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Organic Geochemical Analysis and Thermochronologic Modeling of Potential Petroleum Source Rocks in the Malheur, Jordan and Andrews Resource Areas, Southeastern Oregon

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Abstract

Geochemical and petrographic studies of source rocks in the region of the Malheur, Jordan and Andrews Resource Areas, southeastern Oregon, indicate that some strata may be locally capable of generating and perhaps expelling hydrocarbons. Wildcat wells to date, however, have not demonstrated the existence of commercial hydrocarbon production in or near the Malheur, Jordan and Andrews Resource Areas. Regional geology suggests source rocks may occur in small deposits dispersed throughout the resource areas and this basis three conceptual plays are proposed: Alvord Valley-Steens Mountain, Harney Basin and Vale basin. Geohistory modeling of these conceptual plays shows that the high heat flow characteristic of the area combined with Tertiary to Recent burial to over 1 or 2 km, depending on heat flow, apparently heated the hypothesized source rocks into the hydrocarbon generation window in the Miocene.

Traps in these conceptual plays are considered to be related to fault truncation, stratigraphic pinchouts and secondary porosity related to the diagenesis of volcanic provenance rocks. Permeability is assessed to be generally poor in potential reservoir rocks because unstable volcanic glasses are a common component of the rocks and during diagenesis they have been altered to clays, zeolites and related materials which fill pores and reduce permeability.

In conclusion, the resource areas are considered permissive for small to medium size hydrocarbon discoveries but are not considered favorable.

Introduction

This paper examines the organic geochemistry and petrography of potential source rocks and their geohistory in the Malheur, Jordan and Andrews Resource Areas, southeastern Oregon. These data and geohistory modeling are used to assess conceptual oil and gas plays with potential for hydrocarbon accumulations.

These conceptual plays are formulated to include the geological environments in Malheur, Jordan and Andrews Resource Areas that appear favorable for hydrocarbon generation, accumulation and preservation. Conceptual plays are postulated hydrocarbon "accumulations sharing similar geologic, geographic, and temporal properties such as source rock, migration pathway, timing, trapping mechanism, and hydrocarbon type" (Gautier et al., 1995). Play areas are geographic regions where the defining play concepts are considered valid. Following Barker et al., (1995) these conceptual plays are defined on the ongoing burial of Neogene source rocks in the extensional basins of the Basin and Range Province. As discussed in Barker et al. (1995), because of the sparse drilling, poor sample availability and lack of analyses, information on traps, reservoirs and other geologic details in these conceptual plays is largely speculative. Further, numerous wildcat wells have been drilled in the Malheur, Jordan and Andrews Resource Areas but these tests have resulted in no commercial hydrocarbon production (Olmstead, 1988). Thus, the conceptual plays presented in this study are unproven.

The Malheur, Jordan and Andrews Resource Areas of southeastern Oregon are a subregion of province 18 of the USGS 1995 petroleum assessment (Barker et al., 1995) which encompasses eastern Oregon, western Nevada, and eastern California. The conceptual plays presented here are derived from that analysis of hydrocarbon potential which found low or no potential. The data available for that study have been augmented by additional source rock analyses from samples in wildcat wells and surface exposures in the area. Thus, the purpose of this study is to reexamine the hydrocarbon potential in the light of these new data.

Acknowledgments

I acknowledge the contribution to this study by: James Evans, U.S. Geological Survey, Spokane, Washington who supplied samples; Lanny H. Fisk, Consulting Geologist, who provided several references and his personal knowledge on the plays of the area; Terry Giesler from the U.S. Bureau of Land Management, Burns, Oregon, who arranged a field trip into the Andrews Resource Area; Phyllis Halvorsen, USGS, Menlo Park, California, who provided a gravity map and an interpretation of the Steens Mountain and Harney Basin areas; Mont Warner, Consulting Geologist, who provided geological notes and references on the geology of the Snake River Plain; and Dan Wermiel, Oregon Department of Geology and Mineral Industries, Portland, Oregon, for arranging to examine well records and sample well cuttings and core.

Methods

The well samples were collected from the Oregon Department of Geology and Mineral Industries (DOGAMI) in Portland, Oregon. The well samples derived from cuttings were cleaned of well additives and, if possible, picked for specific rock types thought to be representative of the depth interval at the depth indicated on the sample bag. Surface samples were collected from exposures of Miocene Alvord Creek beds along the eastern side of Steens Mountain by Barker and from the northern edge of the Malheur Resource Area by James Evans. Selected well and surface samples were prepared for Rock-Eval pyrolysis and vitrinite reflectance analysis using the method of Barker (1994).

Rock Eval Pyrolysis

Rock-Eval pyrolysis is a source-rock assay technique that involves heating small quantities (50-400 mg depending on carbon content) of pulverized rock and measuring the mass of hydrocarbon gases evolved as a function of temperature. The carbon dioxide evolved during heating is saved in a trap during heating and later analyzed to estimate the total organic carbon content of the sample. During the initial stages of heating, sorbed or free hydrocarbons in the sample are driven off and are recorded as the S_1 peak. With increasing temperature, the organic matter in the sample breaks down to hydrocarbons and CO_2 ,which are recorded as the S_2 peak and S_3 peak respectively, and other compounds which are not analyzed. Specific definitions for Rock-Eval data reports are: S_1 and S_2 are the first and second peaks of hydrocarbon (HC) yield occurring during pyrolysis of the sample. S_3 is the amount of CO_2 generated during pyrolysis; TOC is total organic carbon. T_{max} is the temperature at which the S_2 peak occurs during pyrolysis of kerogen. Derivative values from these basic measurements are the hydrogen index (HI) = $(S_2/TOC)x100$; the oxygen index (OI) = $(S_3/TOC)x100$; the genetic potential $(S_1 + S_2)$ and the Transformation ratio = PI = $S_1/(S_1+S_2)$. TOC when used in these derivative values is reported as grams carbon (g C).

The analytical results of Rock-Eval pyrolysis are unreliable if the TOC content of the rock sample is less than 0.5 weight-% (Peters, 1986; Bordenave et al., 1993). Furthermore, rocks with less than 0.5 weight-% TOC are probably incapable of expelling hydrocarbons and therefore are not source rocks. Samples with less than 0.5 weight-% TOC are included in the data tables but are not included in the interpretative plots.

It must be emphasized that Rock-Eval pyrolysis only gives a semiquantitative estimate of organic matter properties during rapid heating to extreme temperatures under dry conditions which at best can only be considered a rough analog to natural conditions. There is a strong tendency by geologists to take the semi-quantitative results from this poor experimental analog and use the values to calculate what appear to be excessive volumes of hydrocarbons that could be generated from the organic matter. This study interprets Rock-Eval results from the broad trends of grouped data, ignoring outlier data and avoiding generated hydrocarbon volume calculations. Even with these limitations, the trends shown by Rock-Eval analyses, if checked against other analyses such as organic petrography and hydrous pyrolysis, can be a useful indicator of thermal maturation and petroleum generation potential. This philosophy has evolved from my experience and published discussions of the interpretation of Rock-Eval data by Katz (1983); Peters, (1986); Langford and Blanc-Valleron (1990); and Bordenave et al. (1993). The consensus is that Rock-Eval pyrolysis data and the measurement of total organic carbon (TOC) qualitatively evaluate the source rocks tendency to oil and gas generation, past and residual hydrocarbon generation capacity, and thermal maturity (Table 1).

Besides these technical limitations of Rock-Eval, organic matter contaminants and naturally occurring oils and bitumens can also interfere with the S_1 and S_2 values by increasing them. Organic drilling mud additives often increase the hydrogen index (HI) and TOC. Samples contaminated by particulate mud additives were detected by examination under a binocular microscope and cleaned by sieving, blowing on the sample to remove the lighter organic materials and selectively picking rock chips with tweezers. Rock-Eval pyrolysis is also influenced by migrated oil or bitumen. Such migration produces an S_1 peak greater than 2 mg hydrocarbon (HC)/g rock, an anomalously high transformation ratio and low T_{max} as compared to adjacent samples, and a bimodal S_2 peak. The low T_{max} may also be related to weak S_2 peaks resulting from low TOC values and not from organic contamination. Generally no oil staining or immature bitumen was observed in the Neogene age samples, so migrated bitumen or oil is assumed to not to be a factor in the Rock-Eval analyses.

Table 1. Guidelines to the interpretation of Rock-Eval and Vitrinite Reflectance Results Based on Type II and Type III Organic Matter. Compiled from Peters, (1986), Langford and Blanc-Valleron (1990), and Bordenave et al. (1993), among others.

TOC (Wt.%)	Organic Matter Genetic Potential	Generated Petroleum Type		Thermal Maturity		Source Rock Potential
	S1 + S2 (mg HC/ g rock)	HI (mg HC/ gC)	S2/S3 (mg HC/g CO_2)	Tmax (°C)	R_o (%)	
0.5	< 5 poor			-------	any value	Not a source rock. Rock-Eval parameters not reliable
0.5 to 2	< 5 poor	< 200 Gas 200-300 Mixed >300 Oil	<2.5 Dry Gas 2.5-5 Wet Gas >5 Oil	< 425 immature 425-470 mature >470 post mature	< 0.5 Immature 0.5 - 1.3 mature > 1.3 post mature	Marginal source rock
0.5 to 2	5 fair 10 good 15 excellent	< 200 Gas 200-300 Mixed >300 Oil	<2.5 Dry Gas 2.5-5 Wet Gas >5 Oil			Fair source rock but may not be capable of expulsing oil
> 2	< 4 poor 5 fair 10 good 15 excellent	< 200 Gas 200-300 Mixed >300 Oil	<2.5 Dry Gas 2.5-5 Wet Gas >5 Oil	> 425 Oil >470 Gas	> 0.5 Oil >1.3 Gas	Good to Excellent source rock

Vitrinite or Pryobitumen Reflectance

Vitrinite was selected using standard petrographic criteria (Robert, 1988). Reflectance was measured on polished whole rock samples using vertical illumination on a Zeiss Universal microscope fitted with a MPM-01 microphotometric system. The photometer was restricted with a pinhole diaphragm to read a 3 micron spot on the sample at 500x total magnification, using a 40x/0.85 n.a. lens under oil immersion (n_e = 1.518). The system was calibrated by a Zeiss leucosapphire standard that has a reflectance of 0.58% and (or) glass standard with a reflectance of 1.6 % with filtered 546 nm light. In mixed samples of vitrinite and pyrobitumen, the modal reflectance for that peak (R_o or Rb) that represents each particle type is reported. In kerogen populations with one mode, the mean random vitrinite reflectance (R_o) value is reported.

Thermal History Reconstruction

Thermal history reconstruction in this study utilized Platte River Associates (Denver, Colorado) BASINMOD for windows version 4.02 computer program for burial depth, paleotemperature and thermal maturity computations. The measured thermal maturation data (Appendix 2) and the temperature data presented below were used to constrain the burial history reconstruction. The stratigraphic and variable heat flow models were considered successful when, after fitting the thermal history to predicted peak temperature reconstructed from the heat flow history, the vitrinite reflectance predicted from Lawrence-Livermore National Laboratory kinetic model agreed with the measured reflectance value (see review by Barker and Pawlewicz, 1994). In most cases, these reflectance values agreed with slight alterations to the paleoheat flow and no adjustment of the burial depth history.

Geohistory Reconstruction Data

Thermal Data

Thermal data are required to document or estimate the temporal change in surface temperature, heat flow and rock thermal conductivity which fixes the paleogeothermal gradients. Like burial history reconstruction in deeply eroded areas, thermal history is difficult to reconstruct because the heat flow regime has often changed (Vitorello and Pollack, 1980; Chapman and Pollack, 1975) and the thermal conductivity is altered by diagenetic/metamorphic changes in porosity, mineralogy, and pore fluid composition. However, stable heat flow conditions are probably rare in geologic history, so these thermal models use variable heat flow even though it can only be loosely constrained using present-day analogs.

Surface Temperature

At present, the mean annual surface temperature is about 10°C in eastern Oregon (Piper et al., 1939). Tertiary paleosurface temperature was estimated using fossil evidence for paleoclimate for the western U.S. (Savin, 1977).

Heat Flow

Present heat flow is variable but typically high in the region of the Malheur-Jordan-Andrews Resource Areas. Blackwell et al. (1978) found an average heat flow of about 70mW/m^2, a typical value for the Basin and Range Province. However, during times of rapid extension and crustal thinning, heat flow may have been higher (Vitorello and Pollack, 1980). For example, the areas where geohistory was modeled had measured heat flows of 90 mW/m^2 for Steens Mountain, about 100 mW/m^2 for Alvord Valley, and 100-120 mW/m^2 for Vale Basin. These locally higher heat flow values are similar to the typical heat flow measurement in the Andes Mountains of South America of 90 mW/m^2 (Chapman and Pollack (1975) which is noted as a possible modern analog to the Basin and Range Province in the Cretaceous and Paleogene (Cook, 1988). This analog is used as a rationale for extending present high heat flow values into the past.

Thermal Conductivity

BASINMOD sets thermal conductivity based on lithology mixes and decompacted porosity. The rock lithology input into BASINMOD is as shown in Table 1. Thermal conductivity measurements were recalculated in BASINMOD to a decompacted value of porosity and water saturation. In a sedimentary rock of consistent grain size and framework grain composition, change in porosity with compaction is a significant factor in changing thermal conductivity during burial, as long as the pores remain filled with water. For this reason, contemporary thermal conductivity measurements must be adjusted (lowered) to the former (higher) levels of porosity. Most geohistory modeling programs use the geometric method of recalculating thermal conductivity discussed by Sass et al. (1971).

Erosion Estimates/ Original Strata Thickness

Reconstruction of how much rock was present and when it was removed is innately crude, because the value must be estimated from the eroded rocks that no longer exist. In the region of the Malheur-Jordan-Andrews Resource Areas, relief on unconformities within the volcanic series reported by Piper et al. (1939) are the primary evidence that significant erosion has locally occurred between depositional events. However, in general, because the strata are very young and deposition rates were high, little time is presumed available for appreciable erosion to occur between basin deposition events. Thus, without evidence to the contrary, the assumption was made that negligible erosion occurred between formations for the purpose of the geohistory models.

In this study, compaction of the strata during burial considered the predictions from the Falvey and Middleton (1981) and the Sclater and Christie (1980) methods. The BASINMOD manual (version 4) states that the Falvey and Middleton method gives good results in a wide range of geologic conditions whereas the Sclater and Christie method is best for burial in rift valley conditions. The effect of changing the compaction method is that the Sclater and Christie model tends to predict a higher porosity for rocks at a given depth than the Falvey and Middleton method. Increased porosity causes reduced thermal conductivity in the rocks, such that all other factors remaining the same, Sclater and Christie compaction predicts higher temperatures at a given depth than Falvey and Middleton. Consequently merely switching compaction methods in BASINMOD can produce dramatic changes in the predicted extent and type of hydrocarbon generation because they are largely temperature driven reactions. In well known areas, this issue can be addressed by measuring porosity versus depth and either using this data directly in BASINMOD or determining which compaction method seems to give the best prediction. However, this approach is not possible in the Malheur-Jordan-Andrews Resource Areas as drilling and appropriate samples or analyses are sparse. The geohistory models developed for this study use the Falvey and Middleton method in BASINMOD because it can handle a wider array of geological conditions.

Petroleum Geology

Source Rocks

The portions of the Malheur-Jordan-Andrews Resource Areas with potential hydrocarbon source rocks are located in the western part of the Basin and Range physiographic province of southeastern Oregon and in the Snake River Plain which includes the Vale Basin of eastern Oregon (Fig. 1). The oldest sedimentary rocks in the region are Paleozoic to early Mesozoic carbonate and clastic rocks that have experienced episodic compressive orogenic events in the late Paleozoic and early Mesozoic time. Heating related to these orogenic events and widespread igneous intrusion and metamorphism in middle to late Mesozoic and Cenozoic time have largely destroyed the hydrocarbon generation potential of these Paleozoic to early Mesozoic sedimentary rocks. Paleozoic or Mesozoic basement metasedimentary rocks exposed near the Nevada-Oregon border in the Quinn River Graben area (McDaniels, 1982; Fig. 1) constitute basement rock with respect to oil and gas source rocks there. Fringing the resource areas, in central Oregon and west central Nevada, are Triassic to Jurassic rocks that have traces of oil in them or evidence of altered oils (Bortz, 1983; Brown and Ruth Laboratories, Inc., 1983; Appendix 3, Sunnyvale Mitchell 1-- solid bitumen in Jurassic rocks). Less metamorphosed Triassic to Jurassic age rocks also occur in the Blue Mountains along the northern boundary of the Malheur resource area (Law et al., 1985; Appendix 2 and 3--Weatherby Formation samples) but do not contain sufficient quantity or quality of organic matter to be considered source rocks. Jurassic(?) to Cretaceous lacustrine rocks have source rock potential in the Black Rock Desert and Jackson Range of Nevada just south of the resource areas (Barker et al., 1995) but such lacustrine rocks have not yet been reported in southeastern Oregon.

Within the resource areas, extensive magmatism, occurring during Neogene extension and crustal thinning, emplaced Miocene igneous rocks in the older Upper Paleozoic and Early Mesozoic basement forming a hybridized crust that underlies much of southeast Oregon (Orr et al., 1992). Because the older rocks apparently lack hydrocarbon source potential, only Neogene rocks are considered further.

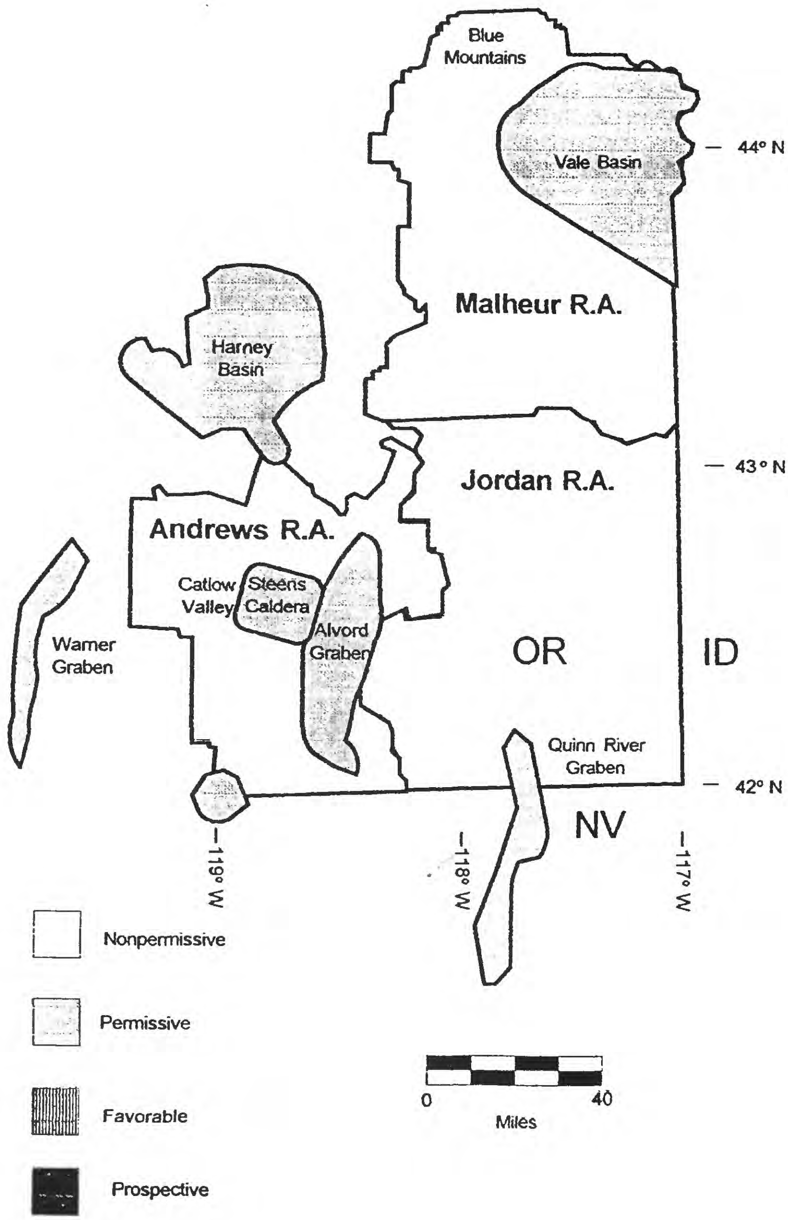

Figure 1. Conceptual plays and their petroleum potential assessment in the region around the Malheur, Andrews and Jordan Resource Areas. the conceptual plays shown are areas within Neogene basins were thick Neogene sedimentation has occurred (from Barker et al., 1995).

Organic Geochemistry and Petrography

Alvord Valley-Steens Mountain Surface Samples

Potential hydrocarbon source rocks in this area consist of a few meters of laminated carbonaceous mudrocks in the upper portion of the Neogene Alvord Creek Beds exposed on the slope that forms the eastern side of Steens Mountain and the western side of Alvord Valley (Appendix 2 and 3). Fossil evidence (Orr et al., 1992) and the organic petrography of the three samples taken in the carbonaceous mudrock indicates apparently lacustrine provenance with mostly humic plant debris but with appreciable amorphous organic matter. Vitrinite reflectance analysis shows that these samples are immature with a thermal maturity of about 0.3 ± 0.1%Ro. Rock-Eval results indicate the samples have 1.6 to 1.8 wt.-% total organic carbon (TOC) and moderate hydrogen indices of 264 to 337 mg HC/g C. These particular lacustrine mudrocks would be oil-prone because they have a S_2/S_3 of over 5 (Table 1). The question is whether they could become effective source rocks which requires that they expel the generated oil. These samples have a genetic potential ($S_1 + S_2$) of 4.8 to 6.2 mg HC/ g rock and have a marginal capacity to expel oil (Bordenave et al., 1993).

Source Rock Samples from Wells

Vitrinite reflectance analysis of samples taken from wells throughout the region of the Malheur-Jordan-Andrews Resource Areas (Appendix 1 and 3) show a regular increase in R_o as depth increases (Fig. 2). Figure 1 suggests that the potential source rocks across the region, considering only burial heating, reach thermal maturation with respect to oil generation, at 0.5 to 0.6%R_o), below 3500 ft (1067 m). Of course, contact metamorphism can increase vitrinite reflectance and cause oil and gas generation at any depth. Rock-Eval data suggests that the H/C composition (S_2 peak/TOC) is mostly consistent with a hydrogen-poor, gas-prone organic matter (Fig. 3). Petrographic observation confirm the presence of a dominantly humic organic matter. The samples with a TOC of 13 and 22 % shown in Figure 3 are coaly samples. In addition to the generally low TOC, the genetic potential of these hydrogen-poor samples is low and in general the expulsion potential is low as well (Fig. 4). In conclusion, these well sample data and well histories (Appendix 1) suggest that no effective oil source rocks can be identified in the subsurface strata in the region of the Malheur-Jordan-Andrews Resource Areas. The coaly rocks are sufficiently mature for gas source rocks. Vitrinite reflectance data suggests that burial to less than 3000 feet (900 m) alone is insufficient to cause appreciable thermal generation of oil and gas.

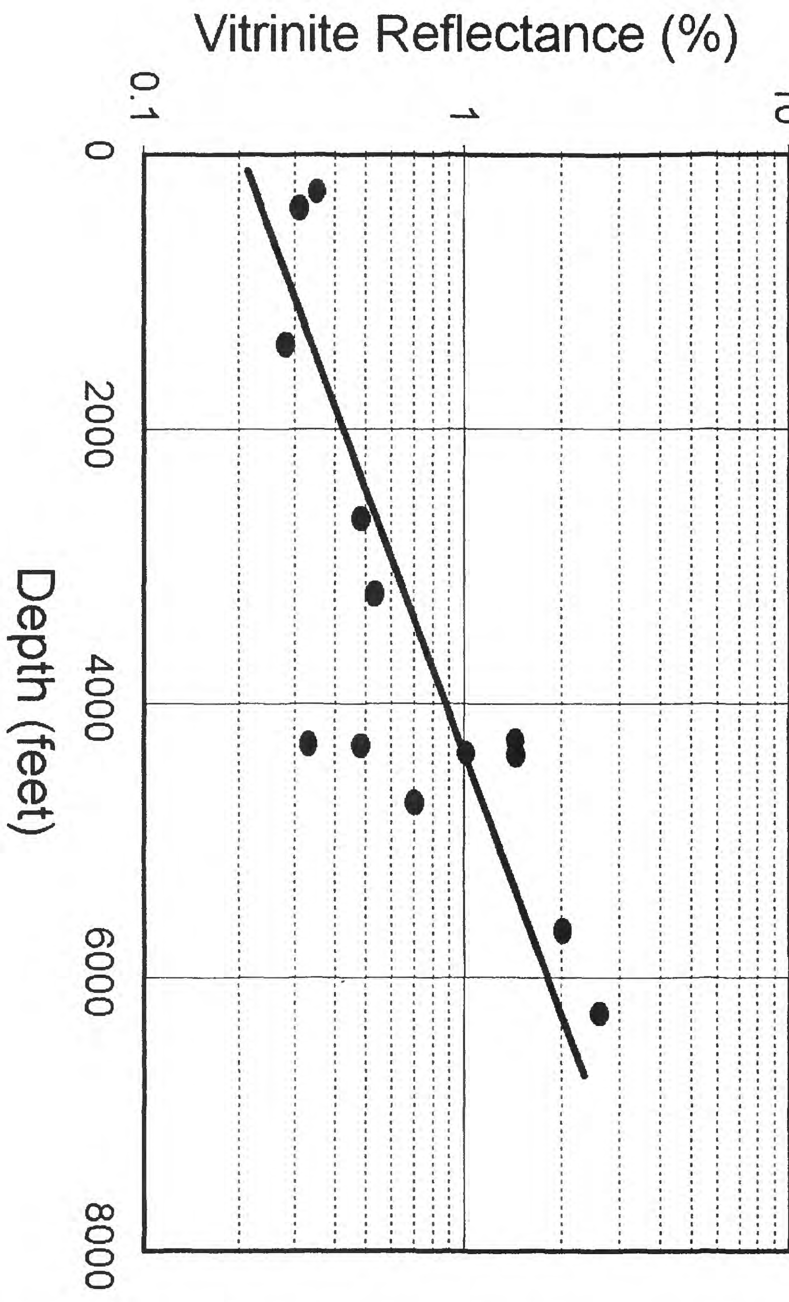

Figure 2. Vitrinite reflectance versus depth for well samples in the region of the Malheur, Jordan and Andrews Resource Areas. The curve shown is a hand fitted interpretive line that suggests thermal maturation with respect to oil generation is reached below 3000 ft (900 m) and an R_o of 2.0 % at about 6,000 ft (1830 m) .

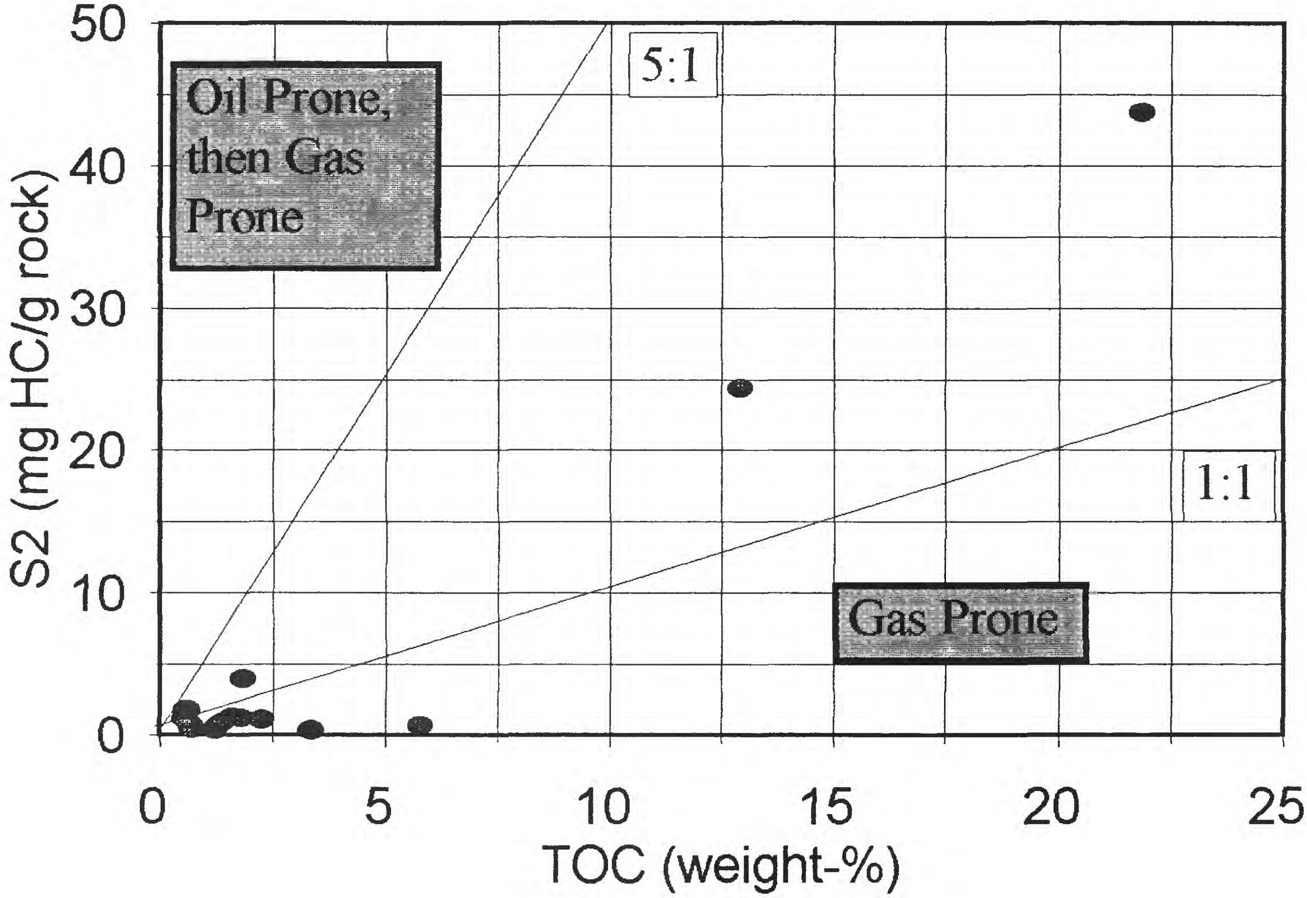

Figure 3. Interpretation of the hydrocarbon generation potential using a plot of S_2 (representing hydrogen content) and TOC (representing carbon content). The sloping lines on the plot S_2/TOC ratios of 5:1 and 1:1. Organic matter with S_2/TOC of 5:1 is interpreted as oil prone and that with 1:1 ratio, gas prone.

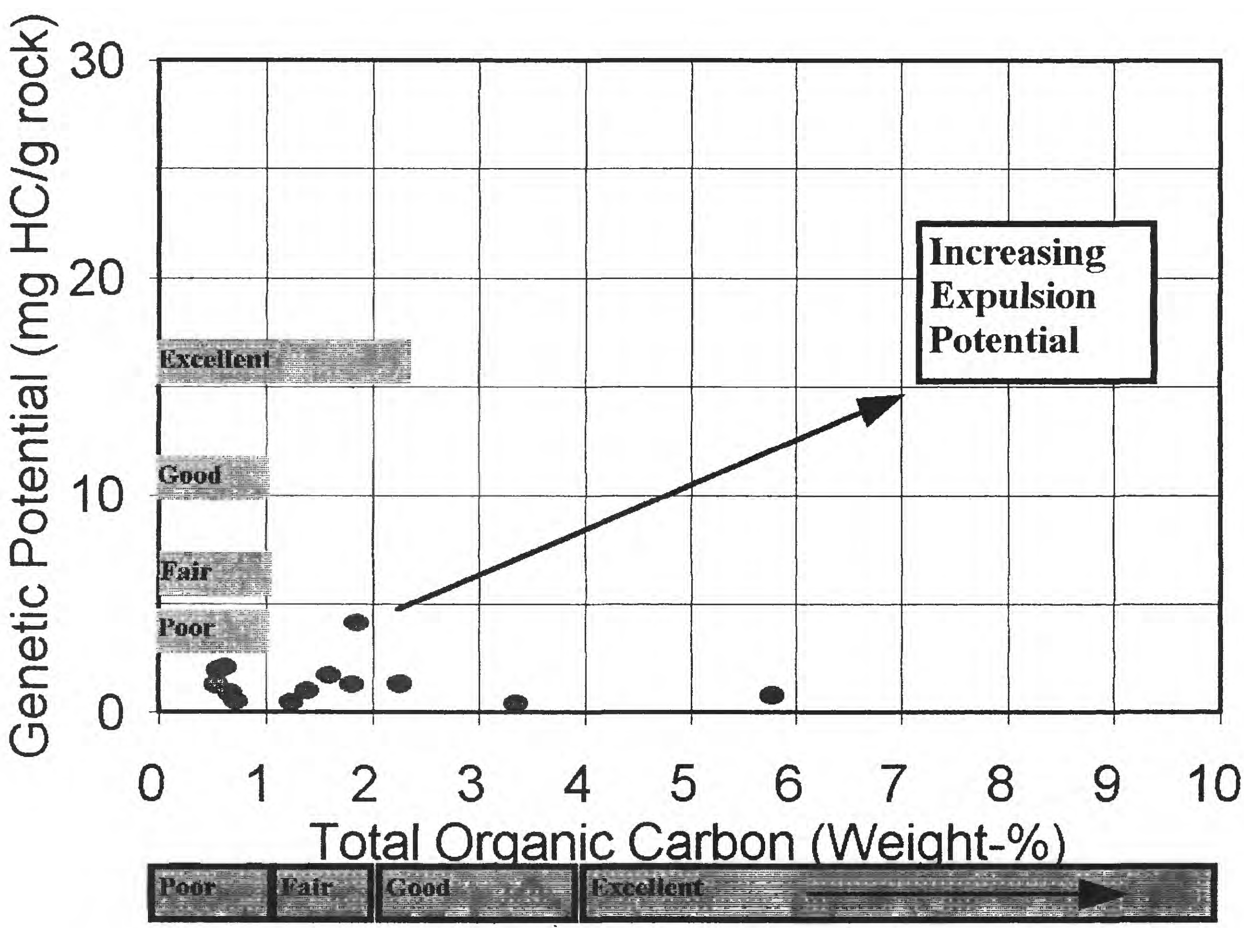

Figure 4. Genetic potential versus expulsion potential (represented by TOC). Only well samples with over 0.5 weight-% TOC are shown. The arrow suggests how oil expulsion potential increases with genetic potential and TOC but is not quantitatively assessed by this figure. Note that oil prone organic matter at higher thermal maturation becomes gas prone.

Identification of Conceptual Plays

The conceptual plays whose burial history reconstructions are presented below are based on the assumption that an effective source rock exists in the play area and Neogene burial heating has caused hydrocarbon generation (Barker et al., 1995). The potential for high-quality, effective, Neogene lacustrine source-rocks is good within calderas, such as Alvord Valley-Steens Mountain area, or areas of local drainage within volcanic terrains, such as Harney Basin or the Vale Basin (northwestern Snake River Plain) before it was breached. These three conceptual plays (Fig. 1) are considered conceptual because they are based on a premise that source rocks do exist-- although thus far, they have only been inferred. The rationale is that local areas of moderate to high hydrogen content, moderate to high carbon content Neogene lacustrine source rocks have been found associated with calderas at the Nevada Test Site in the central Basin and Range Province (Barker, 1993) and extensional terrains in the northern Basin and Range Province like the Carson Sink, Nevada (Hastings, 1979) and Buena Vista Valley, Nevada (Schalla et al., 1993). Other relevant occurrences are discussed by Bortz (1983), Foster and Vincelette (1991), and Frerichs and Pekarek (1994) . Because similar tectonic/volcanic environments occur throughout Malheur, Jordan and Andrews Resource Areas (Orr et al., 1992) effective source rocks can possibly occur locally.

These conceptual plays do not address whether effective reservoir rocks or traps exist in these areas. As discussed below evidence for effective source rocks can be inferred by observing thermogenic oil and gas show which by definition require expulsion of hydrocarbons. Effective traps are demonstrated by drilling and finding commercial oil and gas deposits which has not yet occurred in the Malheur, Jordan and Andrews Resource Areas

Geohistory Reconstruction

Alvord Valley-Steens Mountain Play

The best potential source rocks found in this study are the surface samples from Alvord whose analyses (Appendix 3) may represent minimal source rock potential because: 1) weathering may reduce measured source rock potential; and 2) the strata seem to represent a less organic-matter-rich lake margin facies at the edge of the caldera. The weathering effects seem minor as the samples were taken in a wash that cuts to hard bedrock and under the microscope the samples locally contain fresh pyrite indicating little weathering. Further, the gravity maps of Halvorsen et al. (this volume) suggests that the sample locality is at the edge of the Steens Mountain Caldera where clastic input into the caldera lake deposits can dilute quantity and reduce quality. Thus, it is assumed for the purpose of defining a conceptual play that an effective source rock occurs in the Alvord Valley-Steens Mountain play boundary (Fig. 5).

The controlling structural element of this play is the Steens Mountain fault which separates the up-thrown Steens Mountain block on the west from the down-thrown Alvord Valley block to the east (Fig. 5). Three structural elements Alvord Valley, Steens Mountain and Catlow Valley that compose this conceptual play are lumped together because, before block faulting commenced at about 11.5 Ma, the areas should have experienced a similar deposition and geohistory related to the Caldera Formation. The burial history is different for each structural element after block faulting. The relative upward movement of the Steens Mountain block on its eastern end follows a downward rotation of the block to the west into Catlow Valley. Alvord Valley is formed by the down-dropped block (a half graben) to the east. Subsequently, burial heating increases in both the Alvord and Catlow Valleys because of the enhanced sedimentation or fill by lavas and tuffs derived from the up-thrown Steens Mountain block. The important contribution of the block faulting is: 1) to preserve the source rocks on the down-thrown blocks; 2) to increase the degree of heating due to increased burial on the down-thrown blocks and 3) form structural traps. The geohistories presented here are models that: 1) estimate R_o from maximum burial and temperature before the Steens Mountain fault caused 1000 feet of relative uplift thereby exhuming the Alvord Creek Beds on the east side of Steens Mountain (Figs. 6 and 7) and 2) test the effect of enhanced burial heating related to the corresponding down-dropping of the eastern extension of the Steens Mountain block into the Alvord Valley (Fig. 8).

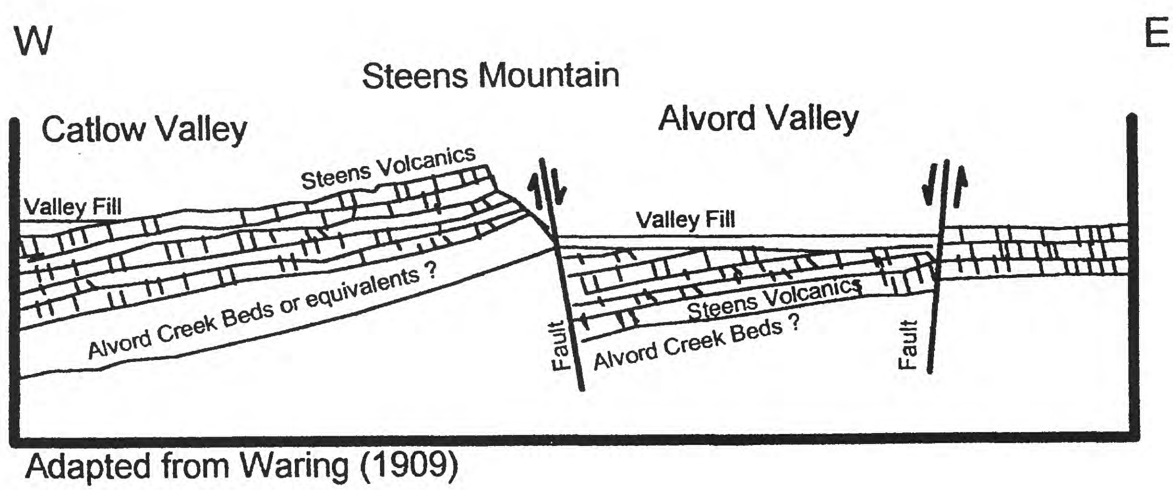

Figure 5. Schematic west to east section showing structural relationships and positions of a hypothesized extension of the Alvord Creek Beds or equivalent rocks towards Catlow Valley and under Alvord Valley. Modified from Waring (1909). Evidence for an extensive low density (lacustrine in part ?) Caldera fill underlying the Steens Mountain Volcanic series is the gravity low reported by Halvorsen et al. (this volume).

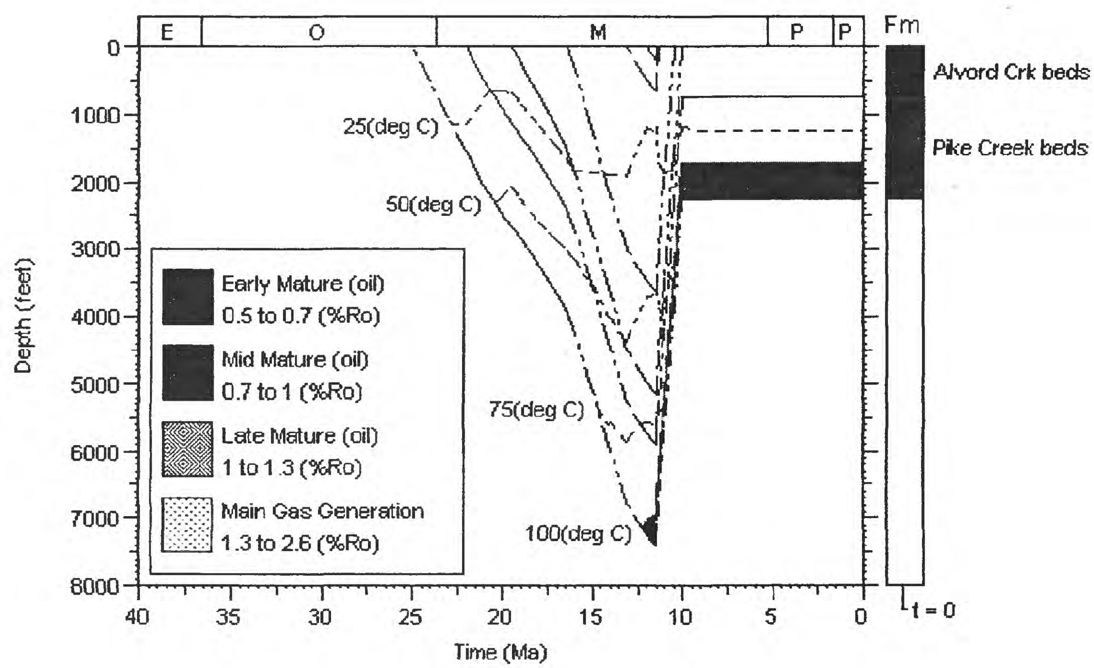

Figure 6. Geohistory reconstruction of the upthrown portion of the Steens Mountain Block, east of Steens Mountain, southeastern Oregon. Note that in this case heating at maximum burial is insufficient to cause oil generation.

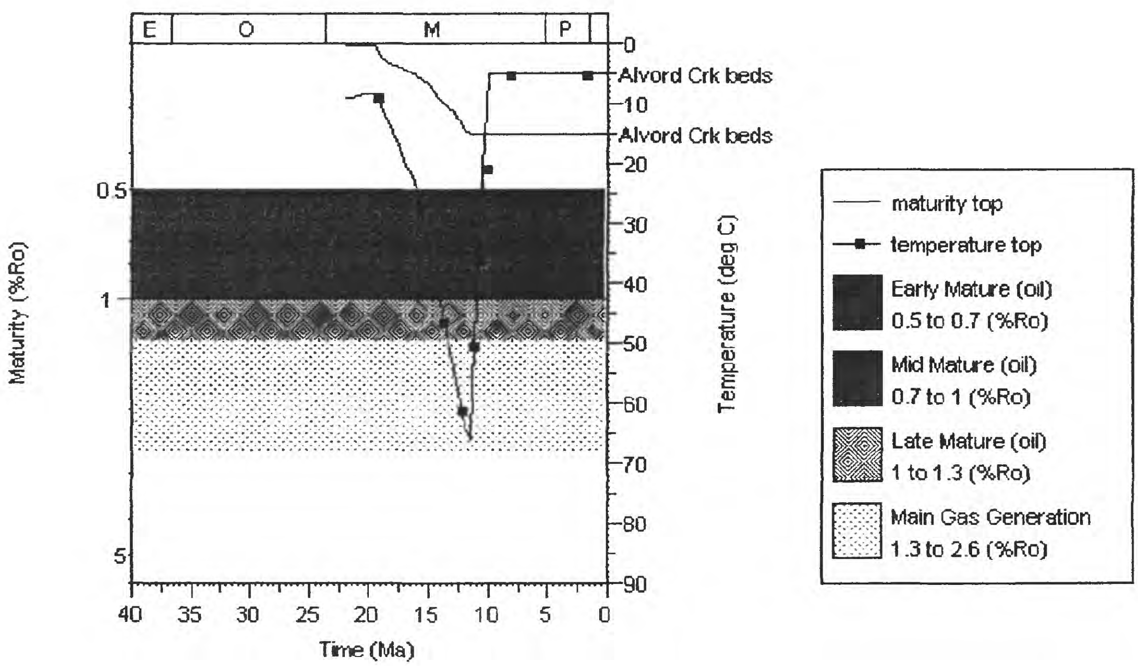

Figure 7. Vitrinite reflectance and temperature history at the top of the Alvord Creek beds predicted by the Steens Mountain geohistory model (Fig. 6).

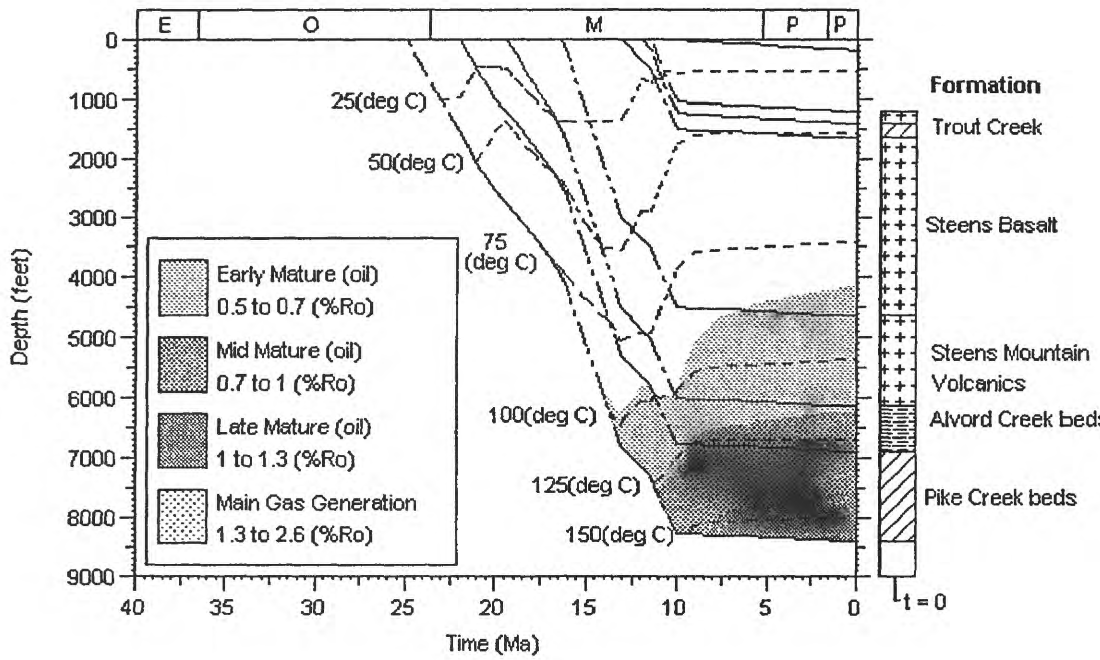

Figure 8. Geohistory reconstruction of the downthrown portion of the Steens Mountain Block in the Alvord Valley, southeastern Oregon. As discussed in the text, because the increase in burial is related to down throw on the Steens Mountain fault and subsequent sedimentation, this burial history is similar to what is expected in the Catlow Valley. Note that in this case heating at maximum burial is sufficient to cause oil generation. This onset of oil generation well before the present may be a disadvantage in extensional tectonic regimes because the ongoing disruption of the seals may preclude accumulation of oils. The short dashed line in the figure represents temperature. The long and short dashed line in the figure represents a formation curve.

These models are based on a composite stratigraphic section (Table 2) in the Steens Mountain area and use a heat flow of 90-100 mW/m^2 suggested by the data of Blackwell et al. (1978). The Alvord Valley model is similar to what would be predicted in the Catlow Valley and no separate geohistory is presented here. The Steens Mountain model predicts a maximum temperature of 65°C and a R_o of 0.4% was reached near the top of the Alvord Creek Beds before faulting exhumed it in the Miocene (Fig. 7). The measured values were 0.3 ± 0.1%R_o. The Alvord Valley model suggests that block faulting is a crucial element in this play that could facilitate hydrocarbon generation by increasing burial heating on the down-dropped block, resulting in a rise in vitrinite reflectance from 0.3 ± 0.1 %R_o to 0.6 to 0.7%R_o corresponding to the oil window. If as suggested by Halvorsen et al. (this volume) pre-caldera rocks exist below the volcanic rocks in the Steens Mountains Caldera (Fig. 5) and they contain hidden lacustrine source rocks, this geohistory model predicts that such rocks, having undergone greater burial heating would be at least thermally mature. In this scenario, the geohistory model predicts that oil generation would have commenced in the Alvord Valley during the Miocene after the onset of movement on the Steens Mountain Fault. However, the onset of oil generation at about 10 Ma may be a disadvantage in extensional tectonic regimes because the ongoing structural deformation and possible rupture of the seals may have precluded accumulation of oil. Ongoing burial heating and the generation of oil and gas to the present seems to be a key element for the preservation of oil fields like those found in the nearby Railroad Valley of Nevada (Barker and Peterson, 1991).

The significance of the Alvord Valley geohistory model is that it is thought to be similar to the geohistory of many other valleys floored by grabens in the Malheur-Jordan-Andrews Resource Areas (Orr et al., 1992) and for the entire Basin and Range Province. Inside the resource areas, this style of geohistory seems applicable to the Cottonwood Basin, south of Vale, Oregon (Kittleman, 1973; Keith et al., 1989) and the Quinn River Valley (Barker et al., 1995); in the area surrounding the resource areas, other examples are the Warner Lakes half graben and Lakeview, Oregon area graben (Barker et al., 1995). These grabens are also considered to contain lacustrine source rocks that are formed in areas of internal drainage caused by extensional faulting, and subsequently entered the oil window because of burial heating from the rapid in -filling of the down-dropped block.

Table 2. Burial History Reconstruction Data, Steens Mountain-Alvord Valley, Southeastern Oregon

Formation/member (event)	Upper contact[1]	Estimated Formation age at Base[2] (Ma)	Strata or erosion thickness[3], or fault throw (Feet)	Lithology for thermal conductivity modeling
(Steens Mountain Fault)	N/A	11.5	1000 of throw	N/A
Volcanics, undifferentiated (heating event ?)	Unconformable	12	About 200	Rhyolite
Trout Creek Formation (local source rock deposition?)	Conformable	13.1	about 200	Tuffaceous mudstone
Steens Basalt (heating event ?)	Conformable	16.4	3000	Basalt
Steens Mountain Volcanic series (heating event ?)	Unconformable	19.5	About 1500	Andesite and basalt breccia and flows
Alvord Creek beds (local source rock deposition?)	Unconformable	22	about 750	Tuffaceous shale
Pike Creek beds	Conformable	25	1500	Tuffs and rhyolitic flows

Notes: 1. Contact type from Piper et al. (1939); 2. Ages from Greene et al. (1972); Walker (1979); 3. Thicknesses compiled from Piper et al. (1939); Greene et al. (1972); Walker (1979); and Terry Gieseler, Bureau of Land Management, Burns, Oregon (field trip log, 1993)

Harney Basin

The Harney Basin is a broad down-warp probably related to caldera formation. The sedimentary fill is cut by small-displacement (tens of feet) normal faults and is intruded by silicic and mafic volcanic vents (Walker and Swanson, 1968).

The geohistory of the Harney basin was not quantified in this study because the burial heating produced by the relatively low heat flow (Blackwell et al., 1978) in the area and a total Tertiary fill of 1.1 to 1.25 km (3600 to 4100 feet; Walker, 1979) is considered to be insufficient to generate thermogenic hydrocarbons. Further, exhumation of the Harney basin commenced some 2.4 Ma as indicated by age dating (Greene et al., 1972) of a basalt capping Wright's Point, near Burns, Oregon. The topographic relief of some 50 meters on Wright's Point indicates that since the basalt covered the strata, considered here to represent the time of maximum sedimentary fill, the Harney basin had been exhumed by an amount equal to the topographic relief. If a near constant heat can be applied to the last 2 Ma then the exhumation of the basin also infers that the sedimentary fill within the Harney Basin is presently starting to cool. All of these lines of evidence suggest the Harney Basin has a poor to low hydrocarbon potential.

Vale Basin (Northwestern Snake River Plain)

The Vale basin is a located in the northwest portion of the Snake River Plain basin in the area around Vale, Oregon. Source rock deposition in the Vale Basin may be related to sediments deposited in lakes formed by closure of the basin by volcanic activity during Miocene and Pliocene time (Kimmel, 1982). Clastic deltas building out into the lake basins may have deposited suitable reservoir rocks (Wood, 1994). At present the area is undergoing erosion related to the Snake River drainage system that has breached the closed basin. Source rock analyses, discussed above ,are largely derived from the Vale Basin and the data seem to indicate only poor source rock prospects. But this is a sparsely drilled area and local areas of better source rocks may occur towards the basin center and what would presumably have been the deeper portions of the lake where organic matter concentration and preservation may have been better. Wells drilled into the Vale Basin have not yet penetrated basement but demonstrate it is at least several kilometers deep (Olmstead, 1988). The Vale basin also has a high heat flow of about 100 to 120 mW/m^2 (Blackwell et al., 1978).

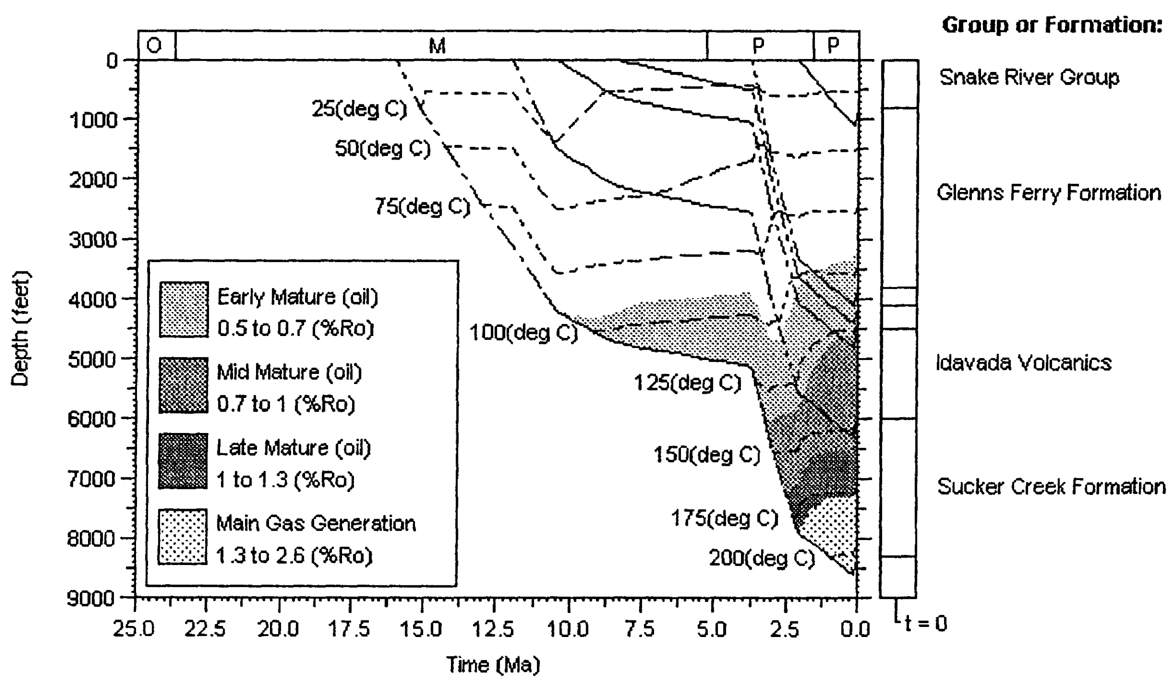

Figure 9. Geohistory reconstruction of the Vale Basin, northwestern Snake River Plain, east-central Oregon. In this model, heating at maximum burial is sufficient to cause the onset of oil generation in the Miocene. Continued burial heating generation continues to the present. The short dashed line represents temperature. The long and short dashed line represents a formation curve.

Table 3. Neogene Stratigraphy and Burial History Reconstruction Data for the Northwestern Snake River Plain near Caldwell, Idaho used to model the Vale basin, eastern Oregon

Group/Formation--Idaho [equivalent Formation name used in Oregon[0]] (important event)	Upper contact[1]	Estimated Formation Age at Base[2] (Ma)	Strata, erosion thickness[3], or fault throw (Feet)	Lithology for thermal conductivity modeling
(Hiatus or slight erosion)	N/A	0.11	200	As in Bruneau Formation
Snake River/ Bruneau [Bruneau] (source rock deposition?)	Unconf.	2.1	Variable, used 500	Basalt 10% Claystone 50% Siltstone 40 %
Idaho/ Glenns Ferry [Glenns Ferry] (source rock deposition?	Unconf.	3.75	3000+ Used 3000	Sandstone 75% Siltstone 25%
Idaho/Chalk Hills [Chalk Butte [4]]	Unconf.	8.4	300+ Used 300	Tuffaceous mudstone
Idaho/ Poison Creek [Grassy Mountain Fm ?[4]]	Unconf.?	10.5	400+ Used 400	Tuff 75% Siltstone 25%
Idavada Volcanic/ [Deer Butte Fm ?[4]]	Unconf.?	12	Variable, used 1500	Rhyolite 30% Tuffs 70%
N/A / Columbia River Basalt [Columbia River Basalt]	Unconf.?	14 to 17	Variable, used 0	Basalt 95% Siltstone 5%
N/A /Sucker Creek [Sucker Creek [4]]	Unconf.?	15 to 17 , used 16	Variable, used 2300	Tuffaceous mudstone 95% Basalt 5%

Notes: 0. Correlation of Idaho formation names with Oregon formation names modified from Kimmel (1982); 1. Contact type from Wood (1994) and Kimmel (1982); 2. Age from Wood (1994) and Kimmel (1982); 3. compiled from Wood (1994); 4. These strata or their stratigraphic equivalents are found in many grabens in southeastern Oregon where they may locally contain lacustrine source rocks. Abbreviations: N/A = not applicable or not available; Fm = Formation; Conf. = conformable; Unconf. = unconformable.

Geohistory reconstruction of the Vale basin (Fig. 9) suggests that oil generation commenced in the Miocene at about 10 Ma at a depth > 4000 ft. Although the basin is being exhumed, increasing burial and heating of the source rocks, along with continued oil and gas generation has continued into the Pleistocene. The model suggests that any source rocks that may exist in the basal strata will have reached an R_o exceeding 2.0% at about 7000 ft. The predicted R_o from this model is comparable with the measured R_o versus depth profile (Fig. 2) that is largely constructed with data from wells in the northwestern Snake River Plain.

Evidence for Effective Source Rocks

Evidence indicates the potential Neogene source rocks appear to have reached the gas generation window in areas of high heat flow as gas quantities reportedly increase towards igneous intrusions in the area (Kirkham, 1935). In large portions of the resource areas, measured well temperatures commonly exceed 100°C (Kinney, 1976; Bowen et al., 1977; Blackwell et al., 1978; Olmstead, 1988; Newton and Corcoran, 1963; and many others) and the organic-rich rocks in the deeper sections could have reached the gas window.

There are common shows of gas at shallow depth in the resource areas but no production has been established (Washburne, 1911a, b; Buwalda, 1921, 1923; and many others). The surface hydrocarbon seeps and shows in wells reported within these resource areas are summarized in Olmstead (1988), Newton and Corcoran (1963) and Brady (1984). Gas analyses indicate the gas is dry (methane-rich) (Newton and Corcoran, 1963). This shallow gas, when it occurs in rocks that have not been heated much by burial, contact metamorphism or hydrothermal fluids is speculated to be of biogenic(?) origin but can also be thermogenic gas that migrated from sources at depth.

One unfilled objective of this ongoing investigation is to determine the origin of this shallow gas. If it is thermogenic gas that has migrated from depth, it would indicate the existence of mature source rocks that are capable of expelling significant gas and would greatly improve the hydrocarbon prospects in the resource areas. Carbon and hydrogen isotope analyses along with determination of the wetness of the gas can indicate the origin of gas, if gas samples can be obtained from water wells or seeps.

Reservoirs, Seals and Traps-- Key but Unknown Elements

Potential reservoir formations include fractured Neogene welded tuff and basalt, and Neogene fluvial sandstones. Tested reservoir rocks may have good to moderate porosity (9 to 25%) and moderate to very low permeability (<1 to 281 md) (Newton and Corcoran, 1963). Permeability is thought to be generally poor in potential reservoir rocks because unstable volcanic glasses are a common component of the rocks and during diagenesis have been altered to clays, zeolites and related materials which fill pores and reduce permeabliity (Walker and Swanson, 1968; among others). Limited reservoirs are confirmed by drill-stem-test histories that record an initial large production of gas that quickly subsides to uneconomic levels (Newton and Corcoran, 1963; Olmstead, 1988) suggesting the well is producing from small pockets of porous and permeable rocks. These stratigraphic traps may have formed where porous reservoirs are encased in carbonate and zeolite-cemented sandstones, and where local lenticular sandstones grade into mudrock. Regional geology suggests that structural traps may be formed by fault truncation of reservoir rocks (Gray et al., 1983), and perhaps by local folding. Seals may be formed by fault planes, mudstones draped over porous fluvial sandstones, densely cemented sedimentary and welded volcanic strata enclosing reservoir pods of fractured volcanic rocks and porous fluvial sandstone (Barker et al., 1995).

Petroleum Potential Assessment

The outline of possible conceptual plays in these resource areas is based on the inferred presence of Neogene source rocks now buried in basins (Fig. 1). Evidence suggests that effective gas source rocks exist but not oil-prone ones. Even the assignment of effective gas source rocks is tenuous as no data is available to quantitatively determine if thermogenic gas is present. Geohistory reconstruction of these conceptual plays shows that during Neogene burial, these source rocks may have reached temperatures sufficient for generating thermogenic hydrocarbons. However, the coincidence of conditions leading to commercial production has not been demonstrated in the resource areas although numerous wildcat wells have been drilled. Thus, the resource areas are considered permissive for small to medium size hydrocarbon discoveries but not favorable (Fig. 1).

Conclusions

1. The best Neogene source rocks found in this study are the carbonaceous beds within the Alvord Creek Beds exposed on the eastern edge of Steens Mountain.
2. Burial heating in the Alvord Valley and Catlow Valley conceptual plays seems to be sufficient to generate thermogenic hydrocarbons commencing in the Miocene.
3. Burial heating in the Steens Mountain and Harney Basin conceptual plays seems to be insufficient to have generated hydrocarbons.
4. Burial heating in the Vale Basin conceptual play is sufficient to generate thermogenic

hydrocarbons.

5. The resource areas are considered permissive for small to medium size hydrocarbon discoveries but not favorable.

Recommendations for Future Work

This initial study indicates that the additional geologic data needed to complete oil and gas resource assessments are: 1) documentation of the origin of natural gases as either thermogenic or biogenic by isotopic analyses, if samples can be obtained; and 2) determination of the reservoir qualities of samples taken from oil and gas exploration wells.

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Appendix 1

Well Data

Malheur, Jordan and Andrews Resource Areas, Southeastern Oregon

ABBREVIATIONS USED IN ALL APPENDICES

(the definitions of Rock-Eval and thermal maturation parameters are in Appendix 3.)

BHT = bottom hole temperature
Carbonaceous = visible DOM in a rock
Coaly = thin wisps or layers coal in a rock
dk = dark
DOM = dispersed organic matter
FF = Final flowing pressure
ft = feet
GR = Elevation of ground level (in ft)
IF = Initial flowing pressure
KB = Elevation of kelly bushing (in ft)
Lat = Latitude
lt = light
Long = Longitude
mdst = mudstone
mtn = mountain
NA = Not available
PSI = pressure in pounds per square inch
R_o = mean random reflectance of vitrinite or solid bitumen, as indicated
T.D. = Total depth of well.

Well locations given as quarter section-section number-township-range.

Formation tops as reported in the well files of the Oregon Department of Geology and Mineral Industries.

Well/ API number/ county/ location	Elevations: Dates: spud/ completion	Tops: Formation and depth	Notes : DST and BHT data; casing points
El Paso Spurrier Federal 1/ 36-045-00017/ Malheur/ NE-5-20S-44E/ Lat = 43.8539°N Long = 117.37099°W	2520 GR 2531 KB 11-25-54 1-12-55	U. Idaho Formation 0-900; Grassy Mtn. Basalt 900-1830; L. Idaho Formation 1830-4440; Deer Butte Formation 4440-6570; Rhyolite (probably Owyhee Formation) 6570 to T.D. at 7470.	DST no. 1 6065 -6196 ft IF 50 PSI FF 480 PSI SIP 2400 PSI Recovered 900 ft of muddy water Casing point: 295 ft
Oroco McBride 1/ 36-045-00020 Malheur/ SE-19-16S-46E Lat = 43.15875°N Long = 117.12917°W	2831.1 GR 11-30-56 1-12-57	formations unknown. Sand 0 ft Shale 590 ft Altered basalt 2040 ft Serpentine 3700 ft	Core sample mentioned in well report at 1515-1525 ft not found. BHT of 185°F, 5 hours after circulation stopped at the TD of 4506ft. Gas shows reported at 1845-1860 ft in tuff and 2780 ft in basalt
Riddle and Oroco Kiesel 1/ 36-045-015-00016/ Malheur/ SW-8-19S-47E/ Lat = 43.92720°N Long = 116.99763°W	2177 GR 10-5-54/ 10-28-55	Idaho Formation 0 ft Grassy Mtn Basalt 4500 ft T.D. 5137 ft	DST at 2152-2178 ft. Open 1 hour to surface. Initial flow 150 PSI. Final pressure nil. Recovered 200 ft of gas cut water. Numerous shows noted in mud log starting at 210-220 ft. BHT at 5106 ft 183°F, 2.5 hours after rig stopped. Casing points at 130; 1970; 5115
Sinclair Eastern Oregon Land Co. 1/ 36-045-00019/ Malheur County/ SW-15-16S-44E Lat = 44.1724°N Long = 117.31783°W	2640 GR 1955	Deer Butte 770 ft; Owyhee 1355 ft; quartz diorite 4505 ft T.D. 4888 ft in pre-Tertiary Elk Ridge Quartz Diorite.	Mud temperature was 126°F at 4630 ft

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Well/ API number/ county/ location	Elevations: Dates: spud/ completion	Tops: Formation and depth	Notes : DST and BHT data; casing points; shows
Wells outside of Resource Areas			
Humble Leavitt 1/ 36-037-00008/ Lake County/ NE-2-40S-20E/ Lat = 42.13347°N Long = 120.31976°W	4783 GR 4796 KB 1960-1961	Oligocene-Eocene age Cedarville Series 0 ft Pre-Tertiary metavolcanics 7570 ft T.D. 9579 ft	Mud temperature 149°F near this sample depth. BHT 295°F at 9561 ft 9 hours after logging started. Casing: 712 ft Gas shows over 7300 to 7500 ft.
Humble Thomas Creek Unit 1/ 36-037-00007/ Lake County/ 18-36S-18E/ Lat = 42.44625°N Long = 120.63151°W	5260 GR 1960	Tertiary undifferentiated volcanics and interbedded sedimentary rocks. 0 ft to T.D. at 12093 ft	The well was drilled on a large northerly trending anticline. No shows.
Sunnyvale Mitchell 1/ 36-023-00003/ Grant County/ SE-14-16S-29E	5200 GR 12-3-57 4-30-58	Jurassic Movine 0 to 1168 ft TD 1168	Casing: 80 ft

Well/ API number/ county/ location	Elevations: Dates: spud/ completion	Tops: Formation and depth	Notes : BHT data; casing points
Wells examined but not sampled			
Halbouty 1-10 Federal/ 36-025-00023 Harney County/ NE-10-23S-29E Lat = 43.59289°N Long = 119.21808°W	4765 GR 4778 KB 6-8-77 9-11-77	Rhyolitic lavas and tuffs of probable Miocene age . Essentially no sedimentary rocks penetrated by well to a total depth of 7684 ft. No samples taken	BHT-1 98°F at 2514 ft 2.5 hours after circulation stopped. BHT -2: 104°F at 6015 ft 6.5 hours after circulation stopped. Casing points :40, 377, 2525 ft.
Two States Oil Co. Vale City no. 1/ 36-045-00021 Malheur/ SW-21-18S-45E Lat = 43.9875°N Long = 117.22172°W	Elevation unknown 8-1961 10-24-62	Idaho Formation 0-760; Grassy Mountain Basalt 760-1030; Idaho Formation 1030-1060; Deer Butte Formation 1090-1130. T.D. 1130. No samples taken	Drilled with cable tool rig. 56°F water encountered during drilling. Casing: 200, 430 ft.
Standard Blue Mountain 1/ 36-045-NA Malheur County sw-34-37S-41E/ Lat = N/A Long = N/A	5608 KB Spud: 6-16-73 Completion unknown	0-8224 ft Miocene-Eocene Basalt. 8224-8414 ft Pre-Tertiary Granodiorite No significant sedimentary rocks penetrated by the well to a total depth of 8414 ft. No samples taken.	BHT-1a 96°F at 2015 ft 2 hr after circulation stopped. BHT-1b 96°F at 2015 ft 3.5 hr after circulation stopped. BHT-1c 98°F at 2015 ft 7 hr after circulation stopped. BHT-2a 180°F at 8421 ft: 5 hr after circulation stopped. BHT-2b 184°F at 8421 ft: 8 hr after circulation stopped. BHT-2c 206°F at 8421 ft: 14.5 hours after circulation stopped. Casing points: 171, 2015 ft.

Appendix 2.

Potential Source Rocks

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Location and Geological information for Surface Samples,
Malheur, Andrews, and Jordan Resource Areas, Southeastern Oregon

Appendix 1. Potential Source Rock Samples from Surface Exposures, Southeastern Oregon

Sampler or well/ depth or number/ locality	Latitude Longitude	Age/ Formation/ lithology	Notes
SURFACE SAMPLES			
J. Evans /CVW99A/ Cow Valley Butte	44.3216°N 117.7502°W	Jurassic/ Weatherby/ metagreywacke	Formation underlies part of the northern Malheur R.A.
J. Evans /CVW109A/ Cow Valley Butte	44.3150°N 117.7506°W	Jurassic/ Weatherby/ metagreywacke	Formation underlies part of the northern Malheur R.A.
J. Evans /CVW267/ Worsham Butte	44.3767°N 117.7783°W	Jurassic/ Weatherby/ metagreywacke	Formation underlies part of the northern Malheur R.A.
J. Evans /WDT 73B/ Baldy Mountain	45.4333°N 117.8067°W	Jurassic/ Weatherby/ metagreywacke	Formation underlies part of the northern Malheur R.A.
J. Evans /WDT 226A/ Porter Gulch	45.4300°N 117.7725°W	Jurassic/ Weatherby/ metagreywacke	Formation underlies part of the northern Malheur R.A.
J. Evans /Tert.-1/ Bully Creek Reservoir	44.0377°N 117.4365°W	Late Miocene/ Willow Creek/ inertinite rich mudstone	A swamp facies of the Late Miocene portion of the Snake River Plain sedimentary assemblage.
C. Barker/ CB-OR-94-1/ Cottonwood Creek	42.6336°N 118.5113°W	Miocene-Pliocene/ Alvord Creek/ calcite vein	Not analyzed.
C. Barker/ CB-OR-94-2a and -2b/ Cottonwood Creek	42.6343°N 118.5131°W	Miocene-Pliocene/ Alvord Creek/ carbonaceous plant debris in mudstone	Sample 2b represents a 0.3 meter thick organic matter rich bed in the generally leaner mudstone unit
C. Barker/ CB-OR-94-3/ Cottonwood Creek	42.6349°N 118.5143°W	Miocene-Pliocene/ Alvord Creek/ carb. mudstone	In a leaner looking mudstone bed

Appendix 3.

Potential Source Rocks:
Results of Vitrinite Reflectance and Rock-Eval analyses,
Malheur, Andrews and Jordan Resource Areas, Southeastern Oregon

Units of measurement

Definitions for Rock-Eval data reports are: S_1 and S_2 are the first and second peaks of hydrocarbon yield occurring during pyrolysis of the sample; S_3 is the amount of CO_2 generated during pyrolysis; TOC is total organic carbon; T_{max} is the temperature at which the S_2 peak occurs during pyrolysis of kerogen. Derivative values based on these values are Hydrogen index (HI) = $(S_2/TOC)x100$; Oxygen index (OI) = $(S_3/TOC)x100$; PI = Transformation ratio = $S_1/(S_1+S_2)$; S2/S3which is a measure of the H/C ratio of the organic matter.

Vitrinite and solid bitumen reflectance are reported as mean random $\%R_o$ with the standard deviaiton of the analyses (std. dev.) and number of measurements (sample size, n).

Notes

Formation names as listed in the well files of the Oregon Department of Geology and Mineral Industries (DOGAMI) in Portland, Oregon.

Sample Type Resource Area Contributed by Sample Number	Age / Formation/ Rock Description	Organic Matter Type	Ro mean (%)	Ro std dev (%)	Ro sample size	Tmax Celsius	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO2/ g rock	PI	S2/S3 HC/CO2	TOC wt-%	HI mgHC/ g C	OI mg CO2/ gC
SURFACE SAMPLES														
Northern Malheur														
James Evans														
CVW-99a	Jurassic /Weatherby/ black mdst	humic	1 5	0 17	18	419	0 01	0 12	0 6	0 08	0 2	0 81	14	74
CVW-109a	Jurassic /Weatherby/ black mdst	humic	1 4	0 1	7	427	0 02	0 17	0 67	0 11	0 25	1 07	15	62
CVW-267	Jurassic /Weatherby/ gray mdst	humic		not run		370	0 00	0 01	0 53	0	0 01	0 41	2	129
WTD-73b	Jurassic /Weatherby/ black mdst	humic	1 2	NA	1	393	0 02	0 1	0 98	0 17	0 1	2 46	4	39
WTD-226a	Jurassic /Weatherby/ black cherty shale	humic		not run		351	0 04	0 2	0 66	0 17	0 3	0 7	28	94
Northern Malheur														
James Evans														
Tert-1	Tertiary /Willow Creek / peaty mdst	humic	0 4	0 06	18	425	0 23	3 17	9 79	0 07	0 32	7 84	40	124
CBOR94-2A	Tertiary /Alvord Creek/ carb mdst	humic +amorph	0 38	0 08	14	442	0 36	4 9	0 61	0 07	8 03	1 71	286	35
CBOR94-2B	Tertiary/ Alvord Creek/ carb mdst	humic +amorph	0 24	0 04	9	441	0 34	4 33	0 59	0 07	7 33	1 64	264	35
CBOR94-3	Tertiary /Alvord Creek/ carb mdst	humic +amorph	0 3	0 06	10	417	0 03	6 18	1 19	0	5 19	1 83	337	65

Resource Area Well name Sample type	Sample Depth Top (feet)	Sample Depth Bottom (feet)	Age / Formation/ Rock Description	Organic Matter Type	Ro mean (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsiu	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO g rock	PI	S2/S3 HC/CO	TOC wt-%	HI mgHC/ g C	OI mg CO gC
WELL SAMPLES																
Malheur R.A.																
Sinclair Ore. Land No. 1																
Cuttings	400	410	Neogene/Idaho Group/lt gray mdst	NA	NA	NA	NA	431	0.17	3.99	1.27	0.04	3.14	1.85	215	68
Cuttings	700	710	Neogene /Deer Butte/ lt gray mdst	NA	NA	NA	NA	425	0.09	0.81	0.53	0.10	1.52	0.67	120	79
Cuttings	1380	1410	Neogene/ Owyhee/dk gray mdst	Humic DOM	0.3	NA	1	429	0	0.05	0.24	0.00	0.2	0	NA	0
Cuttings	2150	2160	Neogene/ Owyhee/dk gray mdst	Barren	NA	NA	NA	350	0	0.02	0.18	0.00	0.11	0	NA	0
Cuttings	2830	2840	Neogene/ Owyhee/dk gray mdst	Barren	NA	NA	NA	523	0.02	0.2	0.41	0.09	0.48	0.01	NA	0
Core	3476	3493	Neogene/ Owyhee/Basalt with bitumen	bitumen(?)	0.4	0.04	20	462	0	0.09	0.19	0.00	0.47	0	NA	0
Cuttings	4170	4180	Neogene/ Owyhee/dk gray mdst	NA	NA	NA	NA	402	0.04	0.29	0.27	0.12	1.07	0.18	161	150
Cuttings	4270	4280	Neogene/ Owyhee/dk gray mdst	Humic DOM	1.4	0.31	38	467	0.07	0.94	0.34	0.07	2.76	1.39	67	24
Cuttings	4380	4390	Neogene/ Owyhee/dk gray mdst	Humic DOM	1.4	0.21	42	522	0.1	1.23	0.41	0.08	3	1.81	67	22
Malheur R.A.																
Riddle and Oroco Kiesel 1																
Cuttings	266	276	Neogene/Idaho/lt gray mdst--gas show	Humic DOM	0.4	NA	1	365	0.09	0.44	0.75	0.17	0.58	0.19	231	394
Cuttings	386	396	Neogene/Idaholt gray mdst--gas show	Humic DOM	0.3	0.09	3	418	0.09	0.47	0.83	0.16	0.56	0.23	204	360
Cuttings	1665	1670	Neogene/Idaho/lt gray mdst	NA	NA	NA	NA	360	0.16	0.72	0.78	0.18	0.92	0.32	225	243
Cuttings	1915	1925	Neogene/Idaho/lt medium gray mdst	NA	NA	NA	NA	426	0.11	0.75	0.45	0.13	1.66	0.24	312	187
Cuttings	3740	3750	Neogene/Idaho/gray mdst	NA	NA	NA	NA	433	0.17	1.82	0.64	0.09	2.84	0.56	325	114
Cuttings	4205	4220	Neogene/Idaho/gray mdst	NA	NA	NA	NA	429	0.29	1.81	0.88	0.14	2.05	0.62	291	1441
Cuttings	4595	4605	Neogene/Grassy Mtn. Basalt/ gray mdst	NA	NA	NA	NA	427	0.19	1.08	0.72	0.15	1.5	0.46	234	156
Cuttings	4730	4740	Neogene/Grassy Mtn. Basalt/gray mdst	Humic DOM	0.7	0.25	2	424	0.11	0.62	0.48	0.15	1.29	0.31	200	154
Malheur R.A.																
El Paso Spurrier Fed. 1																
Cuttings	1260	1300	Neogene/Grassy Mtn. Basalt/gray mdst	Barren	NA	NA	NA	337	0.05	0.3	0.57	0.15	0.52	0.07	428	814

Resource Area Well name Sample type	Sample Depth Top (feet)	Sample Depth Bottom (feet)	Age / Formation/ Rock Description	Organic Matter Type	Ro mean (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsiu	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO g rock	PI	S2/S3 HC/CO	TOC wt-%	HI mgHC/ g C	OI mg CO gC
Cuttings	2660	2680	Neogene/Idaho/Coaly black mdst	Coaly	0.5	0.04	30	431	1.16	43.75	5.58	0.03	7.84	21.9	200	25
Cuttings	3210	3250	Neogene/Idaho/Coaly black mdst	Coaly	0.5	0.05	30	431	1.07	24.4	4.67	0.04	5.22	12.9	188	36
Cuttings	4310	4350	Neogene/Idaho/dk gray mdst	Coaly	0.5	0.06	12	425	0.43	1.33	1.2	0.24	1.1	1.59	83	75
Cuttings	5660	5700	Neogene/Deer Butte/dk gray mdst	Humic DOM	2.0	0.21	30	361	0.08	0.47	0.31	0.15	1.51	0.72	65	43
Cuttings	6260	6300	Neogene/Deer Butte/gray mdst	Humic DOM	2.6	0.35	30	372	0.24	1.11	0.49	0.18	2.26	2.26	49	21
Malheur R.A.																
Oroco McBride 1																
Cuttings	4300	4310	Neogene/NA/lt gray mudstone	Humic DOM	0.3	0.18	5	428	0.08	1.23	0.48	0.06	2.56	0.54	227	88
Cuttings	4365	4370	Neogene/NA/gray mudsotne	Humic DOM	1.0	0.46	8	427	0.14	1.2	0.54	0.10	2.22	0.49	244	110
Outside resource areas																
Humble Leavitt 1																
Cuttings	7300	7330	Paleogene/NA/coaly black shale	NA	NA	NA	NA	377	0.05	0.45	0.31	0.10	1.45	1.24	36	25
Cuttings	7360	7390	Paleogene/NA/coaly black shale	NA	NA	NA	NA	327	0.11	0.69	0.51	0.14	1.35	5.77	11	8
Core	7394	7409	Paleogene/NA/coaly black shale	NA	NA	NA	NA	428	0.01	0.14	0.1	0.07	1.4	0.08	175	125
Cuttings	7480	7510	Paleogene/NA/coaly black shale	NA	NA	NA	NA	338	0.05	0.38	0.25	0.12	1.52	3.35	11	7
Humble Thomas Creek 1																
Core	6248	6263	Paleogene/NA/dk gray mdst	NA	NA	NA	NA	453	0.01	0.07	0.07	0.12	1	0	NA	0
Cuttings	6470	6500	Paleocene/NA/carb. dk gray mdst	NA	NA	NA	NA	435	0.02	0.2	0.15	0.09	1.33	0.01	NA	1500
Core	10840	10856	Paleocene/NA/coaly dk gray mdst	Barren	NA	NA	NA	487	0.01	0.12	0.1	0.08	0	0	0	0
Sunnyvale Mithchell 1																
Core	471	476	Jurassic/Movine/dk gray siltstone	solid bitumen	1.0	0.15	5	462	0.19	0.68	0.15	0.22	4.53	1.6	42	9
Core	1160	1168	Jurassic/Movine/dk gray mdst	solid bitumen	1.3	1.32	4	307	0.08	0.26	0.19	0.24	1.36	1.06	24	17

Resource Area Well name Sample type	Sample Depth Top (feet)	Sample Depth Bottom (feet)	Age / Formation/ Rock Description	Organic Matter Type	Ro mean (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsiu	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO g rock	PI	S2/S3 HC/CO	TOC wt-%	HI mgHC/ g C	OI mg CO gC
Malheur R.A.																
Two States Vale City 1			Essentially no sedimentary rock													
Jordan R.A.																
:andard Oil Blue Mountain 1			Essentially no sedimentary rock													
Outside of R.A.																
Halbouty 1-10 federal			Essentially no sedimentary rock													