MAJOR EPISODES OF PETROLEUM GENERATION IN PART OF THE NORTHERN GREAT BASIN

Forrest G. Poole, George E. Claypool, and Thomas D. Fouch

U.S. Geological Survey, Denver, Colorado 80225

ABSTRACT

Petroleum source beds in the northern Great Basin include marine Paleozoic rocks and nonmarine upper Mesozoic and lower Cenozoic rocks. The organic matter, which is mostly sapropel, ranges from thermally submature through postmature in the Paleozoic rocks, but is mostly submature to mature in the Cretaceous through Tertiary rocks. A discontinuity in thermal maturity occurs between Paleozoic and Cretaceous-Tertiary rocks in uplifted terrains, whereas a more continuous kerogen-maturation profile exists across the Paleozoic and Cretaceous-Paleogene rock boundary in east-central Nevada where these strata are deeply buried beneath Neogene rocks. These data indicate at least two episodes of petroleum generation in the Great Basin region.

INTRODUCTION

Oil and gas shows have been reported in many exploratory wells in the northern Great Basin. Known petroleum accumulations occur in sedimentary and (or) volcanic-rock reservoirs in Railroad Valley in east-central Nevada, in Pine Valley and Huntington Valley in north-central Nevada, and at Rozel Point in northwestern Utah. Most of the petroleum found prior to 1982 is in fractured-rock reservoirs in Paleogene ash-flow tuffs, and in sedimentary beds composing downfaulted blocks that are buried beneath Neogene and Quaternary deposits of intermontane basins. The downthrown blocks that contain petroleum are contiguous with rocks rich in organic matter.

This report briefly describes probable, possible, and potential source beds and their depositional settings, their organic maturation stages, and their rock-temperature history. These data indicate multiple episodes of petroleum generation in part of the northern Basin and Range Province (fig. 1). The conclusions in this report are based on our published and unpublished data.

SOURCE BEDS AND DEPOSITIONAL SETTINGS

Figure 2 shows the principal formations in the Roberts Mountains allochthon in the western part of the area that contain potential or

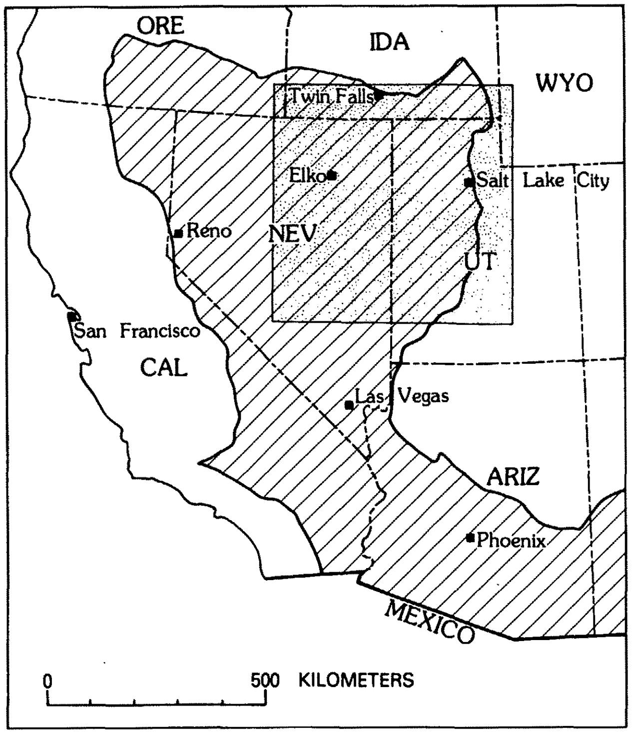

Figure 1. Index map showing extent of the Basin and Range Province (slanted-line pattern) in the Western United States and the area (stippled pattern) that contains evidence of multiple episodes of petroleum generation.

possible petroleum source beds. Solid circles after the formation names indicate submature sapropelic organic-rich marine beds. Oil-shale units occur within the Vinini and Woodruff Formations in central and northern Nevada. The eugeosynclinal Ordovician Vinini and Devonian Woodruff Formations are believed by us to be continental-rise deposits. The depositional environment and structural setting of the eugeosynclinal-like Lower Mississippian Webb Formation has not been established. Most of the Webb, which was deposited during the early stages of the Antler orogeny, is lithologically similar to pre-Mississippian continental-rise deposits exposed in the Antler orogenic belt.

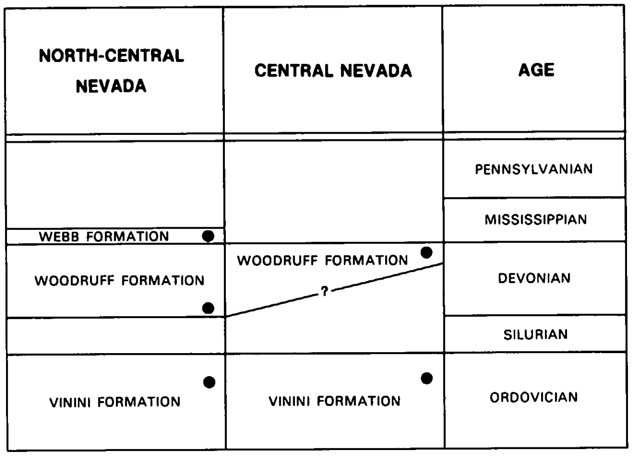

Figure 2. Chart showing principal formations in the Roberts Mountains allochthon that contain petroleum source rocks (solid circles).

Figure 3 shows principal Mississippian formations in the region that contain possible or probable (that is, correlated with oil) petroleum source beds. Solid circles indicate submature to supermature sapropelic to humic organically rich marine beds. In the left column of figure 3, the Chainman Shale and Dale Canyon Formation represent flysch-trough deposits in the western part of the Mississippian Antler foreland basin (Poole and Sandberg, 1977). In the right-center and right column of figure 3 the lower phosphatic members of the Chainman Shale and of the Deseret Limestone represent starved-basin deposits related to the westward prograding Lower Mississippian carbonate bank (Poole and Sandberg, 1977). These starved-basin deposits are along the west side of the carbonate bank in the eastern part of the Antler foreland basin. The concretionary shale member of the Chainman in the right-center column on figure 3 represents starved-basin deposits related to the westward prograding carbonate bank deposits of the Upper Mississippian Great Blue Limestone. By very Late Mississippian time, prodelta deposits in the upper Chainman Shale covered much of the central and eastern part of the Antler foreland basin between the delta systems on the west and the carbonate bank on the east (Poole, 1981). In eastern Nevada (fig. 3, left-center column), the prodelta Chainman Shale contains several organically rich units below the delta-front Scotty Wash Quartzite. Many dense limestone concretions and beds in the Chainman Shale below the Scotty Wash contain oil in open fractures, vugs, and fossil cavities.

Figure 4 shows the principal Cretaceous and Tertiary formations in the area that contain potential or possible petroleum source beds. Solid circles indicate submature sapropelic organic-rich lacustrine beds (Fouch, Hanley, and Forester, 1979). A 3-cm-thick layer of oil shale in the Tertiary Elko Formation near the old Catlin retort site south of Elko, Nevada, yielded 75 gallons of oil per ton of rock.

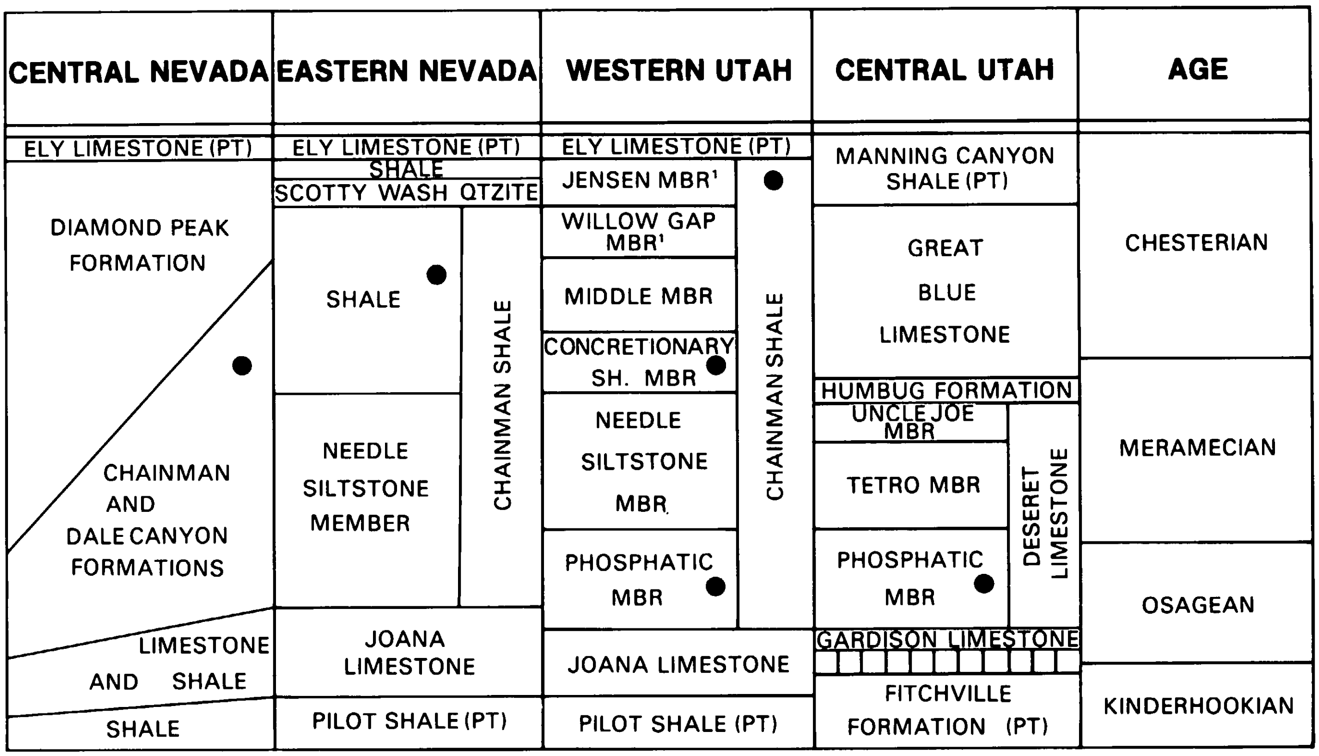

Figure 3. Chart showing principal units in the Mississippian Antler foreland-basin sequence that contain petroleum source rocks (solid circles).

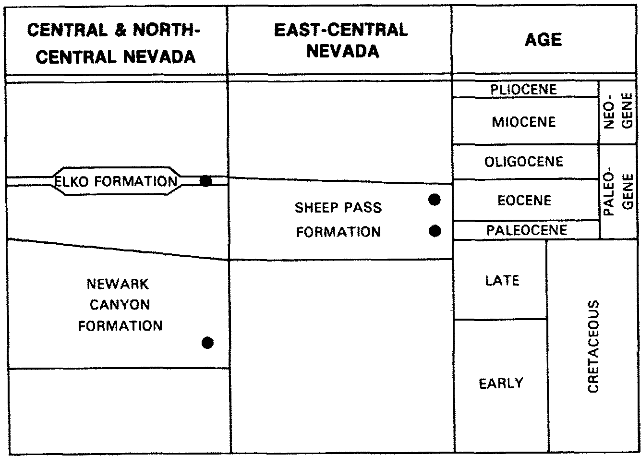

Figure 4. Chart showing principal formations in Cretaceous and Tertiary lake-basin deposits that contain petroleum source rocks (solid circles).

ORGANIC MATURATION STAGES AND ROCK-TEMPERATURE HISTORY

Figure 5 is a generalized map showing the maximum temperatures that some outcropping and subsurface Paleozoic rocks have been subjected to since deposition. Temperature data are not available for Paleozoic rocks in many areas. All available organic maturation data on Ordovician to Permian rocks have been integrated on the map (fig. 5). Although maturation stages in upper Paleozoic and lower Mesozoic formations generally record a lower temperature history than lower Paleozoic formations, there are certain localities where apparent reversals occur. Some of these reversals may reflect different heat-flow regimes for Paleozoic and lower Mesozoic formations during and prior to tectonic transport; however, discussion of these aberrant localities is beyond the scope of this report. Stipple pattern depicts relatively cold rocks ($<100^{\circ}C$), cross-hachuring relatively hot rocks ($>300^{\circ}C$), and diagonal hachuring intermediate-temperature rocks (100-300°C). Estimation of Paleozoic rock temperatures is based on a combination of organic geochemical data and visual estimates of organic maturity using alteration colors of palynomorphs (R. M. Kosanke, written commun., 1981), conodonts (Harris and others, 1980), and kerogen in limestones and shales. Conodont color alteration, which is a relatively new method for assessing organic metamorphism (Epstein, Epstein, and Harris, 1977), was used in conjunction with organic geochemical data to estimate maximum rock temperature. Field and laboratory experiments by Anita Harris and her associates of the U.S. Geological Survey have shown that color alteration in conodonts from limestone beds correlates with fixed carbon, vitrinite reflectance, and palynomorph translucency. Composition of extractable organic matter in rocks with regard to temperature history is, in general, compatible with elemental composition of solid organic matter and thermal alteration color of recognizable spores and conodonts in sediments. The method of maximum paleotemperature assignment is discussed by Epstein, Epstein, and Harris (1977) and assumes that other thermal maturation indices can be used in the same manner as conodont color alteration.

The map (fig. 5) is a type of heat-flow record of the Phanerozoic. Of special interest are the rocks in the stippled areas, where much of the organic matter is thermochemically submature to early mature. Adequate rock temperature increase in the stippled areas could generate petroleum. The cross-hachured areas contain organic matter that is supermature and indicate earlier petroleum generation and possible migration. The diagonal-hachured areas or intermediate temperature areas contain organic matter that is mature to supermature. Within this area of generally moderate rock temperatures, some local cold and hot spots have been recognized.

Two major east-directed thrust systems and a strike-slip fault (Wells fault) are shown on figure 5. The western thrust is the Early Mississippian Roberts Mountains thrust with as much as 100 km displacement and the eastern thrust represents the Cretaceous Sevier belt with 50-100 km displacement. The Roberts Mountains allochthon or Antler orogen contains marine source rocks (fig. 2) near its eastern margin (fig. 5). The area between the two thrust systems contains marine source beds in the Mississippian Antler foreland basin (fig. 3) and nonmarine source beds in Cretaceous and Tertiary lake basins (fig. 4). The solid circles represent drill holes that are known to contain oil. The cluster of drill holes in the lower left on figure 5 are in Railroad Valley. Plus signs (+'s) indicate Ordovician and Devonian outcrops in the Antler orogen that contain oil and x's indicate Mississippian foreland basin outcrops that contain oil.

The rectangular area in the lower left part of figure 5 outlines the larger scale map of figure 6. This east-central Nevada area is important because it contains evidence for at least two episodes of petroleum generation in the northern Great Basin (Poole, Fouch, and Claypool, 1979). Mountains are stippled and valleys are unpatterned. Maturity or stage of thermochemical alteration of organic matter in samples taken from the Chainman Shale at several localities is shown by solid circles, diamonds, and triangles. Circles represent upper-range submature organic matter, diamonds mature, and triangles supermature or overcooked organic matter. Determination of organic maturity at each locality is based on analysis of several samples.

Marine Chainman Shale obtained from drill cores and cuttings of Railroad Valley wells southwest of the village of Currant, and from outcrops in several mountain ranges contains a mixture of marine-sapropel and detrital terrestrial-plant organic matter. The organic matter ranges from submature to supermature in

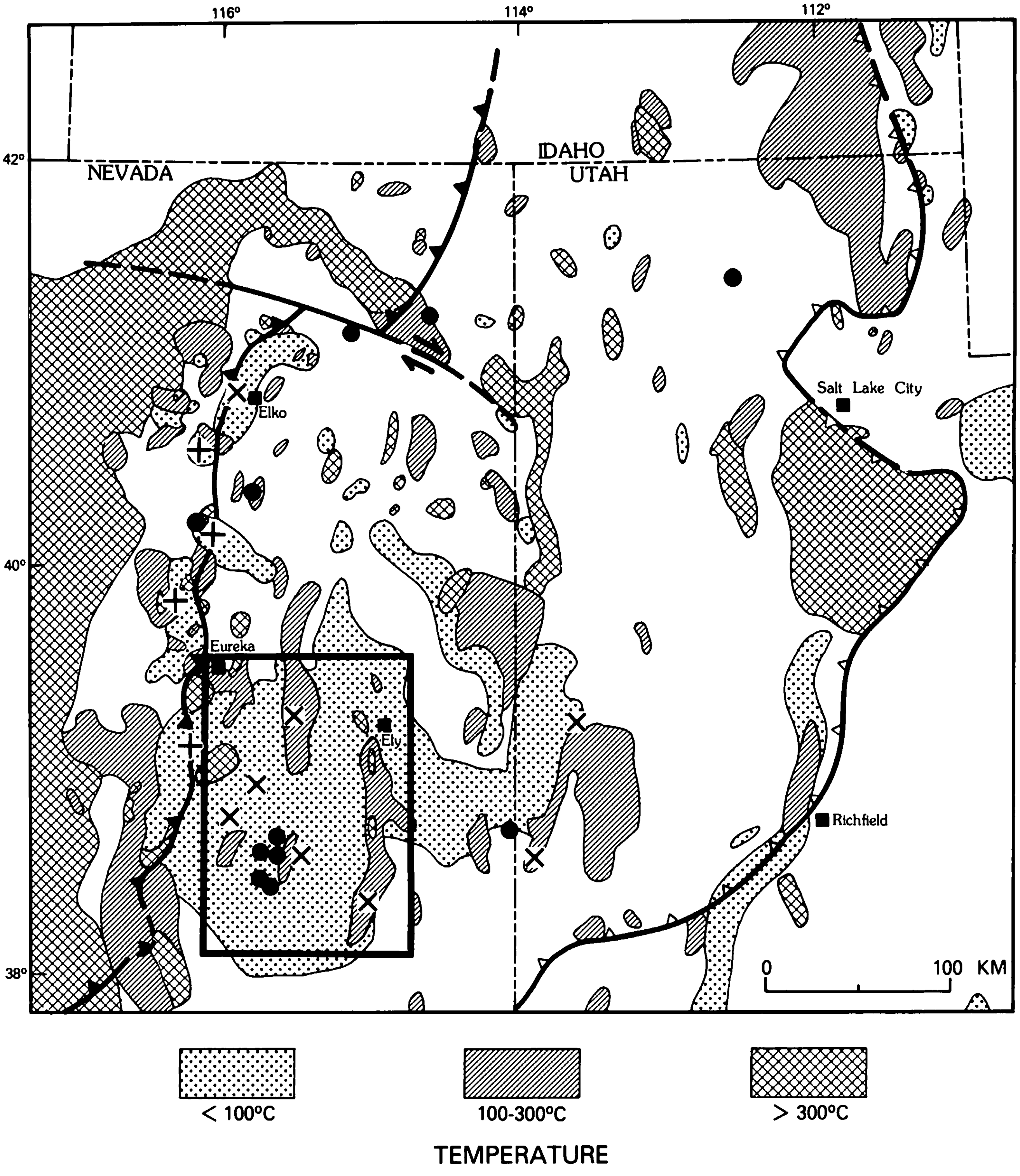

Figure 5. Generalized map of maximum temperatures of some outcropping and subsurface Paleozoic strata in part of the northern Great Basin. Solid circles indicate wells containing oil, +'s indicate Ordovician and Devonian outcrops containing oil, and x's indicate Mississippian outcrops containing oil. See text for explanation of faults.

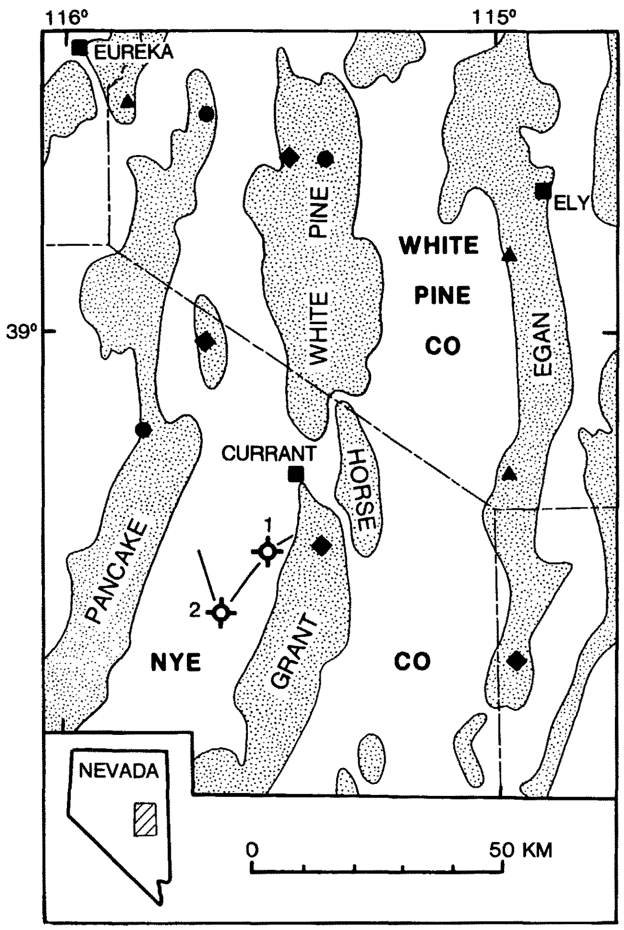

Figure 6. Map of east-central Nevada showing maturity stage of organic matter in the Mississippian Chainman Shale at several localities. Solid circles indicate submature stage, solid diamonds indicate mature stage, and solid triangles indicate supermature stage. Symbols 1 and 2 indicate wells shown in cross section of figure 7. Mountains are represented by stippled pattern.

thermochemical evolution as indicated by organic geochemical data from kerogen and from rock hydrocarbon extracts and oil, by vitrinite reflectance, and by alteration colors of palynomorphs and conodonts. Hydrocarbon contents range from a few parts per million to 2,000 ppm and organic-carbon contents range from almost nil to 7 percent by weight. The presence of significant amounts and different types of both immature and mature organic matter in many Chainman samples in east-central Nevada indicates a history of moderate temperatures. Liquid oil of varying viscosities found in fractures, voids, and invertebrate-fossil cavities of dense limestone concretions and beds in the Chainman Shale at several localities in east-central Nevada indicate that temperatures sufficient for oil generation were reached during burial and prior to uplift.

Figure 7 is a diagrammatic subsurface section across Railroad Valley from the Trap Spring oil field on the west to the Eagle Springs oil field on the east (line of section shown on fig. 6). Shell Unit 2 east of Trap Spring is shown as well number 2. Shell Unit 1 in the Eagle Springs field is shown as well number 1. Chainman cores from Shell Units 1 and 2 were studied in detail as was shale of the Sheep Pass Formation from Shell Unit 1. Major oil-producing zones are shown by the solid wedges. Vitrinite reflectance values (N. H. Bostick, written commun., 1978) are given for the Chainman cores in both Shell holes and for the shale of the Sheep Pass in well number 1. Vitrinite reflectance values indicate mature organic matter in both the Chainman and Sheep Pass Formations in Shell Unit 1 and show a uniform kerogen-maturation profile in the subsurface. Both the Chainman and Sheep Pass formations contain mature to marginally mature organic matter and rank as excellent source rocks (Fouch, 1979). In Railroad Valley, and elsewhere where these formations are buried deeper, they should have reached optimum temperatures for petroleum generation.

Several samples of hydrocarbon extracts from Chainman and Sheep Pass drill cores and cuttings, and crude oil from Tertiary reservoir rocks in the Eagle Springs and Trap Spring fields have been analyzed to evaluate hydrocarbon compositions and to test for genetic relationships among samples. Crude oil compositions, including ratios of sulfur to nitrogen and pristane to phytane and isotopes of sulfur and carbon, indicate that they were derived from different organic source materials (Claypool, Fouch, and Poole, 1979). Hydrocarbon extracts from the Chainman Shale are identical in many respects to Trap Spring oil. Extracts of available Sheep Pass Formation samples are unlike either Eagle Springs oil or Trap Spring oil (Claypool, Fouch, and Poole, 1979).

Data from Sheep Pass and Chainman formation cores and cuttings from drill holes in Railroad Valley indicate that immature and mature organic matter in many Sheep Pass and Chainman rocks in this region is now being thermochemically altered and is generating oil.

An earlier cycle of petroleum generation is indicated by geochemical and conodont color alteration data from outcrop samples of Chainman Shale and associated rocks in the Great Basin. In east-central Nevada, organic matter in outcrop samples of marine Chainman Shale range from submature to postmature as shown on figure 6, whereas all organic matter in outcrop samples of lacustrine Tertiary rocks were found to be submature. In some stratigraphic sections, submature organic matter in Tertiary rocks directly overlie Mississippian rocks containing mature to supermature organic matter. This

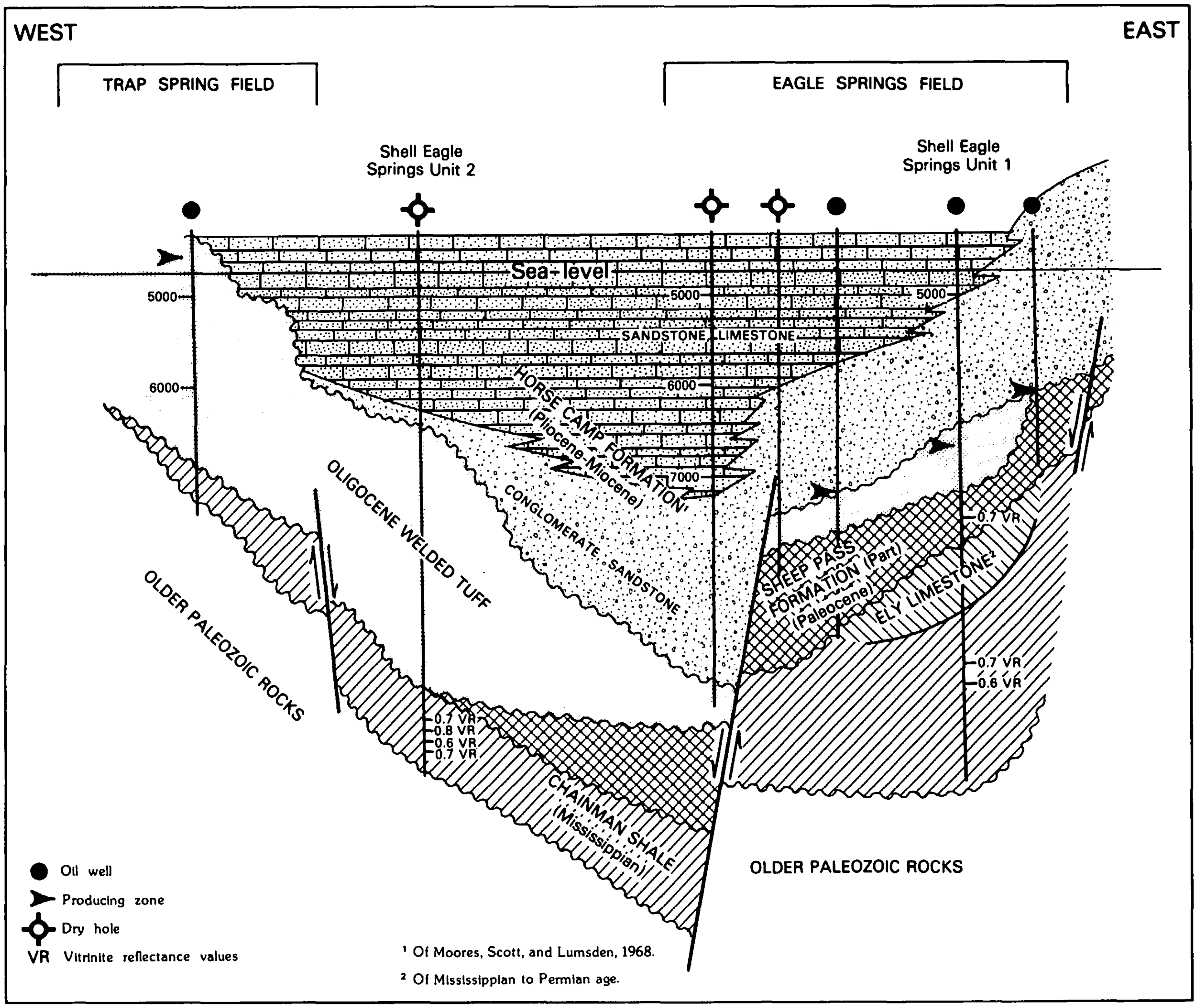

Figure 7. Generalized cross section of Railroad Valley showing rock units and vitrinite reflectance values obtained on cores from two wells.

discontinuity indicates an earlier heating event of the Chainman. The first episode of petroleum generation began probably in early Mesozoic time when the Chainman was buried beneath upper Paleozoic and lower Mesozoic rocks. Depth of burial and hence degree of thermochemical maturation varied with late Paleozoic and Mesozoic folding, faulting, and erosion. Organic matter in the Chainman is supermature in many localities where higher paleotemperatures occurred owing to subcrustal hot spots or deeper burial. In the Diamond Mountains in the northwestern corner of the map area, submature nonmarine Cretaceous rocks overlie supermature marine Mississippian flysch.

Analysis of surface and subsurface data indicates that although Chainman rocks were thermochemically degraded and generated some hydrocarbons in Mesozoic time, as evidenced by oil trapped in fractures, voids, and fossil cavities in dense limestone concretions and beds; petroleum generation was incomplete where rocks were buried at moderate depths. Uplift of buried Chainman Shale prior to the late Mesozoic arrested the first episode of petroleum generation in thermochemically submature and mature rocks.

Many organically submature and mature Chainman rocks in this region are now subjected to a second episode of thermochemical degradation and renewed oil generation in Neogene basins where valley fill has been adequate and temperature has increased. Rocks of the Chainman Shale probably are the major source of petroleum in the Trap Spring and Bacon Flat (about 12 km southeast of Trap Spring field) fields in Railroad Valley where oil has accumulated in fractured welded ash-flow tuffs of Oligocene age. Rocks of the Sheep Pass Formation may be the major source of petroleum in the Eagle Springs and Currant (about 10 km north of Eagle Springs field) fields. Oil is inferred to have accumulated in other valleys in eastern Nevada and western Utah where similar geologic conditions exist.

Oil samples analyzed to date suggest the possibility of several distinct genetically related Paleozoic and Tertiary crude oil/source rock families in the northern Great Basin. Further work to document these genetic relationships and to develop the implications for exploration is still in progress.

REFERENCES

Claypool, G. E., Fouch, T. D., and Poole, F. G., 1979, Chemical correlation of oils and source rocks in Railroad Valley, Nevada: Geological Society of America Abstracts with Programs for 1979, v. 11, no. 7, p. 403.

Epstein, A. G., Epstein, J. B., and Harris, L. D., 1977, Conodont color alteration--an index to organic metamorphism: U.S. Geological Survey Professional Paper 995, 27 p.

Fouch, T. D., 1979, Character and paleogeographic distribution of Upper Cretaceous(?) and Paleogene nonmarine sedimentary rocks in east-central Nevada, in Armentrout, J. M., Cole, M. R., and TerBest, Harry, eds., Cenozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium 3: Pacific Section, Society of Economic Paleontologists and Mineralogists, p. 97-111.

Fouch, T. D., Hanley, J. H., and Forester, R. M., 1979, Preliminary correlation of Cretaceous and Paleogene lacustrine and related nonmarine sedimentary and volcanic rocks in parts of the eastern Great Basin of Nevada and Utah, in Newman, G. W., and Goode, H. D., eds., 1979 Basin and Range Symposium: Rocky Mountain Association of Geologists and Utah Geological Association, p. 305-312.

Harris, A. G., Wardlaw, B. R., Rust, C. C., and Merrill, G. K., 1980, Maps for assessing thermal maturity (conodont color alteration index maps) in Ordovician through Triassic rocks in Nevada and Utah and adjacent parts of Idaho and California: U.S. Geological Survey Miscellaneous Investigations Series Map I-1249.

Moores, E. M., Scott, R. B., and Lumsden, W. W., 1968, Tertiary tectonics of the White Pine-Grant Range region, east-central Nevada, and some regional implications: Geological Society of America Bulletin, v. 79, no. 12, p. 1703-1726.

Poole, F. G., 1981, Molasse deposits of the Antler foreland basin in Nevada and Utah: Geological Society of America Abstracts with Programs for 1981, v. 13, no. 7, p. 530, 531.

Poole, F. G., Fouch, T. D., and Claypool, G. E., 1979, Evidence for two major cycles of petroleum generation in Mississippian Chainman Shale of east-central Nevada, in AAPG Rocky Mountain Section Meeting Abstracts, 1979, Casper, Wyoming: American Association of Petroleum Geologists Bulletin, v. 63, no. 5, p. 838.

Poole, F. G., and Sandberg, C. A., 1977, Mississippian paleogeography and tectonics of the Western United States, in Stewart, J. H., Stevens, C. H., and Fritsche, A. E., eds., Paleozoic Paleogeography of the Western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 67-85.

Sadlick, Walter, 1965, Biostratigraphy of the Chainman Formation (Carboniferous), eastern Nevada and western Utah: Utah University, unpublished Ph. D. thesis, 228 p.