U.S. DEPARTMENT OF THE INTERIOR
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Resource Assessment of the Bureau of Land Management's Winnemucca District and Surprise Resource Area, Northwest Nevada and Northeast California-- Geochemical Analysis and Thermochronologic Modeling to Evaluate Conceptual Petroleum Plays

by

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PREFACE

By Jeff L. Doebrich, Project Coordinator, USGS, Reno, Nevada

The U.S. Geological Survey (USGS) is a party to joint interagency Memorandum of Understandings with the Bureau of Land Management (BLM) and the U.S. Bureau of Mines to coordinate resource assessments and evaluations of BLM administered lands. Resource assessments of BLM Resource Areas, that are conducted by the USGS under these memorandum of understandings, assist the BLM in meeting inventory and evaluation, resource-management planning, and other management requirements of the Federal Land Policy and Management Act of 1976.

The project area is composed of three contiguous BLM Resource Areas, totalling 13.5 million acres, in northwest Nevada and northeast California (Figs. i and ii). The Sonoma-Gerlach and Paradise-Denio Resource Areas in northwest Nevada together comprise the BLM's Winnemucca District. The Surprise Resource Area is located in extreme northwest Nevada and northeast California and is part of the BLM's Susanville District, which is administered by the BLM's California state office. Henceforth in this report, the project area will be referred to as the Winnemucca-Surprise Resource Assessment Area.

The following report on petroleum resources is one of several scheduled to be prepared on the Winnemucca-Surprise Resource Assessment Area. Other reports include geology (Doebrich, 1996), and others in preparation on geochemistry, geophysics, hydrothermal alteration classification using Landsat thematic mapper imagery, assessment of metallic mineral resources and assessment of non-metallic mineral resources.

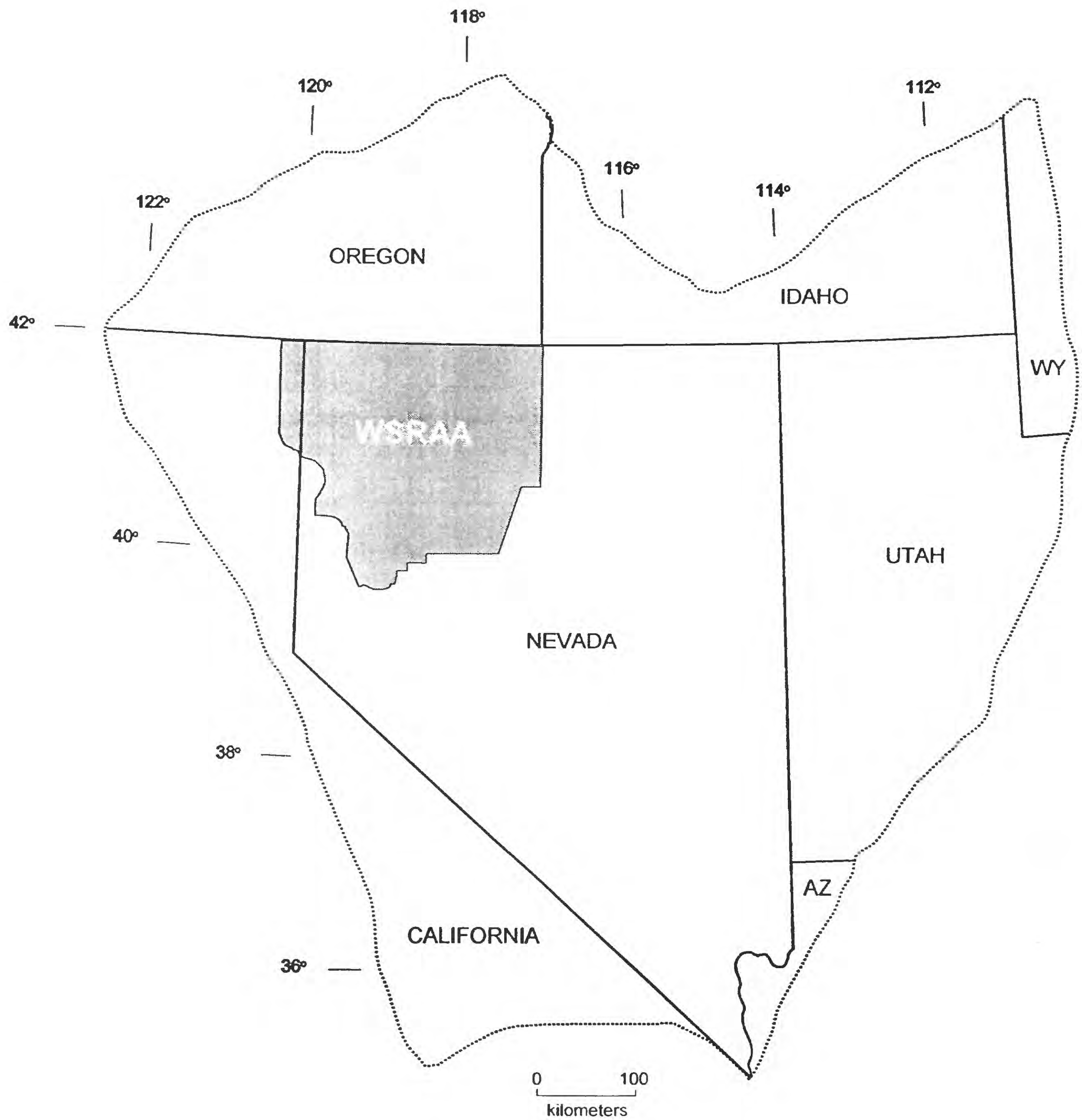


Figure i. Index map of the Project Area, Winnemucca-Surprise Resource Assessment Area.

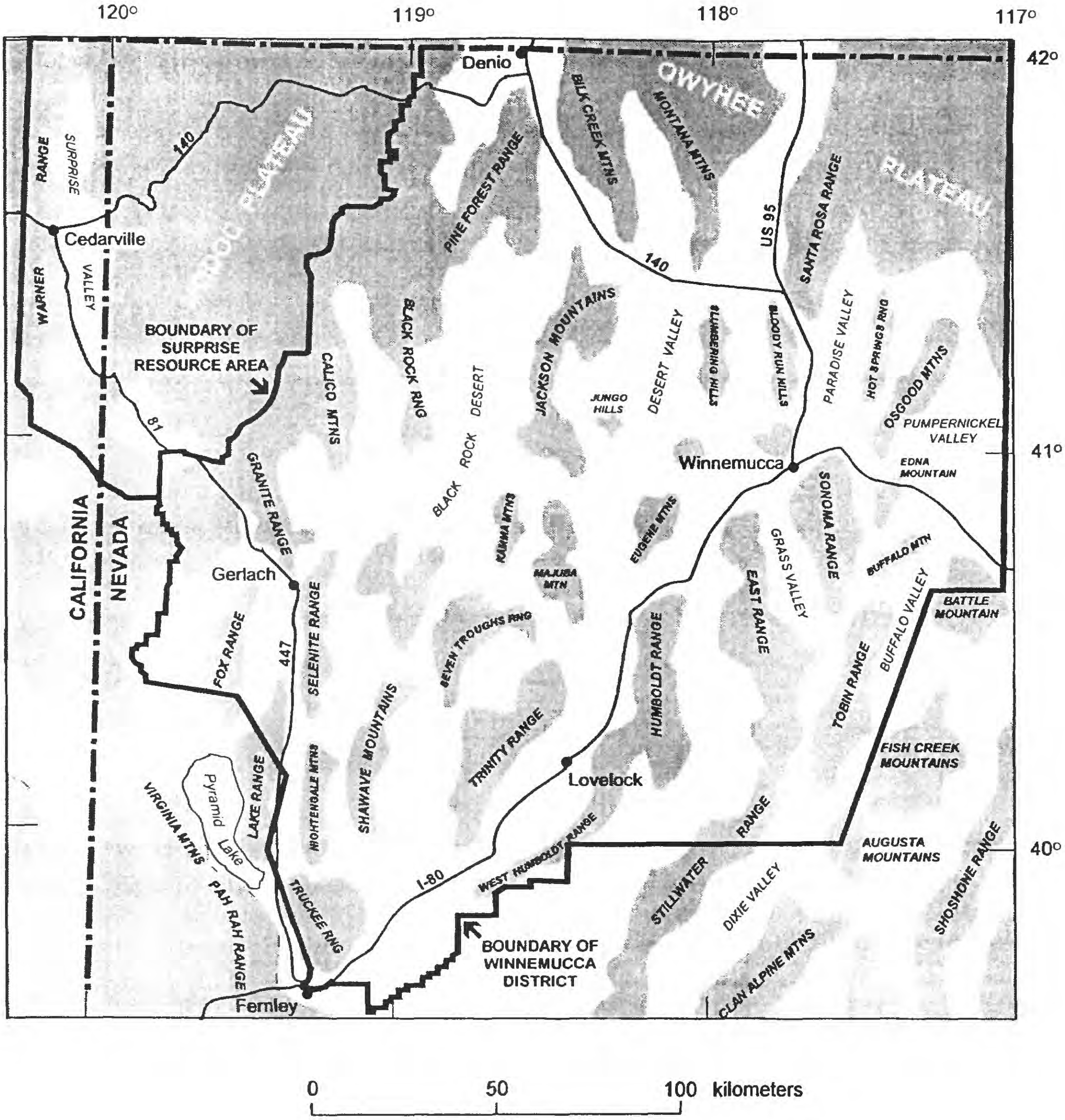


Figure ii. Map of the Project Area, Winnemucca-Surprise Resource Assessment Area.

Geochemical Analysis and Thermochronologic Modeling to Evaluate Conceptual Petroleum Plays

By Charles E. Barker, U.S. Geological Survey, Denver, Colorado

Abstract

Rock-Eval, gas chromatography, mass spectrometry data from well and surface samples identify only in Tertiary age source rocks within the Winnemucca and Surprise Resource Assessment Area. Mesozoic rocks that have been attributed with hydrocarbon generation potential in the southern Tobin Range and Augusta Mountains within the Winnemucca District are found to be marginal or non-source rocks. Published conodont alteration index data show that the Paleozoic rocks are overmature. The lacustrine Tertiary calcareous mudrock and marl sampled from six wells in the Carson Sink basin have a total organic carbon (TOC) range from 0.1 to 3 mass-%, with modes at about 0.5 to 0.7, 1.5, and 2 to 3 mass-%TOC. These rocks are oil-prone with hydrogen indices commonly above 400 mg hydrocarbon/ g $C_{organic}$, and some samples with TOC in the 2-3 mass-% range. These source rocks are thought to have generated the oil shows in the Carson Sink and Buena Vista Valley basins.

Geochemical analysis of an oil show at Kyle Hot Springs in Buena Vista Valley revealed a wax-rich, low sulfur oil interpreted to be from a carbonate-rich, hypersaline lacustrine source rock. This oil is similar to those reported from a well in the Carson Sink and at the Wagon Tire Spring oil seep. This type of oil could be generated from source rock strata similar to those discussed above.

Other Tertiary source rocks in the Winnemucca and Surprise Resource Assessment Area consist of coal that appear to be gas prone and locally perhaps oil prone. Alteration during shallow burial of coal or disseminated organic matter probably give rise to the common shows of biogenic(?) gas from shallow wells in Tertiary to Holocene lacustrine strata of the area.

Thermochronologic modeling in the Carson Sink and Buena Vista Valley basins, used as examples of the possible range of thermal histories in the Winnemucca and Surprise Resource Assessment Area, 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 rocks into the hydrocarbon generation window in the Pliocene to Holocene. The modeling also suggests that potential Tertiary source rocks are only locally rich enough to have expelled oil. Traps in these conceptual plays are considered to be related to fault truncation and(or) stratigraphic pinchout of

the reservoir rock and secondary porosity related to the diagenesis of volcanic provenance rocks. Permeability is assessed to be generally poor in potential reservoir rocks because the commonly present volcanigenic materials during diagenesis are altered to clays, zeolites and related materials which fill pores and reduce permeability. Regional geology suggests the Neogene source rocks or ones deposited in similar geologic environments may occur in small deposits dispersed throughout the resource Area. On this basis, several basins in the Winnemucca and Surprise Resource Assessment Area seem to form a viable conceptual play.

In conclusion, most of the Neogene basins in the Winnemucca and Surprise Resource Assessment Area are considered permissive for small to medium size hydrocarbon discoveries but are not considered favorable. The limited size of the hydrocarbon discoveries stems from the apparently patchy distribution of source rocks and reservoirs. The Carson sink and Buena Vista Valley plays are considered more favorable as oil shows have been reported there.

Introduction

This paper examines the organic geochemistry, petrography and thermochronology of potential source rocks and their in the U.S. Bureau of Land Management Winnemucca and Surprise Resource Assessment Area, Nevada and California. These data and thermochronologic modeling are used to define possible conceptual oil and gas plays. These conceptual plays are formulated to include the geological environments in Winnemucca and Surprise Resource Assessment Area that appear favorable for hydrocarbon generation, accumulation and preservation (Fig. 1). 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 play boundaries are defined by Neogene extensional basins where the ongoing burial of Neogene source rocks in the extensional basins of the Basin and Range Province is occurring . 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 are largely speculative. Further, several wildcat oil exploration wells have been drilled in the Winnemucca and Surprise Resource Assessment Area but these tests have resulted in no commercial hydrocarbon production or major oil or gas shows (Garside et al., 1988; Barker et al., 1995; and Appendix 1). Thus, the conceptual plays presented in this study are still unproven.

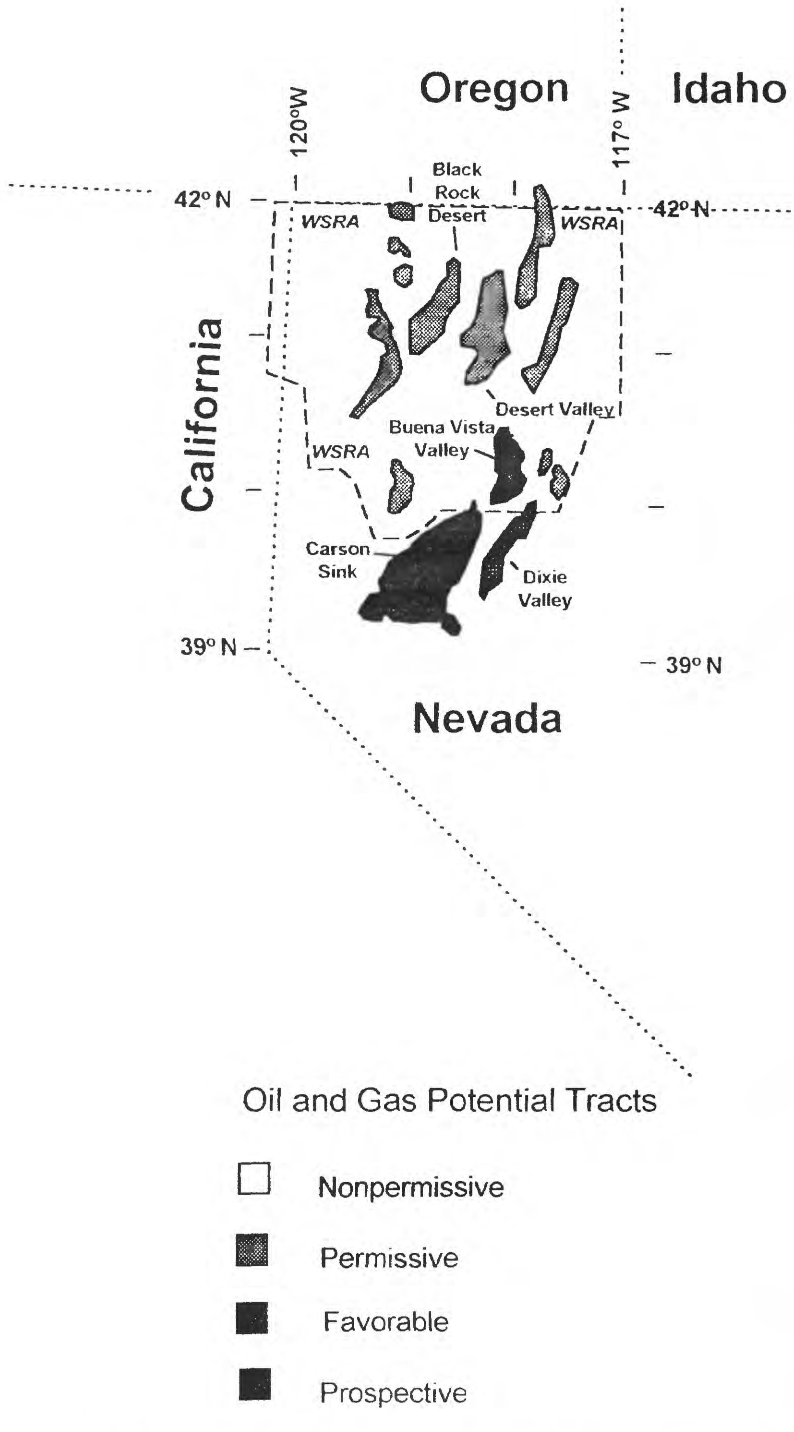


Figure 1. Conceptual plays and their petroleum potential assessment in the region around the Winnemucca and Surprise Resource Assessment Area. The conceptual plays shown are areas within Neogene basins where thick Neogene sedimentation has occurred (from Barker et al., 1995).

The Winnemucca and Surprise Resource Assessment Area of Nevada and California are a part 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 largely derived from that analysis of hydrocarbon potential which overall found low or no potential. The data available for the Barker et al. (1995) estimates of hydrocarbon potential 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 wish to thank Jonathon Price, Larry Garside, Becky Weimer Purkey, and Ron Hess of the Nevada Bureau of Mines and Geology for their cooperation in sampling well cuttings and core, as well as permission to look through their well history and log files. Larry Garside also supplied samples of coal from Nevada. Mike Miller, U.S. Bureau of Mines, Spokane, Washington, collected surface samples in the northern portions of the Winnemucca District. Scott McDaniels and Richard Francis, F and M Exploration, Reno, Nevada, kindly shared their knowledge of Nevada oil and gas resources, as well as taking me the Wagon Tire oil seep. Dave Murphy, Bureau of Land Management, Winnemucca, Nevada provided his petroleum geology reports on the Winnemucca District and an oil sample from the Independence Kyle Hot Springs no. 1 oil show. Mike Evans, Evans-Barton Ltd., , Reno, Nevada, shared his analyses and other information on the Kyle Springs area. Bill Neumann, Minnova (U.S.) Inc., Sparks, Nevada provided drill cutting samples from the Independence Kyle Hot Springs no. 1. Joe McFarlan, Bureau of Land Management, Cedarville, California shared his knowledge of wells drilled in the Surprise Resource Area. Elizabeth Johnson, California Division of Oil and Gas, Sacramento, kindly provided copies of logs for wells in Surprise Valley. Connie Throckmorton, USGS, Denver, Colorado allowed access to the Fish Creek Valley well samples. Bill Barker, brother, Reno, Nevada, accompanied me in the field.

Methods

The well samples were collected from the Nevada Bureau of Mines and Geology, Reno, Nevada and the U.S. Geological Survey core library, Denver, Colorado. 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 indicated on the sample bag. Surface samples were collected from Mesozoic and Tertiary age exposures in the Winnemucca District. 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. 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. The carbon dioxide evolved during heating to the combustion state is combined with the hydrocarbons evolved during pyrolysis to estimate the total organic carbon content (TOC) of the sample. 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 mass-% (Peters, 1986; Bordenave et al., 1993). Furthermore, rocks with less than 0.5 mass-% TOC are probably incapable of expelling hydrocarbons and therefore are not source rocks. Samples with less than 0.5 mass-% 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 crude experimental analog and use the values to calculate what appear to be excessive volumes of hydrocarbons that could be generated from the organic matter (Lewan, 1992). This study interprets Rock-Eval results from the broad trends of grouped data, ignoring outlier data and does not include 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 that is anomalously high relative to adjacent samples, 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.

Weathering may have altered the samples taken from surface exposures or shallow wells. Weathering tends to reduce TOC and hydrogen content and increase oxygen content of the organic matter. These chemical changes potentially can make weathered samples look like poorer source rocks than they are at depth. However, most of the samples contained fresh pyrite suggesting weathering is a negligible factor in these samples (Lewan, 1980).

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), Robert (1988); Langford and Blanc-Valleron (1990), and Bordenave et al. (1993), among others.

TOC mass-%	Organic Matter Genetic Potential	Generated Hydrocarbon Type		Thermal Maturity		Source Rock Potential: Comments
	S1 + S2 (mg HC/ g rock)	HI (mg HC/ g C)	S2/S3 (mg HC/g CO_2)	Tmax (°C)	Vitrinite Reflectance (%)	
< 0.5	Mudrock <0.5 poor. Limestone <0.5 poor or fair(?)	Maybe unreliable	Maybe unreliable	Maybe unreliable	Maybe unreliable	Probably not a source rock.
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 --or-- > 425 Oil >470 Wet gas then dry gas	< 0.5 Immature 0.5 - 1.3 mature > 1.3 post mature --or-- > 0.5 Oil >1.3 Wet gas then dry gas	Marginal source rock: probably not capable of expelling oil
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			Source rock but may not be capable of expelling oil
> 2	< 4 poor 5 fair 10 good >15 excellent	< 200 Gas 200-300 Mixed, oil and gas >300 Oil	<2.5 Dry Gas 2.5-5 Wet Gas >5 Oil			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% in 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.

Thermochronologic Modeling

Thermochronologic modeling utilized Platte River Associates (Denver, Colorado) BASINMOD for windows version 4.02 computer program for burial depth, paleotemperature, thermal maturity and hydrocarbon generation computations. The measured thermal maturation data (Appendix 3) and the temperature data presented below were used to constrain the thermochronologic modeling. The stratigraphic and variable heat flow models were considered successful when, after fitting the thermochronologic model to maximum 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).

Thermochronologic Modeling Data

Thermal Data

Thermal data are required to estimate the temporal changes in surface temperature, heat flow and rock thermal conductivity used to compute the paleogeothermal gradient over time. This data is a key to estimating the thermal maturation and the extent and timing of hydrocarbon generation. Thermochronology in tectonically active or deeply eroded areas is difficult to reconstruct because the heat flow regime has often changed (Vitorello and Pollack, 1980; Chapman and Pollack, 1975; Allen and Allen, 1990) and the thermal conductivity is altered by diagenetic/metamorphic changes in porosity, mineralogy, and pore fluid composition. In any case, stable heat flow conditions are seemingly rare in geologic history, so the thermochronologic models in this study use variable heat flow computations even though the thermal data can only be moderately constrained using present-day analogs.

Surface Temperature

At present, the mean annual surface temperature is about 10°C in western Nevada. Tertiary paleosurface temperature was estimated using fossil evidence for paleoclimate for the western United States. (Savin, 1977).

Heat Flow

Present heat flow is average for continental crust to relatively high in the Winnemucca and Surprise Resource Assessment Area. Sass et al. (1981) found an heat flow of about 60-80 mW/m^2 in the Carson Sink area, similar to the typical value (70 mW/m^2) found in the Basin and Range Province. However, a characteristic of the Basin and Range Province is a widely variable heat flow. For example, just north of the Carson Sink is the Battle Mountain high which that has a heat flow of about 100 mW/m^2 in most of north central Nevada as well as in the Buena Vista Valley area (Sass et al., 1981). As discussed below, the tectonic regime and probably heat flow (Allen and Allen, 1990) extant in the area was established in the early Pliocene (see thermochronologic models presented below) coinciding with the time of source rock deposition and the onset of rapid burial that led to hydrocarbon generation at present. The heat flow regime measured today is used to model the thermochronology because the source appear to be at maximum temperature now and this temperature regime is the key factor in generating hydrocarbons.

Thermal Conductivity

BASINMOD sets thermal conductivity based on lithology mixes and decompacted porosity. The rock lithology input into BASINMOD is as shown in the thermochronologic modeling data (Table 2). 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 thermochronologic 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 for eroded rocks that no longer exist. In the region of the Winnemucca and Surprise Resource Assessment Area, locally deformed and(or) eroded Neogene basin fill is the primary evidence that significant erosion has locally occurred between depositional events. In general, however, 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 thermochronologic modeling 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 if 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 and determining which compaction method seems to give the best prediction. However, this approach is not possible in the Winnemucca and Surprise Resource Assessment Area as drilling and appropriate samples or analyses are sparse. The thermochronologic models developed for this study use the Falvey and Middleton method in BASINMOD because it can handle a wider array of geological conditions.

Conceptual Play Definition Technique

The technique used to define the conceptual play boundaries in the Neogene basins was to identify basins that apparently contain hydrocarbon source rock; and then employ a series of overlays that: 1. outline the areas of probable source rock occurrence and Tertiary-Quaternary fill in basins (usually grabens) from the 1:500,000 scale geologic maps; 2. use gravity data (Jachens and Moring, 1990) to reduce the play area to where the Tertiary fill is deep (>1-2 km or so; based on the conclusions of Barker and Peterson, 1991) ; and 3. extend the play into more shallowly buried portions of the basin adjacent to the deep burial area or where hydrocarbon shows or seeps are known (Brady, 1984; Garside and others, 1988; Schalla et al., 1994; and unpublished reports).

Petroleum Geology

The older sedimentary rocks of the Winnemucca and Surprise Resource Assessment Area consist of Paleozoic to Mesozoic carbonate and clastic rocks that have undergone three major compressive orogenic events in the late Paleozoic to early Mesozoic period. Heating related to these orogenic events and widespread igneous intrusion and metamorphism in the middle to late Mesozoic have largely destroyed the hydrocarbon generation potential of these Paleozoic and Mesozoic sedimentary rocks. The Cretaceous through Cenozoic period is characterized by lacustrine and fluvial deposition overprinted by extensional faulting, volcanism, high heat flow and hydrothermal alteration in the Neogene. As discussed in the thermochronologic models presented below, the Neogene extensional tectonics that commenced about 6 Ma in this area formed north-south trending ranges truncated by extensional faults that bound the adjacent basins characteristic of the northern portion of Basin and Range physiographic province.

The ranges and the floors of the basins are mostly formed by Paleozoic and Mesozoic rocks that are generally overmature or are too lean to have any remaining source rock potential in the Winnemucca and Surprise Resource Assessment Area (Harris et al., 1980; Barker et al., 1995). These overmature Paleozoic and Mesozoic rocks may still retain reservoir potential if they can be charged by other source rocks that retain hydrocarbon generation potential. Potential Paleozoic source rocks appear to be overmature at present and are not considered further. Potential source rocks Mesozoic strata appear to have an unfavorable organic geochemistry and (or) thermal history and are also not considered in detail.

Cenozoic strata that potentially contain hydrocarbon source rocks are found locally throughout the Winnemucca and Surprise Resource Assessment Area but as shown below usually have reached only marginal thermal maturity except in areas of high heat flow or deep burial. These Cenozoic, mostly Neogene, source rocks are present in almost all Basin-and-Range type basins. The Cenozoic source rocks can include oil and gas prone algal organic-matter in lacustrine marls and mostly gas-prone humic coals or coaly rocks.

Identification of Source Rocks

To reiterate, the conceptual plays defined for the Winnemucca and Surprise Resource Assessment Area are based on the presence of source rocks with hydrocarbon generation potential as determined by Rock-Eval and vitrinite reflectance analysis using the criteria listed in Table 1. Paleozoic rocks are overmature and no examples of strata with residual hydrocarbon generation capacity are known. Only Mesozoic rocks--Triassic marine strata or Jurassic-Cretaceous lacustrine strata, and Neogene terrestrial lacustrine strata are considered as source rocks in this study.

Mesozoic

Triassic marine source rocks have been inferred to have oil potential in the Winnemucca District (Bortz, 1983). There are no known Mesozoic strata with oil potential in the Surprise Resource Area. The region in the Winnemucca District thought to have significant hydrocarbon generation potential is the Triassic Prida and Favret Formations in the Augusta Mountains and the Southern Tobin Range and perhaps underlying the Jersey Valley and northern Dixie Valley (N.J. Silberling, USGS, Denver, personal communication; Appendix 2 and 3; Fig. 2). However, five surface samples from the Augusta Mountains and southern Tobin range average only 0.13 mass-% TOC with a range of 0 to 0.25 mass-% TOC making them unlikely hydrocarbon sources (Table 1). Perhaps the common hydrothermal activity in these valleys (Garside and Schilling, 1979) may have locally over matured the rocks and destroyed the hydrocarbon generation potential. Conodont analyses suggest that other areas of Triassic marine strata in the Winnemucca District are overmature and are poor candidates for hydrocarbon source rocks (Harris et al., 1980). The generally poor source nature of the Triassic marine strata was confirmed by sampling a wider area in the. Triassic samples outside of the Augusta Mountains and Tobin Range average 0.41 mass-% TOC (Appendix 3) which is to low for generating significant hydrocarbon. Further, the organic matter in the Triassic marine strata is hydrogen poor-- those samples with over 0.5 mass-% TOC (7 samples) have an average a HI of 54 mg HC/ g C and a range of 21 to 100 mg HC/ g C (Appendix 3) . This is a low HI and these rocks are not considered significant source rocks (Table 1). In conclusion, the hydrocarbon potential of the Mesozoic marine strata is apparently lower than previously thought and appears to be too lean to generate significant oil but may be capable of generating gas.

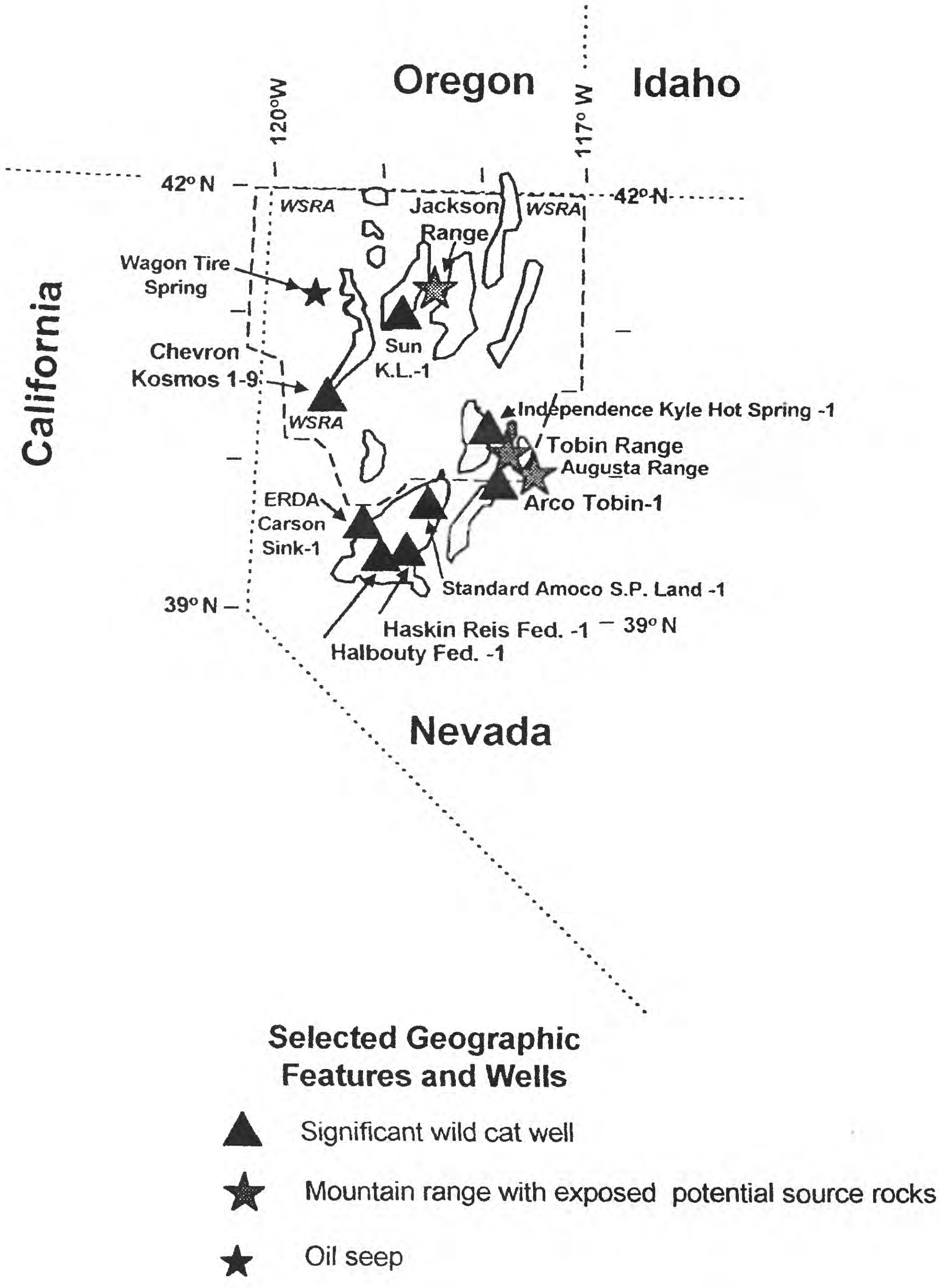


Figure 2. Selected geographic features, oil seeps and wells, Winnemucca and Surprise Resource Assessment Area, Nevada. Basin outlines shown are taken from the plays shown in figure 1. Abbreviations: Sun K.L.-1 = Sun King Lear Federal-1; Fed. = Federal.

Mesozoic continental strata consist of Jurassic(?) to Cretaceous lacustrine rocks in the King Lear Formation are also thought to have source rock potential in the Black Rock Desert, Desert Valley and Jackson Range areas of Nevada (Wilden, 1964; 1979). Based on three samples from a relatively small area of exposures, the King Lear Formation has a TOC range from 0.22 to 0.76 mass-% and averages 0.51 mass-% (Appendix 3). These rocks are hydrogen poor with hydrogen indices near 0 mg hydrocarbon/ g C. Thus, Rock-Eval and vitrinite reflectance (Ro > 2%; Appendix 3) analyses of King Lear Formation samples show that it is low in residual hydrocarbon generation potential (Table 1) and overmature. However, these samples were taken in an area of intrusives into the King Lear Formation and local heating may have over matured the sampled strata. Elsewhere source rock potential may have been preserved on King Lear and Navajo Peak in the Jackson Mountains or where buried below the Tertiary basin fill in Black Rock Desert and Desert Valley but samples to confirm this contention are not readily available. In the Black Rock Desert, a mudstone sample from 6900-7000 feet in the Sun King Lear Federal 1 well thought to be King Lear Formation has about 1.6 mass-% TOC and a HI of 500 mg HC/ g C (Appendix 3) which would make this a marginal to fair hydrocarbon source rock (Table 1). Pieces of coal hand picked out of drill cuttings sampled at 6030-6050 feet in this same well are possibly additives to the drilling mud. This coal has a moderate to high HI of about 300 mg HC/ g C and a TOC of about 70 mass-% . If the coal is indigenous, this geochemistry suggests it could generate hydrocarbons but vitrinite reflectance analysis suggests the rock is immature at 0.5% Ro (Appendix 3) and so is not considered further here as a source of thermal hydrocarbons.

Cenozoic (Neogene)

Cenozoic source rocks consist of Neogene age strata in the Winnemucca and Surprise Resource Assessment Area. Neogene lacustrine source-rocks are potentially good source rocks in areas of local drainage within volcanic terrains, such as is often found in calderas or within the down dropped blocks commonly flooring valleys in the Basin and Range province were hydrocarbon shows have been found (Fig. 3) . The lacustrine Tertiary calcareous mudrocks and marls sampled from five wells in the Carson Sink basin have a TOC range from 0.1 to 3 mass-%(Fig. 4). The higher TOC rocks are mostly oil-prone rocks (Fig. 5). The samples with TOC in the 2-3 mass-% and genetic potential above 5 mg HC/ g rock are probably effective source rocks that could have expelled oil (Table 1; Fig. 6). These source rocks are thought to have contributed to the oil shows in the Carson Sink and Buena Vista Valley basins. Analysis of an oil show at Kyle Hot Springs in Buena Vista Valley revealed a wax-rich, low sulfur oil probably from a carbonate-rich, hypersaline lacustrine source rock (Schalla et al., 1994) This oil is similar to that reported from the Standard Amoco S.P.

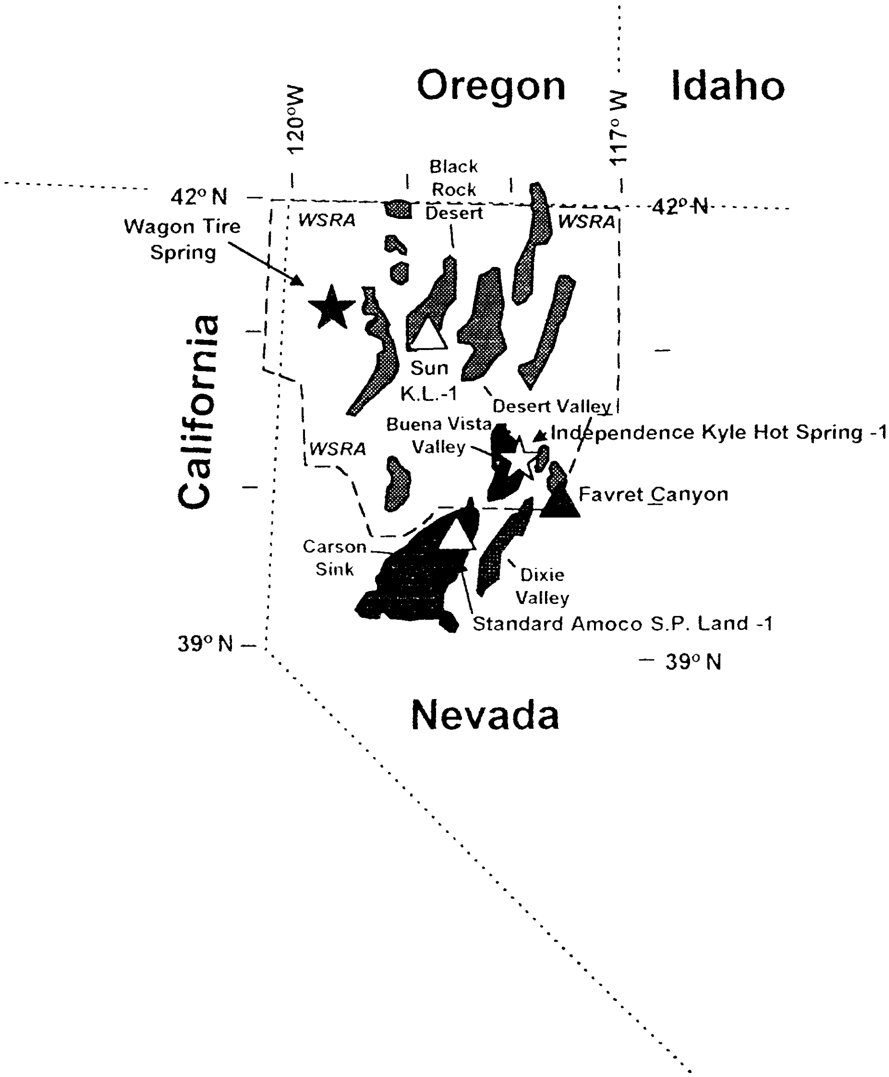
Land -1 well in the Carson Sink (Hastings, 1979;) and at the Wagon Tire Spring oil seep (Figs. 2 and 3; Don Anders, USGS, written communication, 1991; Reported in the Reno Gazette Journal, October 9, 1991). This type of oil could be generated from source rock strata similar to those discussed above.

Organic petrography and Rock-Eval analyses of other Tertiary source rocks in the Winnemucca and Surprise Resource Assessment Area and adjacent areas (Appendix 2) shows that they consist of beds and lenses of humic coals to carbonaceous sandstones or mudrocks that appear to be gas prone and locally perhaps oil-prone in those samples with the higher hydrogen indices (Appendix 3) .

Conceptual Play Definition: Neogene Source Rocks in Extensional Basins

This conceptual play is based on Neogene to Recent burial of Late Cenozoic source rocks in northwest Nevada and northeast California Neogene basins. This play considers any Cenozoic basins with deep valley fill to be conceptually prospective (Figs. 1, 2 and 3). A play model based on the sedimentology of faulted bounded, internally drained basins (Fig. 7) suggests that seals may be formed by fault planes, mudrocks draped over porous fluvial sandstones, densely cemented sedimentary and welded volcanic strata enclosing reservoir pods of fractured volcanic rocks and porous fluvial sandstone. Trapping mechanisms are fault truncation of reservoir rocks, mudrock draped lenticular sandstones and Neogene lacustrine beds laterally interbedded with marginal alluvial fans-- (overlying seal= continental evaporites, lateral seal= fault truncation). The play model also suggests that reservoirs include lacustrine beds laterally interbedded with marginal alluvial fans and fractured Tertiary volcanic rocks. Oil production In the northeastern portion of the Basin and Range province (Railroad and Pine Valleys) occurs from fractured welded tuff and volcanics, fractured Paleozoic rocks, and rarely from sandstones encased in mudrocks (Garside et al., 1988; Foster and Vincelette, 1991). Permeability and porosity tests on reservoir rocks are rare in the Winnemucca and Surprise Resource Assessment Area but permeability is thought to be generally poor in potential reservoir rocks because unstable volcanic glasses are a common component of the rocks that are altered to pore-filling materials during diagenesis that reduce permeability (Walker and Swanson, 1968; among others). In the northernmost Basin and Range Province (East Central Oregon), limited reservoir volumes are confirmed by drill-stem-test histories that record an initial large production of gas that quickly subsides to uneconomic levels (Olmstead, 1988) suggesting the well is producing from small pockets of porous and permeable rocks. These stratigraphic or diagenetic 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, including reservoirs formed by Mesozoic and Paleozoic rocks in faulted into contact with younger source rocks (Barker et al., 1995; Fig. 7), and perhaps by local folding. Tertiary source rocks are apparently locally mature and have produced oil and gas shows but no discoveries. Tertiary to Recent lacustrine rocks are immature when encountered at shallow depth in non-geothermal wells (Barker et al., 1994). Thermal maturation may also occur by heating of source rocks by geothermal convection, shallow intrusions, and fluid flow up basin faults especially near the graben boundaries (Barker and Pawlewicz, 1987; 1990; Barker et al., 1992). The source rocks in this play may be mature to overmature in high heat flow and geothermal areas.



Oil Occurrences

△ Subsurface oil show with well name shown

▲ Surface oil show named by associated geographic feature

☆ New subsurface oil show with well name shown

★ New surface oil show named by associated geographic feature

Figure 3. Location of documented surface and subsurface oil shows in or adjacent to Neogene basins (gray tone areas), Winnemucca and Surprise Resource Assessment Area, Nevada. Old occurrences refers to those shows listed in Bortz (1983) and new occurrences are those found since his paper. Note that non-commercial gas shows are common throughout the area (Brady, 1984) but are not shown individually. Abbreviations: Sun K.L.-1 = Sun King Lear Federal-1; Fed. = Federal.

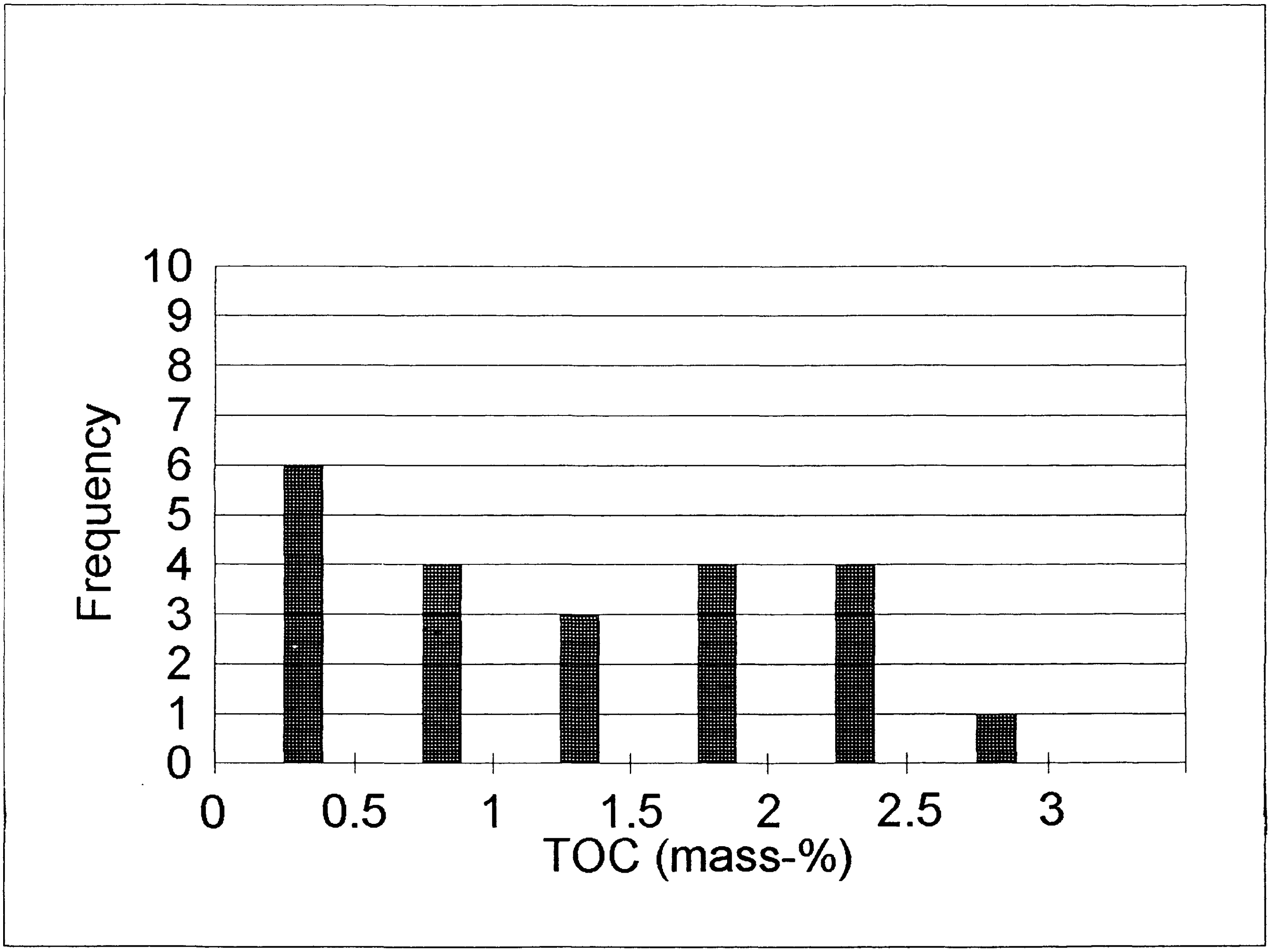


Figure 4. TOC histogram, selected Neogene mudrock samples, Carson Sink, Nevada.

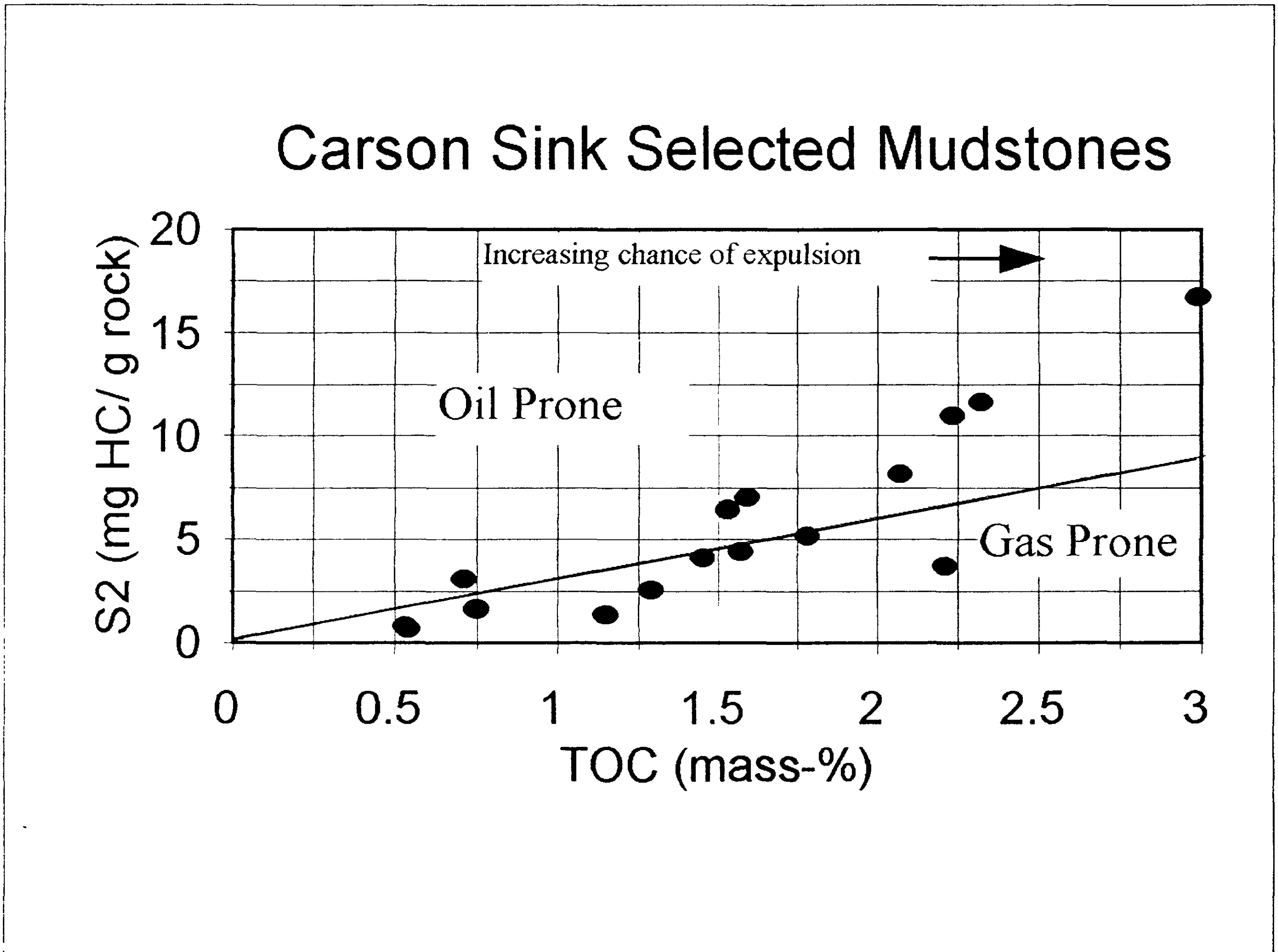


Figure 5. Interpretation of the hydrocarbon generation potential using a plot of S_2 (representing hydrogen content) and TOC (representing carbon content) for selected Neogene mudrock samples, Carson Sink, Nevada. The sloping line on the plot has a slope of 3 which is equivalent to a hydrogen index of 300 (Langford and Blanc-Valleron, 1990).

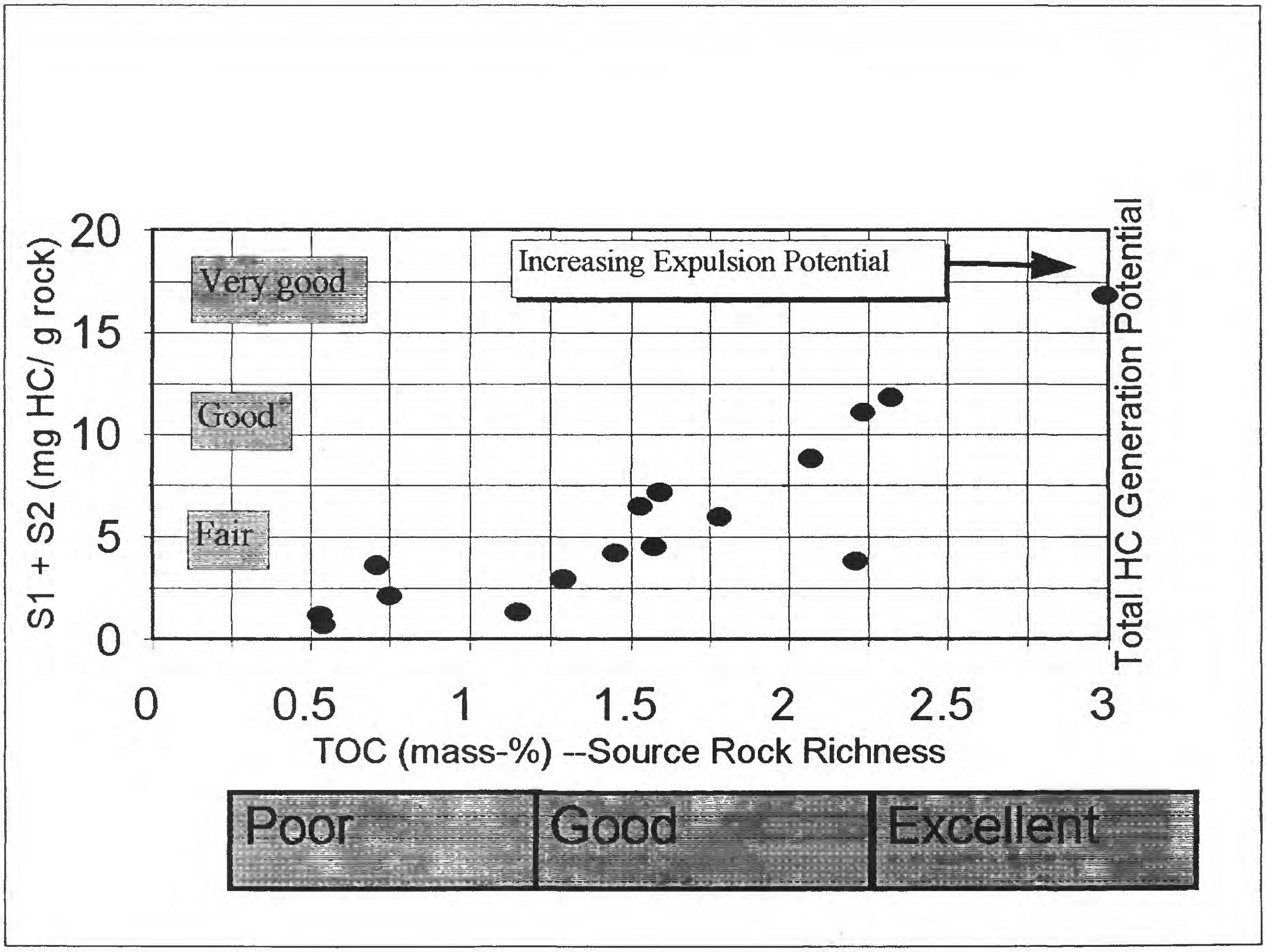


Figure 6. Genetic potential versus expulsion potential (represented by TOC), selected Neogene mudrock samples, Carson Sink, Nevada. Only well samples with over 0.5 mass-% TOC are shown. The arrow suggests how oil expulsion potential increases with genetic potential and TOC but is not quantitatively assessed by this figure. Note that oil prone organic matter at higher thermal maturation becomes gas prone.

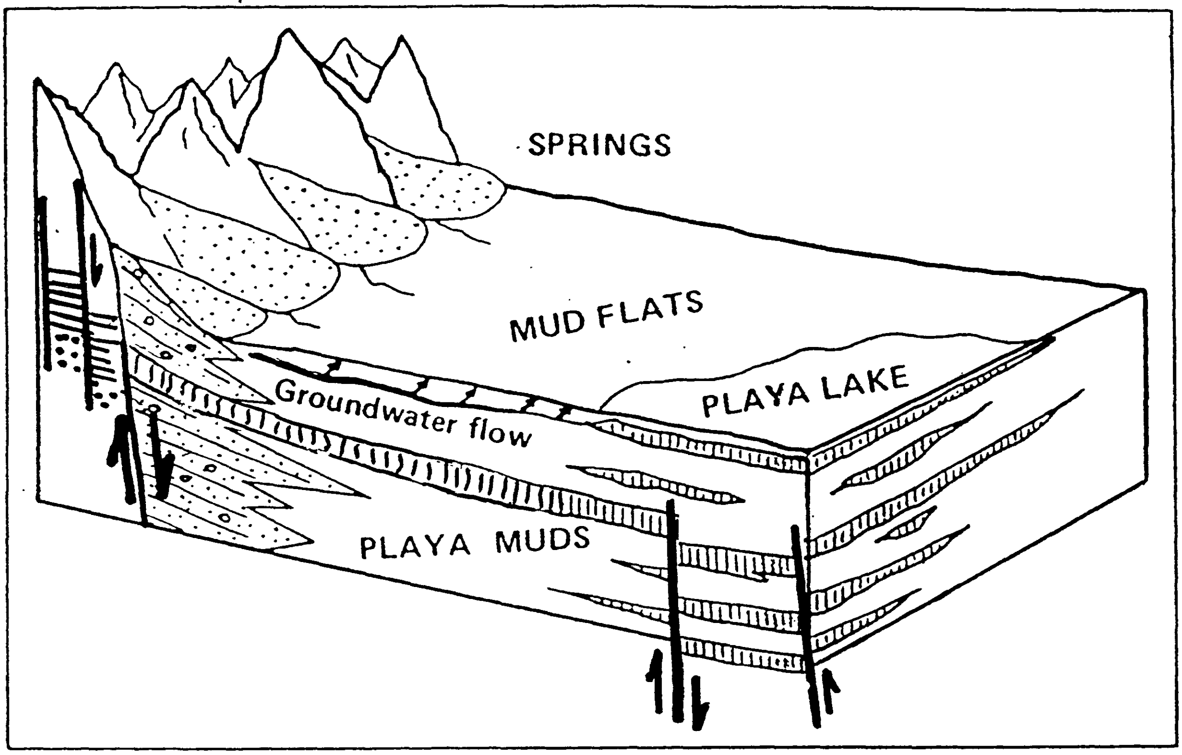


Figure 7. Model of reservoir seal and source rock relationships in Basin and Range type basins. Modified from Eugster and Hardie (1975). Algal limestones, marls, mudrocks and coals deposited in the playa muds and lake deposits apparently form the potential source rocks. Reservoirs are thought to be formed mostly by deltaic, fluvial and alluvial sands deposited by stream flow into the basins as well as fracturing and faulting of older rocks or by secondary porosity formed during diagenesis. Seals are mostly formed by primary deposition of muds, evaporites, secondary alteration of volcanic materials during diagenesis or faulting. Seals are represented by hatchered beds in the playa muds. See text for more discussion.

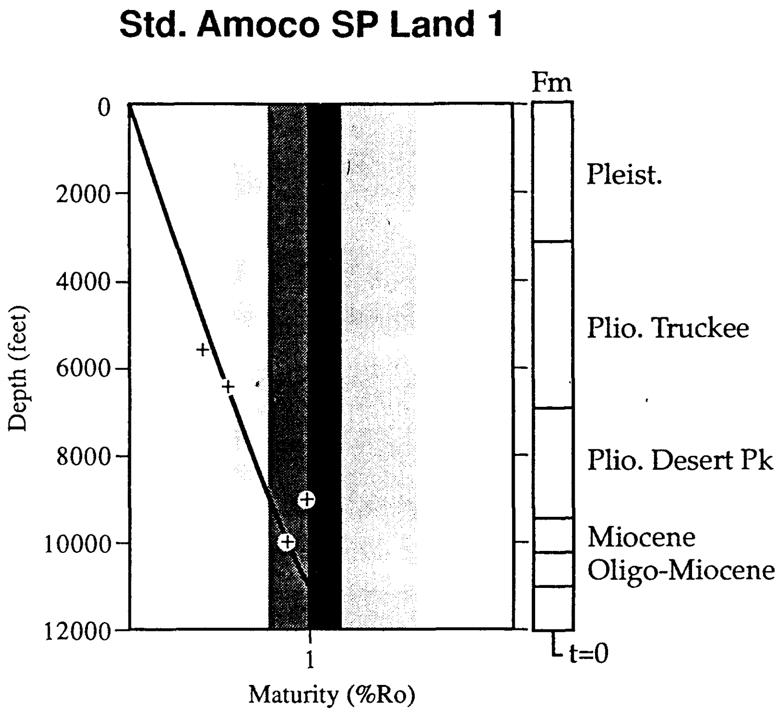
Thermochronologic Modeling of Selected Conceptual Plays

Source rock geochemistry results indicate that significant hydrocarbon potential is found only in the Neogene rocks. The conceptual plays based on Neogene source rocks whose thermochronologic modeling are presented below assume that an effective source rock exists in the play area and Neogene burial heating has caused hydrocarbon generation (Barker et al., 1995). Effective source rocks demonstrated by numerous oil shows that suggest the possibility of widespread oil generation and migration has occurred can only be identified in the Neogene basin fill of Carson Sink and Buena Vista Valleys. The oil show in Wagon Tire Spring and the one in Black Rock Desert may not be significant as they involve limited occurrences. The presence of the effective source rocks limits the thermochronologic modeling to the Neogene source rocks in these two areas.

Carson Sink

The thermochronologic modeling for this play used the formation tops reported for Standard Amoco S.P. Land Co. 1 well by Melhorn (Table 2). The well was drilled along the eastern border of the Carson Sink about 6 miles west from the front of the Stillwater Range which forms the eastern bounding range of the basin. The age of the formation tops were taken from Haq and Eysinga (1994). The heat flow was modeled within the measured range of 60 to 80 mW/m^2 (Sass et al., 1981) because the tectonic regime and, presumably the heat flow, has not changed since extension commenced in the early Pliocene. Mean annual surface temperatures were modeled as decreasing from 15°C at 25 Ma to 10°C at 10 Ma (Savin, 1977). The mean annual surface temperature was held constant at 10°C from 10 to 0 Ma consistent with the 10°C measured at present.

The predicted vitrinite reflectance and basin temperatures from the thermochronologic model generally fit well with the measured vitrinite reflectance (Fig. 8a) and measured borehole temperatures from drill stem test data (Fig. 8b). This model was therefore accepted as a reasonable predictive tool for describing the timing and depth of petroleum generation in the area. The thermochronologic model (Fig. 9) predicts that oil generation commences at about 3 Ma and about 8000 ft depth. Oil and gas shows from 8104 to 8208 ft (Garside, 1988) are consistent with the predicted onset of thermal hydrocarbon generation.



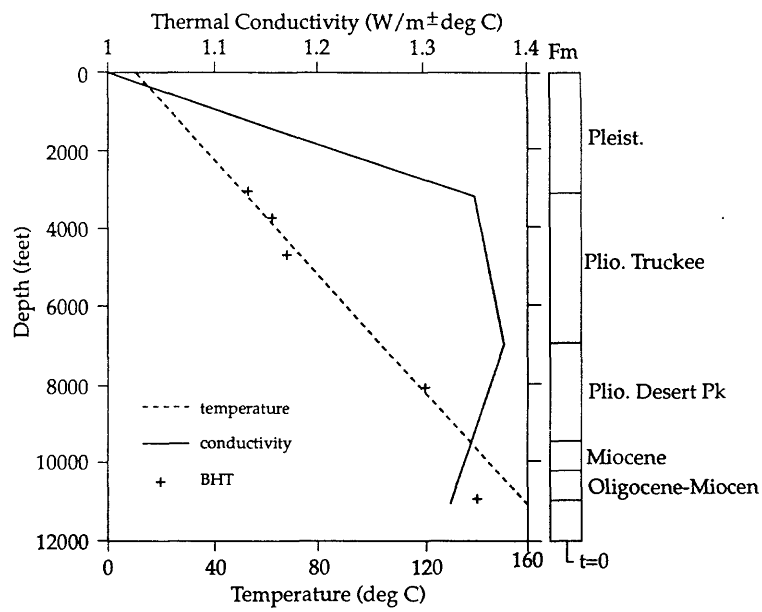


Figure 8. A. Comparison of predicted (solid line) and measured vitrinite reflectance (crosses), Standard Amoco S.P. Land Co. 1 well, Carson Sink, Nevada. The gray shaded areas represent from low to higher maturity; early, main, late and overmature rocks with respect to oil generation. B. Comparison of predicted versus measured borehole (BHT) temperatures from drill stem test data, Standard Amoco S.P. Land Co. 1 well, Carson Sink, Nevada.

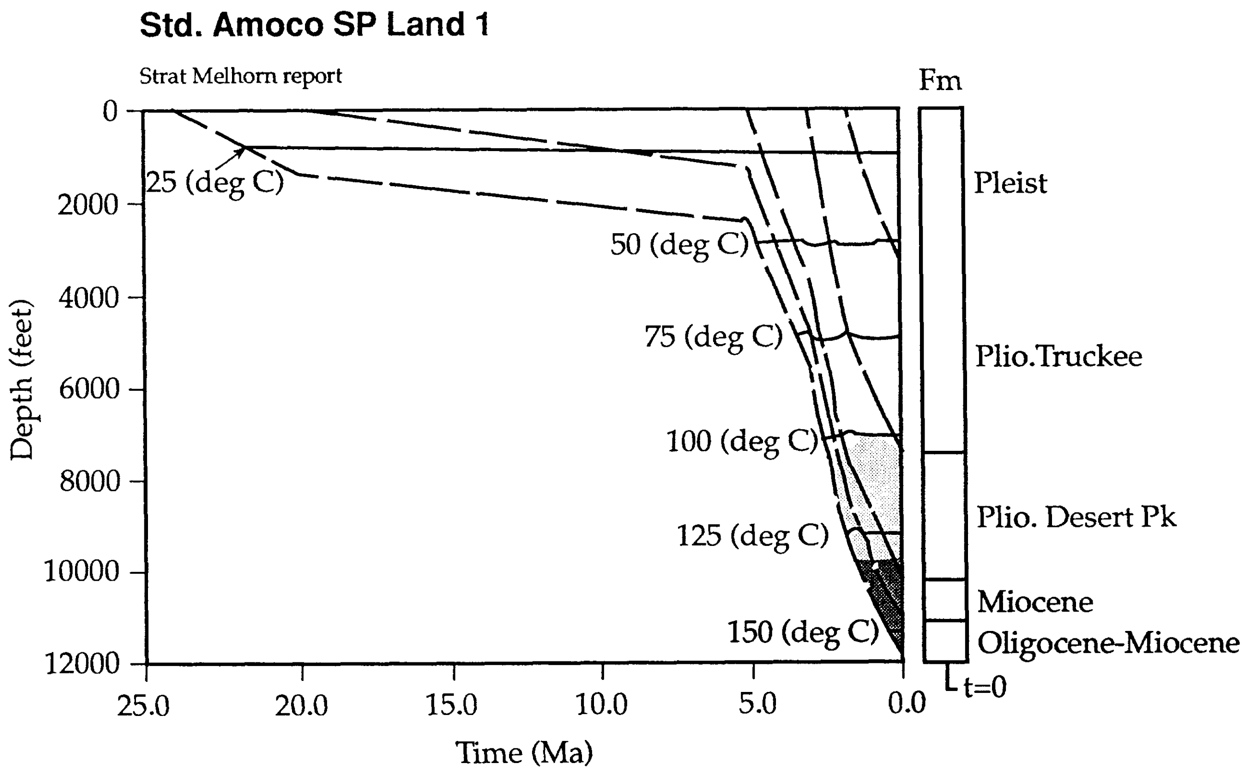


Figure 9. Thermochronologic model, Standard Amoco S.P. Land Co. 1 well, Carson Sink, Nevada. The light and medium gray shaded areas represent the early and main stages, respectively, of oil generation relative to vitrinite reflectance. Data given in Table 2 and in text. The long dashed line in the figure represents a formation curve. The solid line represents an isotherm.

Table 2. Thermochronologic modeling Data, Standard-Amoco S.P. Land Co. 1, Carson Sink, Nevada.

Formation and(or) strata age	Upper contact[1]	Estimated Formation age at Base[2] (Ma)	Strata thickness[3] (Feet)	Lithology for thermal conductivity modeling
Pleistocene	earth surface	1.7	3165	siltstone
Truckee, Pliocene	conformable	3	3785	siltstone
Desert Peak, Pliocene	conformable	5	2520	siltstone
Miocene	conformable	20	770	siltstone
Oligocene-Miocene	conformable	24	760	siltstone

Notes: 1. Assumed conformable in the absence of data to the contrary--see text for discussion; 2. Ages From Haq and Eysinga (1994); 3. Based on a report by Melhorn found in the files of the Nevada Bureau of Mines and Geology . Thicknesses given in the Melhorn report were modified by lumping some strata together.

Buena Vista Valley

There are no published well tops for a stratigraphic column for the Buena Vista Valley making thermochronologic modeling based on direct measurements in the valley impossible. However, the Cenozoic sedimentation history in the Buena Vista Valley is seemingly geologically related to that occurring in the Carson Sink since the Pliocene onset of Basin and Range formation. Because the thermochronologic model for the Carson Sink seems to be a good fit there, that model was adapted to fit the similar but thinner Neogene sedimentation that occurred in the Buena Vista Valley. The depth to base of the pre-Neogene is thought to be about 6,000 ft in the Buena Valley compared to 11,000 feet found in the Carson Sink within Standard-Amoco S.P. Land Co. 1 well (Jachens and Moring, 1990). Another difference between the two areas is that the measured heat flow in the Buena Vista Valley is about 100 mW/m^2. The influence of shallow burial is overwhelmed by the higher heat flow in the thermochronologic model. The model suggests oil generation commences at about 3 Ma and 4000 ft depth. The thermochronologic model suggests that the oil show in Kyle Hot Springs -1 well, at 741 ft depth and at the basin margin, if due to oil generation caused by burial heating, would require considerable vertical and lateral migration from the basin deep. Oil migration may be aided by the hydrothermal convection system related to Kyle Hot Springs. However, local oil generation caused by hydrothermal heating in the Kyle Hot springs geothermal system may also explain the oil show without invoking much migration.

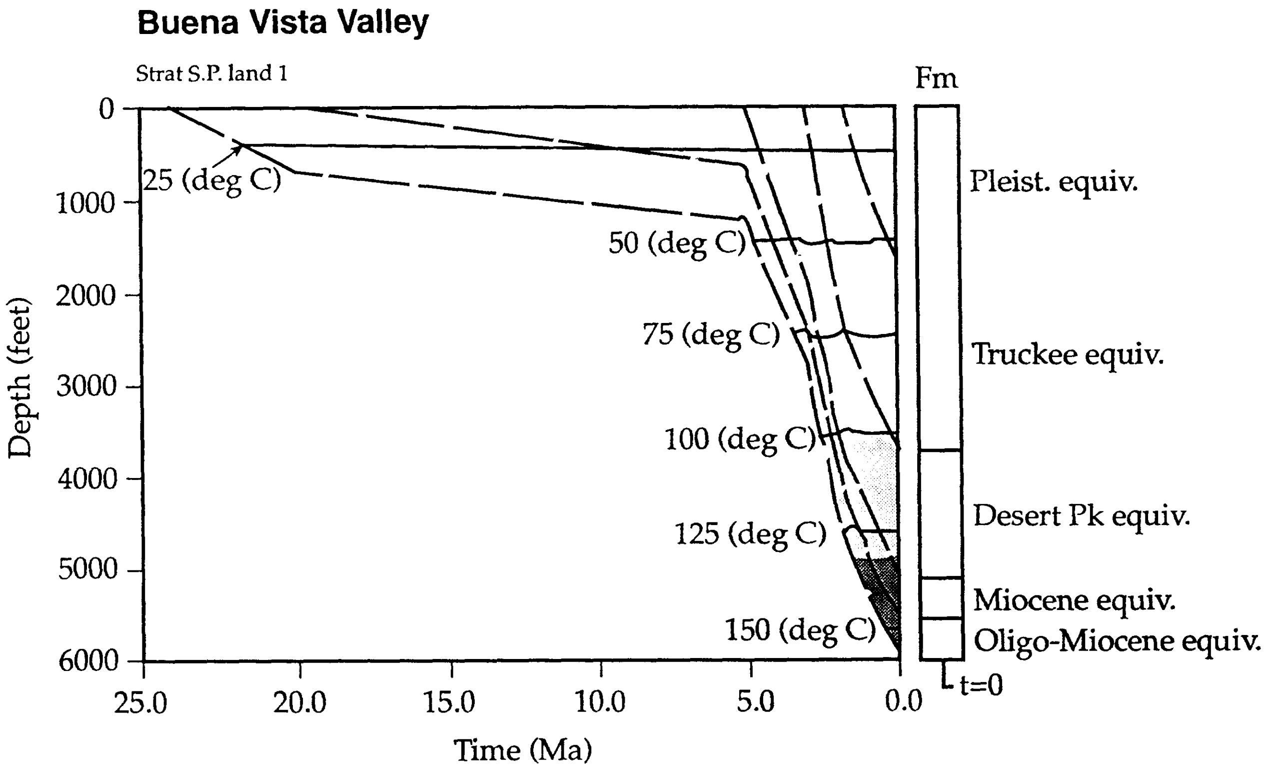


Figure 10. Thermochronologic modeling of the Buena Vista Valley, northwestern Nevada. The short dashed line in the figure represents temperature. The light and medium gray shaded areas represent the early and main stages, respectively, of oil generation relative to vitrinite reflectance. The long dashed line in the figure represents a formation curve. The solid line represents an isotherm.

Petroleum Potential Assessment

The plays identified by Barker et al. (1995) and used in this study (Fig. 1) are considered conceptual because they are based on a premise that source rocks do exist-- although thus far, they have only been identified in the Carson Sink within the Winnemucca and Surprise Resource Assessment Area. However, Cenozoic source rocks may be much more widespread in the Winnemucca and Surprise Resource Assessment Area than is currently known. The rationale is that moderate to high hydrogen content, moderate to high carbon content Neogene lacustrine source rocks have been found associated with extensional terrains in the northern Basin and Range Province like the Carson Sink, Nevada (Hastings, 1979); Buena Vista Valley, Nevada (Schalla et al., 1994) and at calderas at the Nevada Test Site in the central Basin and Range Province (Barker, 1993) . Other occurrences of potential source rocks are discussed by Schrader (1947); Wilden (1964); Bonham (1969); Moore (1969); Johnson, (1977); Albers and Stewart (1972); Wilden and Speed (1974); Stewart and McKee (1977); Bortz (1983), Garside (1983), Foster and Vincelette (1991) ; Frerichs and Pekarek (1994); Pekarek and Frerichs (1994) and Barker (1993). In some of these areas, effective source rocks have been demonstrated by oil and gas shows found in the Carson sink, Buena Vista Valley and perhaps the Black Rock Desert area (Fig. 3). Numerous gas shows are found in most Cenozoic basins of the Winnemucca and Surprise Area (Brady, 1984; not shown in detail on Fig. 3). The gas shows are thought to be largely biogenic in the shallow subsurface but deeper gas shows are possibly thermogenic in origin. A few oil shows and seeps are documented in the north and central portions of the Winnemucca and Surprise Area (Garside et al., 1988; Schalla et al., 1994). The oil shows in Cenozoic rocks are typically, and perhaps genetically, related to contact or hydrothermal metamorphism. All of the major plays have been tested by drilling but no commercial production has been established in the Winnemucca and Surprise Resource Assessment Area.

The outline of possible conceptual plays in the Winnemucca and Surprise Resource Assessment Area is based on the inferred presence of Neogene source rocks now buried in basins (Fig. 1). Oil and gas shows indicate that effective oil and gas source rocks exist. Thermochronologic modeling 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 Winnemucca and Surprise Resource Assessment Area based on numerous wildcat wells. Overall, the Winnemucca and Surprise Resource Assessment Area are considered permissive for small to medium size hydrocarbon discoveries (Fig. 1). Exceptions to this generalization are the Carson Sink and Buena Vista Valleys which are considered favorable. The Wagon Tire Spring oil seep is not associated with any known area of Neogene basin fill that could have caused oil generation by burial heating: the oil found there is thought to be related to local oil generation by contact metamorphism of lacustrine rocks exposed nearby. The basinal areas around Wagon Tire Spring are considered only to be permissive for small to medium size hydrocarbon discoveries mostly based on the oil shows reported in the Sun King Lear-1 Well drilled into the Black Rock Desert.

Conclusions

1. The better source rocks considered in this study are found in Neogene sedimentary basins like those in the Carson Sink area. Regional geologic studies suggest similar coal and lacustrine source rock deposits can locally occur in any similar basin throughout the northern Basin and Range Province.
2. Heating by deep burial in a moderate heat flow regime in the Carson Sink basin and moderate burial in a high heat flow regime in the Buena Vista Valley basin seems to be sufficient to generate thermogenic hydrocarbons commencing in the Pliocene and continuing to the Holocene. Oil and gas shows in these basins suggest effective source rocks exist in these basins.
3. Neogene basins in the Winnemucca and Surprise Resource Assessment Area are considered permissive for small to medium size hydrocarbon discoveries. Buena Vista Valley and Carson Sink basins are favorable.
4. Thermally mature Mesozoic lacustrine strata exposed in the Jackson Mountains and Mesozoic marine strata in the Southern Tobin Range and Augusta Mountains based on limited sampling program do not seem to have good source rock qualities.

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Appendix 1

Wells Examined for Potential Source Rocks

Winnemucca and Surprise Resource Assessment Area, Nevada and California

ABBREVIATIONS USED IN ALL APPENDICES

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

BHT = bottom hole temperature
Carb = Carbonaceous = visible DOM in a rock
Coaly = thin wisps or layers coal in a rock
Cyn = Canyon
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
Ls = limestone
mdst = mudrock
mtn = mountain
NA = Not available
PSI = pressure in pounds per square inch
rec = recovered
R_o = mean random reflectance of vitrinite or
R_b = mean random reflectance of solid bitumen, as indicated by asterisk.
sp = spring
ss = sandstone
T.D. = Total depth of well.
T= reported downhole temperature

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

Formation tops as reported in the well files of the Nevada Bureau of Mines and Geology or as noted.

Appendix 1.Wells examined for potential source rocks

Well/ API number/ county/ location	Elevations: Dates: spud/ completion	Tops: age and Formation, or age pick, and depth	Notes : DST and BHT data; casing points
American Thermal Resources Goodwin 1-11 /049-90010/ Modoc/ 11-42N-16E	NA 11-22-74 12-20-74	Tertiary silt, mudst, sand (lake beds) and conglomerate with occasional tuffs to T.D. at 7005 ft. No coal noted on mud log	BHT 242°F Numerous methane kicks detected in mud log.
Arco Antelope Valley 1/ 27-015-05005/ Lander/ NE-26-25N-40E/ Lat = 40.0163 °N Long = 117.43605 °W	4948 ft GR Spud: NA 1-13-85	Valley fill: 0 ft Tertiary tuff 1: 692 ft Tertiary tuff 2: 1250 ft Tertiary tuff 3: 2438 ft Pre-Tertiary: 2938 ft T.D. 4600 ft	The Pre-Tertiary strata looks hydrothermally altered and is locally cut by veins. Casing points: 12; 1204; 3271 ft
Arco Tobin 1/ 27-027-05000/ Lander/ NE-4-25N-39E/ Lat = 40.0534 °N Long = 117.61281 °W	3814 ft GR Spud: NA 12-6-84	Valley Fill: 0 ft Triassic: 406 ft (?) Paleozoic 2050 ft (?) T.D. 2065 ft (?) Tops listed elsewhere go to 3050 ft But drill cutting samples only go to 2065 ft	The Triassic strata is hydrothermally altered and heavily veined. BHT: 12-3-84 at 0130 hours, 1943 ft, 112°F; 12-3-84 at 0400 hours, 1940 ft, 114°F. Casing points: 121; 851 ft
Bendix ERDA Carson Sink 1/ NA/ Churchill/ SE-16-19N-27E Lat =NA Long =NA	4057 ft GR 4082 ft KB 2-1-77 3-8-77	Valley Fill: 0 ft Amoco found Pliocene, maybe Late Pliocene: 950 ft Basalt : 5260-70 ft-- Age dated at 11.9 ± 0.7 Ma. by Krueger Labs. T.D. 8487 ft	Multiple sidewall cores 2375-8352 ft; BHT reported as 242°F presumably at T.D. but unclear. Casing point: 699 ft
Chevron Ginn 1-13/NA/ Lander/ 13-31N-47E Lat = about 40.5 °N Long = 116.6 °W	about 5000 ft GR Dates: NA	Valley fill and Tertiary(Miocene?) mudrock ± volcanic rocks to 400 0 ft Ordovician-Upper plate of Roberts Mountain thrust to apparent T.D. at 6350 ft	Mostly hard, meta-mudrocks in well. This well is in the Beowave Geothermal field.
Chevron Kosmos 1-9/NA/ Washoe/ 9-29N-23E Lat = about 40.4 °N Long = about 119.4 °W	NA	Valley fill and Tertiary(?) mudrock to 5356 ft apparent T.D.	Mostly hard, meta-mudrocks in well. Rocks at T.D. have a phyllite-like sheen. This well is in the San Emidio Geothermal field.

Appendix 1.Wells examined for potential source rocks

Well/ API number/ county/ location	**Elevations: Dates: spud/ completion**	**Tops: age and Formation, or age pick, and depth**	**Notes : DST and BHT data; casing points**
Fallon Naval Air station FOH 2/ NA/ 36-18N-29E Lat = 39.393°N Long =118.680 °W	3918 ft GR 3923 ft KB NA	Lake beds: 0 ft Volcanics: 2223 ft T.D. 4488 ft In volcanics	BHT : 155°C
Gulf Surprise Valley 1-ST/ 049-90001/ Modoc/ 30-44N-16E	4682 ft GR 4692 ft KB 8-21-73 9-12-73	Mostly Tertiary (?) mudrock, sandstone and volcanics to T.D. at 6841 ft	BHT: 245°F at 6800 ft by Temperature log on 10-15-73 Casing points: 998; 6806 ft
Halbouty Federal 1/ 27-001-05063/ Churchill/ 14-17N-28E Lat =39.33054 °N Long =118.8127 °W	3927 ft GR 3943 ft KB Spud: NA 8-21-76	Based on diatoms: Holocene: 0 ft Pliocene: 100 ft Late Miocene: 960 ft Igneous: 2500 ft to T.D. T.D. 7074 ft on logs.	Numerous sidewall core Casing points: 521; 2983 ft
Haskin Reis Federal 1/ 27-001-05058/ Churchill/ SE-36-18N-30E Lat = 39.3729 °N Long = 118.55778 °W	3962 ft GR 1-1-90 1-15-90	Cenozoic to T.D. at 4117 ft	Casing point: 418 ft
Humboldt Associates Ellison 1/ 27-013-05001/ Humboldt/ SE-19-35N-42E Lat = 40.89334 °N Long =117.28423 °W	4400 ft GR Spud: NA 4-9-80	Upper Humboldt Formation: 0 ft to T.D. at 986 ft	
Independence Mining Co. Kyle Hot Springs 1/ NA/ Pershing/ SW-12-29N-36E Lat = 40.3977 °N Long =117.8895 °W (by non-precise GPS)	4430 ft GR 1994	Well inclined 44° --true depths shown. Alluvium and sinter: 0 ft Tertiary Volcanics: 17 ft Triassic: 292 ft T.D. 747 ft.	Oil shows reported near 741 ft (Neumann and Ehny, 1994).

Appendix 1. Wells examined for potential source rocks

Well/ API number/ county/ location	Elevations: Dates: spud/ completion	Tops: age and Formation, or age pick, with depth	Notes : DST and BHT data; casing points
Nevada VRS 1/ 27-009-05201/ Esmeralda/ NE-16-1S-36E/ Lat =37.8591 °N Long = 117.97810 °W	4754 ft KB Spud: NA 11-25-70	Valley fill: 0 ft Volcanics: 5000 ft Metasediments: encountered at about 6700 ft T.D. 9178 ft	Casing points 30; 536 ft BHT 318°F
Ouida Dixie 1/ 27-027-05003/ Pershing/ NE-25-25N-37E Lat = NA Long =NA	3492 ft GR 3510 KB 1994-1995	NA. Reportedly hit Triassic rocks below valley fill.	Testing Triassic Favret in the northern portion of Dixie Valley
Standard-Amoco S.P. Land Co. 1/ 27-001-05062/ Churchill/ NW-33-24N-33E Lat =39.91147 °N Long =118.28409 °W	3900 ft GR 7-19-74 10-10-74	Quaternary lake beds: 0 ft Pliocene Truckee: 3165 ft Pliocene Desert Peak : 6950 ft Miocene: 9470 ft Oligocene-Miocene: 10240 ft T.D. 11000 ft	Numerous cores. DST 1: 8104-8208 ft rec 500 ft of 16000 ppm brine. T = 248°F DST 2: 10810-11000 ft. Rec. 3700 ft of fluid; minor ga show. FHP 5888 psi DST 3: 4708-4735 ft rec 100 ft fluid. T = 154°F. DST 4: 3070-3708 ft rec 1850 ft of slightly gas cut fluid. T = 129°F at 3070 ft and 144°F at 3708 ft. FHP= 1885 psi DST 5: failed DST 6: 3070-3708 ft rec 2810 ft of 23,000 ppm brine. T = 126°F at 3070 ft and 155°F at 3708 ft. FHP = 1659 psi. Oil and gas shows reported 8104 to 8208 ft (Garside, et al., 1988). Oil in core reported at 8168 ft (Hastings, 1979). Casing points: 73; 372; 874; 3076 ft

Appendix 1. Wells examined for potential source rocks

Well/ API number/ county/ location	**Elevations: Dates: spud/ completion**	**Tops: age and Formation, or age pick, and depth**	**Notes : DST and BHT data; casing points**
Sun King Lear Federal 1-17/ 27-013-05002/ Humboldt/ SW-17-37N-29E Lat = 41.0927°N Long = 118.70505 °W	3950 ft GR 4-21-83 6-4-83	Only approximate tops available: Valley Fill + Volcanics: 0 ft Tertiary +Mesozoic: 5500 ft Paleozoic limestone (?): about 7000 ft plutonic rock (?): >7100 ft T.D. 7931 ft	Oil show reported at 6880-7052 ft DST 1: 6880-6920 ft FHP 3255 psi, T = 218°F DST 2: 6894-6930 ft FHP 3307 psi, no T DST 3: 6986-7060 ft packer failed. T = 310°F DST 4: 6990-7060 ft FHP 3268 psi. T = 327°F Numerous cores. Casing points: 1498, 6019 ft
Thermal Power Co. Dixie Federal 45-14/ 27-001-90025 Churchill/ SW-14-23N-35E Lat = 39.86142 °N Long =118.01164 °W	3410 ft GR 3432 ft KB 4-25-79 7-10-79	Valley fill: 0 ft Tuff: 1100 ft Tertiary(?) mudrock: 2500 ft T.D. 9022 ft	Casing points: 120, 1330, 5398, 6290 ft BHT: 385°F: 6-29-79 BHT: 379°F: 7-24-79
USGS Fish Lake Valley core hole no. 1/ NA Esmeralda 25-2S-35E Lat =37.7365 °N Long = 118.0128°W	NA 1991 (?)	Holocene peat and mudrock: 0 ft to T.D. at 37 ft	
USGS Fish Lake Valley core hole no. 7/NA Esmeralda 25-2S-35E Lat = 37.7459 °N Long = 118.0450 °W	NA 1991 (?)	Holocene peat: and mudrock: 0 ft to T.D. at 33 ft	

Appendix 2.

Potential Source Rocks Exposed at the Surface:
Location and Geological Information for Selected Samples

Winnemucca and Surprise Resource Assessment Area, Nevada and California

Appendix 2. Potential source rocks sampled at the surface, Northwestern Nevada

Sample or API number/ well or locality	Latitude Longitude	Age/ Formation/ lithology	Notes
SURFACE SAMPLES			
93-NV-TR-1/ Augusta Mountains	39.8760°N 117.5245°W	Triassic/NA/ gray limestone	Sample from wash at South end of Augusta Mountains
93-NV-TR-2/ Augusta Mountains	39.8762°N 117.5252°W	Triassic/NA/ gray Fetid limestone	Sample from wash at South end of Augusta Mountains.
93-NV-TR-3/ Augusta Mountains	39.8775°N 117.5273°W	Triassic/NA/ gray limestone	Sample from wash at South end of Augusta Mountains
93-NV-TR-4a/ Augusta Mountains	40.0033°N 117.5500°W	Triassic/Favret/ gray limestone	Sample from Favret Canyon
93-NV-TR-5/ Augusta Mountains	40.0567°N 117.5478°W	Triassic/Favret/ gray limestone	Sample from Favret Canyon
93-NV-TR-6/ Augusta Mountains	40.0033°N 117.5485°W	Triassic/Favret/ gray limestone	Sample from Favret Canyon
CB-NV-95-1a/ Black Jack mine, Humboldt Range	40.5224°N 118.2105°W	Triassic/Prida/ gray fetid limestone	Mine on the west side of Humboldt Range. Sample from the larger open pit.
CB-NV-95-1b/ Black Jack mine	40.5224°N 118.2105°W	Triassic/Prida/ black mudrock	As above.
CB-NV-95-2/ Tobin Range	40.1539°N 118.2105°W	Triassic/Prida/ black limestone	Laminated Stromatolitic(?) limestone near base of unit.
CB-NV-95-3/ Tobin Range	40.1553°N 117.5892°W	Triassic/Prida/ gray limestone	sample about 100 feet above base of the unit.
CB-NV-95-4/ Just NNE of Imlay, Nevada	40.6657°N 118.1501°W	Holocene/NA/oil soaked dune sand	Reported oil seep in "Tar Flat" appears to be oil sprayed on dune sands.
CB-NV-95-5/ Seven Troughs Range	40.7685°N 118.7274°W	Neogene/NA/ mudrock, lacustrine?	In eroded beds exposed on the north end of the range.
CB-NV-95-6/ Ten Mile Hills	40.9744°N 117.9214°W	Triassic/Prida/ phyllitic mudrock	Sample from mine entrance. Some coaly debris on bedding planes.

Appendix 2. Potential source rocks sampled at the surface, Northwestern Nevada

Sample or API number/ well or locality	Latitude Longitude	Age/ Formation/ lithology	Notes
SURFACE SAMPLES			
CB-NV-95-7/ Able Canyon	**40.9990°N 118.0598°W**	**Triassic/NA/ dark gray mudrock**	**Sample from mine shaft at the head of Able Canyon**
CB-N-V95-8/ Jackson Mountains	**41.29328°N 118.4577°W**	**Jurassic-Cretaceous/King Lear/ dark gray mudrock**	**Sample from shallow road cut on the saddle between Jackson and Trout Creek.**
CB-NV-95-9/ Jackson Mountains	**41.2878°N 118.4590°W**	**Jurassic-Cretaceous/King Lear/ dark gray mudrock**	**Sample from shallow road cut on the saddle between Jackson and Trout Creek.**
CB-NV-95-10/ Jackson Mountains	**41.2878°N 118.4590°W**	**Jurassic-Cretaceous/King Lear/ dark gray mudrock**	**On access road to the Red Bird Mine.**
CB-NV-95-11/	**40.8898°N 118.4869°W**	**Triassic/NA/ med. gray phyllite**	
Miller-1 Winnemucca Area	**40.7969°N 117.9058°W**	**Triassic/NA/ black limestone**	**Collected by Mike Miller, U.S. Bureau of Mines.**
Miller-2 Winnemucca Area	**40.1022°N 117.7483°W**	**Triassic/NA/ black limestone**	**Collected by Mike Miller, U.S. Bureau of Mines.**
Miller-3 Winnemucca Area	**40.6778°N 117.2031°W**	**Triassic/NA/ black limestone**	**Collected by Mike Miller, U.S. Bureau of Mines.**
Miller-4 Winnemucca Area	**40.0775°N 117.8192°W**	**Triassic/NA/ black limestone**	**Collected by Mike Miller, U.S. Bureau of Mines.**
Miller-5 Winnemucca Area	**40.6719°N 117.8561°W**	**Triassic/NA/ black limestone**	**Collected by Mike Miller, U.S. Bureau of Mines.**
Miller-6 Winnemucca Area	**40.6575°N 117.2214°W**	**Triassic/NA/ black limestone**	**Collected by Mike Miller, U.S. Bureau of Mines.**

Appendix 2. Potential source rocks sampled at the surface, Northwestern Nevada

Sample or API number/ well or locality	Latitude Longitude	Age/ Formation/ lithology	Notes
SURFACE SAMPLES			
1a/Coaldale	38.0028°N 117.8778°W	Miocene-Pliocene/ Esmeralda/ Coal -"C" bed	Coal sample collected by Larry Garside. See Garside and Papke (1980).
2b/Coaldale	37.9972°N 117.8778°W	Miocene-Pliocene/ Esmeralda/ Coal-"D" bed	As above
3b/Coaldale	38.0028°N 117.8778°W	Miocene-Pliocene/ Esmeralda/ Coal- "C" bed	As above
1a or 2a/ Eldorado Canyon	39.10278°N 119.5583°W	Miocene/ unnamed/Coal	As above
1b/Gamma	39.2097°N 117.7806°W	Miocene/ unnamed/Coal	As above
1a or 2a/ Lewis	38.5111°N 118.9139°W	Pliocene/ Coal Valley/ Coal	As above
1b, 1c/Verdi	39.5306°N 119.9583°W	Tertiary/ unnamed/ coal	As above
2b, 2c/Verdi	39.5333°N 119.9611°W	Tertiary/ unnamed/ coal	As above

Appendix 3.

Potential Source Rock--Geochemistry and Thermal Maturation
Results of Vitrinite Reflectance and Rock-Eval analyses,
Winnemucca and Surprise Resource Assessment Area, Nevada and California

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/S3 which is a measure of the H/C ratio of the organic matter.

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

Notes

1. Formation names as listed in the well files of the Nevada Bureau of Mines and Geology, Reno, Nevada.

2. For more analytical data on the surface coal samples refer to Garside and Papke (1980).

Sample type and locality - or- Well name and sample depth interval (in feet)	Rock type/ Age -or- Formation	Ro mean * =Rb (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsius	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO2/ g rock	S2/S3 HC/CO2	TOC mass-%	HI mgHC/ g C

Notes:

1. Rock-Eval results for samples that contained less than 0.5 mass-% TOC are not reported
2. * denotes mean random reflectance measured on solid bitumen particles.
3. This table includes revised data from Barker et al. (1994)
4. Well samples are from drill cuttings except where noted as core.

Surface Samples

CBNV95-1A	Fetid Ls /Prida									0.08	
CBNV95-1B	Black mdst/Prida	5.14*	NA	1						0.7	
CBNV95-2	Black Ls/Prida	Barren								0.0	
CBNV95-3	Ls/Prida	0.76*	NA	1						0.03	
CBNV95-4	Oil-soaked dune sand/ Holocene	NA			Not analyzed by Rock-Eval						
CBNV95-5	Gray mdst/Tertiary	0.27	0.03	8						0.06	
CBNV95-6	Meta-mdst/Prida	1.48	0.34	15						0.02	
CBNV95-7	Black mdst/Triassic	2.04	NA	1						0.02	
CBNV95-8	Gray mdst/King Lear				457	0	0.01	0.19	0.05	0.56	1
CBNV95-9	Gray mdst/King Lear									0.22	
CBNV95-10	Gray mdst/King Lear	2.67	0.32	25	NA	0	0	0.18	0.00	0.76	0
CBNV95-11	Phyllite/Triassic									0.14	
93NVTR-1	Gray Ls/ Triassic									0	
93NVTR-2	Gray Ls/ Triassic									0	
93NVTR-3	Gray Ls/ Triassic									0	
93NVTR-4A	Black Ls/ Favret	1.85*	NA	1						0.15	
93NVTR-5	Black Ls/ Favret	0.25	0.02	2						0.23	
93NVTR-6	Black Ls/ Favret	0.20	0.05	18						0.25	

Sample type and locality - or- Well name and sample depth interval (in feet)	Rock type/ Age -or- Formation	Ro mean * =Rb (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsius	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO2/ g rock	S2/S3 HC/CO2	TOC mass-%	HI mgHC/ g C
MILLER 1	**Black Ls/Triassic**									0	
MILLER 2	**Black Ls/Triassic**	1.17	0.09	2						0.17	
MILLER 3	**Black Ls/Triassic**	2.34*	0.8	14						0.16	
MILLER 4	**Black Ls/Triassic**									0.22	
MILLER 5	**Black Ls/Triassic**									0	
MILLER 6	**Black Ls/Triassic**									0	
Surface Samples											
Coal											
Lewis 1A	Coal/Pliocene **Coal** Valley				403	0.25	22.85	31.93	0.71	36.95	61
Leiws 2A	Coal/Pliocene **Coal** Valley	0.39	0.03	29	406	0.43	40.35	36.54	1.10	45.22	89
Coaldale 1A	Coal/Miocene-**Pliocene** Esmeralda	0.62	0.03	30	431	0.32	22.9	12.5	1.83	24.59	93
Coaldale 2B	Coal/Miocene-**Pliocene** Esmeralda				431	0.38	52.01	16.53	3.14	54.4	95
Coaldale 3B	Coal/Miocene-**Pliocene** Esmeralda	0.56	0.04	31	430	0.86	122.36	4.17	29.34	33.89	361
Gamma 1B	**Coal/Miocene**	0.31	0.02	30	416	0.89	25.31	35.58	0.71	21.73	116
El Dorado Cyn 1A	**Coal/Miocene**				424	0.48	86.02	37.59	2.28	55.72	154
El Dorado Cyn 2A	**Coal/Miocene**	0.36	0.04	27	422	0.31	81.89	28.21	2.90	45.31	180
Verdi 1B	**Coal/Tertiary**	0.28	0.03	16	431	0.38	72.53	34.8	2.08	44.37	163
Verdi 1C	**Coal/Tertiary**				436	0.09	70.65	40.37	1.75	50.5	139
Verdi 2B	**Coal/Tertiary**				434	0.3	21.43	20.3	1.05	23.37	91
Verdi 2C	**Coal/Tertiary**				420	0.16	69.83	37.33	1.87	52.94	131
Well Samples											
Arco Antelope Valley 1											
3140-3150	Medium **gray mdst/ Triassic** (?)				439	0.19	0.91	0.64	1.42	0.91	100
4220-4240	Medium **gray mdst/ Triassic** (?)				NA	0.11	0.34	0.56	0.60	0.69	49

Appendix 3 Page 2

Sample type and locality - or- Well name and sample depth interval (in feet)	**Rock type/ Age -or- Formation**	Ro mean * =Rb (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsius	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO2/ g rock	S2/S3 HC/CO2	TOC mass- %	HI mgHC/ g C
4290-4310	Dark gray **carb. mdst/** Triassic (?)				NA	0.1	0.28	0.47	0.59	0.52	53
4590-4600	Medium **gray ss/ Triassic** (?)									0.24	
Arco Tobin 1											
1050-1070	Medium **gray Ls/** Triassic (?)									0.07	
1880-1890	Medium **gray Ls/** Triassic (?)				NA	0.07	0.31	0.47	0.65	0.55	56
Haskin Reis Federal 1											
790-800	Light **gray ss/** Tertiary									0.05	
1270-1290	medium **gray ss/** Tertiary				443	0.55	3.09	0.75	4.12	0.71	435
3370-3380	Dark **gray mdst/** Tertiary									0.44	
4020-4030	**NA / Tertiary**									0.07	
Standard Amoco S.P. Land Co. 1											
2380	Light **gray mdst/Pleistocene**				432	0.1	4.12	1.79	2.30	1.45	284
2900	Light **gray mdst/ Pleistocene**				423	0.1	4.41	1.71	2.57	1.57	280
3020	Light **gray mdst/ Pleistocene**				423	0.1	3.71	1.61	2.30	2.21	167
3180	Light **gray mdst/** Truckee				428	0.2	11.65	4.28	2.72	2.32	502
3400-3420	Light **gray mdst/** Truckee				431	0.1	16.75	4.05	4.13	2.99	560
3840	**NA / Truckee**				443	0.1	10.98	1.51	7.27	2.23	492
5320-5330	Light **gray mdst/** Truckee				440	0.0	6.45	0.88	8.19	1.53	421
5510-5520	Selected **coaly pieces/** Truckee				420	0.19	19.12	28.15	0.67	29.98	63
5510-5520	Bulk **gray mdst/** Truckee				437	0.1	7.05	0.86	7.32	1.59	443
6400-6410	Selected **coaly pieces/** Truckee				430	0.56	31.38	6.22	5.04	13.85	226
6410-6420	Medium **gray mdst/** Truckee				430	0.0	1.37	0.6	2.28	1.15	119
7700-7710	Medium **gray mdst/ Desert** Peak				453	0.0	0.71	0.68	1.04	0.54	131

Sample type and locality - or- Well name and sample depth interval (in feet)	Rock type/ Age -or- Formation	Ro mean * =Rb (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsius	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO2/ g rock	S2/S3 HC/CO2	TOC mass-%	HI mgHC/ g C
9129-core	Bulk mdst/ Desert Peak									0.13	
9129-core	Selected gray mdst/ Desert Peak	0.94	0	2	342	0.01	0.2	0.27	0.74	0.1	200
10130-10150	Coal for reflectance only/ Miocene	0.82	0.09	22	NA	NA	NA	NA	NA	NA	NA
Bendix ERDA Carson Sink 1											
2900-3100	NA-composite sample/ Tertiary				422	0.81	5.17	1.66	3.11	1.78	290
3400-3500	NA-composite sample/ Tertiary				427	0.62	8.2	1.24	6.62	2.07	396
3700-3750	NA-composite sample/ Tertiary				431	0.41	2.54	1.34	1.89	1.29	197
Halbouty Federal 1											
1100-1200	NA-composite sample/ Tertiary									0.34	
1800-1900	NA-composite sample/ Tertiary				423	0.39	0.81	0.82	0.98	0.53	152
2000-2100	NA-composite sample/ Tertiary				426	0.51	1.64	1.13	1.45	0.75	218
2200-2300	NA-composite sample/ Tertiary									0.31	
Haskin Reis Federal 1											
790-800	Light gray ss/ Tertiary									0.05	
1270-1290	Medium gray ss/ Tertiary				443	0.55	3.09	0.75	4.12	0.71	435
3370-3380	Dark gray mdst/ Tertiary									0.44	
4020-4030	Dark gray mdst/ Tertiary									0.07	
Sun King Lear Federal 1-17											
6030-6050	Selected coal pieces/ Cretaceous(?)				432	1.05	230.17	14.38	16.00	72.55	317
6030-6050 (rerun)	Selected coal pieces/ Cretaceous(?)	0.50	0.04	31	434	1.66	190.59	7.73	24.65	67.75	281
6900	Medium gray mdst/ Cretaceous (?)				431	0.14	0.81	1.37	0.59	0.56	144
6900-7000	Medium gray mdst/ Cretaceous(?)				444	1.02	8.02	1.64	4.89	1.59	504

Sample type and locality - or- Well name and sample depth interval (in feet)	**Rock type/ Age -or- Formation**	Ro mean * =Rb (%)	Ro std. dev. (%)	Ro sample size	Tmax Celsius	S1 mgHC/ g rock	S2 mgHC/ g rock	S3 mg CO2/ g rock	S2/S3 HC/CO2	TOC mass- %	HI mgHC/ g C
Nevada Oil and Gas VRS 1											
5900-5920	Dark gray **phyllite/** Triassic(?)				529	0.23	0.56	0.35	1.6	2.61	21
5900-5920-rerun	Dark gray **phyllite/** Triassic(?)	4.88*	1.27	19	424	0.56	1.47	1.08	1.36	2.54	57
6690-6700	Dark gray **phyllite/** Triassic(?)				445	0.02	0.14	0.26	0.53	0.34	41
Fallon Naval Air Station FOH-2											
2042-2044-core	**Coaly mdst/ Tertiary**	0.39	0.02	27	412	0.32	6.28	10.54	0.59	8.44	74
2143-core	**Coaly mdst/ Tertiary**	0.52	0.03	31	434	0	1.38	2.59	0.53	3.08	44
2191-core	**Coaly mdst/ Tertiary**	0.49	0.03	30	425	0.07	4.26	8.54	0.49	9.25	46
Independence Kyle Hot Spring -1											
875-880	**Marl/ Triassic**	Barren								0.08	
985-990	**Marl/Triassic**	0.76	0.12	6						0.41	
1045-1050	**Mdst/ Triassic**	Barren								0.13	
1065-1070	**meta-Ls (?)/ Triassic**	Barren								0.08	
Thermal Power Dixie Federal 45-14											
2580-2620	**Mdst (?)/ Tertiary**	2.80	0.82	2							
3000-3100	**Mdst (?)/ Tertiary**	3.24	0.84	3							