Evolution of the Lower Tertiary Elko Formation, a Potential Lacustrine Petroleum Source Rock in Northeast Nevada*

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Abstract

The Eocene-Oligocene Elko Formation of northeastern Nevada was deposited in a structural and sedimentary basin containing a fresh to moderately saline lake (or a series of lakes) following a long period of fluvial deposition. The Elko Formation includes thick intervals of petroliferous mudrocks, some of which contain sufficient organic matter to have been mined as an oil shale resource in the early twentieth century. The organic-rich intervals are also presumed to be the source for oil deposits in northeastern Nevada.

Lithology, mineralogy and organic geochemistry of the Elko Formation were studied in outcrop and core samples. The core and outcrop samples are all thermally immature and, with the exception of a few very organic-rich intervals in two cores, show moderate to good source rock potential. Generally, these outcrop and core samples have limited value as an oil shale resource in comparison to the lacustrine basins of the nearby and similarly aged Eocene Green River Formation. The majority of samples (62%) had total organic carbon contents between 1 and 5 weight % and most (78%) had hydrogen index (HI) values of 500 mg/g or higher. Oil yields determined by Fischer assay were generally between 1 and 4 weight % (3 to 11 gallons per ton), but the yields from many samples were less than 1 weight % (about 3 GPT). The organic matter in the Elko cores consists of varying mixtures of Type I and Type III kerogen.
Results from X-ray diffraction indicate the Elko Formation contains abundant quartz and feldspar, alternating dolomite-rich and calcite-rich intervals, along with some intervals rich in opal-CT and clay minerals. The Elko Formation paleolake may have become hydrologically closed leading to increased salinity as widespread lacustrine conditions developed. This is indicated by the disappearance of freshwater mollusks just above the base of the lacustrine interval. Organic-rich laminated carbonates were deposited in offshore areas of the lake, contemporaneous with pebbly sandstones and mudstones in marginal areas. Scattered air-fall tuffs indicate volcanism in northeastern Nevada during deposition of the lower part of the organic-rich interval. Greater volcanism, indicated by thick, reworked tuffaceous intervals interspersed with organic-rich mudrocks, appears to have occurred just prior to deposition of the richest oil shale in the Elko Formation. Large volumes of volcanic material are found in the remaining Elko lacustrine beds due to a period of prolonged volcanism in northeastern Nevada during this time.

References Cited


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A related manuscript was published in 2016:


The publication includes 3 oversized plates.
Map showing present-day extent of lower Tertiary lacustrine deposits in northeast Nevada. Blue is extent of Eocene Elko Formation. Green is extent of lacustrine rocks that may be equivalent to the Elko Formation.

The Elko Formation was mined and retorted as an oil shale resource in the 1920s. Recently, oil has been discovered in the Elko Formation.
“In 1924 five-thousand gallons of lubricating oil were shipped to New York. Five tunnels, 600 feet down stretched four miles. Unfortunately, while there was talk of oil, the primary product was paraffin. Oil was secondary because of its high cost of refining. Labeled ‘Hi-Power Catlin Oil,’ it sold for $5 a gallon. The lubricant, because of its high paraffin base, worked well in the summer but in winter it congealed and gummed up engines. Durant Motor Company tested the oil in the 1924 Indianapolis 500. E.E. ‘Monte’ Mouton used the lubricant on his Elko to Reno air mail route and claimed his engine ran more than fifty revolutions per minute faster compared to standard oil.” (Howard Hickson, Great Basin College, written commun., 2003).
Index map showing area in northeast Nevada where the Eocene rocks including the Elko Formation crop out (beige). Location shown on previous Nevada index map.

Approximate original extent of Elko lacustrine basin shown in blue.

The Ruby Mountains, a metamorphic core complex (dark red), were present during deposition of the Elko Formation.

The other ranges (salmon) rose during basin and range faulting that postdated deposition of the Elko Formation.

Lacustrine rocks also are present northeast of the Elko lake (green). It is not known if this lake is the same age as the Elko lake.

Pink dots indicate recent oil and gas tests targeting the Elko Formation.

Modified from Stewart and others (1977), Coats (1987).
Detailed studies of the Elko Formation were conducted where it crops out in the northern Adobe Range, Elko Hills, and Pinon Range.

In addition, cores of the Elko Formation (EOS-1, EOS-6, and EOS-3/3A), which are stored at the Nevada Bureau of Mines core facility, were described and extensively sampled for programmed pyrolysis (Rock-Eval), X-ray, and thin-section analysis. All of the cores are from the immediate Elko area, where oil shale was mined in the past.
Plate 1 of Johnson and Birdwell (2016) showing detailed descriptions of core holes EOS-1, EOS-2, EOS-4, and EOS-6. Oil-yield histograms are from Moore and others (1983).
Plate 2 of Johnson and Birdwell (2016) showing detailed measured sections of the lower Tertiary section in the Northern Adobe Range, in the Elko Hills, and in the Pinon Range.
Plate 3 of Johnson and Birdwell (2016) showing detailed measured sections of the lower Tertiary rocks west of Twin Bridges about 15 miles south of Elko (blue), in the Elko Hills just east of Elko (pink), and near the Bullion Road about 6 miles south of Elko (green).
Example of x-ray diffraction data included in Johnson and Birdwell (2016). Numbers are peak heights normalized to the highest peak. Green denotes rocks from the early nonvolcanic period and pink denotes the later volcanic period in the Elko Basin. These two periods will be discussed in detail later. Note that clinoptilolite and opal-CT are confined to the volcanic-rich interval.
The Laramide orogeny in the Rocky Mountain region (Upper Cretaceous through Eocene) was a period of basement-involved thrusting that affected a large area east of the Sevier orogenic belt (light pink) creating a number of basins and uplifts. Modified from King (1969).
Lakes formed in many Laramide basins including Lake Uinta in the Uinta and Piceance Basins, Lake Gosiute in the Greater Green River Basin, Lake Waltman in the Wind River Basin, and Lake Tatman in the Bighorn Basin. Age of these lakes is shown in red. Modified from King (1969).
The Elko Basin began to form about 42 millions of years ago (Ma) during the initial stages of basin and range extension. Basin subsidence ended about 39 Ma. The lake that occupied the Elko Basin does not appear to overlap in time with lakes in Laramide basins to the east. Modified from King (1969).
The early stages of regional extension created metamorphic core complexes in which lower crustal rocks were brought to the surface. Sedimentary basins, such as the Elko Basin, formed on the flanks of these complexes. From DeGrey and Link (2017).
West-east cross section of the Huntington Valley, where the Elko Formation was deposited, the Ruby Mountain metamorphic complex, and the Ruby Valley to the east. Note the mylonitic shear zone. (Modified from a seismic line by Satarugsa and Johnson, 2000). Location shown on slide 7.
Lacustrine rocks of the Elko Formation were brought to the surface during a later stage of extension that began about 17 Ma producing the half graben “basin and range” topography that characterizes the province today.
South to north cross section of lower Tertiary rocks in the Elko area subdivided into: (1) an early fluvial and alluvial period (orange), (2) a largely nonvolcanic paludal and lacustrine period (green and brown), and (3) a volcanic lacustrine period (pink). It is assumed that the onset of widespread volcanism represents a time line.
A variety of radiometric dating techniques give varying results for lower Tertiary strata in the Elko area. A relatively thin interval of alluvium may have begun to accumulate locally in the Elko area as early as 46 Ma with widespread lacustrine conditions developing by about 42 Ma. Volcanism in the area began about 40 Ma.
Fluvial and Alluvial Period
Measured thicknesses of fluvial and alluvial rocks beneath the lacustrine interval varies from about 284 ft to more than 845 ft and consists largely of variegated maroon and gray mudstone and conglomeratic channel sandstones with clasts from nearby uplands. Mass-movement deposits, with clasts to small boulder-sized fragments were also observed. Collapsed karsts developed locally on the underlying Paleozoic limestones. A cherty limestone is the oldest lacustrine unit in most areas.
Nonvolcanic Paludal and Lacustrine Period
The overlying nonvolcanic lacustrine interval consists of dolomitic low-grade oil shale in offshore areas. It can be conglomeratic in marginal lacustrine areas and appears to grade into a paludal interval with coal beds up to 6-ft thick in the northern Adobe Range.
In the limited outcrop and trench exposures available, the basal contact of the lacustrine interval is everywhere sharp with no evidence of intertonguing.
The Elko Basin Lake at this time appears to have been moderately saline and alkaline, producing laminated dolomitic and calcareous sediments with some analcime, a common mineral found in saline-alkaline lake deposits including the Green River Formation (Sheppard and Gude, 1973).
If you want to work on the Elko Formation bring a shovel. Outcrops are typically poor.
Sample numbers:
Red, X-ray analysis
Black, other samples collected

Vitrinite Reflectance in percent

LITHOLOGY
- Sandstone
- Siltstone
- Claystone, clay shale or mudstone
- Limestone
- Conglomerate
- Breccia
- Chert nodules
- Calcareous mudstone
- Dolomitic mudstone
- Siliceous
- Rip up clasts
- Tuffaceous
- Air-fall tuff bed

INTERNAL CHARACTERISTICS
- Cross-beds, less than 1 ft high
- Cross-beds, 1 to 3 ft high
- Cross-beds, greater than 3 ft high
- Horizontal lamina
- Gastropods
- Ostracodes
- Plant remains

Cherty limestone of Solomon and Moore (1982a; 1982b)
In the northern Adobe Range, paludal rocks (orange interval), with coal beds to 6 ft thick in their upper parts, occur between the alluvial and overlying volcanic-rich lacustrine rocks. Thickness of the paludal interval (brown) is about 210 ft.

The paludal interval overlies a 300-ft thick conglomeratic fluvial interval.
In the measured section near the city of Elko, the prevolcanic lacustrine interval is marginal lacustrine with chert pebble conglomerates. One rhyolite pebble was found.

This conglomeratic marginal lacustrine interval grades into mostly well-laminated, low-grade dolomitic oil shale in the EOS-3 corehole 3 miles to the southeast. Note the basal lacustrine cherty limestone unit (blue).
The nonvolcanic lacustrine interval in the EOS-3 core (between white arrows) consists of dolomitic and calcareous mudstone and low-grade oil shale. Oil shale is typically well laminated. X-ray analysis indicates that both lithologies consist of varying amounts of quartz, calcite, dolomite, and smectite.
Volcanic Lacustrine Period
The onset of volcanism in the Pinon Range and northern Adobe Range is marked by airfall tuffs to 2.5 ft thick. In the Elko area, the onset is marked by a 46.3 ft sandstone consisting of reworked volcanic material.
Tuffs in the Adobe Range section are marked by pink arrows. The lowest tuff is 1.5 inches thick and is in the uppermost coal bed.

The onset of volcanism appears to correspond to the expansion of the Elko Basin Lake into this area.
Sandstone, white, highly altered, rhyolitic?  

Very rich, non-dolomitic oil shale  

46.3-feet thick white, highly altered rhyolitic Ss  

A shift from low-grade dolomitic oil shale to very rich clayey oil shale occurred after deposition of reworked volcanic sandstone.  

Programmed pyrolysis (Rock-Eval) and Fischer assay data indicate that the kerogen is thermally immature in all coreholes and at all surface localities.
The rich oil shale and tuffaceous sandstone interval is highly variable over relatively short distances. These two coreholes are about 3 miles apart.

Tuffaceous sandstones consist mainly of plagioclase, orthoclase, clinoptilolite, opal-CT, and biotite.
The rich oil shale was exposed near the two previous coreholes and described in detail. The rich oil shale beds are fairly well-laminated and contain abundant plant debris and some clam shells. Tuffaceous beds contain large oil shale and siltstone ripups.
Conclusions on Geology of Elko Formation

- The Elko Formation is entirely younger than the Green River Formation.
- The Elko oil-shale basin formed during a period of regional extension (basin and range faulting), whereas the Green River oil-shale basins formed during an earlier period of regional compression (Laramide orogeny).
- The rich oil-shale interval in the Elko was deposited immediately after the onset of volcanism in the area, suggesting that the input of volcanic material to the lake may have initiated a period of high organic productivity.
Geochemistry of Elko Oil Shale
Palmer (1984) performed a study of the hydrocarbon potential and thermal maturity of Elko Formation oil shales outcropping in the Adobe Range. Two organic-rich facies, immature oil shale and siltstones, were identified.

Analyses included XRD, organic petrography, kerogen isolation and elemental analysis, programmed pyrolysis (Rock-Eval), TOC, and biomarker analysis of extractable organic matter.

Hydrous pyrolysis experiments were also conducted to assess potential crude oil quality in the Elko.

INTRODUCTION

In a recent review of oil shale resources, Knutson and Dana (1983) outline the economics of mining the stratigraphically and structurally complex Elko oil shale. The Elko was mined briefly in the early 1900s, the Southern Pacific Company and the U.S. Bureau of Mines constructed an oil shale plant in 1918 and the Cathin Shale Products Company operated an experimental report from 1918 to 1924 at Elko, Nevada (Solomon and others, 1975 and Knutson and Dana, 1983). Although a poor candidate for mining and shale oil production, the organic-rich Elko Formation is considered by many to have good potential as a petroleum source rock. However, stratigraphic and structural complexities also make it difficult to estimate the volume and quality of organic source rock in the subsurface. For example, it is possible that the outcrops of the Elko Formation contain only non-source deposits (i.e., lignite, siltstones, and oil shale, etc.) while offshore rocks of unknown source rock quality may occur only in the subsurface (Solomon and others, 1979).

In spite of these geologic complexities, the occurrence of the Elko Formation in outcrops provides an opportunity to geochemically delineate two very distinct organic facies which, according to Solomon and others (1979), were deposited in a shallow, alkaline, freshwater lake. The geochemical signature of the two specific organic facies would aid in recognizing oils sourced from the Elko Formation. The study of the assemblage of organic matter present in the Elko Formation includes the insoluble fraction (kerogen) and extractable C₉₊ hydrocarbons. In this study emphasis is placed on the use of sterane and terpane biomarkers as indicators of lacustrine depositional environments and also on the use of hydrous pyrolysis in the study of low maturity possible source rocks and for simulating oil generation.

SAMPLE COLLECTION AND EXPERIMENTAL METHODS

Twenty-four samples of three lithologically distinct units (i.e., lignite, siltstone, oil shale, and mudstone) were collected from depths of at least one foot into the trenched outcrop. The multiple sampling of each of these units allowed monitoring of the amount of variation in mineralogical and organic geochemical parameters and as well as selection of representative samples for detailed geochemical study.

Total organic carbon was determined using a LECO 1512 carbon analyzer. Kerogen was isolated by HCl, HF treatment, followed by ZnBr₂ flotation. Kerogen quality and thermal maturity (i.e., spore coloration and vitrinite reflectance) were determined by transmitted and reflected light microscopy using a Zeiss Photomicroscope III and Zeiss Universal Microscope, respectively. Kerogen fluorescence studies were made using a Zeiss Photomicroscope III equipped with a vertical illuminator III RS and UV filter package. Rock-Eval pyrolysis was performed on crushed rock samples using a New Version Rock-Eval, and elemental analysis of solvent-extracted kerogen samples was performed by the Willamette Brothers Laboratories (Tulsa) using a Carlo Erba Model 1106 elemental analyzer.

Hydrous pyrolysis experiments were conducted using a 75 milliliter capacity stainless steel Parr bomb equipped
The Fischer assay method does not distinguish between oil that is present in the sample and oil that is generated by kerogen during the retort process and does not analyze the composition of the uncondensed gas.

100 g -8 mesh (<2.36 mm) rock is heated from 25 to 500 °C in 40 minutes and held at 500 °C for an additional 40 minutes.
The Fischer assay results show that most of the EOS-core samples yielded less than 10 wt% oil (~27 gallons per ton) and ~2 wt% gas. EOS-6 had a few oil shales with high yields (10–20 wt%) at depths of 120-180 ft.
Elko oil shale **Fischer assay** product distribution (GOR) compared to average values for Green River Mahogany zone oil shale (Piceance Basin).

Range of Elko GOR values exceed those of all non-nahcolitic oil shale from Piceance Basin, not just Mahogany zone.
TOC-normalized Fischer assay oil yield

Elko oil shale oil-generating potential (normalized to TOC) compared to average values for Green River Mahogany zone oil shale (Piceance Basin).

Although both are Eocene lacustrine oil shales with (mostly) hydrogen-rich kerogen, Elko oil shales generate significantly more gas and less oil than those from the Green River Formation.
The organic matter in the Elko samples range in composition with what appears to be varying Type I and Type III kerogen content, primarily Type I. Samples with type III kerogen or type I–III mixtures were also common, consistent with Palmer (1984) geochemical and petrographic results. Plots based on method described in Langford and Blanc-Valleron (1990).
The U.S. Geological Survey examined a set of Elko samples (58) from four cores by programmed pyrolysis (Rock-Eval)/total organic carbon (TOC) as part of an examination of the Elko oil-shale resource to supplement the larger Fischer assay dataset (640) generated by the U.S. DOE.

The Rock-Eval and TOC results showed a wide range of organic carbon and hydrogen contents, similar to what Palmer (1984) noted for samples from the Adobe Range.
Elko oil shale **Fischer assay** oil yield compared to programmed pyrolysis (Rock-Eval) S1+S2 values show much more scatter than is usually observed in these kinds of correlations.

The correlations shown are mostly for oil shales with very hydrogen-rich, oil-prone kerogen. The Green River oil shales show a strong correlation between these parameters. This further illustrates the differences in these lacustrine rocks.
Relative-abundance mineralogy data in the EOS-3 (below) show the Elko Formation contains carbonate (calcite and dolomite) and quartz-rich intervals. The EOS-4 core is similar but contains more dolomite, and EOS-1 is richer in quartz and clays.

The upper section, where the richest oil shale is found (depth approximately 100 feet), is bracketed by rocks high in K-spar, clay, and opal-CT.
Recently, Noble Energy drilled test wells in the Elko Formation to assess its potential as a tight-oil play. The oils being produced resemble the hydrous pyrolysis oils generated by Palmer (1984). Pristane/phytane (Pr/Ph) ratios are generally consistent with mildly reducing and dysoxic conditions. The low Pr/nC-17 and Ph/nC-18 ratio values and carbon preference indices (CPI) near 1 indicate that the oils are thermally mature. Beta carotane was present but not abundant and could indicate that Lake Elko was a brackish to saline lake.

See Peters and others (2005) for details on CPI, Pr, and Ph parameters. Oil samples provided by Jerry Hansen, Great Basins Exploration.
Conclusions on Geochemistry of Elko Formation

- The Elko Formation, with its variable hydrogen content, high oxygen content, and high gas-generating potential appears to be a mixture of lacustrine-algal and terrestrially derived organic matter.
- The organic matter in the Elko Formation is distinctive from that of the Green River oil shale in that it is less dominated by Type I kerogen in much of the oil shale and therefore, it produces more gas and less oil per unit of organic carbon.
- To date, substantial gas resources have not been found.