoked (Barker and Pawlewicz, 1994). In either case, the paleothermal gradient appears to have been purely conductive, smoothly increasing with depth without significant isothermal intervals corresponding to convective heat transfer.

Sample	Formation	Depth (ft)	TOC	Tmax	HI	%Ro	n	sd	Specimen Type	Comment
96002R	Diamond Peak	1635	4.03	439	642	0.55	56	0.05	whole rock & kerogen	
96003R	Diamond Peak	1645	4.42	442	518	0.59	29	0.07	whole rock	low fluorescence rims on rock fragments
96004R	Diamond Peak	1715	0.98	440	460	0.54	37	0.06	whole rock & kerogen	
96005R	Diamond Peak	1765	1.05	443	473	0.58	13	0.07	whole rock	
96006R	Chairman shale	3095	4.71	442	696	0.58	64	0.08	whole rock & kerogen	
96012R	Chairman shale	3195	4.1	443	690	0.61	20	0.1	whole rock & kerogen	sparse vitrinite
96013R	Chairman shale	3295	1.31	443	389	0.77	26	0.07	whole rock	trace mesophase in bitumen
96014R	Chairman shale	3345	0.79	444	437	0.78	18	0.09	whole rock	trace strongly anisotropic bitumen
96015R	Chairman shale	3395	1.03	444	370	0.77	7	0	whole rock	unusual green mineral (abundant), with massive pyrite, trace anisotropic bitumen.
96016R	Pilot shale	4045	0.97	456	456	0.95	9	0.08	whole rock & kerogen	caved population or lignite contaminant.
96020R	Pilot shale	4085	3.51	448	448	1.03	19	0.06	whole rock	migrabitumen associated with vein carbonate.

Table 6. Petrographic, Rock-Eval pyrolysis, and vitrinite-reflectance data for cuttings from Pioneer Oil and Gas Co. well YMF 27-23X.

from Wavrek et al., 1997

Figure 21. Vitrinite reflectance vs depth for organic-rich cuttings samples from Pioneer Oil and Gas Co. well YMF 27-23X. Shown for reference are conventional petroleum-generation stages. Note that even deep sample of the Pilot Shale, formerly believed to be overmature in the Alligator Ridge area (Ilchik et al., 1986) are in fact still in the favorable “oil window.”

The reflectance profile shown on Figure 20 can be used to estimate independently the depth of burial at the time the causative thermal gradient prevailed. This analysis depends upon the assumption that the gradient was continuous to the paleosurface. If we accept this premise, we can project the reflectance regression line upward to 0.2%Ro, the baseline value (Tissot and Welte, 1984), to determine the position of the contemporaneous paleosurface. Doing so yields a paleodepth, from the surface to the base of the Pilot Shale, of 2.3 km. This value compares favorably with the depth of Pilot burial in the Vantage area as determined by Ilchik et al. (1986) on the basis of stratigraphic reconstruction.

Finally, the reflectance regression line in combination with the vitrinite geothermometry of Barker and Pawlewicz (1994) can be used to estimate the peak paleogeotherm for the penetrated rocks. Assuming deep burial heating, that value is about 60°C per km -- 90°C/km if short-term heating in a geothermal system is invoked. We prefer the former value, because a 90°C/km conductive profile, three times the normal geotherm, almost always implies a vigorous magmatic heat source, for which there is absolutely no evidence in the Yankee area. 60°C/km compares with the modern geotherm in the Battle Mountain heat-flow high of northern Nevada (Figure 1), and, at the southern flank of this heat anomaly, with

the currently measured thermal gradient at the geothermally active (but amagmatic) Blackburn oil field (Fig. 1).

DISCUSSION

Results of this multidisciplinary research project have confirmed many aspects of Hulen et al.'s (1994a,b) geothermal-origin hypothesis for many B&R oil reservoirs, and have bolstered the companion concept that the paleohydrothermal systems which formed the Yankee gold deposits also concentrated a once-sizable oil reservoir. Details of the latter concept, however, have required some revision.

For example, Hulen et al. (1994b) suggested that the Yankee paleohydrothermal oil reservoir formed largely contemporaneously with gold mineralization. We now believe that the process of oil introduction and entrapment was more complex than implied by this simple assessment.

Oil in the Yankee deposits was clearly introduced in at least two major stages -- contemporaneously with early calcite veining (the fluid-inclusion oils) and post-calcite veining (the free oils). Isotopic and other evidence suggests that the oil-bearing calcite veins are of hydrothermal rather than diagenetic origin. The veins are concentrated around high-grade gold centers in the district, and do not appear to be

regional features (they were not intersected in the Pioneer well). However, the veins are decalcified and corroded at the margins of most of the orebodies, typified by partial to complete decalcification and moderate to intense silicification. This textural relationship suggests that the calcite veins either were precipitated prior to gold mineralization then leached by the pre-gold decalcification, or were formed at essentially the same time, with fluctuating precipitation and dissolution fronts at the silica-calcite vein interface. In any case, the oil-bearing calcite veins do not cut across the silicified material, so even if formed near-simultaneously with the silicification and gold mineralization, they were in place prior to the final phase of that mineralization. Put another way, the calcite-hosted fluid-inclusion oils in all probability had already been introduced when the most intense phase of gold mineralization and attendant decalcification/silicification/sulfidation was inaugurated. Therefore, these fluid-inclusion oils should record the effects of subsequent thermal events *if* those events were higher-temperature than those of the calcite-depositing hydrothermal fluids.

There is no evidence that such higher temperatures were ever experienced by the fluid-inclusion oils. Therefore, the gold-mineralizing event must either have been a low-temperature one, or, if higher-temperature, of sufficiently short duration,

hypothetically, that the entrapped oils would simply not have time to re-equilibrate thermally. D. Wavrek (pers. comm., 1997) believes that had the inclusion oils been heated to higher temperatures however briefly, they would quickly have recorded the causative heating event. It seems inescapable that the gold-mineralizing fluids were no hotter than 150°C.

Free oils of the Yankee deposits show slightly lower thermal maturities than the fluid-inclusion oils (though this will be subject to re-interpretation when the oils are analyzed at EGI by the same laboratory, for consistency of analytical and interpretation procedures}. They are clearly later than the fluid-inclusion oils, but their age relative to gold mineralization is less certain. The choices are: (1) the oils were introduced after calcite veining but prior to gold mineralization; or (2) the oils were introduced during or after gold mineralization. The former scenario seems less likely. The relative thermal maturities of the oils would dictate that after the oil-bearing calcite veins were emplaced, the temperature dropped by 10-20°C, then presumably warmed again during gold mineralization, a process which in this scheme of events would have left the pre-existing oils mostly unaffected. It seems much more likely that the free oils were introduced after gold mineralization, at a slightly lower temperature.

Neither oil-bearing calcite veins nor significant quantities of free oil were encountered in the Pilot Shale by the Pioneer well -- it was a "dry hole with show of oil" (M. Pinnell, Pioneer Oil and Gas, pers. comm., 1995). Neither do regional exposures of the Pilot show the intense calcite veining clustered around the Yankee orebodies. These relationships, together with the isotopic composition of the calcite veins, make it very likely, however, that the oil-bearing calcite veins *were* formed in the Yankee hydrothermal system(s), but at a pre-gold stage in the evolution of these systems. This likelihood, coupled with the coincidence of abundant live oil and fluid-inclusion oil in the unoxidized Pilot Pods (and the much broader distribution of the calcite vein-hosted fluid-inclusion oil) strongly supports Hulen et al.'s (1994b) original contention that the Yankee mine oil occurrence is an oxidized paleogeothermal petroleum reservoir.

The way in which such a geothermal oil reservoir might form in a Carlin-type hydrothermal system is envisioned as follows: Oil either freshly generated from Pilot Shale or remobilized from an older reservoir of Pilot-derived oil is entrained in upward-migrating, moderate-temperature hydrothermal fluids. These fluids, which are slightly acidic due to contained carbon dioxide and perhaps organic acids (Hulen et al., 1994b) dissolve carbonate wholesale in

the rocks they traverse, thus creating much additional porosity and permeability. The main fluid-flow pathways are faults and allied fracture networks which disrupt an earlier-formed anticline affecting the Paleozoic section. A portion of this acidic fluid is diverted along a relatively porous and permeable contact zone between the Devils Gate Limestone and the Pilot Shale (a zone perhaps structurally prepared as a result of differential slip and concomitant brecciation between massive Devils Gate micrite and shaly basal Pilot). Along this discontinuity, the fluids simultaneously dissolve carbonate and precipitate silica (e.g. Fournier, 1985) to form the semi-regional stratiform jasperoid. This jasperoid later serves to insulate upflowing acidic fluids from the neutralizing effects of the carbonate host rocks. The fluids can thus make their way into the Pilot maintaining their mild acidity. Encountering faults of the inherited divergent wrench-fault system in the Yankee area (Fig. 4), the fluids are channeled upward into the Pilot, where their concentrated effects remove large quantities of carbonate from the siltstone matrix (and from the basal Pilot argillaceous limestone); these structures of opportunity are enlarged by dissolution, some to the point that they become collapse breccias. The acidic fluids, continually replenished from below, are nonetheless neutralized as they penetrate outward into the host rocks, at the same time precipitating calcite as veins and breccia cements and trapping oil in the

veins as fluid inclusions. The locally cavernous porosity of the dissolution breccias and leached lower Pilot in general creates a perfect physical environment for the precipitation of silica and gold. The geochemical trigger for this mineralization remains to be determined, and in fact is an issue separate from the principal aim of the present research. A novel mechanism is probably necessary, since the evidence is strong that the mineralization took place at unusually low temperatures.

These low temperatures, however -- $<150^{\circ}\text{C}$ -- were ideal for the migration, entrapment, and preservation of oil. Few inclusions of any sort are preserved in the ultrafine-grained silica of the Yankee gold orebodies, but some of these silica-hosted inclusions contain oil, indicating that oil continued to be introduced during mineralization.

Maturation parameters suggest that the Yankee free oils were introduced at slightly lower temperature than the thermal maximum. It is our interpretation, consistent with the observations presented earlier in this report, that oil continued to migrate into the trap (the aforementioned gentle anticline; see Figs. 5 and 6) as the hydrothermal system waned, but with perhaps only a 10°C temperature drop. The oil once occupied or partially occupied all available fractures and vugs throughout the Yankee area. Its present distribution reflects deep and thorough oxidation, leaving only scattered

pod of oily limestone in the basal Pilot Shale. It should be noted that the top-seal for this interpreted hydrothermal oil reservoir most likely was the upper part of the Pilot Shale, a tight, carbonate-poor shale (Ilchik et al., 1986). The faults which guided the introduction of hydrothermal fluids, and now host much of the Yankee gold ore, are envisioned to have "died out" upward into the ductile upper Pilot. Even where the faults totally breached the shale, they were probably capped by clay-rich Oligocene tuffs (as in the base of the volcanic sequence penetrated by the Pioneer well) or top-sealed with secondary minerals like the kaolinite which commonly accompanies the gold mineralization.

The Yankee oil-bearing gold deposits and their host rocks we now believe are not precise analogues for the nonetheless geologically quite similar and geothermally active B&R oil fields. For one thing, the oil fields, like Blackburn and Grant Canyon, are developed in Miocene to Holocene fault blocks of various sorts, whereas the Yankee area trap is an older anticlinal structure. The oil reservoirs and the Yankee deposits share similar host rocks; the presence of oil; apparently similar formation temperatures; similar hydrothermal alteration; and enrichment in the pathfinder elements mercury, arsenic, antimony, and thallium. Nowhere in the oilfields, however, has gold enrichment above 50 ppb been detected --

the Yankee deposits locally reach several *thousand* ppb. Moreover, the scale of alteration and mineralization is much different in the orebodies vs the oil fields. The oil fields are relatively restricted in volume, seldom more than a few hundred acres in extent. By contrast, literally tens of square miles have been affected by hydrothermal alteration in the Alligator Ridge-Bald Mountain mining district (Ilchik, 1991; Hitchborn et al., 1996; Howald, 1994; Stout, 1994). The scope of the Alligator Ridge hydrothermal systems must have been enormous, almost basin-scale in extent. "Deep-circulation", amagmatic convective geothermal systems might be expected to produce just such a vast alteration signature. Such large, vigorous hydrothermal systems might also be expected to have formed when the regional heat flow was much more intense than at present in this area. Goppliger et al. (1997) suggest that the ancestral Yellowstone "hot spot", which now underlies the giant late Cenozoic calderas of Yellowstone National Park, may have had its origins in north-central Nevada. The elevated heat flow associated with such a vast mantle plume we speculate may have engendered the large-volume, deep circulation hydrothermal systems which in the Yankee area not only formed low-temperature gold deposits but also a sizable oil reservoir.

Hydrothermal systems can and do move

large amounts of oil, and hydrothermal processes like carbonate dissolution and porosity sealing can act in harmony to entrap that oil. The oil-bearing fossil hydrothermal systems discussed in this report -- Alligator Ridge and Gold Point -- are thoroughly oxidized to considerable depth. If, however, they were concealed by, say, a thousand meters of volcanics, and were beneath the water table, we contend that they could yield considerable quantities of liquid hydrocarbon.

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— Jeff Hulen —

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APPENDIX 1

Publications and presentations supported wholly or in part by Grant No. DE-FG02-90ER14133 to the Principal Investigator (most recent first)

— In Preparation —

Hulen, J.B., et al., The role of active and ancient geothermal systems in the formation of oil reservoirs in the Basin and Range province of the western United States: For submission to *American Association of Petroleum Geologists Bulletin*.

Hulen, J.B., et al., The exhumed, fracture-controlled, "Carlin-type" oil reservoir in the Yankee area of the southern Alligator Ridge district, Nevada: For submission to *Economic Geology*.

— Published to Date —

(1) -- **Hulen, J.B., and Wavrek, D.A.,** 1997, An update on the Yankee mine oil occurrence, White Pine County, Nevada -- Hydrocarbon source rocks; burial and hydrothermal history; oil migration and entrapment mechanisms; and moderate-temperature gold mineralization (extended abstract): Nevada Petroleum Society Bulletin, v. 12, p. 1-2 (*written to accompany invited oral presentation at the Society's monthly meeting, held February 6, 1997*) -- SEE APPENDIX PAGE A1.

(2) -- **Fisher, R.V., Heiken, G., and Hulen, J.B.,** 1997, Volcanoes, crucibles of change: Princeton University Press, 342 p. *Note -- this book, a popular account of volcanoes and their impact on humanity, was not directly supported by the subject grant. It does, however, contain a chapter written by the Principal Investigator and devoted to natural resources including oil which are found in association with volcanoes and volcanic geothermal systems* -- APPENDIX PAGE A5.

(3) -- **Castor, S.B., and Hulen, J.B.,** 1996, Electrum and organic matter at the Gold Point mine, Currant mining district, Nevada in Ore deposits of the American cordillera: Geologica Society of Nevada, U.S. Geological Survey, and Sociedad Geologica de Chile, v. 1 (of 3), p. 547-565 -- APPENDIX PAGE A17.

(4) -- **Castor, S.B., and Hulen, J.B.,** 1996, Organic matter at the Gold Point and Bullfrog mines, gold-bearing epithermal systems in Nye County, Nevada: Reno, Nevada, University of Nevada, Ralph Roberts Center for Research in Economic Geology, Forum on Hydrocarbons and Ore-Forming Fluids (November 13-15, 1996), Proceedings, p. 29-30 (*extended abstract written to accompany invited oral presentation*).

APPENDIX (Grant-Related Publications) -- continued

- (5) -- Hulen, J.B., and Wavrek, D.A., 1996, Oil-bearing, Carlin-type gold deposits in the southern Alligator Ridge district, Nevada [*and*] The role of active and ancient geothermal systems in the generation, migration, and entrapment of oil in the Great Basin: Reno, Nevada, University of Nevada, Ralph Roberts Center for Research in Economic Geology, Forum on Hydrocarbons in Ore-Forming Fluids (November 13-15, 1996), Proceedings, p. 2-6 (*written to accompany invited oral presentation*).
- (6) -- Hulen, J.B., and Wavrek, D.A., 1996, Oil-bearing, Carlin-type gold deposits in the southern Alligator Ridge district, Nevada -- Evidence for gold mineralization and oil-reservoir evolution in a moderate-temperature geothermal system: Geological Society of America, 1996 Annual Meeting (Denver, Colorado), Abstracts with Programs, p. A-86 (*written to accompany invited oral presentation in a special session devoted to organics and ore deposits*) -- APPENDIX PAGE A29.
- (7) -- Castor, S.B., and Hulen, J.B., 1995, Gold and hydrocarbons at the Gold Point mine, Currant mining district, Nevada *in* Geology and ore deposits of the American cordillera: Geological Society of Nevada, U.S. Geological Survey, and Sociedad Geologica de Chile, Program with Abstracts, p. A-18.
- (8) -- Hulen, J.B., The role of convective geothermal systems in the generation, migration, and entrapment of oil: American Association of Petroleum Geologists Bulletin, v. 79, p. 919 (*abstract written to accompany invited oral presentation at Rocky Mountain Section Meetin, Reno, Nevada -- D.E. French and J.B. Hulen, session co-chairs*) -- APPENDIX PAGE A31.
- (9) -- 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, Railroad Valley, Nevada: American Association of Petroleum Geologists Bulletin, v. 78, p. 596-623 -- APPENDIX PAGE A33.
- (10) -- Hulen, J.B., Pinnell, M.L., Nielson, D.L., Cox, J.W., and Blake, J., 1994, The Yankee mine oil occurrence, Alligator Ridge district, Nevada -- An exhumed and oxidized, paleogeothermal oil reservoir *in* Oil fields of the Great Basin (R.A. Schalla and E.W. Johnson, editors): Nevada Petroleum Society Guidebook, p. 131-141 -- APPENDIX PAGE A59.
- (11) -- Goff, F., Hulen, J.B., Adams, A.I., Trujillo, P., Counce, D., and Evans, W.C., 1994, Geothermal characteristics of some oil field waters in the Great Basin, Nevada *in* Oil fields of the Great Basin (R.A. Schalla and E.H. Johnson, editors): Nevada Petroleum Society Guidebook, p. 93-106 -- APPENDIX PAGE A73.
- (12) -- Castor, S.B., and Hulen, J.B., 1994, Gold and hydrocarbons at the Gold Point mine, Currant mining district, Nevada (*abstract*): Geological Society of America, 1994 Annual Meeting (Seattle, Washington), Abstracts with Programs, p. A-518 -- APPENDIX PAGE A83.

APPENDIX (Grant-Related Publications) -- continued

- (13) -- Pinnell, M.L., and Hulen, J.B., 1993, Results of deep exploratory drilling between Long and Newark Valleys, Nevada -- Implications for oil migration in the nearby Yankee gold mine paleohydrothermal system (*abstract*): American Association of Petroleum Geologists Bulletin, v. 77, p. 1458 -- APPENDIX PAGE A84.
- (14) -- French, D.E., and Hulen, J.B., 1993, Origin and nature of the hydrocarbon seal in Railroad Valley, Nevada (*abstract*): American Association of Petroleum Geologists Bulletin, v. 77, p. 1448 -- APPENDIX PAGE A85.
- (15) -- Hulen, J.B., and Nielson, D.L., 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 (*abstract*): American Association of Petroleum Geologists Bulletin, v. 77, p. 1452 (*written to accompany invited oral presentation at the Rocky Mountain Section Meeting, Salt Lake City, Utah*) -- APPENDIX PAGE A86.
- (16) -- Hulen, J.B., Cox, J.W., Nielson, D.L., and Lamborn, J.C., 1993, Oil in Carlin-type, sediment-hosted gold deposits -- Significance for petroleum exploration (*abstract*): American Association of Petroleum Geologists Bulletin, v. 77, p. 244.
- (17) -- Goff, F., Hulen, J.B., and Adams, A.I., 1992, Geochemistry and geothermal implications of oil field waters in eastern Great Basin (*abstract*): EOS, v. 73, p. 547.
- (18) -- Hulen, J.B., Cox, J.W., and Pinnell, M.L., 1992, Implications of oil in a precious-metal deposit, Alligator Ridge, Nevada (*abstract*): American Association of Petroleum Geologists Bulletin, v. 76, p. 42.
- (19) -- Hulen, J.B., Bortz, L.C., and Bereskin, S.R., 1991, Geothermal processes in development of the Grant Canyon oil reservoir, Railroad Valley, Nye County, Nevada *in* Geology of White River Valley, the Grant Range, eastern Railroad Valley, and western Egan Range, Nevada (D.M.H. Flanigan, M. Hanson, and T.E. Flanigan, editors): Reno, Nevada, Nevada Petroleum Society, 1991 Fieldtrip Guidebook, p. 47-54 -- APPENDIX PAGE A87.
- (20) -- Pinnell, M.L., Blake, J.G., and Hulen, J.B., 1991, Active oil seep at Nevada gold mine holds intrigue for more exploration: Oil and Gas Journal, v. 89, p. 74-70 -- APPENDIX PAGE A95.
- (21) -- Hulen, J.B., Bortz, L.C., and Bereskin, S.R., 1991, The role of active and ancient geothermal systems in evolution of the Grant Canyon oil field, Railroad Valley, Nevada (*abstract*): American Association of Petroleum Geologists Bulletin, v. 75, p. 1128.
- (22) -- 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 (*abstract*): GSA, Abstracts with Programs, p. 25 (*written to accompany invited oral presentation*).

Appendix (Grant-Related Publications) -- continued

(23) Hulen, J.B., Bereskin, S.R., and Bortz, L.C., 1990, High-temperature hydrothermal origin for fractured carbonate reservoirs in the Blackburn oil field, Nevada: American Association of Petroleum Geologists Bulletin, v. 74, p. 1262-1272 -- APPENDIX PAGE A101.

(24) -- Allison, M.L., and Hulen, J.B., 1990, Oil and igneous intrusions in Nevada (*abstract*): American Association of Petroleum Geologists Bulletin, v. 74, p. 1329 -- APPENDIX PAGE A115.

(25) -- Hulen, J.B., Bereskin, S.R., and Bortz, L.C., 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 (*abstract*): American Association of Petroleum Geologists Bulletin, v. 74, p. 679.

(26) -- Hulen, J.B., Bereskin, S.R., and Lemieux, M.M., 1990, Timing and temperature of petroleum entrapment in the Grant Canyon oil field, Nevada (*abstract*): American Association of Petroleum Geologists Bulletin, v. 74, p. 1328 -- APPENDIX PAGE A116

reprints and abstracts removed

Appendix 2

Vitrinite Reflectance Histograms

Data by Jeffrey C. Quick

96-002

mean random reflectance of vitrinite = 0.55 %

number of counts = 56

standard deviation = 0.05

note: 1635 feet, Chainman or Diamond Peak Fm., cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas,

A118

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96-003

mean random reflectance of vitrinite = 0.59 %

number of counts = 29

standard deviation = 0.07

note 1645 feet, Chainman or Diamond Peak, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

96-005

mean random reflectance of vitrinite = 0.58 %

number of counts = 13

standard deviation = 0.07

note, 1765 feet, Chainman or Diamond Peak, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

A120

96-004

mean random reflectance of vitrinite = 0.54 %

number of counts = 37

standard deviation = 0.08

note, 1715 feet, Chainman or Diamond Peak, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

A121

96-008

mean random reflectance of vitrinite = 0.58 %

number of counts = 64

standard deviation = 0.08

note: 3095 feet, Chainman, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas,

96-012

mean random reflectance of vitrinite = 0.61 %

number of counts = 20

standard deviation = 0.10

note: 3195 feet, Chainman, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas,

A123

96-013

mean random reflectance of vitrinite = 0.77 %

number of counts = 26

standard deviation = 0.07

note, 3295 feet, Chainman, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

A124

96-014

mean random reflectance of vitrinite = 0.78 %

number of counts = 18

standard deviation = 0.09

note, 3345 feet, Chainman, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

A125

96-015

mean random reflectance of vitrinite = 0.77 %

number of counts = 7

standard deviation = 0.10

note, 3395 feet, Chainman, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

96-018

mean random reflectance of vitrinite = 0.95 %

number of counts = 9

standard deviation = 0.08

note: 4045 feet, Pilot Shale, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

A127

96-020

mean random reflectance of vitrinite = 1.03 %

number of counts = 19

standard deviation = 0.06

note: 4085 feet, Pilot Shale, cutting sample from well YMF 27-23X, sec 27, T21N, R57E, White Pine Co., NV, Pioneer Oil & Gas

A128

Appendix 3

Rock Extract Data

Gas Chromatography-Flame Ionization Detection and Gas Chromatography-Mass Spectrometry

Data by Nicolas F. Dahdah

96003B

96005B

96006B

96007B

96009B

96010B

96011B

96013B

96014B

96015B

A140

96017B

96019B

96020B

96031B

96032B

96036B

A146

Appendix 4

Crude Oils and Fluid Inclusion Extract Data

Gas Chromatography-Flame Ionization Detection and Gas Chromatography-Mass Spectrometry

Data by Nicolas F. Dahdah

95002CW

A148

96001CW

96002CW

A150

96041C

96043C

96044C

96045C