UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Geology and Oil Shale Resources near Elko, Nevada

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Open-File Report 81-709

1981

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ABSTRACT

The Elko Formation of Eocene and Oligocène(?) age and unnamed lithostratigraphic units of Eocene and probable Eocene age are exposed near Elko, Nevada, unconformably overlying the Mississippian and Pennsylvanian Diamond Peak Formation. Intertonguing facies of these Eocene and Oligocene(?) units are interpreted as representing lacustrine and related continental environments. Lithofacies of alluvial origin include channel-form sandstone and conglomerate deposited in fluvial channels, and variegated, nodular, fine-grained rock of floodplain origin. Marginal lacustrine rocks include ostracode- and gastropod-rich micrite deposited in a carbonate-flat environment, and channel-form sandstone, conglomerate, and fine-grained rock of deltaic, interdeltaic, and mudflat origin. Siliceous oil shale and other fine-grained rocks of the Elko Formation were deposited in a nearshore, open-lacustrine environment.

Lacustrine rocks of the Elko Formation were deposited over an extensive area in northeast Nevada. A radiometric age from near the base of the Eocene sequence near Elko shows that lacustrine sedimentation commenced at least as early as middle Eocene time, about 43 million years (m.y.) ago. Additional dates as recent as about 37 m.y. ago indicate that deposition persisted for 6 or 7 m.y.

The Indian Well Formation was deposited during Oligocene time and is composed of tuff and volcaniclastic sedimentary rocks deposited in alluvial environments. This formation was deformed during early Oligocene time. Andesitic lava flows and mudflow conglomerate were deposited from approximately 35 to 31 m.y. ago, and lie with angular discordance upon the Indian Well Formation. A lithostratigraphic unit composed mainly of calcareous siltstone and sandstone, herein called the siltstone and sandstone unit, was deposited in a floodplain environment after extrusion of the andesite. This siltstone and sandstone unit formerly was assigned to the upper part of the Indian Well Formation. A tuff near the base of the siltstone and sandstone unit has a fission-track age of about 27 m.y.

Organic-rich beds of the Elko Formation, where accessible in blocks uplifted during post-Oligocene faulting, may serve as a future source of oil shale. Analyses of oil shale exposed near Elko indicate yields of as much as 358 L/metric ton (85.5 gal/short ton) of 24° to 35° API oil. The richest beds occur in an 8-m-thick (26-ft-thick) section of the Elko Formation which yields in excess of 63 L/metric ton (15 gal/short ton). The Elko Formation, where exposed near Elko, contains at least 30 million m^3 (191 million barrels) of oil in oil shale that is noncoking. Where buried in deep basins by the Miocene Humboldt Formation and younger unconsolidated deposits, the oil shale may serve as a source for the generation of petroleum.

INTRODUCTION

Scope of Investigation

A revised stratigraphic framework, new mapping of structural relationships, and radiometric dates (Solomon and others, 1979a) form the basis for a detailed interpretation of depositional conditions, volcanic history, and tectonic events near Elko, Elko County, Nevada (fig. 1). The stratigraphic framework, structural relationships, and new oil shale analyses of J. F. Smith and W. A. Robb (written commun., 1969, 1970, 1972, 1977) were helpful in the interpretation of the extent and quality of oil shale resources near Elko.

The area chosen for study, in Ts. 33 and 34 N., Rs. 55 and 56 E., of the Elko West and Elko East 7 1/2-minute quadrangles, is about 65 km^2 in extent. The area is bounded on the north by the Humboldt River, on the west by Paleozoic strata that form a linear ridge referred to by Dott (1955, fig. 5) as Hot Spring Ridge, on the south by rolling hills composed of Tertiary volcanic rocks, and on the east by Burner Basin. The geology near Elko was mapped on aerial photographs having a scale of approximately 1:12,000. The geology was transferred to a 1:12,000 enlargement of parts of the U. S. Geological Survey Elko East and Elko West 7 1/2-minute topographic quadrangles.

The sequence of lacustrine mudstone, siltstone, and limestone with intertonguing sandstone, conglomerate, and a variety of calc-alkalic volcanic rocks that occurs near Elko, Nevada, is typical of Paleogene deposits of the eastern Great Basin. These rocks accumulated in a

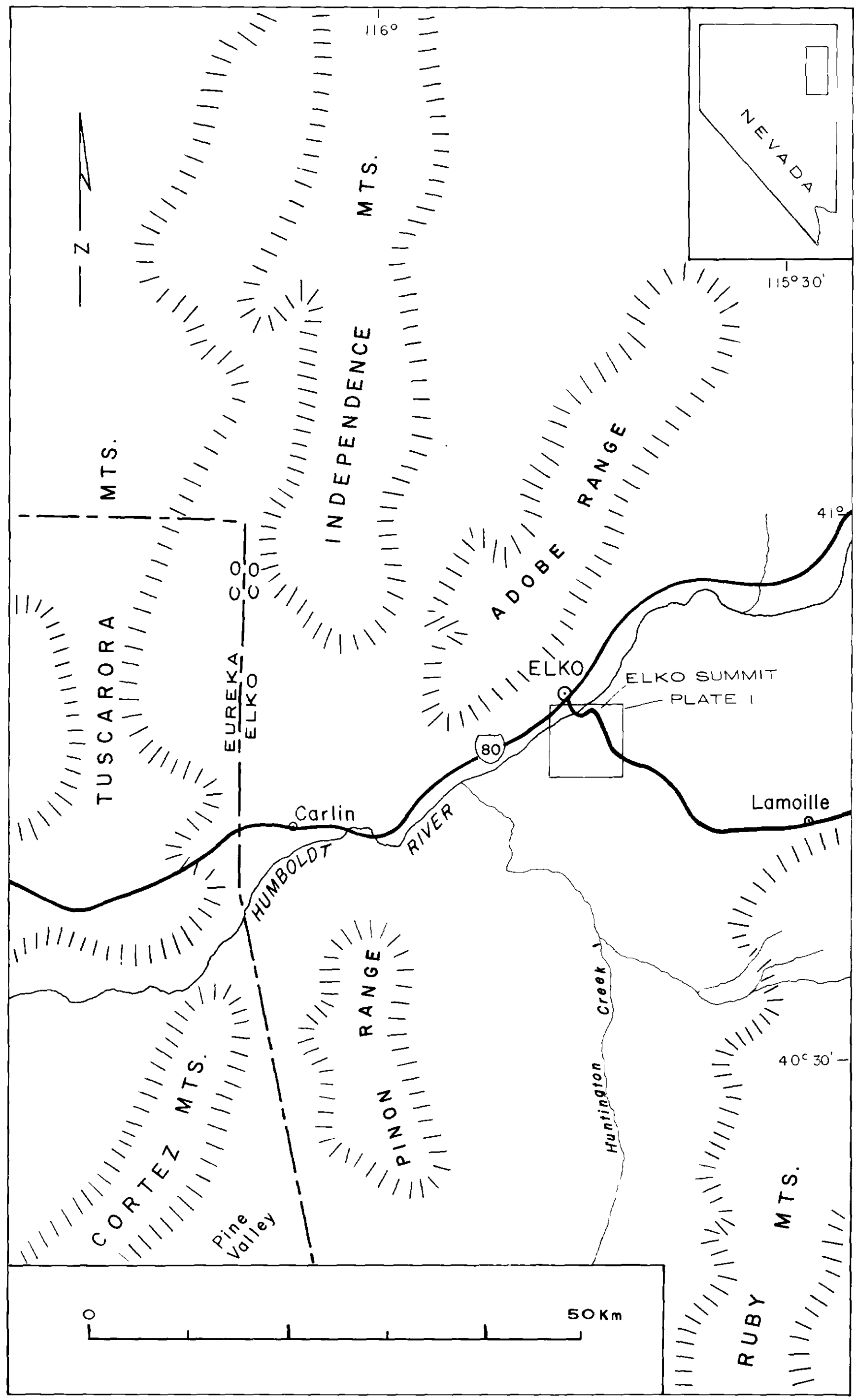


Figure 1.--Index map of part of northeast Nevada showing geologic map area (plate I) and localities discussed in text.

broad, shallow basin, one of many inland basins developed on an extensive erosion surface cut into a Paleozoic and Mesozoic terrain. The Paleogene rocks contrast markedly with the thick and very lenticular Neogene clastic wedges that fill local fault-bounded basins formed by Basin and Range rift faulting.

Previous Investigations

Published geological investigations in the Elko area have been limited, for the most part, to regional reconnaissance studies. Paleozoic rocks of this area first were examined by members of the 40th Parallel Survey (King, 1876, 1878; Hague and Emmons, 1877), who made reference to the Weber Quartzite. This nomenclature was continued by J. P. Buwalda, in his unpublished report summarized by Winchester (1923), but Dott (1955) assigned the Paleozoic rocks near Elko to the Tonka Formation. On more recent maps of the region, these rocks were referred to as the Diamond Peak Formation (Hope, 1970; Hope and Coats, 1976).

Members of the 40th Parallel Survey also were the first to study post-Paleozoic rocks near Elko. They assigned the oil shales and associated rocks to the Eocene Green River Formation, based upon lithologic similarities with rocks of that unit in Utah (King, 1876, 1878; Hague and Emmons, 1877). The name "Humboldt Group" was assigned to upper Tertiary rocks (King, 1876). Knowlton (1919) studied fossil plant remains from the oil shale near Elko, which he considered to be Miocene. Buwalda (Winchester, 1923) initially agreed with the assignment of the oil shales to the Eocene Green River Formation, but he later found mammalian remains in beds northwest of Elko that he considered to be equivalent to the oil shale at Elko and to be of Miocene age. Mason (1927) mentioned two conifers from the Tertiary beds near Elko and gave the age of these deposits as Oligocene or Miocene. Sharp (1939), referring to all Tertiary rocks near Elko, formally named the upper Miocene Humboldt Formation and discontinued the reference to Eocene rocks. Van Houten (1956), in his survey of the Cenozoic of Nevada, made many references to the area of the present report and suggested broad correlations of the oil shales with rocks of Eocene and Oligocene age. However, the Elko County geologic report of Granger and others (1957) continued to refer to all Tertiary rocks near Elko as part of the Miocene Humboldt Formation. In reports of studies of ostracodes from the oil shale near Elko (Dickinson, 1959; Swain, 1964; Dickinson and Swain, 1967; Becker, 1969; Swain and others, 1971), the oil shale continued to be referred to as the Miocene Humboldt Formation. Eocene and Oligocene rocks are differentiated from Miocene rocks on the recent Elko County geologic map (Hope and Coats, 1976), but only on a reconnaissance scale.

Published analyses of Elko oil shales are scarce. Winchester (1923), in his summary of the unpublished report of Buwalda, discussed the distribution of oil shale near Elko. Buwalda described several parallel zones of oil shale, but assumed that these zones are stratigraphically distinct from each other and are not repeated by faulting. Winchester (1923) also presented analyses of nine oil-shale samples. Analyses of Elko shales, as well as information concerning shale-oil production, were noted briefly in several other publications (Winchester, 1917, p. 152-161; Alderson, 1920, p. 31-32, 42-44; Day, 1922, p. 98, 838, 890-892; Lincoln, 1923, p. 43-44; Gavin, 1924, p. 23, 29-34, 102; McKee and others, 1925; Couch and Carpenter, 1943, p. 42; Smith and Ketner, 1976, p. 22). Harper (1974) provided a historical overview of attempts at commercial exploitation of the shales near Elko.

The present study has been summarized by Solomon and others (1978, 1979a, 1979b). Regional correlations between Paleogene rocks in parts of the eastern Great Basin of Utah and Nevada were suggested by Fouch (1979) and by Fouch and others (1979).

ACKNOWLEDGMENTS

I am grateful to David W. Andersen, Department of Geology, San Jose State University, for his suggestions regarding this project and for his constant advice and guidance during this investigation. Special thanks also to E. V. Stephens, U. S. Geological Survey, Menlo Park, Calif., for preliminary data collected by him in earlier reconnaissance trips to the Elko region and for numerous discussions. Calvin H. Stevens, Department of Geology, San Jose State University, E. H. McKee, U. S. Geological Survey, Menlo Park, and T. D. Fouch and J. Fred Smith, U. S. Geological Survey, Denver, Colo., have provided many helpful suggestions during their reviews of this manuscript.

Special appreciation is extended to John Ward Smith, Laramie Energy Technology Center, Department of Energy, Laramie, Wyo., for his analysis of oil shales and for his comments regarding oil-shale genesis. I am grateful to William A. Robb, Laramie Energy Technology Center, for X-ray diffraction examination of shales; to Richard A. Sheppard, U. S. Geological Survey, Denver, for X-ray diffraction examination of tuffs; to Richard M. Forester, U. S. Geological Survey, Denver, for ostracode identification; to John H. Hanley, U. S. Geological Survey, Denver, for bivalve identification; to Fred May, U. S. Geological Survey, Denver, for palynomorph identification; to Edwin H. McKee, U. S. Geological Survey, Menlo Park, for K-Ar ages; and to Charles W. Naeser, U. S. Geological Survey, Denver, for a zircon fission-track age. I am also grateful to Steven W. Moore, U.S. Geological Survey, Menlo Park, for making final modifications required for the publication of this report.

STRATIGRAPHY

The stratigraphic sequence recognized in the Elko area is shown in figure 2. The oldest sedimentary rocks in the area belong to the Mississippian and Pennsylvanian Diamond Peak Formation. This unit is overlain by several Tertiary rock units and by unconsolidated Quaternary deposits (pl. 1). The Tertiary rocks are bounded above and below by unconformities, and seven unconformities are recognized within the Tertiary sequence. Quaternary deposits include a unit of gravel, sand, and silt; stream terrace deposits; hot spring deposits; and alluvium.

Fossils from the stratigraphic sequence are listed in table 1, and locations of samples analyzed for fossil content are shown in figure 3. Fossils were used to identify the ages and depositional environments of stratigraphic units in the Elko area.

Mississippian and Pennsylvanian Systems

Upper Mississippian and Lower Pennsylvanian Series

Diamond Peak Formation. The oldest sedimentary rock in the vicinity of Elko is a unit composed mainly of conglomerate and lesser amounts of sandstone, mudstone, and limestone. These rocks were originally referred to as the Weber Quartzite (Hague and Emmons, 1877). Hague (1892) later described the Weber Conglomerate at Eureka, Nevada, which he correlated with the Weber Quartzite at Grindstone Mountain, west of Elko.

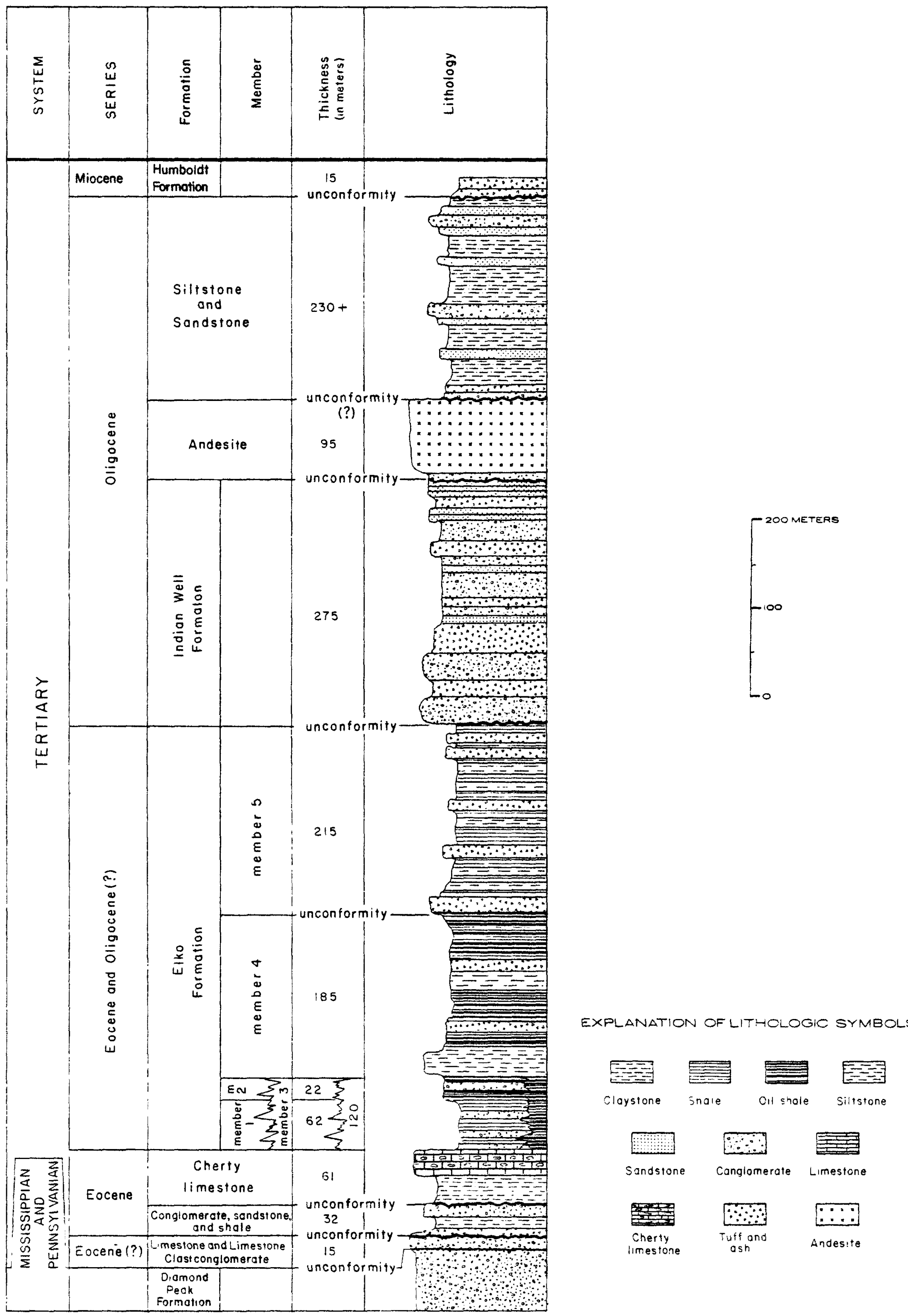


Figure 2.--Generalized stratigraphic section of Tertiary and older rocks near Elko, Nevada.

Table 1.--Fossils from the Elko area, Nevada.
[Ostracodes identified by R. M. Forester; bivalves identified by J. H. Hanley; palynomorphs identified by F. E. May.]

Humboldt Formation:
- Ostracodes - *Limnocythere* aff. *L. pterygoventrata*
- Diatoms - genus and species indeterminate

Indian Well Formation:
- Petrified wood - genus and species indeterminate

Elko Formation, member 5:
- Ostracodes - genus and species indeterminate

Elko Formation, member 4:
- Ostracodes - genus and species indeterminate
- Plants - genus and species indeterminate

Elko Formation, member 3:
- Ostracodes - genus and species indeterminate

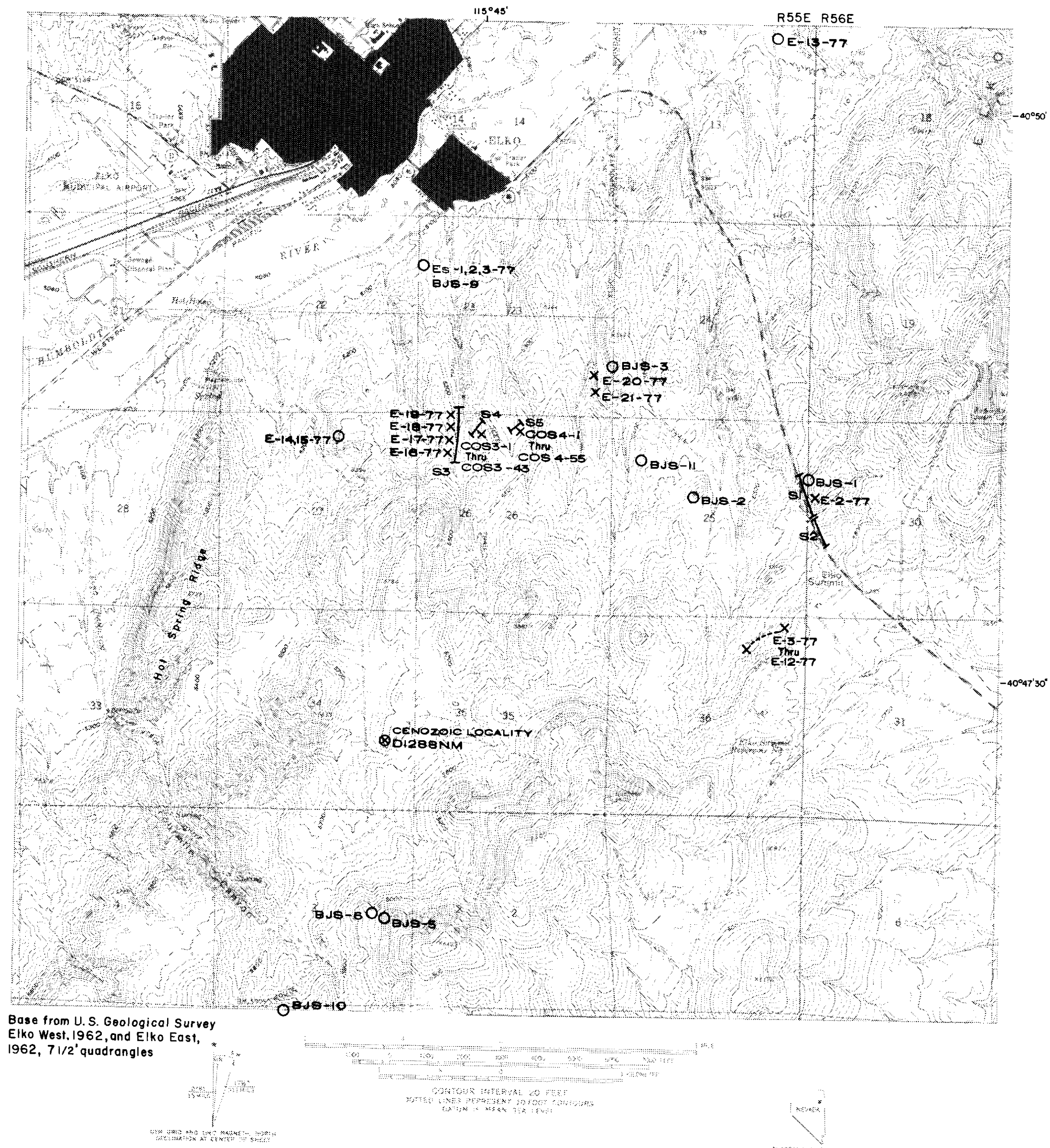
Elko Formation, member 2:
- Bivalves - *Sphaerium*? sp.
  - Pisidiidae, gen. and sp. indet.
- Ostracodes - *Candona* sp.
  - Other unidentified genera
- Algal spores - *Ovoidites*
  - *Schizosporis*
  - spiney, spheroidal algal spores
- Pollen - Conifer pollen
- Diatoms - Diatom(?) fragment

Elko Formation, member 1:
- Ostracodes - genus and species indeterminate
- Bivalves - *Sphaerium*? sp.
  - Pisidiidae, genus and species indeterminate
- Gastropods - Dextral gastropod, gen. and sp. indet.

Table 1.--Fossils from the Elko area, Nevada.--Continued

Cherty limestone:	
Ostracodes - gen. and sp. indet.	
Bivalves - Mollusca?	
Gastropods 1/ -	*Biomphalaria* sp.
	Lymnaea sp. cf. *L.* Form C from the Sheep Pass Formation (J. H. Hanley, 1978, written commun.)
	Lymnaea sp.
Diamond Peak Formation:	
Crinoids, brachiopods, corals	

1/Gastropods in cherty limestone collected at Cenozoic Locality D1288NM; location shown on figure 3.



EXPLANATION

× BJS-19 SAMPLE LOCATION OF FINE-GRAINED SEDIMENTARY ROCKS (MINERALOGY-TAB.5; OIL SHALE ANALYSES-TAB.6).

×---× E-3-77 Thru E-12-77 CLOSELY SPACED SAMPLE LOCATIONS.

○ BJS-1 SAMPLE LOCATION OF VOLCANIC ROCKS (MINERALOGY-TAB.2; CHEMICAL ANALYSES-TAB.3; RADIOMETRIC DATES-TAB.4).

⊢—⊣ S1 LOCATION OF MEASURED STRATIGRAPHIC SECTIONS.

⊗ CENOZOIC LOCALITY D1288NM FOSSIL LOCATION (TAB.1).

Figure 3.--Localities of rock samples and measured stratigraphic sections discussed in text.

Dott (1955, p. 2222-2223) assigned the coarse, clastic Paleozoic rocks near Elko to the Tonka Formation, the type section of which is located in Carlin Canyon, approximately 26 km southwest of Elko. The use of the terms "Weber Conglomerate" and "Weber Quartzite" to describe the Paleozoic rocks near Elko was discontinued by Dott (1955, p. 2222) because of the uncertainty of the stratigraphic position of the beds originally described by Hague (1883, 1892). The name "Diamond Peak" was not chosen by Dott (1955) to denote Paleozoic rocks near Elko because the rocks at the type locality of the Diamond Peak Formation, at the south end of the Diamond Mountains near Eureka, contain more fine-grained material than the Paleozoic rocks near Elko. Moreover, there was no proof of physical connection between the Tonka and Diamond Peak Formations, the type localities of which are about 145 km apart. A tentative correlation of the Tonka and Diamond Peak Formations was suggested by Dott (1955), who pointed out that rocks of the Diamond Peak at the north end of the Diamond Mountains bear more resemblance to the Tonka than do those at the south end of that range.

Smith and Ketner (1975, p. 44) discontinued the use of the Tonka Formation at its type locality near Carlin, and suggested that the intimate relation between the fine- and coarse-grained clastic rocks near Carlin and Eureka, as well as the similar stratigraphic position beneath the Ely Limestone or equivalent rocks, justifies use of the name Diamond Peak in the area near Carlin. This terminology was extended to other areas of outcrop on the geologic map of Elko County

(Hope and Coats, 1976) and will be used in this study to designate the coarse, clastic Paleozoic rocks that occur near Elko. The Diamond Peak Formation is exposed on Hot Spring Ridge near the western margin of the mapped area and on the edge of Burner Basin at the eastern margin of the mapped area (pl. 1).

At the type section near Eureka, the Diamond Peak Formation is 1,075 m (3,525 ft) thick (Brew, 1971, p. 18). The composite stratigraphic section of the Diamond Peak in the Carlin-Pinon Range area has a thickness of 1,905 m (6,245 ft; Smith and Ketner, 1975, p. 46). Owing to lack of stratigraphic control, thickness of this unit near Elko has not been estimated, but it must be at least several hundred meters.

Lithology. The Diamond Peak Formation is characterized by prominent outcrops of dark-reddish-brown conglomerate (fig. 4). Stratification generally is indistinct except where thin layers of sandstone are intercalated within conglomeratic units. Bedding, ranging in thickness from 15 cm to 2.5 m, generally is planar or horizontal. Locally, conglomeratic lenses fill shallow channels cut into underlying beds.

The conglomerate clasts are composed of chert and quartzite, and range in size from granules to boulders. Pebbles and cobbles are most common. Clasts of chert are gray, green, black, and brown, and are subangular to subrounded. Clasts of quartzite are white, gray, and brown, and are subrounded to rounded. Most beds are poorly sorted, but finer grained beds are moderately sorted.

Figure 4.--Indistinctly bedded conglomerate of the Diamond Peak Formation on the west side of Burner Basin.

Several minor lithologic variations occur in the section. Well-sorted quartzose sandstone, with varying amounts of reddish clay matrix, occurs as beds 2 - 10 cm thick within conglomeratic intervals. Sand-size grains are fine to medium and are subrounded. Poorly sorted sandstone, pebbly sandstone, and sandy conglomerate occur as massive outcrops north of the Elko-Hamilton Stage Route in sec. 33, T. 34 N., R. 55 E. These rocks fill channels cut into underlying conglomerates. Gravel clasts are composed primarily of quartzite, with very minor amounts of chert. Dark-bluish-gray limestone, which contains abundant corals, crops out on the northern side of Fourmile Canyon in NW$\frac{1}{4}$ sec. 3, T. 33 N., R. 55 E. Dark-greenish-gray, calcareous mudstone, interbedded with bluish-gray, crystalline limestone, occurs on the southwestern edge of Hot Spring Ridge in NE$\frac{1}{4}$ sec. 33, T. 34 N., R. 55 E. The mudstone is fossiliferous, containing fragments of crinoids and brachiopods. The basal contact of the Diamond Peak Formation is not exposed.

Age and Correlation. No fossils were identified from the Diamond Peak Formation during the present study because of the poor quality of fossil preservation. Owing to the lack of paleontologic and radiometric age data, the age of this formation near Elko must be inferred from lithologic similiarities with rocks of confirmed age in nearby areas.

The Diamond Peak Formation occurs extensively in the Carlin-Pinon Range area south and southwest of Elko (Smith and Ketner, 1975, 1978), and there it includes, but is not limited to, the type section of the Tonka Formation of Dott (1955). Smith and Ketner (1975, p. 50) assigned an Early Mississippian to Late Pennsylvanian age to the Diamond Peak in the Carlin-Pinon Range area, on the basis of several species of corals, bryozoans, echinoderms, brachiopods, pelecypods, gastropods, trilobites, fish, and worms. Gordon and Duncan (1961, p. 234) pointed out, however, that the Tonka Formation in its type section contains beds of Late Mississippian and Early Pennsylvanian age only. As the Diamond Peak Formation near Elko is lithologically similar to the type section of the Tonka Formation, the Diamond Peak Formation near Elko is considered to be of Late Mississippian and Early Pennsylvanian age.

Depositional Environment. Dott (1955, p. 2226) thought the Tonka Formation, which included the Diamond Peak Formation near Elko, was deposited by rapid accumulation of sediment seaward from a rugged, rising, seacliff coast. Brew (1971, p. 25-26) concluded that coarse-grained rocks of the Diamond Peak near Eureka probably were deposited by submarine slides or turbidity flows. A similar hypothesis was presented by Silitonga (1974, p. 34-35), who believed that the siliceous clasts may have been dislodged from coalescing deltas at the edge of the basin and carried into deeper water by subaqueous slides. The present study indicates that the indistinctly bedded conglomerates of the Diamond Peak Formation near Elko are similar to the disorganized conglomerates of Walker and Mutti (1973).

These are characterized by a dominance of pebble- to boulder-size clasts. Stratification, graded bedding, elongation of clasts, and imbrication are lacking. Rocks of this type probably were deposited by sediment gravity flows in relatively deep water.

The high proportion of siliceous clasts in the Diamond Peak Formation suggests that it was derived from lower Paleozoic siliceous-assemblage rocks of the upper plate of the Roberts Mountains thrust; most of the chert and quartzite clasts could have come from the Valmy and Vinini Formations of Ordovician age (Smith and Ketner, 1975). Although no consistent trend for variation of thickness, clast size, or sorting has been noted in the area of study, Silitonga (1974) has described an increase in thickness of the Diamond Peak Formation toward the north-northwest in the Adobe Mountains, 13 km north of Elko. Moreover, Silitonga (1974) noted that clasts are larger and less well sorted to the northwest, and Smith and Ketner (1975) noted a lateral decrease in clast size to the southeast, suggesting a northwestern source area.

Poorly sorted sandstone and pebbly sandstone filling channels cut into the underlying conglomerates may represent submarine channel fills deposited in submarine canyons or channels on slopes. Limestone and mudstone were deposited in relatively quiet water. The faunal assemblage of corals, brachiopods, and crinoids in the limestone and mudstone suggests a source for the fossils of relatively shallow water in the neritic zone. The large size of the brachiopod and crinoid fragments and the presence of unfragmented corals suggest that the shallow-water fauna was transported without much abrasion to deeper water.

Tertiary System

The Tertiary stratigraphic sequence near Elko ranges in age from Eocene(?) to Miocene. Stratigraphic nomenclature in the Elko area has largely been adopted from nomenclature established by Smith and Ketner (1976). Correlations of Paleogene units near Elko with Paleogene units in the western Uinta Basin, Utah, in east-central Nevada, and elsewhere in northeast Nevada are shown in figure 5.

New information about the composition of Tertiary rocks near Elko has been generated to assist in the interpretation of the stratigraphic sequence. This information includes new analyses of the mineralogy of tuffs (table 2), chemical composition of volcanic rocks (table 3), radiometric ages (table 4), and the mineralogy of fine-grained sedimentary rocks (table 5).

Eocene(?) Series

Limestone and Limestone-Clast Conglomerate. This unit was informally named by Smith and Ketner (1976) for rocks that occur in the Dixie Flats quadrangle south of Elko. In the Dixie Flats quadrangle, the unit consists principally of pale-yellow, dense limestone and some gray limestone, and of conglomerate composed mostly of limestone pebbles to boulders that were identified as derived from Paleozoic rock units in the immediate vicinity. In the area of this study, the unit contains

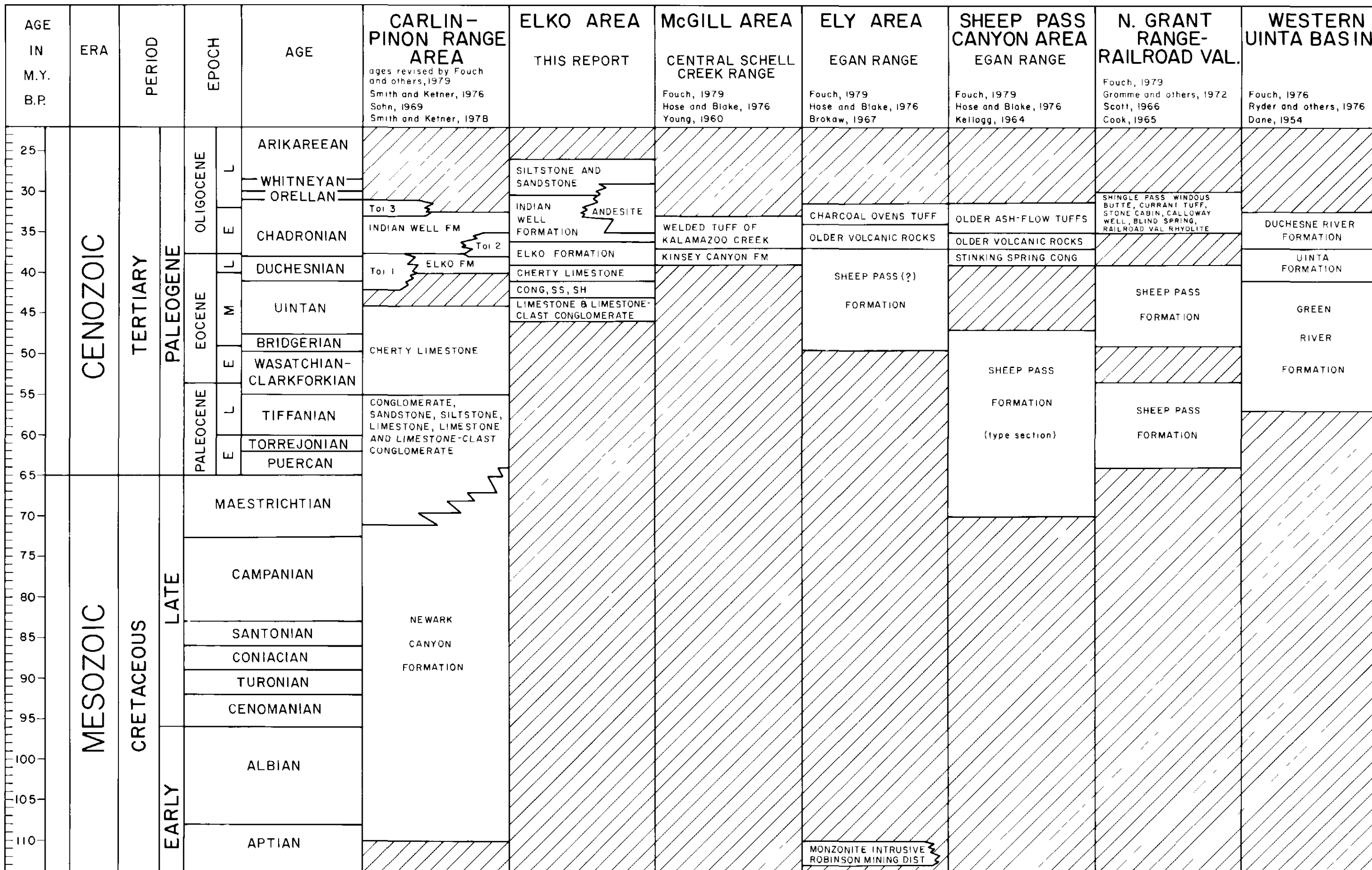


Figure 5.--Correlation chart of Cretaceous and Paleogene units in northeast Nevada, east-central Nevada, and the western Unita Basin, Utah (modified from Fouch and others, 1979, fig. 2). In the Carlin-Pinon Range area, Toi 1 indicates the older intermediate volcanics of Smith and Ketner (1976); Toi 2 indicates the silicic intrusive rocks of Smith and Ketner (1976); Toi 3 indicates the mafic to intermediate plugs and dikes of Smith and Ketner (1976).

Table 2.--Mineralogy of tuffs from Elko, Nevada, as determined by X-ray diffraction.
[Analyst: R. A. Sheppard. Minerals in all capital letters are present in major quantities. Minerals with first letter capitalized are present in minor quantities. Minerals in all lower-case letters are present in traces.]

Unit	Sample No. (Locations shown on figure 3)	Mineralogy
Humboldt Formation	E-13-77	QUARTZ, CALCITE, Plagioclase, Biotite
Indian Well Formation	Es-1-77	OPAL-CT, Quartz, Plagioclase, clinoptilolite (?)
	Es-2-77	OPAL-CT, QUARTZ
	Es-3-77	MONTMORILLONITE, Plagioclase, Quartz, Biotite
	BJS-9	MONTMORILLONITE, Plagioclase, quartz
Elko Formation, member 5	BJS-3	CLINOPTILOLITE, Quartz, Biotite, opal-CT, plagioclase
	BJS-11	QUARTZ, OPAL-CT, Plagioclase, biotite
Elko Formation, member 4	E-15-77	CLINOPTILOLITE, Opal-CT, Quartz, Unidentified clay mineral, biotite
Elko Formation, member 2	E-14-77	CLINOPTILOLITE, Opal-CT, Plagioclase, biotite
Conglomerate, sandstone, and shale	BJS-1	KAOLINITE, QUARTZ, Montmorillonite, Calcite, Biotite

Table 3.--Chemical analyses of volcanic rocks near Elko, Nevada (in weight percent). [Analysts: P. R. Klock and S. Morgan. FeO, H_2O+, H_2O-, CO_2, Cl, F, and S measured with full wet-chemical techniques; other analyses by X-ray flourescence. BJS-1 from conglomerate, sandstone and shale; BJS-3 and BJS-6 from Elko Formation, member 5; BJS-9 from Indian Well Formation; BJS-5 and BJS-10 from andesite; BJS-2 from siltstone and sandstone. Sample locations shown on figure 3.]

Sample No.:	BJS-1	BJS-3	BJS-6	BJS-9	BJS-5	BJS-10	BJS-2
Lab No.:	M-134290	M-134285	M-134287	M-134288	M-134286	M-134289	M-134284
SiO_2	66.58	67.08	70.56	66.81	59.32	57.21	70.66
Al_2O_3	14.92	13.24	12.87	14.75	15.54	16.02	12.27
Fe_2O_3	4.01	.81	1.20	1.30	1.95	2.13	1.21
FeO	.29	.29	.42	.47	3.62	4.84	.60
MgO	.94	.82	.55	1.04	4.34	4.76	.23
CaO	2.92	2.67	1.40	2.67	6.69	6.97	1.47
Na_2O	.68	1.06	2.02	2.80	2.67	2.87	2.69
K_2O	.60	4.30	5.30	2.89	2.50	2.21	6.55
H_2O+	5.45	6.09	3.78	3.68	1.32	.76	2.90
H_2O-	3.00	4.28	1.87	4.03	.50	.42	1.08
TiO_2	.42	.24	.24	.19	.80	.78	.21
P_2O_5	.15	.09	.10	.09	.27	.25	.09
MnO	.05	.01	.05	.07	.10	.12	.04
CO_2	2.02	.19	.66	.10	.10	.08	.88
Cl	.08	.03	.10	.04	.10	.10	.10
F	.08	.02	.05	.06	.03	.04	.06
S	.15	.01	.02	.03	.06	.02	.03
Total	102.35	101.23	101.22	101.03	99.93	99.62	101.08

Table 4.--Radiometric ages of rocks near Elko, Nevada (from Solomon and others, 1979a).

Unit	Sample number	Location (Shown on figure 3)	Material dated	U ppm K_2O percent	$^{40}Ar_{rad}$ mole/gx10^{10}	$^{40}Ar_{rad}$ percent	Apparent age m.y.$\pm\sigma$
Tuff in siltstone and sandstone	BJS-2 Fission track 1/	40°48'20"N 115°44'00"W	Zircon 6 crystals counted	320	--	--	27.0 ± 1.2 (2σ)
Andesite (flow)	BJS-5 K-Ar 2/	40°46'30"N 115°45'30"W	Andesite	3.06	1.3710	39	30.9 ± 1.0
	BJS-10 K-Ar	40°46'00"N 115°46'00"W	Andesite	2.86	1.4265	39	35.2 ± 1.1
Tuff, member 5, Elko Formation	BJS-6 K-Ar	40°46'30"N 115°45'30"W	Biotite	7.67	4.1347	44	37.1 ± 1.0
	BJS-3 K-Ar	40°48'50"N 115°44'10"W	Biotite	8.87	5.0149	83	38.9 ± 0.3

Table 4.--Radiometric ages of rocks near Elko, Nevada.--Continued

Unit	Sample number	Location (Shown on figure 3)	Material dated	U ppm K_2O percent	$^{40}Ar_{rad}$ mole/gx10^{10}	$^{40}Ar_{rad}$ percent	Apparent age m.y.$\pm$
Tuff in conglomerate, sandstone, and shale	BJS-1 K-Ar	40°48'20"N 115°43'00"W	Biotite	6.63	4.1847	74	43.3 ± 0.4

1/Fission-track age by Charles W. Naeser (1978, written commun.). $U^{238} = 7.03\times10^{-17}\ yr^{-1}$

2/K-Ar ages: Ar analyses by standard isotope dilution procedures using a 60° sector 15.2 cm radius Neir-type mass spectrometer. K analyses performed by a lithium metaborate flux fusion-flame photometer technique. $\lambda_\varepsilon = 0.572\times10^{-10}\ yr^{-1}$, $\lambda_\beta = 4.963\times10^{-10}\ yr^{-1}$, $^{40}K/K$ total $= 1.167\times10^{-4}$ mole/mole

Table 5.--Mineralogy of fine-grained sedimentary rocks near Elko, Nevada, as determined by X-ray diffraction. [Analysts: W. A. Robb and J. W. Smith. Minerals listed in relative order of abundance. Minerals in all capital letters are present in major quantities. Minerals with first letter capitalized are present in minor quantities. Member 2 samples collected from 30-cm-thick (1-ft-thick) intervals in trench COS-4. All other samples collected from surface outcrops at irregular intervals.]

Unit	Sample No. (Locations shown on figure 3)	Mineralogy
Elko Formation, member 4	E-20-77	QUARTZ, Feldspar, Illite
	E-21-77	QUARTZ, Calcite, Feldspar, Analcime
Elko Formation, member 3	E-12-77	QUARTZ, Smectite, Calcite, Feldspar, Analcime
	E-11-77	QUARTZ, Smectite, Feldspar, Dolomite, Calcite, Illite
	E-10-77	QUARTZ, Smectite, Calcite, Feldspar, Dolomite
	E-9-77	CALCITE, QUARTZ, Smectite, Dolomite, Clinoptilolite?
	E-8-77	QUARTZ, Smectite, Calcite, Dolomite, Feldspar
	E-7-77	QUARTZ, Calcite, Smectite, Feldspar
	E-6-77	QUARTZ, Feldspar, Calcite, Smectite, Dolomite
	E-5-77	QUARTZ, Dolomite, Feldspar, Calcite, Smectite
	E-4-77	QUARTZ, Calcite, Dolomite, Feldspar, Smectite
	E-3-77	QUARTZ, Dolomite, Calcite, Feldspar, Smectite
Elko Formation, member 2	COS4-1	QUARTZ, Feldspar, Smectite
	COS4-2	QUARTZ, Feldspar, Smectite, Jarosite
	COS4-3	QUARTZ, Feldspar, Illite
	COS4-4	QUARTZ, Feldspar, Illite, Jarosite
	COS4-5	QUARTZ, Feldspar, Smectite, Jarosite
	COS4-6	QUARTZ, Feldspar, Smectite, Jarosite
	COS4-7	QUARTZ, Jarosite, Pyrite, Feldspar
	COS4-8	QUARTZ, Pyrite, Feldspar
	COS4-9	QUARTZ, Jarosite

Table 5.--Mineralogy of fine-grained sedimentary rocks near Elko, Nevada, as determined by X-ray diffraction.--Continued

Unit	Sample No. (Locations shown on figure 3)	Mineralogy
Elko Formation, member 2	COS4-10	QUARTZ, Jarosite, Feldspar, Gypsum
	COS4-11	QUARTZ, Jarosite, Gypsum, Pyrite
	COS4-12	QUARTZ, Smectite, Jarosite, Feldspar, Gypsum, Pyrite
	COS4-13	QUARTZ, Illite, Smectite, Feldspar, Jarosite, Gypsum
	COS4-14	QUARTZ, Illite, Feldspar
	COS4-15	QUARTZ, Illite, Feldspar, Gypsum
	COS4-16	QUARTZ, Illite, Feldspar
	COS4-17	QUARTZ, Illite, Smectite, Kaolinite, Feldspar, Gypsum
	COS4-18	QUARTZ, Smectite, Illite, Kaolinite
	COS4-19	SMECTITE, Quartz
	COS4-20	QUARTZ, Smectite, Illite, Feldspar, Gypsum
	COS4-21	QUARTZ, Smectite, Feldspar, Illite, Gypsum
	COS4-22	QUARTZ, Smectite, Feldspar, Gypsum
	COS4-23	QUARTZ, Smectite, Feldspar, Jarosite, Gypsum
	COS4-24	QUARTZ, Smectite, Illite, Feldspar
	COS4-25	QUARTZ, Smectite, Feldspar
	COS4-26	QUARTZ, Smectite, Feldspar
	COS4-27	QUARTZ, Jarosite, Gypsum, Pyrite
	COS4-28	QUARTZ, Smectite, Gypsum
	COS4-29	QUARTZ, Smectite, Gypsum, Feldspar
	COS4-30	QUARTZ, Smectite, Gypsum, Pyrite
	COS4-31	QUARTZ, Smectite, Gypsum
	COS4-32	QUARTZ, Smectite, Gypsum
	COS4-33	QUARTZ, Smectite, Gypsum, Feldspar
	COS4-34	JAROSITE, Quartz, Gypsum
	COS4-35	QUARTZ, Smectite, Feldspar, Gypsum
	COS4-36	QUARTZ, Smectite, Feldspar, Gypsum
	COS4-37	QUARTZ, Smectite, Feldspar, Gypsum

Table 5.--Mineralogy of fine-grained sedimentary rocks near Elko, Nevada, as determined by X-ray diffraction.--Continued

Unit	Sample No. (Locations shown on figure 3)	Mineralogy
Elko Formation, member 2	COS4-38	QUARTZ, Smectite, Feldspar
	COS4-39	QUARTZ, Smectite, Feldspar
	COS4-40	QUARTZ, Smectite, Feldspar, Gypsum
	COS4-41	QUARTZ, Smectite, Feldspar
	COS4-42	QUARTZ, Smectite, Feldspar, Gypsum
	COS4-43	QUARTZ, Smectite, Feldspar, Illite, Gypsum, Unknown
	COS4-44	SMECTITE, QUARTZ, Feldspar, Gypsum
	COS4-45	GYPSUM, Smectite, Quartz
	COS4-46	QUARTZ, GYPSUM, Smectite, Illite, Feldspar
	COS4-47	QUARTZ, Smectite, Gypsum, Feldspar
	COS4-48	QUARTZ, Smectite, Gypsum, Feldspar
	COS4-49	QUARTZ, GYPSUM, Smectite, Feldspar
	COS4-50	QUARTZ, GYPSUM, Smectite
	COS4-51	QUARTZ, GYPSUM, Smectite
	COS4-52	QUARTZ, GYPSUM, Smectite, Analcime?
	COS4-53	GYPSUM, Quartz, Smectite
	COS4-54	QUARTZ, Smectite, Feldspar
	COS4-55	QUARTZ, Smectite, Gypsum
Elko Formation, member 1	E-16-77	QUARTZ, Calcite, Smectite, Feldspar
	E-17-77	QUARTZ, Illite
	E-18-77	QUARTZ, Illite Feldspar
	E-19-77	QUARTZ, Calcite, Illite
Conglomerate, sandstone, and shale	E-2-77	QUARTZ, Illite, Kaolinite, Feldspar

only the conglomeratic facies, but this may be the result of the small area of outcrop rather than a change in the intrinsic lithology of the unit. In the Elko area, the limestone and limestone-clast conglomerate crop out on a small hill in NW¼ sec. 4, T. 33 N., R. 55 E., just west of the range-front fault along which Hot Spring Ridge has been uplifted (pl. 1).

Where the unit appears to be thickest and best exposed in the Dixie Flats quadrangle, approximately 11 km southwest of Elko, a partial thickness of more than 194 m was measured (Smith and Ketner, 1976, p. 14). In the Elko area, no more than 15 m of the limestone and limestone-clast conglomerate is exposed (fig. 2).

Lithology. In the Elko area, this unit is composed solely of conglomerate containing pebble- to boulder-size, bluish-gray limestone clasts as much as 30 cm across. The clasts are angular to subangular and are moderately sorted. Sand-size matrix material is rare. Rare fractures are filled with light-gray calcite and with reddish-orange clay.

In the Carlin-Pinon Range area, the limestone and limestone-clast conglomerate unit rests unconformably on Paleozoic rocks (Smith and Ketner, 1976, p. 18). In the area of the present study, the basal contact of this unit is covered by Quaternary gravel, sand, and silt, but presumably the limestone and limestone-clast conglomerate unit unconformably overlies Paleozoic rocks near Elko.

Age and Correlation. No fossils were found in this unit near Elko, nor was there any material that can be radiometrically dated.

Ostracodes collected from this unit in the Dixie Flats quadrangle, however, suggested an Eocene age to I. G. Sohn (Smith and Ketner, 1976, p. 15). Charophyte gyrogonites collected by Smith and Ketner were examined by R. E. Peck, who estimated the age of the sample as late Cretaceous (Smith and Ketner, 1976, p. 15). Smith and Ketner (1976) assigned the limestone and limestone-clast conglomerate to the Eocene(?) because the unit is more similar to younger strata of probable Tertiary age than it is to units of known Cretaceous age, and because the limestone and limestone-clast conglomerate unit occurs in the present basins, whereas the Mesozoic rocks occur mostly in the mountains. The limestone and limestone-clast conglomerate unit is considered Eocene(?) in the present study because of the presumed stratigraphic position of the unit below rocks of known Eocene age in the Elko area, and because of the age assignment by Smith and Ketner (1976) for similar rocks in the Dixie Flats quadrangle.

The limestone and limestone-clast conglomerate may be equivalent to the lowermost part of the section tentatively mapped as the Sheep Pass Formation near Ely, Nevada (Brokaw, 1967; Hose and Blake, 1976; Fouch, 1979; Fouch and others, 1979), to the uppermost part of the type section of the Sheep Pass Formation south of Ely (Kellogg, 1964; Hose and Blake, 1976; Fouch, 1979; Fouch and others, 1979), and to portions of the Sheep Pass Formation near Railroad Valley, Nevada (Cook, 1965; Scott, 1966; Gromme and others, 1972; Fouch, 1979; Fouch and others, 1979) as shown in figure 5. The limestone and limestone-clast conglomerate may be coeval with portions of the Green River Formation in the western Uinta Basin (Fouch, 1976).

Depositional Environment. Clasts of the conglomerate that occur in the mapped area were derived from a lithologically similar Permian limestone source. The Permian limestone has been mapped as undivided Permian and Pennsylvanian rocks 3 km south of the conglomerate outcrop (Smith and Ketner, 1975). The conglomerate evidently was deposited in a high energy, alluvial environment. This is indicated by the large clast size and by the angularity of the clasts, which are suggestive of material that was not transported a great distance. Smith and Ketner (1976, p. 14-15) surmised, from the more extensive area of outcrop in the Dixie Flats quadrangle, that the conglomerate was deposited on an irregular surface probably very similar to the present one.

Chert and quartzite clasts are dominant in this unit 3 km southeast of the present study area. Although limestone clasts are predominant in this unit near Elko and in the Dixie Flats area, the dominance of chert- and quartzite-bearing conglomerate in this unit 3 km to the southeast reflects the varied provenance of the limestone and limestone-clast conglomerate unit. These siliceous clasts probably were derived from the Diamond Peak Formation, rather than the Permian limestone that was the source of the carbonate clasts. The distribution of the siliceous and carbonate clasts in the Eocene(?) unit reflects the present-day distribution of the Paleozoic source rocks; the Eocene(?)conglomerate with siliceous clasts rests on the east side of Hot Spring Ridge, which is composed of the Diamond Peak, whereas the Eocene(?) conglomerate with carbonate clasts occurs west of Hot Spring Ridge in an area underlain, for the most part, by Permian limestone. The clasts evidently were not transported very far or mixed with clasts from other sources.

Eocene Series

Units in the Eocene Series include the informally named conglomerate, sandstone, and shale, and the informally named cherty limestone. The conglomerate, sandstone, and shale unit occurs east of Hot Spring Ridge, and contains evidence of the earliest known Tertiary volcanism in northeast Nevada. Outcrops of the cherty limestone are scattered throughout the Elko area. These units record the initial stages of lacustrine and related alluvial deposition in the Elko area.

Conglomerate, Sandstone, and Shale. A sequence of shale, siltstone, claystone, and tuff, overlain by several beds of sandstone and conglomerate, is mapped as the conglomerate, sandstone, and shale unit near Elko (pl. 1). This unit may be in part laterally equivalent to the limestone and limestone-clast conglomerate, but this relationship is unclear. The conglomerate, sandstone, and shale unit is known only from the Elko area, but it occupies a similar stratigraphic position below the cherty limestone as does the Eocene(?) conglomerate, sandstone, siltstone, and limestone south of Elko (Smith and Ketner, 1976) and the conglomerate and sandstone unit and a breccia unit north of

Elko (Silitonga, 1974). Unlike similar units north and south of Elko, the conglomerate, sandstone, and shale unit contains tuffaceous matter.

The conglomerate, sandstone, and shale unit is approximately 32 m thick near Elko. In contrast, the conglomerate, sandstone, siltstone, and limestone unit has a maximum thickness of at least 760 m about 55 km south of Elko (Smith and Ketner, 1976, p. 17). The conglomerate and sandstone unit is about 146 m (480 ft) thick 8 km north of Elko (Silitonga, 1974, p. 42).

Lithology. The predominant rock types in the lower part of this unit are claystone, shale, and siltstone (fig. 6). Light-brown to gray claystone is present in thin to very thin, horizontally stratified beds, some of which grade laterally into shale with wavy laminations. The claystone and shale are unfossiliferous, but contain a small amount of disseminated organic matter. Interbedded with the claystone and shale are moderate-reddish-brown, thin-bedded, horizontally stratified siltstone and minor amounts of medium-gray, thin-bedded, unfossiliferous clayey limestone and light-gray, conglomeratic sandstone. Near the base of the unit is a 50-cm-thick tuff bed. X-ray diffraction analysis shows that the tuff, the location of which is shown in figure 3, is composed mainly of kaolinite and quartz, with minor montmorillonite, calcite, and biotite (R. A. Sheppard, 1978, written commun.; table 2). A chemical analysis of the tuff is shown in table 3.

Figure 6.--Thin- to very thin bedded, horizontally stratified fine-grained rock in the lower part of the conglomerate, sandstone, and shale unit in a roadcut north of Elko Summit on the Elko-Lamoille Highway.

The upper part of the unit consists of conglomerate and sandstone in laterally persistent, medium-scale, trough cross-stratified units up to 3 m thick (fig. 7). Grain size and scale of stratification types generally do not decrease upward in these sequences. Locally, the conglomerate and sandstone fill channel-form lenses. The sandstone is a yellowish-orange, poorly sorted litharenite. Grains of chert, volcanic rock fragments, and quartz are mixed with lesser amounts of feldspar. Rounded to subrounded pebbles of chert and quartzite are common in the sandstone. In many places, pebbly layers and silty laminae are intercalated within the sandstone. The conglomerate is similar in composition to the sandstone, with chert and quartzite clasts in a subangular, medium-grained, sandy matrix. Convolute bedding is present within some sandstone beds (fig. 8). The sandstone and conglomerate beds are unfossiliferous.

The conglomerate, sandstone, and shale unit unconformably overlies the Mississippian and Pennsylvanian Diamond Peak Formation. The contact between the two units is placed at the top of the uppermost dark-reddish-brown conglomerate in the Diamond Peak Formation.

Very good exposures of the conglomerate, sandstone, and shale unit exist north of Elko Summit in a roadcut for the Elko-Lamoille Highway (fig. 1). Although present elsewhere, outcrops are extremely poor owing to the easy erosion of the finer grained, lowermost strata. Coarser clastic beds at the top of the unit are more resistant and well exposed, and are thus more readily identified.

Figure 7.--Cross-stratified conglomerate and sandstone beds in the upper part of the conglomerate, sandstone, and shale unit.

Figure 8.--Sandstone with convolute bedding in upper part of conglomerate, sandstone, and shale unit.

A stratigraphic section measured north of Elko Summit is presented as a representative section of these rocks. An additional 2 m of claystone and shale present elsewhere may once have underlain unit 1 of this measured section, but now are missing owing to faulting at the base of the section. The maximum thickness of the conglomerate, sandstone, and shale unit, estimated from measurement on the geologic map, is 32 m.

Measured stratigraphic section (S1 on fig. 3) of the conglomerate, sandstone, and shale unit in NE¼ sec. 25, T. 34 N., R. 55 E., Elko East quadrangle (measured by use of Brunton compass and steel tape).

Thickness (m)

Cherty limestone (Eocene):
Claystone, siltstone, and minor limestone. Not measured; contact with conglomerate, sandstone, and shale conformable or disconformable.

Conglomerate, sandstone, and shale (Eocene):

9. Conglomerate and sandstone, with minor shale and limestone. Conglomerate, moderate-yellowish-orange; beds up to 60 cm thick; quartzite and chert clasts, up to 7.5 cm diameter, rounded to subrounded, in matrix of medium-grained, poorly sorted, angular, sand-size grains. Sandstone, moderate-yellowish-orange; beds up to 30 cm thick; commonly cross-bedded or contorted; mainly chert, quartz, and volcanic rock fragments, with minor feldspar; texture similar to sandy matrix of conglomerate; rare thin, silty laminae and pebbly layers. Limestone, reddish-orange, finely crystalline, and shale, light-brown to gray, intercalated as minor, thin beds throughout the unit, but more abundant near the base............. 4.57

8. Limestone, clayey, with minor siltstone and claystone. Limestone, medium-gray; finely crystalline; dense; forms resistant beds up to 10 cm thick. Siltstone, light-gray to brown, and claystone, light-gray to brown,

Measured section (SI) of conglomerate, sandstone, and shale--continued.

	Thickness (m)
Conglomerate, sandstone, and shale (Eocene)--continued:	
occur as minor, thin beds throughout the unit..	4.68
7. Siltstone, with minor shale and claystone. Siltstone, moderate-reddish-brown; beds up to 10 cm thick; calcareous. Shale, light-gray to brown, and claystone, light-gray to brown, occur as minor, thin beds throughout the unit..........................	12.18
6. Claystone, shale, and minor siltstone. Claystone, light-brown to gray; beds up to 0.3 cm thick. Grades laterally into shale, similar to claystone but with shaly parting and wavy laminations. Siltstone, moderate-reddish-brown; hard; resistant beds, 1 to 10 cm thick...............	2.43
5. Claystone and shale; same as in unit 6 but without siltstone............................	3.05
4. Sandstone, light-gray; well indurated and resistant; coarse to very coarse grained, with pebbles as much as 1.0 cm across of green, blue, and brown quartzite, black chert, and minor pale-green claystone; sand-size grains subangular to subrounded, and poorly to moderately sorted..............	0.45
3. Claystone, gray to light-brown.................	1.07
2. Tuff, very light-gray; moderately indurated; abundant medium to coarse biotite, trace of quartz and potassium feldspar.............	0.50
1. Claystone and shale; same as in unit 6 but without siltstone............................	1.05+
Measured thickness, base not exposed and top conformable or disconformable.........................	29.98+

Age and Correlation. The conglomerate, sandstone, and shale unit is lithologically distinct, but occupies a stratigraphic position below the cherty limestone similar to that of the Eocene(?) conglomerate, sandstone, siltstone, and limestone south of Elko (Smith and Ketner, 1976) and the Eocene conglomerate and sandstone unit and the Eocene breccia unit north of Elko (Silitonga, 1974). All four units contain coarse-grained alluvium that accumulated prior to deposition of open-lacustrine sediments in northeast Nevada. The conglomerate, sandstone, siltstone, and limestone unit is exposed in widely scattered areas on the east side of, and east of, the Pinon Range, and is considered Eocene(?) because of stratigraphic position and similarity to strata of known early Tertiary age (Smith and Ketner, 1976). The conglomerate and sandstone and the breccia units, exposed on the south flank of the Adobe Mountains, are considered Eocene because of their similarity to Eocene strata (Silitonga, 1974; Smith and Ketner, 1972). Tuff near the base of the conglomerate, sandstone, and shale unit near Elko has been dated by the K-Ar method at 43.3 ± 0.4 m.y. (table 4). Because the conglomerate, sandstone, and shale unit underlies rocks of known Eocene age, and because the base of the unit has been radiometrically dated as Eocene, the unit must be entirely Eocene.

The radiometric age obtained on tuff near the base of the conglomerate, sandstone, and shale is of particular significance to the Tertiary history of the Great Basin, because the tuff records one of the earliest known dates of Tertiary volcanism in northeast Nevada (McKee and others, 1976). Moreover, because the tuff is interbedded with rocks deposited near the edge of a lake in the Elko region, it suggests that Tertiary lacustrine deposition in the area commenced at least as early as middle Eocene time.

The conglomerate, sandstone, and shale unit may be equivalent to some beds tentatively mapped as the Sheep Pass Formation near Ely, Nevada (Brokaw, 1967; Hose and Blake, 1976; Fouch, 1979; Fouch and others, 1979) and to portions of the Sheep Pass Formation near Railroad Valley, Nevada (Cook, 1965; Scott, 1966; Gromme and others, 1972; Fouch, 1979; Fouch and others, 1979) as shown in figure 5. The unit near Elko is slightly younger than the Sheep Pass Formation south of Ely (Kellogg, 1964; Hose and Blake, 1976; Fouch, 1979; Fouch and others, 1979). It may be coeval with portions of the Green River Formation in the western Uinta Basin (Fouch, 1976).

Depositional Environment. The conglomerate, sandstone, and shale are thought to represent alluvial and either marginal lacustrine or floodplain pond environments. The reddish-brown color of the fine-grained rocks in the lower part of the unit suggests subaerial exposure. The interbedded, horizontally stratified carbonate rocks resemble those of the Flagstaff Member of the Green River Formation, described by Ryder and others (1976), and interpreted by them to represent deposition on a mudflat that was intermittently covered by lake water. Alternatively, the lower part of the unit may represent deposits of a floodplain and small ponds similar to deposits described by Andersen and Picard (1974) in the Dry Gulch Member of the Duchesne River Formation.

In the upper part of the conglomerate, sandstone, and shale unit, reddish-brown, fine-grained rocks are interbedded with cross-stratified, channel-form sandstone and conglomerate. Grain size and scale of stratification do not decrease upward in the coarse-grained rocks. The upper part of the unit resembles deposits of braided streams described by Ore (1964) and Williams and Rust (1969), and is interpreted to be channel-bar deposits of prograding, braided streams. These streams drained a source area composed mainly of older, siliceous sedimentary and metamorphic rocks. The source area included older or contemporaneous volcanic rocks.

Cherty Limestone. A unit primarily composed of limestone, cherty limestone, claystone, and siltstone crops out in the western and eastern parts of the mapped area (pl. 1). This informally designated unit, herein called cherty limestone, is of Eocene age (fig. 2).

The cherty limestone unit is approximately 61 m thick near Elko. It has been estimated to be in excess of 305 m thick in the Carlin-Pinon Range area (Smith and Ketner, 1976, p. 17). Sharp (1939, p. 142), describing what was then known as the lower member of the Humboldt Formation, but evidently is correlative with the cherty limestone (Smith and Howard, 1977), measured 265 m (870 ft) of limestone near Huntington Creek, south of Elko. Correlative beds also have been mapped north of Elko in the foothills of the Adobe Range, where their thickness has been estimated to be 335 m (1100 ft; Silitonga, 1974, p. 46-47).

Lithology. Thin to thick beds of mottled, reddish-brown and greenish-gray, poorly sorted, silty claystone and clayey siltstone are dominant in the lower portion of this unit. Stratification is indistinct and discontinuous, and is marked in places by layers with a concentration of light-gray, calcareous nodules up to 1 cm long. Where exposures are poor, slopes developed on these fine-grained rocks are similar in appearance to those developed on fine-grained rocks at the base of the conglomerate, sandstone, and shale unit. Distinctive dark-red claystone beds that aid in the identification of the cherty limestone are present in the lower part of the unit (fig. 9).

Near the middle of the cherty limestone, greenish-gray and brownish-yellow, thin- to very thin-bedded claystone and silty claystone are more distinctly laminated than fine-grained rocks of the lower part of the unit, and they contain very thin lignitic layers. These rocks grade upward into grayish-yellow and light-gray, thick- to very thin-bedded, calcareous siltstone and claystone. The calcareous, fine-grained beds contain ostracodes.

The upper part of the cherty limestone consists of light-gray to yellowish-gray, thin- to very thin-bedded limestone and calcareous siltstone (fig. 10). Bedding of the limestone is laterally persistent and generally planar, but in some places is wavy and indistinct. The limestone emits a fetid, petroliferous odor when treated with dilute hydrochloric acid. Gastropods and ostracodes are abundant (table 1). One cherty limestone sample is dominated by gastropods of the genus _Biomphalaria_; the gastropod _Lymnaea_ cf. _L_. Form C of

Figure 9.--Dark-red claystone beds in lower part of cherty limestone unit in a roadcut north of Elko Summit on the Elko-Lamoille Highway.

Figure 10.--Thin to very thin, horizontally stratified beds of limestone and calcareous siltstone in upper part of cherty limestone unit.

the Sheep Pass Formation and other species of Lymnaea also were identified (U.S. Geological Survey Cenozoic Locality D1288NM; J. Hanley, 1978, written commun.). Pelecypods are less common. Most limestone beds consist of mud-supported biomicrite. A single thin bed of limestone, in SW¼ sec. 25, T. 34 N., R. 55 E., contains abundant coated grains of microcrystalline carbonate aggregates. Dolomite has not been observed in the unit. Most fossils are at least partly silicified, and chert nodules flattened along bedding surfaces are common. Some limestone beds contain elongated, rounded calcareous concretions up to 20 cm long. Other limestone beds have scattered, medium sand-sized, black, chert grains and minor quartz, feldspar, and biotite. Limestone beds near the top of the unit are tuffaceous and contain glass shards.

The cherty limestone unit in places conformably and at others disconformably, overlies the unit of conglomerate, sandstone, and shale. The contact between the two units was mapped at the top of the uppermost sandstone bed in the conglomerate, sandstone, and shale unit. Where the conglomerate, sandstone, and shale unit is absent, the cherty limestone unconformably overlies the Diamond Peak Formation. In the area of the present study, the cherty limestone and the limestone and limestone-clast conglomerate units are nowhere in direct contact, but less than 2 km southwest of the area the cherty limestone appears to be conformable or slightly disconformable on the limestone and limestone-clast conglomerate. In their description of contact relationships of the cherty limestone where it was first described in the

Carlin-Pinon Range area south of Elko, Smith and Ketner (1976) noted that this unit probably is slightly disconformable in most places on older Eocene rocks, and it may be in angular discordance with some Eocene units. The limestone with chert nodules unit of Silitonga (1974), which is equivalent to the basal portion of the cherty limestone of this study, conformably overlies older Eocene rocks or, where those are absent, unconformably overlies Paleozoic rocks.

The cherty limestone unit is well exposed north of Elko Summit in a roadcut for the Elko-Lamoille Highway. A stratigraphic section measured at that location is presented as a representative section of these rocks. Elsewhere, the resistant limestone forms elongate ridges parallel to the strike of the beds, but the underlying fine-grained beds are obscured by platy limestone float. Thus, unless the unit is well exposed, the relative amount of limestone may be greatly exaggerated.

Measured stratigraphic section (S2 on fig. 3) of the cherty limestone unit in SW¼ sec. 30., T. 34 N., R. 56 E., Elko East quadrangle (measured by use of Brunton compass and steel tape).

Thickness (m)

Elko Formation (Eocene and Oligocene?):
Member 3. Not measured; contact with cherty limestone conformable.

Cherty limestone (Eocene):

16. Limestone, light-gray; siliceous, tuffaceous, with occasional small biotite grains; unfossiliferous; beds up to 10.0 cm thick; forms platy pieces on slopes; often breaks with conchoidal fracture. Unit not well exposed...................... 15.20

Measured section (S2) of cherty limestone--continued.

	Thickness (m)
Cherty limestone (Eocene)--continued:	
15. Limestone with minor chert and siltstone. Limestone, light-gray to yellowish-gray; dense; beds up to 10.0 cm thick; bedding is planar, locally wavy and indistinct; highly fossiliferous, with ostracodes and gastropods abundant and pelecypods less common; contains minor rounded, coarse sand-sized grains of black chert; often emits a fetid, petroliferous odor when treated with dilute hydrochloric acid. Chert, black, brown, and yellowish-gray; occurs as nodules and lenses within limestone; lenses up to 3.0 cm thick and 90 cm long; contains silicified fossil fragments similar to those in limestone; boundary with enclosing limestone sharp to gradational. Siltstone, yellowish-gray; soft, calcareous; beds up to 5.0 cm thick, intercalated with limestone; contains abundant ostracodes................	4.57
14. Limestone; same as in unit 15, but with elongate, rounded limestone concretions; concretions similar in appearance to matrix, but denser; up to 20 cm long, with long axes parallel to bedding...............	0.91
13. Limestone, with minor chert and siltstone; same as in unit 15..........................	9.14
12. Claystone, grayish-yellow and light-gray; rarely silty; noncalcareous to slightly calcareous; beds up to 0.5 cm thick; contains scattered ostracodes..................	1.22
11. Clay, black; silty, soft......................	0.06
10. Claystone, greenish-gray and brownish-yellow; rarely silty; noncalcareous to slightly calcareous, beds up to 2.0 cm thick; contains very thin lignitic layers.............	2.44

Measured section (S2) of cherty limestone--continued.

Thickness (m)

Cherty limestone (Eocene)--continued:

9. Claystone, dark-red; noncalcareous; unfossiliferous; minor, thin beds of greenish-gray claystone near top.................... 2.46

8. Limestone, gray, weathers to reddish brown; dense; unfossiliferous; minor, small flakes of biotite.................................. 0.50

7. Clay, claystone, and minor limestone. Clay, gray to light-reddish-brown; soft; beds up to 5.0 cm thick. Claystone, greenish-gray; beds up to 5.0 cm thick. Limestone, light-gray weathers reddish brown; hard; abundant biotite; unfossiliferous; beds up to 5.0 cm thick.......................... 1.07

6. Claystone, greenish-gray; silty; beds up to 1.5 cm thick; unfossiliferous; noncalcareous to slightly calcareous, with occasional layers of light-gray, calcareous nodules; indistinct and discontinuous stratification.. 1.83

5. Sand, brown; clayey; very loosely consolidated quartz sand in a clayey matrix; sand is fine to medium grained, poorly to moderately sorted, subrounded to subangular; few subrounded, gray quartzite and black chert pebbles up to 0.7 cm diameter.......... 0.23

4. Claystone; same as in unit 6.................. 1.22

3. Claystone, dark-red; noncalcareous; unfossiliferous................................ 0.15

2. Claystone; same as in unit 1.................. 2.13

1. Claystone, siltstone, and minor limestone. Claystone, mottled greenish-gray and dark-reddish-brown; dense; silty; rarely porcelaneous; beds up to 35.0 cm thick; slightly calcareous; scattered ostracodes. Siltstone, clayey, same as claystone. Limestone,

Measured section (S2) of cherty limestone--continued.

	Thickness (m)
Cherty limestone (Eocene)--continued:	
yellowish-gray; beds 2.5 to 5.0 cm thick; scattered ostracodes. Unit not well exposed.	18.29
Total thickness....................................	61.42

Conglomerate, sandstone, and shale (Eocene): Conglomerate and sandstone, with minor shale and limestone. Measured in section Sl; contact with overlying cherty limestone conformable or disconformable.

Age and Correlation. The cherty limestone unit is lithologically similar to rocks of the same unit in the Carlin-Pinon Range area (Smith and Ketner, 1976) and along Huntington Creek (Smith and Howard, 1977), south of Elko. Rocks of the same age and lithology have been identified in the foothills of the Adobe Range, north of Elko (Silitonga, 1974). The cherty limestone unit is Eocene. K-Ar dates of 43.3 ± 0.4 m.y. from the underlying conglomerate, sandstone, and shale, and of 38.9 ± 0.3 m.y. from member 5 of the overlying Elko Formation (table 4) provide a fairly short time interval in the middle or late Eocene during which the cherty limestone was deposited. Fossils do not refute an Eocene age. According to Van Houten (1956, p. 2812), D. I. Axelrod reported the presence of snails from the Elko area that suggests an Eocene or Oligocene age. At the south end of the Elko area, D. W. Taylor reportedly found that the petroliferous limestone yielded snails of early Cenozoic (pre-Miocene) age (Van Houten, 1956, p. 2812).

The cherty limestone may be equivalent to some beds tentatively mapped as the Sheep Pass Formation near Ely, Nevada (Brokaw, 1967;

portions of the Sheep Pass Formation near Railroad Valley, Nevada (Cook, 1965; Scott, 1966; Gromme and others, 1972, Fouch, 1979; Fouch and others, 1979; fig. 5). The unit near Elko is slightly younger than the Sheep Pass Formation south of Ely (Kellogg, 1964; Hose and Blake, 1976; Fouch, 1979; Fouch and others, 1979). It may be coeval with the upper part of the Green River Formation in the western Uinta Basin (Fouch, 1976).

Depositional Environment. The cherty limestone unit is thought to represent a transition from fluvial to marginal lacustrine environments. The lower part, composed of variegated, poorly stratified, poorly sorted fine-grained rocks, is interpreted as a floodplain deposit. It is suggested that the calcareous nodules and reddish-brown color of the lower part, similar to features described by Hubert (1978), developed in response to soil-forming processes on the ancient floodplain. The variegated beds grade upward into distinctly horizontally stratified, lignitic, calcareous, fine-grained rocks that record a change from predominantly oxidizing to predominantly reducing conditions. These in turn grade upward to mud-supported, fossiliferous limestone with rare beds of algal(?) coated grains. The middle and upper parts of the cherty limestone unit, which consists mostly of calcareous siltstone and thin- to very thin-bedded limestone, resemble rocks in the Flagstaff Member of the Green River Formation of northeast Utah interpreted by Ryder and others (1976) to be of lake-margin carbonate flat and mudflat origin. Some rocks of the upper part of the cherty limestone, particularly the mud-supported biomicrite, resemble Green River rocks interpreted by Williamson and Picard (1974) as lagoonal in origin. The low-diversity, high-abundance faunal assemblage of the cherty limestone, dominated by the gastropod *Biomphalaria* with Lymnaeid gastropods, is very similar to assemblages of the Sheep Pass Formation interpreted to have inhabited a shallow lacustrine environment (J. Hanley, 1978, written commun.).

Biotite and glass shards near the top of the unit, probably deposited as pyroclastic material, indicate volcanic activity. Silica for the chert probably was derived by alteration of silicic volcanic glass.

Eocene and Oligocene(?) Series

Elko Formation. The Elko Formation is composed of claystone, siltstone, and oil shale, with smaller amounts of chert-pebble conglomerate, sandstone, limestone, and tuff. This formation is of economic importance, both as a potential source of oil shale and as potential petroleum source beds. The type section of the Elko Formation, approximately 25 km southwest of Elko in the Pinon Range, was described by Smith and Ketner (1976, p. 18-19).

The Elko Formation has here been subdivided into five informally named units designated members 1 through 5, in ascending order, except for member 3, which is the lateral equivalent of members 1 and 2 (fig. 2; pl. 1). These units are: (1) claystone, chert-pebble conglomerate, and minor sandstone; (2) rich oil shale, carbonaceous shale, bituminous siltstone, lignite, and tuff; (3) lean oil shale and minor, thin beds of silty limestone; (4) lean oil shale, siltstone, mudstone, and minor tuff, lignite, and limestone; and (5) tuff, shale, and siltstone.

J. P. Buwalda (Winchester, 1923) divided the oil shale near Elko into several zones of outcrop, which he designated A through F. Buwalda assumed that each zone was stratigraphically unique, and that the sequence at Elko was unfaulted. Buwalda's zones A, B, C, and D represent the strata of member 2 of this study, repeated on adjacent ridges by faulting (fig. 11). Zone F corresponds to member 3, whereas zone E is stratigraphically higher and has been mapped as member 4 of the Elko Formation.

The Elko Formation is about 520 m thick near Elko. At its type section in the Carlin-Pinon Range area, the thickness of these beds was measured at 633 m, and a maximum thickness of 760 m was postulated (Smith and Ketner, 1976, p. 21). In the foothills of the Adobe Range, north of Elko, the oil shale unit is only about 100 m (330 ft) thick (Silitonga, 1974, p. 50).

Lithology of Member 1. This member is composed primarily of brown and gray claystone, chert-pebble conglomerate, and minor sandstone (fig. 12). The claystone is present in thin, horizontally stratified beds and contains small amounts of pyrobituminous material. X-ray diffraction analyses show that the claystone is composed of quartz with minor amounts of calcite, smectite, illite, and feldspar (W. A. Robb and J. W. Smith, 1977, written commun.; table 5). These

FORMATION	MEMBER (this report)	OIL SHALE ZONES OF BUWALDA (Winchester, 1923)
ELKO FORMATION	5	
	4	E
	3	F
	2	A, B, C, D
	1	

Figure 11.--Correlation of members of the Elko Formation (this report) with oil shale zones of Buwalda (Winchester, 1923). Buwalda assumed each outcropping zone, which he designated A through F, to be successively younger; the present study shows zones A, B, C, and D to represent the same member repeated on adjacent ridges by faulting, and shows zone E to be stratigraphically higher than zone F.

Figure 12.--Hills in foreground are composed of member 1 of the Elko Formation. Darker bands to the left and right are conglomerate beds; lighter bands in the center are finer-grained rock.

rocks contain ostracodes of the genus Candona, as well as several other unidentified genera (R. M. Forester, 1977, written commun.; table 1). Interbedded chert-pebble conglomerate and sandstone are conspicuous. Varicolored clasts in the conglomerate, up to 5 cm in diameter, are well rounded and poorly sorted. They are loosely cemented in sandy matrix material. The conglomerate and sandstone are rarely crossbedded in small- and medium-scale sets. The base of each bed commonly is irregular and truncates underlying strata. Minor thin beds of reddish-brown, silty limestone are intercalated throughout the unit. Several thin beds of brown, silty biosparite at the top of the member contain individuals of the fingernail clam Sphaerium? sp. (T. D. Fouch and J. H. Hanley, 1978, written commun.; table 1). These beds are excellent markers defining the contact between members 1 and 2, which is placed at the top of the highest biosparite bed.

Member 1 conformably overlies the cherty limestone unit in the study area. In the Carlin-Pinon Range area, the Elko Formation unconformably overlies all older units (Smith and Ketner, 1976). The oil shale unit of Silitonga (1974), which is equivalent to the Elko Formation, conformably overlies older Eocene rocks in the Adobe Range.

Member 1 is poorly exposed, but outcrops are visible in some stream channels. This member weathers to form gentle slopes covered by bands of chert pebbles eroded from the loosely cemented conglomerate beds. Member 1 is approximately 62 m thick, but thins to the east and grades laterally, with member 2, into member 3. A stratigraphic section measured at an outcrop in the central portion of the mapped area is presented as a representative section of these rocks.

Measured stratigraphic section (S3 on fig. 3) of member I of the Elko Formation in NW¼ sec. 26, T. 34 N., R. 55 E. and in SW¼ sec. 23, T. 34 N., R. 55 E., Elko West quadrangle (measured by use of Brunton compass and steel tape).

	Thickness (m)
Elko Formation (Eocene and Oligocene?):	
Member 2. Not measured; contact with member I conformable.	
Member I:	
26. Claystone, conglomerate, and minor limestone. Claystone, dark-brown, weathers light brown to light gray; slightly calcareous; highly fossiliferous, with abundant ostracodes; horizontally stratified in beds I to 10 cm thick. Conglomerate, dark-brown to dark-gray; black chert, with lesser amounts of gray, brown, and green quartzite clasts, up to 5 cm in diameter, in matrix of very fine- to very coarse-grained, poorly sorted, well rounded, sand-sized grains; slightly calcareous; beds up to 75 cm thick, commonly with irregular bases, rarely cross-bedded in small- and medium-scale sets. Limestone, moderate-brown, weathers light reddish brown; silty; abundant, unbroken fingernail clams concentrated on bedding planes; beds 2 to 7 cm thick. Unit not well exposed..................................	7.60
25. Sandstone, moderate- to dark-brown; well indurated; calcareous; unfossiliferous; green, brown, and gray quartzite and black chert grains, coarse to very coarse grained, moderately sorted, subrounded to rounded; irregular base...........	0.33
24. Claystone and conglomerate; same as in unit 26, but without fossiliferous limestone. Not well exposed.................	4.60
23. Conglomerate and sandstone. Conglomerate same as in unit 26, with clasts up to 2.5 cm in diameter. Grades upward into sandstone, moderate-brown; soft; non-calcareous; unfossiliferous; very-coarse	

Measured section (S3) of Elko Formation, member 1--continued:

		Thickness (m)
Elko Formation, member 1 (Eocene and Oligocene?)--continued:		
	to very-fine chert and quartzite grains; moderately sorted; subrounded; pebbly........	0.33
22.	Claystone, minor sandstone and limestone. Claystone same as in unit 26. Sandstone, moderate-brown; loosely consolidated; noncalcareous; unfossiliferous; very fine grained; moderately sorted; subrounded. Limestone, reddish-brown; silty; in two 2.5-cm-thick beds near top of unit; contains scattered ostracodes..	3.10
21.	Conglomerate and sandstone. Conglomerate same as in unit 26, with clasts up to 1.2 cm in diameter. Intercalated with thin beds of sandstone, same as in unit 22, with pebbles up to 1.2 cm in diameter........	0.46
20.	Conglomerate; same as in unit 26, with clasts up to 6.3 cm in diameter..............	1.07
19.	Claystone, conglomerate, and minor sandstone. Conglomerate and claystone same as in unit 26. Sandstone, moderate-brown; loosely consolidated; noncalcareous; unfossiliferous; very coarse to fine grained; poorly sorted; subrounded; 5 cm thick near base of unit. Unit not well exposed........................	3.70
18.	Limestone, same as in unit 22, in beds 0.3 cm thick................................	0.15
17.	Claystone, dark-gray; same as in unit 26.......	0.60
16.	Conglomerate same as in unit 26, with clasts up to 7.5 cm in diameter..............	0.45
15.	Claystone with minor limestone. Claystone, dark-gray; same as in unit 26. Limestone same as in unit 22, in beds 0.4 cm thick............................	2.60

Measured section (S3) of Elko Formation, member I--continued.

Thickness (m)

Elko Formation, member I (Eocene and Oligocene?)--continued:

14.	Conglomerate same as in unit 26, with clasts up to 7.5 cm in diameter..............	1.22
13.	Claystone and minor limestone. Claystone, dark-gray; same as in unit 26. Limestone same as in unit 22, in beds 4 cm thick......................................	2.00
12.	Conglomerate same as in unit 26, with clasts up to 2.1 cm in diameter..............	0.31
11.	Claystone, very dark-gray to moderate-reddish-brown, weathers moderate brown to light bluish gray. Same as in unit 26. Unit not well exposed...................	8.54
10.	Sandstone, brown; loosely consolidated; noncalcareous; unfossiliferous; chert and quartzite grains, very fine to very coarse grained, poorly sorted, subrounded to rounded; crossbedded; irregular base.............................	0.15
9.	Claystone same as in unit 26..................	2.44
8.	Claystone with minor conglomerate; same as in unit 26. Unit not well exposed........	8.85
7.	Claystone same as in unit 26..................	1.22
6.	Limestone same as in unit 22, in beds 0.5 cm thick....................................	0.15
5.	Claystone same as in unit 26..................	1.50
4.	Limestone same as in unit 22, in beds 0.5 cm thick....................................	0.15
3.	Claystone same as in unit 26, but typically weathers into paper-thin layers..............	1.37
2.	Claystone and minor limestone. Claystone same as in unit 26, typically weathers	

Measured section (S3) of Elko Formation, member 1--continued.

	Thickness (m)
Elko Formation, member 1 (Eocene and Oligocene?)--continued:	
into paper-thin layers. Limestone same as in unit 22, intercalated as thin beds in claystone..................................	2.90
1. Claystone and minor conglomerate, same as in unit 26. Unit not well exposed...........	6.10
Total thickness....................................	61.89

Cherty limestone (Eocene):
Limestone. Not measured; contact with overlying Elko Formation, member 1, conformable.

Lithology of Member 2. This member consists of alternating strata of rich oil shale, carbonaceous shale, bituminous siltstone, lignite, and tuff (fig. 13). All rock types are present in horizontally stratified, thin beds, although the lignite typically is lenticular. The shale has wavy and indistinct horizontal laminae. Light-gray tuff is present near the top of the member.

Member 2 contains rich oil shale, which has been the focus of mining activity in the past (Harper, 1974). Fischer analyses indicate that high and low oil yields alternate abruptly within short vertical intervals of shale (J. W. Smith, 1970, 1972, written commun.). The thickest continuous sequence of oil shale in member 2 is 60 cm. The oil shale is dark brown, weathering light bluish gray. X-ray diffraction analyses show that most of the oil shale beds contain quartz, and smaller amounts of smectite, illite, feldspar, and pyrite (W. A. Robb and J. W. Smith, 1970, 1972, written commun.; table 5).

Figure 13.--Oil shale in member 2 of the Elko Formation in trench COS-4.

Carbonate minerals are notably absent, and smectite is the dominant clay mineral. Gypsum and jarosite are alteration products, filling fractures and partings between beds. The shale contains ostracodes of the genus Candona, as well as other unidentified genera (R. M. Forester, 1977, written commun.; table 1). The clam Sphaerium also is present (T. D. Fouch and J. H. Hanley, 1978, written commun.; table 1). Palynomorphs include Ovoidites, Schizosporis, conifer pollen, and spiny, spheroidal algal spores (T. D. Fouch and Fred May, 1977, written commun.; table 1).

Member 2 conformably overlies member 1 in the Elko area. The contact between the two members is placed at the top of the uppermost biosparite bed in member 1.

Member 2 typically crops out as moderately dipping strata on north-trending ridges capped by resistant tuffaceous beds (fig. 14). These ridges have been tilted and uplifted along steeply dipping normal faults now followed by stream channels. Two stratigraphic sections were measured on adjacent ridges in the central portion of the mapped area. The stratigraphic sections demonstrate the equivalency of the rocks, and are presented as representative sections of member 2. Section S4 corresponds to oil shale zone C of Winchester (1923), and is approximately 0.8 km south of the section measured by Buwalda (Winchester, 1923, p. 99). Section S5 corresponds to oil shale zone D of Winchester (1923). Member 2 is about 22 m thick and grades laterally into member 3.

Figure 14.--North-trending ridge composed of members 2 and 4 of the Elko Formation. Light-gray beds at top of ridge are tuffaceous siltstone at the base of member 4; oil shale of member 2 underlies the siltstone. Ridge has been uplifted by fault near stream channel to the left of the ridge. Trench COS-4 is at the right (south) end of the ridge.

Measured stratigraphic section (S4 on fig. 3) of member 2 of the Elko Formation in NW¼ sec. 26, T. 34 N., R. 55 E., Elko West and Elko East quadrangles (measured by use of Brunton compass and steel tape).

	Thickness (m)
Elko Formation (Eocene and Oligocene?):	
Member 4. Not measured; contact with member 2 conformable.	
Member 2:	
17. Shale, dark-brown, weathers light bluish gray; rare patches of yellow jarosite and white gypsum on bedding planes and fracture surfaces; wavy and indistinct horizontal laminae; noncalcareous, fossiliferous, with scattered ostracodes.........................	0.37
16. Siltstone, light-brown, weathers very light brown to light gray; rare patches of yellow jarosite on bedding surfaces; slightly bituminous; horizontally stratified, in beds up to 6 cm thick; noncalcareous; unfossiliferous.....................................	0.45
15. Shale same as in unit 17, with fingernail clams on bedding surfaces....................	0.18
14. Claystone, bluish-gray, rarely weathers dark reddish brown; minor yellow patches of jarosite; waxy luster; faintly cross-laminated in upper 60 cm, shaly near base; noncalcareous; unfossiliferous...............	1.65
13. Siltstone, very light-gray and light-reddish-brown; clayey; minor gypsum in fractures and on bedding surfaces; horizontally stratified in beds up to 3 cm thick; noncalcareous; unfossiliferous..................	0.75
12. Shale same as in unit 17......................	0.24
11. Siltstone same as in unit 13, but with faint laminations near base........................	0.85
10. Shale same as in unit 17......................	0.10

Measured section (S4) of Elko Formation, member 2--continued:

	Thickness (m)
Elko Formation, member 2 (Eocene and Oligocene?)--continued:	
9. Siltstone same as in unit 13; faintly laminated	0.60
8. Shale same as in unit 17	0.25
7. Siltstone same as in unit 13; faintly laminated	0.45
6. Shale same as in unit 17	0.42
5. Tuff, light-gray, weathers light reddish brown; minor biotite and quartz; most biotite has weathered out, leaving small, reddish-brown, iron oxide stained cavities; scattered white, lenticular pumice fragments up to 1 cm long	2.28
4. Claystone, mottled light-greenish-gray and reddish-brown; gypsum-filled fractures; noncalcareous; unfossiliferous	0.09
3. Shale same as in unit 17; unfossiliferous	0.08
2. Siltstone, shale, and lignite. Siltstone same as in unit 13; slightly bituminous; beds up to 7.5 cm thick. Shale same as in unit 17; commonly weathers into paper-thin layers. Lignite, moderate-brown; in lenses up to 10 cm thick; more abundant near base of unit	3.20
1. Siltstone, claystone, shale, and minor lignite. Siltstone same as in unit 13. Claystone same as in unit 14. Shale same as in unit 17. Lignite same as in unit 2. Unit not well exposed	10.50
Total thickness	22.46

Elko Formation (Eocene and Oligocene?):
Member 1. Not measured; contact with overlying member 2 conformable.

Units 17 through 5 of section S4 are equivalent, respectively, to units 15 through 3 of section S5. Units 4, 3, and 2 of section S4 are equivalent to unit 2 of section S5. Unit 1 of both sections S4 and S5 represent the same stratigraphic interval.

Measured stratigraphic section (S5 on fig. 3) of member 2 of the Elko Formation in NE¼ sec. 26, T. 34 N., R. 55 E., Elko East quadrangle (measured by use of Brunton compass and steel tape).

	Thickness (m)
Elko Formation (Eocene and Oligocene?):	
Member 4. Not measured; contact with member 2 conformable.	
Member 2:	
15. Shale, dark-brown, weathers light bluish gray; rare patches of yellow jarosite and white gypsum on bedding planes and fracture surfaces; wavy and indistinct horizontal laminae; noncalcareous; fossiliferous, with scattered ostracodes..	0.40
14. Siltstone and minor shale. Siltstone, light-brown, weathers very light brown to light gray; rare patches of yellow jarosite on bedding surfaces; slightly bituminous; horizontally stratified, in beds up to 6 cm thick; noncalcareous; unfossiliferous. Shale same as in unit 15, in 7.5-cm-thick bed, 5 cm above base of unit.................................	0.68
13. Shale same as in unit 15, but very-dark-gray, very well indurated, with fingernail clams on bedding surfaces...............	0.18
12. Claystone and minor lignite, siltstone, and shale. Claystone, bluish-gray; minor yellow patches of jarosite; waxy luster; faintly cross-laminated in upper 1.35 m. Lignite, moderate-brown; two beds, 2.5 cm and 10.0 cm thick, in upper 30 cm of unit. Shale same as in unit 15, intercalated as	

Measured section (S5) of Elko Formation, member 2--continued.

		Thickness (m)
Elko Formation, member 2 (Eocene and Oligocene?)--continued:		
	very thin layers, in upper 1.35 m and in lower 40 cm; lower portion often weathers into paper-thin layers..............	2.95
11.	Siltstone and minor shale. Siltstone, very light-gray and light-reddish-brown; minor gypsum on fractures and on bedding surfaces; horizontally stratified in beds to 3 cm thick; non-calcareous; unfossiliferous. Shale same as in unit 15, intercalated in very thin layers; weathers in paper-thin layers.........................	0.61
10.	Shale same as in unit 15; rarely weathers in paper-thin layers................	0.37
9.	Siltstone same as in unit 11; clayey; faint laminations near base.................	0.91
8.	Shale same as in unit 15; weathers in paper-thin layers............................	0.06
7.	Siltstone and minor shale. Siltstone same as in unit 11. Shale same as in unit 15; intercalated in very thin layers near base of unit; weathers in paper-thin layers.........................	0.85
6.	Shale and minor siltstone. Shale same as in unit 15. Siltstone same as in unit 11; 5.0-cm-thick bed near top of unit......................................	0.18
5.	Siltstone and minor shale. Siltstone same as in unit 11. Shale same as in unit 15; intercalated as very thin layers; weathers in paper-thin layers........	0.60
4.	Shale same as in unit 15; commonly weathers in paper-thin layers................	0.60

Measured section (S5) of Elko Formation, member 2--continued:

	Thickness (m)
Elko Formation, member 2 (Eocene and Oligocene?)--continued:	
3. Tuff and minor clay. Tuff, light-gray, weathers light reddish brown; minor quartz; small, reddish-brown, iron-oxide stained cavities where, presumably, biotite has weathered out. Clay, very dark-gray, in layers 0.6 cm thick, intercalated in upper 60 cm; minor associated gypsum............................	3.20
2. Siltstone and shale. Siltstone same as in unit 11; commonly bituminous; slightly calcareous. Shale same as in unit 15. Unit not well exposed........................	2.65
1. Siltstone, claystone, shale, and minor lignite. Siltstone same as in unit 11; rarely bituminous; slightly calcareous. Claystone, mottled light-greenish-gray and reddish-brown; gypsum-filled fractures; noncalcareous; unfossiliferous. Shale same as in unit 15. Lignite same as in unit 12......	7.90
Total thickness.....................................	22.14

Elko Formation (Eocene and Oligocene?):
Member 1. Not measured; contact with overlying member 2 conformable.

Lithology of Member 3. This member is composed primarily of moderate- to dark-brown, lean oil shale that weathers light bluish gray and light brown. These rocks are faintly laminated and typically weather into paper-thin layers. The uniform shaly lithology of member 3 is broken only by rare, thin intercalations of reddish-orange, silty limestone. The shale is composed dominantly of quartz and minor amounts of dolomite, calcite, feldspar, smectite, illite, analcime, and clinoptilolite(?) (W. A. Robb and J. W. Smith, 1977, written commun., table 5). Ostracodes are present throughout the member. Oil yields so far determined on samples of this member are significantly lower than those of member 2, although only weathered surface samples have been analyzed.

This unit is easily eroded and is present as low, rounded hills with a muddy soil cover (fig. 15). Member 3 is about 120 m thick and conformably overlies the cherty limestone unit. The contact between the two units is defined as the surface at the top of the uppermost light-gray limestone bed in the cherty limestone unit.

Lithology of Member 4. Beds of member 4 contain much greater amounts of tuffaceous material than do underlying units. Basal strata of this member are dominantly light-gray, indistinctly cross-stratified and graded tuffaceous siltstone. Cross-strata are small to medium scale. X-ray diffraction analyses show that the tuffaceous siltstone is composed of about 60 percent clinoptilolite, with minor amounts of opal, quartz, plagioclase, and an unidentified clay mineral, and with a trace of biotite (R. A. Sheppard, 1978, written commun.; table 2). Rare, small ball-and-pillow structures occur in intercalated claystone. Carbonaceous shale and bituminous siltstone with leaf imprints and reed fragments are interbedded with, and overlie, the tuffaceous rocks. The carbonaceous shale commonly is silicified and weathers reddish orange. The rock generally is faintly laminated, and silicification tends to accentuate the shale laminae, aiding in the differentiation of shale of member 4 from that of underlying units. The upper part of the section

Figure 15.--Member 3 of the Elko Formation forms low, rounded, reddish-brown hills in the center of the photograph. Light-colored ridge in the foreground is cherty limestone unit. Hill with "E" in the distance is the Diamond Peak Formation at the western side of Burner Basin.

contains moderate- to very-dark-brown, lean oil shale interbedded with subordinate amounts of siltstone, limestone, lignite, and tuff. X-ray diffraction analyses of the oil shale show that the mineral matter within the shale is composed of quartz, and smaller amounts of feldspar, illite, calcite, and analcime (W. A. Robb and J. W. Smith, 1977, written commun.; table 5). Limestone of this unit consists mostly of calcite and minor dolomite and analcime. Ostracodes are present in some shale beds, but are not as abundant as in members 2 or 3. Some shale beds exhibit disturbed bedding (fig. 16). Member 4 has a maximum thickness of approximately 185 m.

Member 4 conformably overlies members 2 and 3 of the Elko Formation. the contact between member 4 and members 2 and 3 is placed at the base of the lowest tuffaceous siltstone of member 4.

Lithology of Member 5. This member is characterized by abundant pyroclastic material and by a relative paucity of organic material. The lowermost bed is a light-gray quartz-biotite tuff, approximately 2 m thick, containing lapilli of tuff and pumice (fig. 17). X-ray diffraction analysis shows the tuff to be composed of about 70 percent clinoptilolite, with minor quartz and biotite, and with traces of opal and plagioclase (R. A. Sheppard, 1978, written commun.; table 2). It is overlain by light-brown to light-gray, thinly and evenly bedded shale and siltstone, as well as by thin to thick, apparently structureless beds of tuff. Beds of fine-grained tuff commonly are zeolitized or silicified. X-ray diffraction analysis of one fine-grained tuff sample

Figure 16.--Disturbed beds of shale in member 4 of the Elko Formation

Figure 17.--Light-colored beds in front of dark hills in the distance are tuff at base of member 5 of Elko Formation. Light-colored beds in foreground are tuffaceous siltstone at base of member 4. Dark hills in the distance are Diamond Peak Formation at Burner Basin

shows the tuff to contain major amounts of quartz and opal, minor plagioclase, and a trace of biotite (R. A. Sheppard, 1978, written commun.; table 2). Rare limestone beds consist of well-sorted, rounded ostracode fragments and coated grains in sparry cement. Dolomite has not been observed in the limestone, but analcime is common.

Member 5, which is separated from underlying members by an intraformational unconformity, has a maximum thickness of 215 m. The contact between member 5 and older units is placed at the base of the lowermost thick lapilli tuff bed.

Age and Correlation. The Elko Formation has been mapped in the Carlin-Pinon Range area (Smith and Ketner, 1976) and near Huntington Creek (Smith and Howard, 1977). Rocks of the same age and lithology have been identified in the foothills of the Adobe Range, north of Elko (Silitonga, 1974). The Elko Formation is lithologically similar to oil shale that occurs in widely separated outcrops elsewhere in northeast Nevada. These other rocks have been assigned a variety of names and ages; recently, some of them have been accepted as belonging to the same period of deposition as the Elko Formation (Smith and Ketner, 1976, p. 22; Hope and Coats, 1976). Oil shale once mapped as part of the Miocene Humboldt Formation in the Bull Run quadrangle 90 km north of Elko (Decker, 1962), oil shale previously considered as Miocene or Pliocene by Van Houten (1956) in the north end of the Pequop Mountains 100 km east of Elko, and oil shale interpreted as Eocene or Oligocene by Smith and Ketner (1976) in the Carlin-Pinon Range area 25 km west and 65 km south of Elko, lie at the perimeter of exposed rock units probably correlative with all or part of the Elko Formation.

At its type section in the Carlin-Pinon Range area, the Elko Formation was considered of Eocene or Oligocene age based upon a K-Ar date of 38.6 ± 1.2 m.y. obtained from its oldest tuff and upon ages of ostracode, bivalve, and plant fossils (Smith and Ketner, 1976, p. 22). Near Elko, a K-Ar date from the base of member 5 is 38.8 ± 0.3 m.y., and a K-Ar date from a tuff near the top of member 5 is 37.1 ± 1.0 m.y. (Solomon and others, 1979a; table 4). Berggren (1972) and Berggren and others (1978) place the Eocene-Oligocene boundary at 37.5 m.y. Accordingly, the Elko formation is considered Eocene and Oligocene(?) in age.

Paleogene lacustrine units are common over much of the western interior of the United States, and they represent a wide range of ages (Fouch and others, 1979). The Elko Formation may be slightly younger than the Paleocene and Eocene Green River Formation in the western Uinta Basin (Fouch, 1976), and may be equivalent to the sandstone and limestone facies and to overlying parts of the Eocene Uinta Formation of Dane (1954) in the western Uinta Basin (Ryder and others, 1976; Fouch, 1979; fig. 5). The Elko Formation also may be slightly younger than the Sheep Pass Formation south of Ely (Kellogg, 1964) and near Railroad Valley (Cook, 1965), but may be coeval with the uppermost part of beds tentatively mapped as the Sheep Pass Formation near Ely (Brokaw, 1967; Fouch, 1979; Fouch and others, 1979). The Elko Formation is temporally equivalent to the Kinsey Canyon Formation of Young (1960), near McGill, Nevada (Fouch, 1979; Fouch and others, 1979).

Depositional Environment. Light-brownish-gray claystone and channel-form conglomerate and sandstone of member 1 are interpreted to represent marginal-lacustrine deltaic and interdeltaic deposits. These rocks grade eastward into nearshore, open-lacustrine rocks of member 3, and upward into nearshore, open-lacustrine rocks of member 2. Several ostracode genera in the claystone, including Candona, suggest deposition in an alkaline, fresh-water body with at least seasonally cold water (R. M. Forester, 1977, written commun.). Chert-pebble conglomerate and sandstone were deposited in channels near the lake margin during intermittent periods of increased energy. Clasts were derived mainly from the Mississippian and Pennsylvanian Diamond Peak Formation, which is the basement rock in much of the area.

Rocks of open-lacustrine origin dominate members 2 through 5 of the Elko Formation. The presence of several ostracode genera in member 2, including Candona, suggests that the water was alkaline, but with a low salinity, and was at least seasonally cold (R. M. Forester, 1977, written commun.). The rocks of members 2 through 5, composed primarily of oil shale and siltstone in thin to very thin, horizontally stratified and laminated beds, suggest that tractive current activity was minor. Rare cross-laminated siltstone and distorted shale beds in member 4 record uncommon intervals of tractive current activity and penecontemporaneous folding and slumping. Penecontemporaneous deformation possibly was initiated by relatively rapid sediment influx near the lake margin, or by postdepositional sliding on very gentle slopes.

The abrupt fluctuation in member 2 between thin strata of rich oil shale and beds with very low organic content may be indicative of rapid shoreline fluctuations. Lake floor gradients evidently were so gentle that minor fluctuations in lake level resulted in large lateral movements of the shoreline, and in consequent destruction and reestablishment of the reducing conditions necessary for preservation of organic matter.

The fine grain size of the terrigenous clastic rocks of member 3, compared to the laterally equivalent rocks of member 1, suggests that rocks of member 3 represent sediment that was deposited farther from shore. Member 1 may represent relatively near-shore conditions, and offshore, open-lacustrine conditions might have existed to the east and southeast.

Members 4 and 5 of the Elko Formation contain smectite, opaline material, and zeolites in amounts that increase up section. These probably are alteration products of siliceous volcanic glass and are most common in deposits of slightly to strongly alkaline lakes (Sheppard and Gude, 1969). The increasing abundance of zeolitic material near the top of the Elko Formation may reflect an increase in the alkalinity of the lake water, in the abundance of siliceous glass, or both.

Thin beds and lenses of lignite are present within the nearshore, open-lacustrine sequence, interbedded with shale rich in organic matter. A similar association, and an analysis of fossils, have led Hanley and others (1976) and Fouch and Hanley (1977) to suggest that some Paleogene coal in the Uinta Basin at Soldier Summit and Willow Creek Canyon accumulated in a nearshore, open-lacustrine environment.

No evidence has been found to support a playa-lake origin for the Elko Formation. Evidence cited by supporters of a playa-lake origin for part of the Green River Formation includes mudcracks, indicative of periodic desiccation; flat-pebble conglomerate, deposited as a transgressive lag by expansion of a shallow lake over an exposed mudflat; evaporites, deposited when salinity increased during lake recessions; and ripple-marked and cross-bedded sandstone, deposited in fluvial channels (Wolfbauer, 1973; Eugster and Hardie, 1975; Lundell and Surdam, 1975). The absence of carbonate minerals in most oil shale beds of the Elko Formation and the rarity of dolomite throughout the Elko Formation also are difficult to reconcile with a playa-lake model. Oil shale of the Elko Formation probably was deposited in a perennial, alkaline, fresh-water lake. Climate at the time was temperate, cooler, and more moist than at present (Axelrod, 1966, 1968).

Smith and Ketner (1976) postulated that the large minimum thickness of the Elko Formation in the Carlin-Pinon Range area suggests that the lake basin of deposition must have been of regional scale. However, they indicate that terrestrial volcanic flows near the south end of the Independence Mountains and at Pine Valley were contemporaneous with deposition of Elko lake beds, so the Elko lake deposition probably did not extend as far west as the western part of the Carlin-Pinon Range area. Elko lake deposition extended to the east of Elko as suggested by facies relationships among members 1, 2, and 3 of the Elko Formation and by the distribution of outcrops of the Elko Formation elsewhere in northeast Nevada, and the Elko Lake reached its maximum extent during deposition of the richest oil shales of member 2.

Oligocene Series

Units of the Oligocene Series include the Indian Well Formation, an unnamed andesite unit, and the informally named siltstone and sandstone unit. The Indian Well Formation, previously divided into two informal members by Solomon and others (1979a, 1979b), is herein restricted to tuffaceous rocks of the lowermost member. The upper member of Solomon and others (1979a, 1979b) is reassigned to the siltstone and sandstone unit.

The Indian Well Formation marks the end of Paleogene lacustrine sedimentation near Elko. The Oligocene also represents the culmination of Tertiary volcanism in the region.

Indian Well Formation. The Indian Well Formation consists of sandstone, conglomerate, and tuff (fig. 2). The type section, approximately 25 km south of Elko near Dixie Flats, was described by Smith and Ketner (1976, p. 24-25).

The Indian Well Formation is about 275 m thick near Elko. At its type section in the Carlin-Pinon Range area, the thickness of these beds is 1,015 m (Smith and Ketner, 1976, p. 24). In the foothills of the Adobe Range, north of Elko, equivalent rocks of the vitric tuff unit are about 335 m (1100 ft) thick (Silitonga, 1974, p. 51).

Lithology. The Indian Well Formation consists mostly of tuff and of sandstone and conglomerate containing reworked pyroclastic rocks

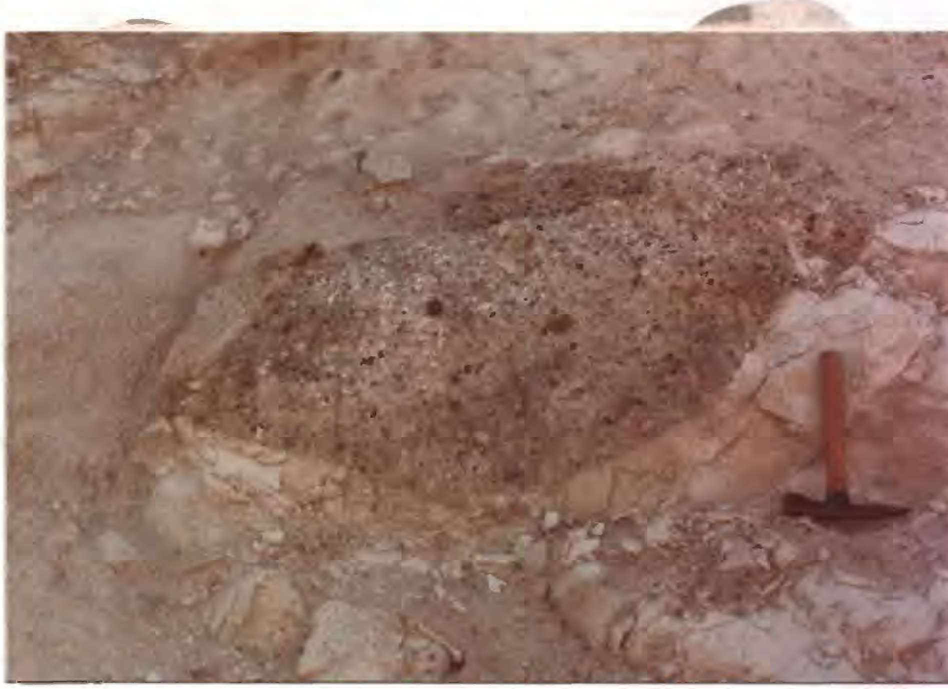


Figure 18.--Reworked pyroclastic rock fills channel cut into tuff of the Indian Well Formation near northern edge of mapped area.

(fig. 18). Sandstone beds, up to 25 cm thick, consist of fine- to medium-grained quartz, feldspar, biotite, tuff fragments and rare chert and quartzite clasts in a light-gray, fine-grained, glassy matrix. Conglomerate beds consist of subrounded pebbles of dark-grayish-blue, silicic tuff and chert in a matrix of the same composition as the grains of the sandstone. Conglomerate beds commonly fill scours cut into underlying finer-grained rocks.

The sedimentary rocks are interbedded with tuff, much of which contains phenocrysts of quartz and biotite. X-ray diffraction analysis shows that one tuff sample is composed primarily of montmorillonite, with minor plagioclase and a trace of quartz (R. A. Shepard, 1978, written commun.; table 2). A chemical analysis of this tuff is shown in table 3. The tuff is light gray in thin to very thick, apparently structureless beds, and commonly contains white, angular pumice lapilli and blocks up to 20 cm in diameter. A petrified tree trunk, approximately 45 cm in diameter and 2 m long, was removed from the tuff during construction activity in NW$\frac{1}{4}$ sec. 23, T. 34 N., R. 55 E.

At the northern edge of the area, the rocks are relatively fresh and moderately indurated. In sec. 24, T. 34 N., R. 55 E., the beds are more steeply dipping and have been silicified. At that location, the rocks are very hard and brittle, and commonly are stained light green. Van Houten (1956, p. 2815) has noted that, where similar strata have been tilted or faulted, such as at the north end of Pine Valley (NW$\frac{1}{4}$, T. 31 N., R. 52 E.) and in the middle part of the Reese River Valley (N$\frac{1}{2}$, T. 23 N., R. 43 E.; S$\frac{1}{2}$, T. 24 N., R. 43 E.), the generally soft, gray deposits are silicified and stained green.

The Indian Well Formation unconformably overlies the Elko Formation and the cherty limestone unit (plate 1). In the Carlin-Pinon Range area, the Indian Well unconformably overlies older Tertiary, Jurassic, and Paleozoic rocks (Smith and Ketner, 1976, p. 25). Equivalent rocks north of Elko, called the vitric tuff unit by Silitonga (1974, p. 51), are separated from older Tertiary rocks by a disconformity or by a slightly angular unconformity. The basal contact of the Indian Well Formation near Elko is at the base of the lowermost thick sequence of interbedded tuff and tuffaceous sedimentary rock, and at the top of the uppermost shale or limestone of underlying units.

Age and Correlation. Smith and Ketner (1976) named the Indian Well Formation for rocks in the Carlin-Pinon Range area previously included in the Safford Canyon Formation and the basal member of the overlying Raine Ranch Formation, both named by Regnier (1960). The Indian Well Formation is extended to lithologically similar rocks near Elko, but is restricted to member 1 of the Indian Well Formation of Solomon and others (1979a, 1979b). The lithologic similarity between the tuffaceous rocks that overlap the Elko oil shale and tuffaceous rocks on the east flank of the Pinon Range was first noted by Van Houten (1956, p. 2818), who assigned the rocks to the vitric tuff unit, which was extended to include similar rocks in the foothills of the Adobe Range by Silitonga (1974, p. 53).

No radiometric age was obtained from the Indian Well Formation near Elko, but an Oligocene age is assigned based upon stratigraphic and structural relationships. The Indian Well overlies the Eocene and

Oligocene(?) Elko Formation; the unconformity at the base of the Oligocene andesite truncates faults that cut the Indian Well Formation. Radiometric dates for the Indian Well Formation in the Carlin-Pinon Range area range from 37.6±1.3 m.y. to 33.2±0.7 m.y. (Smith and Ketner, 1976).

Oligocene volcanic activity was widespread over northern and eastern Nevada. The sequence of lacustrine sedimentation followed by the outpouring of siliceous tuffs, such as occurred near Elko, is evident in several areas. Figure 5 shows these sequences as they are found near Ely and Eureka (Fouch and others, 1979).

Depositional Environment. Sandstone and conglomerate are interpreted as deposits of fluvial channels, indicated by coarse-grained material in beds with irregular bases. The Indian Well Formation contains evidence of intense volcanic activity, and Paleogene lacustrine sedimentation ended prior to the onset of this intense volcanism. In the sandstone and conglomerate of the Indian Well, composed of volcaniclastic material set in a glassy matrix, grains and matrix both may have been derived from penecontemporaneous volcanism.

Andesite. Andesite flows are exposed south of Elko (pl. 1) and further south in the Carlin-Pinon Range area where they have been mapped as "andesite and basaltic andesite" (Smith and Ketner, 1976). In the foothills of the Adobe Range, similar rocks are designated the basalt lava flow unit and the lahar and volcanic breccia unit (Silitonga, 1974).

Figure 19.--Rolling, brush-covered hills in background are composed of andesite. Light-colored tuffaceous rock of member 5 of the Elko Formation underlies the andesite and is visible in the distance. Light-colored rock in the foreground is cherty limestone.

Near Elko, the andesite flows overlie an andesitic mudflow conglomerate (fig. 2). The andesite flows and mudflow conglomerate are herein considered a unit designated "andesite."

The andesite unit is estimated to be 95 m thick near Elko. The flows in the Carlin-Pinon Range area have a minimum thickness of 305 m (Smith and Ketner, 1976, p. 39). The basalt lava flow of Silitonga (1974, p. 58) is about 23 m (75 ft) thick.

Lithology. The mudflow conglomerate contains poorly sorted, subrounded to angular clasts of silicic tuff and andesitic flow rock up to 30 cm in diameter, in a brownish-gray, tuffaceous matrix. The conglomerate is approximately 10 m thick. The overlying andesite flows are dark gray to black with phenocrysts of plagioclase feldspar and hypersthene in a cryptocrystalline and glassy matrix. Chemical analyses of the flows are shown in table 3. The andesite flows are estimated to be 85 m thick near Elko.

The andesite unit dips gently to the southeast and unconformably overlies the cherty limestone unit and the Elko Formation (fig. 19). The unconformity at the base of the andesite unit truncates faults that cut the Indian Well Formation, indicating that the andesite must be younger than the Indian Well, although no physical contact between the two units is present.

Age and Correlation. Because no rocks overlie the andesite unit near Elko, much confusion has arisen concerning the age of the andesite. Sharp (1939) considered the andesite to be Pliocene. He based his interpretation upon the marked angular discordance between the volcanic rocks and underlying sedimentary rocks, which he assigned to the Miocene Humboldt Formation. The underlying sedimentary rocks near Elko, though, have been shown in this study to be of Eocene and Oligocene(?) age.

Smith and Ketner (1976) thought that similar flows mapped as "andesite and basaltic andesite" in the Carlin-Pinon Range area, some of which are laterally continuous with the andesite near Elko, probably are late Miocene. The gently tilted strata of the Humboldt Formation, as restricted by Smith and Ketner (1976), and considered to be late Miocene, contrast with the subhorizontal nature of the andesite elsewhere, which indicated to them that the andesite was younger than the Humboldt Formation. They noted that nowhere in the Carlin-Pinon Range area do the flows lie on rock younger than the Oligocene Indian Well Formation (Smith and Ketner, 1976, p. 40); the flows are never in direct contact with Humboldt (restricted) beds, nor are the flows ever closer than 5 km to outcrops of the Humboldt Formation. The same relationship also exists south of Elko in the area of this report.

Radiometric ages from the andesite near Elko, 35.2 ± 1.1 and 30.9 ± 1.0 m.y. (Solomon and others, 1979a; table 4), suggest it is of Oligocene age. These volcanic rocks are younger than the Indian Well Formation. The presence of andesite clasts in conglomeratic beds of the siltstone and sandstone unit confirm that the volcanic rocks are older than the siltstone and sandstone.

Depositional Environment. The conglomerate was deposited as a volcanic mudflow or lahar. The poor sorting and angularity of the clasts may indicate a relatively nearby source area. Deposition of the conglomerate was followed by extrusion of andesitic flows.

Siltstone and Sandstone. A unit primarily composed of siltstone and sandstone crops out in the northeastern part of the mapped area (pl. 1). This informally designated unit is of Oligocene age (fig. 2) and includes strata formerly assigned to member 2 of the Indian Well Formation by Solomon and others (1979a, 1979b). The siltstone and sandstone unit is now separated from the Indian Well Formation because the two units are lithologically dissimilar. A minimum thickness of 230 m has been estimated for the siltstone and sandstone unit, although the unit may be much thicker. An accurate estimation of the thickness is not possible because the outcrops of the unit are scattered and not easily correlated.

Lithology. This unit is dominantly light-brown, unfossiliferous, calcareous siltstone in beds up to 1 m thick (fig. 20). Bedding is indistinct, but rocks appear to be horizontally stratified. Scour-and-fill features are rare. The basal part of the member is mostly light-brown to gray conglomerate, which contains angular shale clasts and moderately rounded andesite clasts up to 15 cm in diameter. The clasts are set in a poorly sorted, fine- to coarse-grained, calcareous matrix composed of feldspar and volcanic rock fragments and minor amounts of quartz and biotite. Some thin beds of fine- to coarse-grained sandstone and conglomerate are interbedded throughout the unit. Sandstone is

Figure 20.--Interbedded calcareous siltstone and sandstone of the siltstone and sandstone unit in a roadcut on the Elko-Lamoille Highway.

typically feldspathic litharenite or lithic arkose with abundant volcanic rock fragments and feldspar set in carbonate cement. All lithologies are unfossiliferous.

A tuff bed is present approximately 6 m above the base of this unit. This is the only tuff in the siltstone and sandstone, and it is exposed on a single hill near the center of sec. 25, T. 34 N., R. 55 E. The tuff is dark gray, about 5 m thick, and is composed almost entirely of dark-green and black, fresh, angular glass shards. Minor constituents include plagioclase, potassium feldspar, and zircon. A chemical analysis of this tuff is shown in table 3.

The siltstone and sandstone unit unconformably overlies older Tertiary rocks. The basal contact of the unit is placed at the base of the lowermost andesite-clast conglomerate.

Age and Correlation. A fission-track date from tuff near the base of the siltstone and sandstone unit is 27.0±1.2 m.y. (table 4), indicative of an Oligocene age. No lithologically similar units are described from nearby areas.

Depositional Environment. The siltstone and sandstone unit is rich in both pyroclastic and terrigenous grains. The mixed clast types, improved sorting, and dominance of carbonate cement over glassy matrix in this unit relative to the Indian Well Formation may indicate a decrease in the amount or proximity of volcanism during deposition of the siltstone and sandstone. The Elko Formation and the unnamed andesite served as source beds for clasts in the conglomerate. Sandstone and conglomerate are interpreted as fluvial channel deposits because of their coarse grain size. Siltstone, which constitutes the largest portion of this unit, is interpreted to be of floodplain origin because of the indistinct, horizontal stratification, fine grain size, and lack of fossils. The vitric tuff exhibits a vitroclastic texture of arcuate shards of glass lying in a matrix of glass dust, typical of explosive, acid ejecta.

Miocene Series

Humboldt Formation. The name "Humboldt group" was applied to upper Tertiary rocks covering a wide area in westen Utah and eastern Nevada by members of the 40th Parallel Survey (King, 1878, p. 434-443). Sharp (1939) designated the Tertiary basin deposits in northeast Nevada as the Miocene Humboldt Formation. On many maps of parts of northeast Nevada since then, all Tertiary sedimentary rocks have been shown as the Humboldt Formation, although Van Houten (1956, p. 2813) pointed out that the oil shale at Elko and some of the rocks in the Dixie Flats-Huntington Valley area are older than the Miocene rocks and not part of the same formation. Smith and Ketner (1976, p. 32) restricted the name Humboldt Formation to an upper Miocene sequence of beds that contains vitric ash and tuffaceous rocks. They designated a section along the east side of Huntington Creek about 25 km south of Elko, in an area later mapped by Smith and Howard (1977), as a reference section. Near Elko, rocks of the Humboldt Formation, as restricted by Smith and Ketner (1976), are lithologically similar to those near Huntington Creek.

Near the type section, the Humboldt Formation is assumed to reach a maximum thickness of about 610 m (Smith and Ketner, 1976, p. 35), and near Elko, it is only about 15 m thick. North of Elko, equivalent rocks are about 105 m (350 ft) thick (Silitonga, 1974, p. 57).

Lithology. The Humboldt Formation crops out on the slopes of low bluffs in sec. 13, T. 34 N., R. 55 E., and in sec. 18, T. 34 N., R. 56 E. (plate 1). The unit consists of horizontally stratified calcareous ash in beds to 35 cm thick (figs. 2 and 21). The ash is light gray, soft, and contains abundant ostracodes and diatoms. The ostracodes are fairly well preserved, and belong to a single species identified as _Limnocythere_ aff. _L_. _pterygoventrata_, where the affinity status is primarily due to the lack of comparative material (R. Forester, 1978, written commun.; table 1).

In the Carlin-Pinon Range area, the Humboldt Formation lies unconformably on Paleozoic rocks and on several older Tertiary units (Smith and Ketner, 1976). North of the Humboldt River, equivalent rocks are separated from Oligocene deposits by an unconformity (Silitonga, 1974). Near Elko, the Humboldt Formation lies unconformably on Paleozoic rocks, and must also have unconformable relationships with older Tertiary units.

Age and Correlation. The Humboldt group of King (1876), generally equivalent to the Humboldt Formation as restricted by Smith and Ketner (1976), was interpreted to be Pliocene in age. Sharp (1939) later described the Humboldt Formation, and assigned it a Miocene age. He included in this unit, however, all older Tertiary rocks. Van Houten

Figure 21.--Horizontally stratified beds of calcareous ash of the Humboldt Formation exposed in a sanitary landfill east of Elko.

(1956, p. 2813) recognized the disparity, pointing out the Eocene and Oligocene age of older Tertiary units. He included upper Tertiary deposits in his "vitric tuff" unit. Regnier (1960), aware of this inconsistency, chose to discontinue the name "Humboldt" in his description of Cenozoic geology near Carlin, Nevada. His late Tertiary sedimentary units included the Raine Ranch Formation of late Miocene age, and the Carlin Formation of early Pliocene age, which were dated on the basis of vertebrate fossils. Smith and Ketner (1976, p. 32) restricted the name Humboldt Formation to the middle and part of the upper members of the Humboldt Formation of Sharp (1939). The late Miocene age of the Humboldt Formation as restricted by Smith and Ketner (1976) was based on several fossil collections and on a fission-track date of a tuff. Smith and Ketner (1976) included in the Humboldt Formation the upper part of the Raine Ranch Formation and all of the Carlin Formation of Regnier (1960), although these two units are separated by a minor unconformity. Silitonga (1974, p. 57) correlated the upper member of the Humboldt Formation in the Kittridge Springs quadrangle north of Elko with the Miocene tuffaceous sedimentary rocks and ash of Smith and Ketner (1972), which were later designated the Humboldt Formation by Smith and Ketner (1976). Rocks of the present study are assigned to the upper Miocene Humboldt Formation, as restricted by Smith and Ketner (1976), on the basis of lithologic similarities with rocks of the Carlin-Pinon Range area, as well as on stratigraphic position.

R. Forester (1978, written commun.) states that the ostracode _L. pterygoventrata_ is only known from the middle and upper Humboldt Formation of Sharp (1939), and that the upper Humboldt Formation is thought to represent middle-late Miocene to Pliocene deposition. This species, however, may occur in many other areas in rocks of different ages.

Depositional Environment. Upper Miocene rocks were deposited after the formation of small, isolated basins by Basin and Range block faulting. The rocks reflect varied depositional environments and source areas.

In the present area of study, Humboldt strata probably were associated with lacustrine deposition. The horizontally stratified, fine-grained beds were deposited in a low-energy environment; a lake is indicated by the presence of *Limnocythere* aff. *L. pterygoventrata*. The occurrence of numerous instars with the adults of this species suggests a very low energy environment, one in which none of the valves are transported (R. Forester, written commun., 1978). This could mean either a deep-water or a protected, shallow, quiet-water environment.

Most modern species of *Limnocythere* can tolerate conditions ranging from nearly fresh water to salinities of about 10 parts per thousand. The same tolerances can be inferred for the genus throughout the Neogene (R. Forester, written commun., 1978). Many other fresh water ostracodes cannot tolerate salinities above 2 or 3 parts per thousand. Thus *Limnocythere* occurs by itself, as in the Humboldt strata, one can assume a salinity of 3 to 10 parts per thousand (R. Forester, 1978, written commun.). It is inferred that the Humboldt strata were deposited in a slightly saline lake.

Smith and Ketner (1976) described both lacustrine and fluvial rocks in the Humboldt Formation of the Carlin-Pinon Range area. They noted that the source of detrital material in beds west of the Pinon Range was the volcanic rocks in the Cortez Mountains, and the source of much of the material east of the Pinon Range was the carbonate and crystalline rock terrane of the Ruby Mountains (Smith and Ketner, 1976, p. 38).

Quaternary System

Pleistocene and Holocene Series

The Quaternary stratigraphic sequence near Elko includes four lithologic units of Pleistocene and Holocene age (plate 1). Three of these units, the gravel, sand, and silt unit, the stream terrace deposits, and the alluvium, are unconsolidated. The fourth unit consists of well-indurated hot spring deposits.

The gravel, sand, and silt unit occurs in various topographic positions, from high benches or pediment remnants to stream levels. Stream terrace deposits occur as thin veneers of unconsolidated material that overlie Tertiary and older rock. Hot spring deposits occur at the northern and western margins of Hot Spring Ridge, in areas of both past and present geothermal activity. Alluvium occurs principally in the channel of the Humboldt River, but it also is present in smaller, ephemeral stream channels.

Gravel, Sand, and Silt. Material included in the gravel, sand, and silt unit has a wide range of particle size, from boulder to clay, and occurs in various topographic positions. These deposits are almost all fluviatile, as indicated by coarse grain size and cut-and-fill features, but some fine-grained, horizontally stratified beds may be pond deposits; in places some slope wash or colluvium is included. In secs. 34 and 35, T. 35 N., R. 55 E., and in secs. 2 and 3, T. 33 N., R. 55 E., this unit contains abundant andesitic clasts, forms gently sloping aprons at the base of hills underlain by andesite, and probably is predominantly of slope wash origin. A similar genesis is likely for this unit in secs. 24 and 25, T. 34 N., R. 55 E., and in secs. 19 and 30, T. 34 N., R. 56 E., because these sediments form aprons near the base of bedrock outcrops. The remainder of the deposits assigned to this unit, generally those that border the margins of pre-Quaternary outcrops near Elko, are predominantly fluviatile sediments related to rejuvenation of the Humboldt River drainage (Sharp, 1940, p. 357). These were deposited on broad surfaces at various levels that slope gently toward the river, and are evident throughout the region (fig. 22). The gravel, sand, and silt unit may be as much as 90 m thick in places, although no accurate determination of the thickness is possible because the exposures are poor.

The gravel, sand, and silt unit lies with angular unconformity on the Humboldt Formation. No fossils have been found in this unit near Elko. Fossils from similar sediment in the Carlin-Pinon Range area include a mammoth tooth of Pleistocene age and ostracodes that do not contradict a Pleistocene age (Smith and Ketner, 1976, p. 41-42). Although Smith and Ketner (1976) suggest that the unit probably is

Figure 22.--Several terrace levels cut into the gravel, sand, and silt unit north of Humboldt River. Hills in distance are Adobe Mountains.

entirely Quaternary, it is possible that the unit may be as old as latest Pliocene (Hope and Coats, 1976).

Stream Terrace Deposits. These deposits consist of poorly sorted mixtures of boulders, gravel, sand, and silt. The coarser material is moderately to well rounded, and commonly is covered with a thin coating of white caliche. The clasts predominantly are andesite derived from the unnamed andesite unit, and less commonly are quartzite and chert derived from the Diamond Peak Formation.

The deposits are generally less than 1.5 m thick. They occur as thin veneers on Oligocene and older rocks south of the Humboldt River (fig. 23). The sediment was deposited as the Humboldt River approached its present base level. The deposits are at several terrace levels, but deposits at each level are not differentiated in the present study.

Hot Spring Deposits. Pale yellowish-gray, calcareous tufa crops out in two locations. The smaller outcrop, in SE¼ sec. 28, T. 34 N., R. 55 E., is not associated with current geothermal activity. The larger outcrop, in secs. 21, 22, and NE¼ 28, T. 34 N., R. 55 E., is associated with several active hot springs in the Elko Hot Springs Known Geothermal Resources Area (fig. 24).

Temperature of the spring water is 88.9°C (192°F; Waring, 1965, p.33). Mariner and others (1974) have estimated the reservoir temperature at 103.9°C (219°F) with the silica geothermometer (conductive). Tufa at the edge of one pool is slightly radioactive, at 19 mR/hr (Wollenberg, 1974).

Figure 23.--Hills underlain by Elko Formation, in the foreground, have gently sloping, terraced upper surfaces commonly covered by thin gravel veneers. Hills in background form the western edge of Burner Basin.

Figure 24.--Hot spring, known as Hot Hole on the Elko West topographic quadrangle, at the northern tip of Hot Spring Ridge. Calcareous tufa forms the rim of the spring.

Figure 25.--Quaternary alluvial deposits of the Humboldt River near the north tip of Hot Spring Ridge.

Hot spring deposits lie along a range front fault. This fault acts as a permeable conduit through which geothermal waters circulate. Hot spring activity is related to high geothermal gradients and heat flow characteristics of the Basin and Range province, believed to be related to extensional continental plate rifting, crustal thinning, and fluid magma convection (Blackwell, 1969).

Alluvium. Alluvium consists of younger deposits of gravel, sand, and silt along modern stream courses (fig. 25). Much of the alluvium along the Humboldt River is composed of silt and sand, whereas intermittent streams draining bedrock at higher elevation have steeper gradients and have much gravel intermixed. Some intermittent stream deposits mapped as alluvium also may contain some colluvium; in places, it is impractical to separate them because one grades imperceptibly into the other. The maximum thickness of the alluvium probably is a few meters.

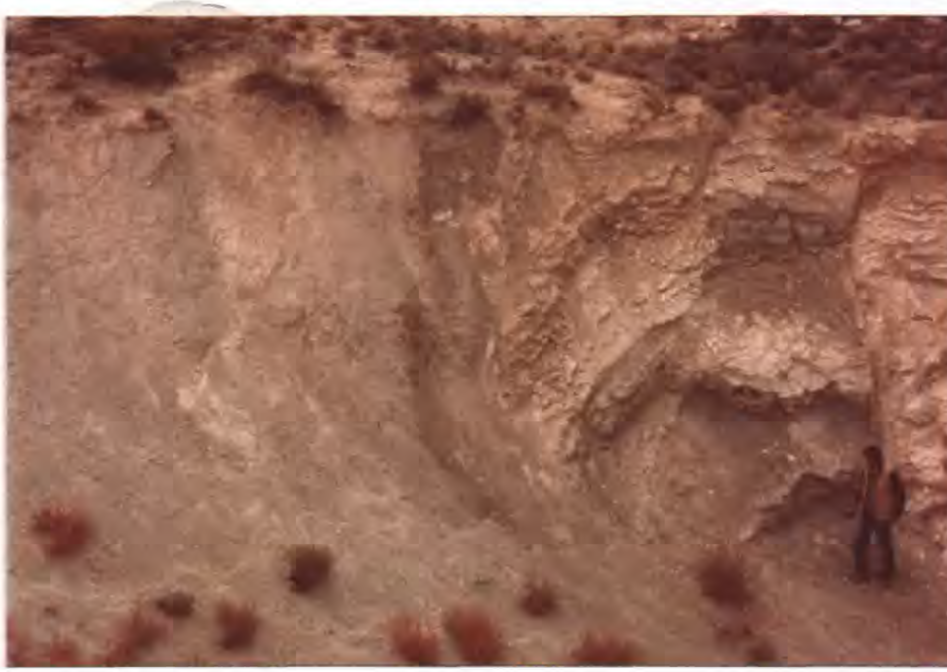


Figure 26.--Fault in member 4 of the Elko Formation in SE¼SW¼ sec. 14, T. 34 N., R. 55 E. Gray area in left half of photo is composed of pulverized rock in the main fault zone. Folds are present adjacent to the main zone near the center of the photo. Subsidiary fault with small offset is at right.

STRUCTURAL GEOLOGY

Rocks near Elko record three major deformational episodes. The earliest episode prior to Eocene(?) time was that of regional uplift, termination of marine conditions, and the formation of broad, inland basins. This was followed by tilting, faulting, and local folding during Oligocene time. The final episode was that of block faulting with little associated tilting of strata, and was part of Miocene and younger Basin and Range deformation. Several minor deformational episodes are indicated by the presence of minor angular unconformities in the Tertiary sequence. The structure of the area is shown in the cross-sections on plate 1.

Unconformities

Several unconformities are present within the stratigraphic sequence near Elko (fig. 2). None, however, are visible in the field. All unconformities are inferred from the attitude and distribution of mapped units.

Of major significance is the unconformity between the Mississippian and Pennsylvanian Diamond Peak Formation and Eocene rocks. During the intervening interval of time the area was uplifted, leading to the cessation of marine conditions.

Unconformities of lesser magnitude in the Tertiary reflect periods of gentle tilting and erosion. Such periods occurred in the Eocene and Oligocene, as well as in late Miocene, Pliocene, or early Pleistocene time. More intense deformation, inferred from the contrast between moderately tilted Indian Well and older strata and the more gently dipping younger rock, is related to the unconformity at the base of the andesite.

Folds

Several small, gentle folds are present in the Indian Well Formation and older rocks. In general, the folds are symmetric and have nearly vertical axial planes, with strata on both limbs dipping 20° to 40°. Fold axes trend N. 10-50° E., and plunge gently northeastward. Folding may have been earlier than, or contemporaneous with, development of north- and northeast-trending normal faults because the folds are cut by these faults.

At least one fold, the syncline in SE¼ sec. 23, T. 34 N., R. 55 E., may be the result of drag along the adjacent normal fault. Northwest dips on the southeast limb of this fold differ from the regional easterly dip of the Tertiary rocks, and occur in a restricted area adjacent to the downthrown side of a normal fault. Reversal of dip on the downthrown side of normal faults was observed frequently in the area, and is interpreted to be the result of drag. Because of the positions of other folds, however, it seems unlikely either that they could be drag folds caused by normal faults or that they are due to differential compaction.

Because the gently dipping unconformity at the base of the andesite unit truncates faults which, in turn, cut the axis of a fold, it appears that the folding must be older than the andesite. The andesite is Oligocene in age, so the folding must be earlier Oligocene or older.

If it can be assumed that the local folds in the Elko area occurred during one deformational episode, that episode must have occurred in Oligocene time, because Oligocene rocks of the Indian Well Formation are affected. Evidence of early Oligocene deformation also was noted in the Carlin-Pinon Range area by Smith and Ketner (1977, p. 12-13). There, folds affecting the Elko Formation and older rocks were interpreted to be the result of essentially compressional forces. Limits on the duration of early Oligocene deformation in the Carlin-Pinon Range area are established by K-Ar ages. A date determined for the Elko Formation is 38.6 ± 0.8 m.y. and dates determined on units above the unconformity developed on the Elko Formation are 33.2 ± 0.7 and 34.9 ± 0.7 m.y. (Smith and Ketner, 1977, p. 13). This interval of folding in the Carlin-Pinon Range area is remarkably similar to the age of folding in the Elko area. Radiometric dates from the Elko area show that folding is no older than the 43 to 37 m.y. age of folded strata, and is no younger than the 35 to 31 m.y. age of the andesite, which is not folded.

Faults

Faults in the Elko area may be allocated into three categories on the basis of their magnitude of offset and upon their relationship to pre-Quaternary deposits. The first category includes faults with up to several hundred meters of vertical separation that are bounded on both sides by Oligocene or older bedrock. The second category includes faults of several hundreds to thousands of meters of vertical separation that are bounded on one side by upthrown blocks of pre-Quaternary rock, and on the other by downthrown blocks underlain by unconsolidated Quaternary deposits. The third category includes faults of small displacement that offset both bedrock and unconsolidated deposits.

Faults of the first category trend northerly and northeasterly. Some faults truncate fold axes. North-trending faults commonly truncate northeasterly ones, but the opposite never occurs.

Northeast-trending faults generally are not well exposed. The single exception is the fault zone in SE¼SW¼ sec. 14, T. 34 N., R. 55 E. There, a zone approximately 40 m wide is exposed in a cut bank behind a trailer court. The zone consists of high- and low-angle, normal and reverse faults of small offset, adjacent to a principal high-angle, normal fault of large offset (fig. 26). The small, subsidiary faults have displacements of 2 m or less, and they offset shale, siltstone, and lignite of member 4 of the Elko Formation. Thin beds of lignite and of lignitic shale are injected into the faults. The main fault is at least 2 m wide, dips steeply to the southeast, and juxtaposes tuff of the Indian Well Formation with member 4 of the Elko. The fault is filled with light-gray, pulverized rock, small amounts of grayish-green fault gouge, and dusky-red, silicified fault breccia. Slickensides are common. Brecciated material is common in float.

Other northeast-trending faults are inferred from linear stream channels and from contrasting lithologies across suspected fault traces. A conspicuous example of this occurs in SE¼ sec. 22 and NE¼ sec. 27, T. 34 N., R. 55 E. Here, a stream channel trends approximately N15°E. At the stream's southern extremity, member 2 and the base of member 4 of the Elko Formation form a resistant ridge west of the

Figure 27.--View southward toward linear range-front scarp on west side of Hot Spring Ridge.

channel. East of the channel, along the projected strike of ridge-forming beds, gravel eroded from member 1 of the Elko Formation occurs. A prominent knob of member 1 conglomerate and mudstone crops out slightly farther northeast, adjacent to the oil shale retort's waste pile. Such a configuration of lithologies is most easily explained by faulting. A steep dip is attributed to the fault because of the linearity of the stream.

North-trending faults also are not well exposed. They are, though, easily recognizable on aerial photographs and in the field. Northtrending faults bound several northeast-dipping blocks in secs. 22, 23, 26, and 27, T. 34 N., R. 55 E., and have caused repetition of section on five adjacent ridges. These ridges are separated by linear stream channels that indicate the presence of steeply dipping faults. The observation of unfaulted strata within the channels suggests that the fault traces are actually slightly west of the streams. Several northtrending, linear stream channels occur in secs. 24, 25, and 26, T. 34 N., R. 55 E., transecting the Indian Well Formation and member 5 of the Elko Formation. These linear stream channels are suggestive of faults, but extremely poor exposures within these units preclude a definitive interpretation.

Faults of the second category include the fault in sec. 33, T. 34 N., R. 55 E. that extends southwest to the Dixie Flats quadrangle (Smith and Ketner, 1975, 1976), the linear fault that forms the western edge of Hot Spring Ridge, and the northwest-trending fault in secs. 18 and 19, T. 34 N., R. 56 E., which forms the western edge of Burner

Basin. All three faults are characterized by linear range-front scarps rising abruptly from the waste-filled valleys (fig. 27).

Faults of the third category include those in sec. 13, T. 34 N., R. 55 E. In the SW¼, faults are visible in a roadcut on the Elko-Lamoille Highway (fig. 28). These faults are in the Oligocene siltstone and sandstone unit. The faults are steeply dipping, and have offsets of 1 m or less. In the NE¼, faults are exposed in a refuse disposal site. At that location the faults cut both the Miocene Humboldt Formation and the Quaternary gravel, sand, and silt (fig. 29). The faults have offsets of 2 m or less.

North- and northeast-trending faults of the first category are truncated by the unconformity at the base of the andesite, and so were formed during the same interval of Oligocene time as were the folds near Elko and in the Carlin-Pinon Range area. Possible Oligocene faulting was also noted in the Ruby Mountains, about 65 km southeast of Elko (Sharp, 1942; Willden and others, 1967). A maximum age for the Ruby Mountain deformation, which consisted of thrust faulting, falls within the span of 29 to 40 m.y., established by radiometric dates from the Harrison Pass pluton (Willden and others, 1967).

Block faulting of the second category appears to be related to Basin and Range faulting. A post-early Miocene age seems established for inception of Basin and Range faulting in northern Nevada (for summaries, see McKee and others, 1976; Christiansen and McKee, 1978). Block faulting has given rise to physiography typical of the Basin and Range province. Faulting of small magnitude in younger deposits, such

Figure 28.--Faults with small offset in the siltstone and sandstone unit exposed in a roadcut for the Elko-Lamoille Highway.

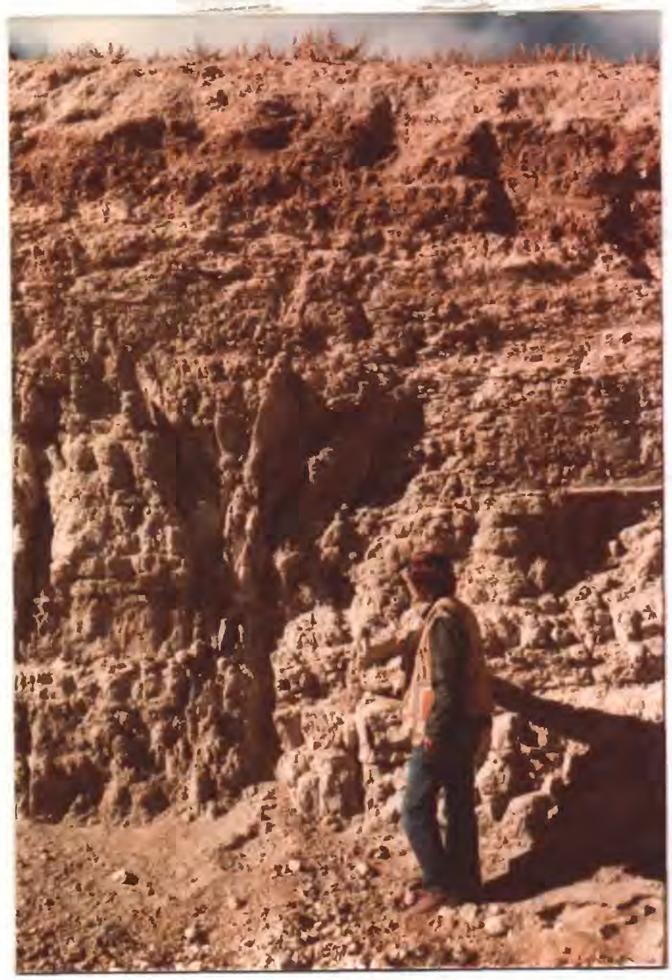


Figure 29.--Fault in Humboldt Formation east of Elko. The fault appears also to offset the Quaternary unconsolidated deposits that overlie the Humboldt. The fault is exposed in a refuse disposal site and has no surface expression, although it does lie along the trend of the range-front fault that bounds the northern edge of Burner Basin.

as faulting of the third category, may indicate a continuation of Basin and Range deformation. Such deformation may be related to historical seismicity in the Elko area, as exemplified by the magnitude 5.0 earthquake of 1901 (Slemmons and others, 1964).

GEOLOGIC HISTORY

In Late Mississippian and Early Pennsylvanian time, indistinctly bedded conglomerate of the Diamond Peak Formation was deposited by sediment gravity flows in relatively deep water. The coarse detritus was derived from lower Paleozoic cherty and quartzitic rocks of the upper plate of the Roberts Mountain thrust. A northwestern source area is probable.

During an extended interval of time between the Early Pennsylvanian and the Eocene, a profound change in paleogeography occurred. Evidence from adjacent areas, including the presence of lower Triassic marine rocks in the Adobe Range and the presence of upper Jurassic nonmarine rocks in the Carlin-Pinon Range area, indicates that the region was uplifted in the early Mesozoic resulting in the permanent end of marine conditions (Smith and Ketner, 1977).

The first evidence of nonmarine deposition near Elko is in the Eocene(?) limestone and limestone-clast conglomerate unit. The composition and texture of the conglomerate of this unit in the Elko area suggests that Permian limestone was eroded from an area of some relief and was deposited near Elko in a high-energy, alluvial environment.

Lacustrine deposition was initiated during the Eocene. Fine-grained rocks near the base of the conglomerate, sandstone, and shale unit were deposited in a mudflat, or perhaps floodplain and pond environments, near the lake margin. The deposition began at least as early as 43 million years ago, and coincided with the earliest known volcanism in the eastern Basin and Range province. Coarse-grained rocks near the top of the conglomerate, sandstone, and shale were deposited in prograding, braided streams that drained a source area of siliceous sedimentary and metamorphic rocks.

After a period of erosion during the Eocene, during which the disconformity at the top of the conglomerate, sandstone, and shale unit was formed, the cherty limestone unit was deposited. This unit represents a transition from fluvial to marginal lacustrine environments. Poorly stratified fine-grained rocks in the lower part of the cherty limestone were deposited on a floodplain. Lake-margin mudflat and carbonate flat, or perhaps lagoonal, sedimentation followed during deposition of the upper part of the cherty limestone. Volcanic activity continued to play a minor role.

Marginal lacustrine sedimentation continued during deposition of member 1 of the Elko Formation. Intermittent coarse clastic incursions resulted from channel deposition in a fluvial-deltaic environment adjacent to a fluctuating shoreline. Coarser detritus was shed from adjacent highlands composed of the Diamond Peak Formation. As distance from shoreline or depth of water, or both, increased, tractive current activity became minor. Fine-grained rocks of members 2 through 5 of the Elko Formation were deposited in an open-lacustrine environment. The sediments were deposited in water that was alkaline, but with a low salinity and at least seasonally cold temperatures. Lake floor gradients were evidently so gentle that minor fluctuations in lake level resulted in large lateral movements of the shoreline and in consequent destruction and reestablishment of the reducing conditions necessary for preservation of organic matter. As lacustrine sedimentation continued, volcanic activity gradually increased. Approximately 37 million years ago, in early Oligocene time, lacustrine sedimentation ceased near Elko. Thus, for approximately 6 million years, sediment was deposited in a perennial, alkaline, freshwater lake during a climatic period that was temperate, cooler, and more moist than at present.

Volcanic activity culminated in the Elko area in the Oligocene. Following a period of erosion and gentle tilting in the early Oligocene, deposits of the Indian Well Formation accumulated as volcaniclastic sediment deposited in fluvial channels, interspersed with siliceous tuffs. Tilting, accompanied by faulting and local folding, was renewed after deposition of the Indian Well Formation. Calc-alkalic volcanism resumed with the extrusion of andesitic flows approximately 35 to 31 million years ago.

Between approximately 31 and 27 million years ago, the region was again slightly tilted. Afterwards, the siltstone and sandstone unit was deposited primarily in a floodplain environment. During floodplain deposition, volcanic activity was minimal.

The unconformity between the siltstone and sandstone and the overlying Humboldt Formation was formed during the initiation of Basin and Range deformation. Block faulting profoundly affected the regional physiography and small, isolated basins, much like those of today, were formed. The Humboldt Formation near Elko was deposited in one such basin, in a slightly saline lake, during the late Miocene.

During Quaternary time, the area was periodically subjected to regional uplift, resulting in the rejuvenation of the Humboldt River drainage and in the formation of small faults in young sediment. Historical seismicity indicates that deformation continues today.

OIL SHALE RESOURCES

Shale rich in organic matter occurs in all Eocene units near Elko, but organic-rich shale is particularly concentrated in member 2 of the Elko Formation. Commercial shale oil was produced from these strata by the Catlin Shale Products Company beginning in 1917 (Lincoln, 1923; Harper, 1974; fig. 30). From 1917 to 1918, 41.7 t (46 short tons) of oil shale were mined, with a production value of approximately $1,920 (Couch and Carpenter, 1943, p. 42). A second retort was constructed near Elko in 1919. This plant had produced about 57,000 L (15,000 gal) of shale oil through January 1, 1920, but was not regarded as beyond the experimental stage (Winchester, 1923, p. 101). Another experimental retort was constructed approximately 0.5 km east of Elko and was jointly operated by Southern Pacific Railroad Company and the U.S. Bureau of Mines from 1918 to 1919 (Winchester, 1923).

Interest in this deposit was renewed several decades later. Subsequent activity included the excavation of two trenches in member 2 of the Elko Formation by the U.S. Geological Survey in 1970. The locations of the trenches, designated COS-3 and COS-4, coincide with the locations of measured stratigraphic sections S4 and S5, respectively, of this report (fig. 3). The trenches were sampled in 1970, and the samples were analyzed for oil yield and geochemical characteristics (table 6). In 1977, surface samples were collected from the conglomerate, sandstone, and shale unit, as well as from members 1, 3, and 4 of the Elko Formation. These were also analyzed. Analyses are presented in table 6.

Figure 30.--Ruins of the Catlin Shale Products Company retort near Elko.

Table 6.--Oil shale assays by modified Fischer retort method.

[Analysts: J. W. Smith and W. A. Robb. Sample locations shown in figure 3. Member 2 samples collected from 30-cm-thick (1-ft-thick) intervals in trenches COS-3 and COS-4. All other samples collected from surface outcrops at irregular intervals.]

	Yield of product								
	Weight percent				liters/metric ton (gallons/short ton)		Specific gravity		Tendency of spent shale to coke
Sample number	Oil	Water	Spent shale	Gas & loss	Oil	Water	Oil[1/]	Oil shale[2/]	
Elko Formation, member 4:									
E-20-77	2.0	2.4	94.9	0.7	21.8 (5.2)	24.3 (5.8)	--	--	None
E-21-77	3.9	1.4	93.5	1.2	42.7 (10.2)	14.2 (3.4)	0.910	--	None
Elko Formation, member 3:									
E-12-77	0.6	8.3	89.7	1.4	6.7 (1.6)	83.4 (19.9)	--	--	None
E-11-77	1.2	6.2	91.5	1.1	13.0 (3.1)	62.4 (14.9)	--	--	None
E-10-77	1.1	7.0	90.8	1.1	11.7 (2.8)	70.4 (16.8)	--	--	None
E- 9-77	2.6	7.5	88.1	1.8	31.0 (7.4)	75.4 (18.0)	0.852	--	None
E- 8-77	0.0	7.3	91.6	1.1	Trace	72.9 (17.4)	--	--	None
E- 7-77	1.9	6.5	90.1	1.5	20.1 (4.8)	65.4 (15.6)	--	--	None
E- 6-77	2.5	5.9	89.5	2.1	29.3 (7.0)	59.1 (14.1)	0.869	--	None
E- 5-77	1.2	4.5	92.9	1.4	13.0 (3.1)	45.3 (10.8)	--	--	None
E- 4-77	1.5	5.0	92.1	1.4	16.3 (3.9)	50.3 (12.0)	--	--	None
E- 3-77	6.2	5.0	86.1	2.7	72.1 (17.2)	50.3 (12.0)	0.869	--	None
Elko Formation, member 2:									
COS4- 1	0.2	2.5	96.4	0.9	2.1 (0.5)	25.1 (6.0)	--	2.62	None
COS4- 2	0.1	3.2	95.2	1.5	0.8 (0.2)	32.7 (7.8)	--	2.63	None
COS4- 3	0.2	2.0	97.1	0.7	1.7 (0.4)	20.1 (4.8)	--	2.62	None
COS4- 4	0.2	3.1	95.3	1.4	2.1 (0.5)	31.0 (7.4)	--	2.62	None

Table 6.--Oil shale assays by modified Fischer retort method.--Continued

	Yield of product						Specific gravity		Tendency of spent shale to coke
	Weight percent				liters/metric ton (gallons/short ton)				
Sample number	Oil	Water	Spent shale	Gas & loss	Oil	Water	Oil[1/]	Oil shale[2/]	
Elko Formation, member 2:									
COS4- 5	0.1	3.9	94.2	1.8	0.4 (0.1)	39.0 (9.3)	--	2.63	None
COS4- 6	0.1	2.9	95.6	1.4	0.8 (0.2)	29.3 (7.0)	--	2.63	None
COS4- 7	22.2	5.0	65.8	7.0	252.7 (60.3)	50.3 (12.0)	0.881	1.73	Slight
COS4- 8	22.8	5.4	63.9	7.9	258.5 (61.7)	54.1 (12.9)	0.885	1.72	Slight
COS4- 9	0.1	4.3	92.9	2.7	0.8 (0.2)	43.6 (10.4)	--	2.63	None
COS4-10	0.1	5.9	91.4	2.6	1.3 (0.3)	59.1 (14.1)	--	2.62	None
COS4-11	21.7	6.5	65.4	6.4	250.1 (59.7)	65.4 (15.6)	0.870	1.74	Slight
COS4-12	13.3	6.0	76.2	4.5	154.2 (36.8)	60.3 (14.4)	0.865	2.02	None
COS4-13	0.9	4.9	92.8	1.4	10.1 (2.4)	48.6 (11.6)	--	2.58	None
COS4-14	0.0	2.1	96.8	1.1	Trace	21.0 (5.0)	--	2.63	None
COS4-15	0.0	2.5	97.2	0.3	Trace	24.7 (5.9)	--	2.63	None
COS4-16	0.0	2.8	96.8	0.4	Trace	28.5 (6.8)	--	2.63	None
COS4-17	0.0	2.8	97.0	0.2	Trace	27.7 (6.6)	--	2.63	None
COS4-18	0.0	3.3	95.9	0.8	Trace	32.7 (7.8)	--	2.63	None
COS4-19	0.0	6.2	92.2	1.6	Trace	62.9 (15.0)	--	2.63	None
COS4-20	12.9	5.5	77.2	4.4	146.7 (35.0)	55.3 (13.2)	0.884	2.04	None
COS4-21	0.1	4.0	94.5	1.4	0.8 (0.2)	40.2 (9.6)	--	2.63	None
COS4-22	0.0	4.0	95.2	0.8	Trace	39.8 (9.5)	--	2.63	None
COS4-23	21.4	5.0	68.4	5.2	243.4 (58.1)	49.9 (11.9)	0.885	1.75	None
COS4-24	1.4	5.3	91.9	1.4	15.9 (3.8)	53.2 (12.7)	--	2.55	None

Table 6.--Oil shale assays by modified Fischer retort method.--Continued

Sample number	Yield of product: Weight percent: Oil	Weight percent: Water	Weight percent: Spent shale	Weight percent: Gas & loss	liters/metric ton (gallons/short ton): Oil	liters/metric ton (gallons/short ton): Water	Specific gravity: Oil[1/]	Specific gravity: Oil shale[2/]	Tendency of spent shale to coke
Elko Formation, member 2:									
COS4-25	0.0	3.5	96.2	0.3	0.0	34.8 (8.3)	--	2.63	None
COS4-26	5.0	4.0	89.0	2.0	57.4 (13.7)	40.2 (9.6)	0.877	2.37	None
COS4-27	10.8	6.0	79.9	3.3	123.6 (29.5)	60.3 (14.4)	0.877	2.12	None
COS4-28	0.0	6.7	92.5	0.8	Trace	67.5 (16.1)	--	2.63	None
COS4-29	0.0	7.2	91.8	1.0	Trace	71.6 (17.1)	--	2.63	None
COS4-30	19.5	5.0	70.5	5.0	222.9 (53.2)	50.3 (12.0)	0.877	1.81	Slight
COS4-31	0.2	3.5	95.7	0.6	1.7 (0.4)	35.2 (8.4)	--	2.62	None
COS4-32	2.4	6.9	89.1	1.6	26.8 (6.4)	69.1 (16.5)	0.883	2.50	None
COS4-33	11.8	6.0	76.9	5.3	131.6 (31.4)	60.3 (14.4)	0.897	2.09	None
COS4-34	0.1	6.3	91.7	1.9	0.8 (0.2)	63.7 (15.2)	--	2.63	None
COS4-35	0.0	3.0	96.5	0.5	0.0	30.2 (7.2)	--	2.63	None
COS4-36	0.0	4.2	95.2	0.6	0.0	42.3 (10.1)	--	2.63	None
COS4-37	0.0	3.1	96.5	0.4	0.0	31.0 (7.4)	--	2.63	None
COS4-38	0.0	2.9	96.6	0.5	0.0	28.9 (6.9)	--	2.63	None
COS4-39	0.4	2.7	96.8	0.1	4.2 (1.0)	27.7 (6.6)	--	2.61	None
COS4-40	0.0	2.9	97.0	0.4	Trace	29.3 (7.0)	--	2.63	None
COS4-41	0.0	2.7	97.0	0.3	Trace	27.2 (6.5)	--	2.63	None
COS4-42	0.0	2.9	96.9	0.2	Trace	29.3 (7.0)	--	2.63	None
COS4-43	0.0	2.6	97.1	0.3	Trace	26.0 (6.2)	--	2.63	None
COS4-44	0.1	4.1	95.6	0.2	1.3 (0.3)	41.1 (9.8)	--	2.62	None

Table 6.--Oil shale assays by modified Fischer retort method.--Continued

Sample number	Yield of product: Weight percent: Oil	Water	Spent shale	Gas & loss	Liters/metric ton (gallons/short ton): Oil	Water	Specific gravity: Oil[1/]	Oil shale[2/]	Tendency of spent shale to coke
Elko Formation, member 2:									
COS4-45	0.0	8.3	91.2	0.5	0.0	83.4 (19.9)	--	2.63	None
COS4-46	5.2	9.5	81.8	3.5	59.5 (14.2)	95.5 (22.8)	0.878	2.36	None
COS4-47	2.3	5.9	89.3	2.5	26.4 (6.3)	59.1 (14.1)	0.885	2.50	None
COS4-48	0.0	7.1	92.2	0.7	0.0	70.8 (16.9)	--	2.63	None
COS4-49	0.0	8.6	90.6	0.8	0.0	86.7 (20.7)	--	2.63	None
COS4-50	1.6	10.0	85.8	2.6	17.2 (4.1)	100.6 (24.0)	--	2.54	None
COS4-51	3.1	8.6	85.5	2.8	35.6 (8.5)	20.6 (86.3)	0.878	2.46	None
COS4-52	0.0	11.0	87.7	1.3	0.0	110.6 (26.4)	--	2.63	None
COS4-53	0.0	11.1	87.8	1.1	0.0	111.0 (26.5)	--	2.63	None
COS4-54	3.4	5.5	87.3	3.8	38.1 (9.1)	55.3 (13.2)	0.893	2.45	None
COS4-55	0.4	7.5	89.4	2.7	4.2 (1.0)	75.4 (18.0)	--	2.61	None
Elko Formation, member 2:									
COS3-+2	0.0	3.3	95.4	1.3	0.0	33.5 (8.0)	--	2.63	None
COS3-+1	1.0	3.6	93.7	1.7	10.5 (2.5)	36.0 (8.6)	--	2.58	None
COS3- 1	0.0	2.9	95.2	1.9	0.0	29.3 (7.0)	--	2.63	None
COS3- 2	0.0	5.6	93.3	1.1	0.0	55.7 (13.3)	--	2.63	None
COS3- 3	11.2	8.5	72.6	7.7	126.5 (30.2)	85.5 (20.4)	0.893	2.11	None
COS3- 4	1.0	4.9	91.1	3.0	11.3 (2.7)	48.6 (11.6)	--	2.57	None
COS3- 5	6.4	8.0	82.0	3.6	72.1 (17.2)	80.4 (19.2)	0.891	2.31	None

Table 6.--Oil shale assays by modified Fischer retort method.--Continued

Sample number	Yield of product: Weight percent: Oil	Weight percent: Water	Weight percent: Spent shale	Weight percent: Gas & loss	liters/metric ton (gallons/short ton): Oil	liters/metric ton (gallons/short ton): Water	Specific gravity: Oil[1]	Specific gravity: Oil shale[2]	Tendency of spent shale to coke
Elko Formation, member 2:									
COS3- 6	10.8	10.0	74.8	4.4	124.4 (29.7)	100.6 (24.0)	0.874	2.12	None
COS3- 7	0.0	8.0	90.7	1.3	0.0	80.0 (19.1)	--	2.63	None
COS3- 8	0.0	4.7	94.4	0.9	0.0	46.9 (11.2)	--	2.63	None
COS3- 9	0.0	4.9	93.8	1.3	0.0	49.4 (11.8)	--	2.63	None
COS3-10	0.0	5.2	92.9	1.9	0.0	52.0 (12.4)	--	2.63	None
COS3-11	0.0	7.3	91.2	1.5	0.0	73.3 (17.5)	--	2.63	None
COS3-12	0.0	11.0	87.6	1.4	0.0	110.6 (26.4)	--	2.63	None
COS3-13	0.2	8.4	90.1	1.3	2.1 (0.5)	84.2 (20.1)	--	2.62	None
COS3-14	0.0	8.0	91.2	0.8	0.0	80.0 (19.1)	--	2.63	None
COS3-15	0.0	8.8	90.8	0.4	0.0	88.8 (21.2)	--	2.63	None
COS3-16	0.0	3.0	95.5	1.5	0.0	33.9 (8.1)	--	2.63	None
COS3-17	3.0	8.0	86.5	2.5	34.4 (8.2)	80.4 (19.2)	0.874	2.47	None
COS3-18	0.0	8.8	90.4	0.8	0.0	88.0 (21.0)	--	2.63	None
COS3-19	0.0	10.9	87.8	1.3	0.0	109.4 (26.1)	--	2.63	None
COS3-20	1.7	11.0	84.7	2.6	18.9 (4.5)	110.6 (26.4)	--	2.54	None
COS3-21	0.0	10.1	87.0	2.9	Trace	101.8 (24.3)	--	2.63	None
COS3-22	6.3	10.0	79.7	4.0	71.6 (17.1)	100.6 (24.0)	0.878	2.31	None
COS3-23	7.9	10.5	77.2	4.4	89.7 (21.4)	105.6 (25.2)	0.878	2.24	None
COS3-24	4.2	10.0	82.4	3.4	48.2 (11.5)	100.6 (24.0)	0.882	2.41	None
COS3-25	7.3	11.0	78.5	3.2	83.4 (19.9)	110.6 (26.4)	0.884	2.28	None

Table 6.--Oil shale assays by modified Fischer retort method.--Continued

Sample number	Yield of product: Weight percent: Oil	Weight percent: Water	Weight percent: Spent shale	Weight percent: Gas & loss	liters/metric ton (gallons/short ton): Oil	liters/metric ton (gallons/short ton): Water	Specific gravity: Oil[1]/	Specific gravity: Oil shale[2]/	Tendency of spent shale to coke
Elko Formation, member 2:									
COS3-26	0.0	7.5	91.5	1.0	Trace	75.0 (17.9)	--	2.63	None
COS3-27	0.0	5.1	94.0	0.9	0.0	51.5 (12.3)	--	2.63	None
COS3-28	0.0	6.5	92.9	0.6	0.0	65.4 (15.6)	--	2.63	None
COS3-29	0.0	4.9	94.0	1.1	0.0	49.4 (11.8)	--	2.63	None
COS3-30	0.0	5.8	93.9	0.3	0.0	58.2 (13.9)	--	2.63	None
COS3-31	0.0	6.2	93.4	0.4	0.0	62.0 (14.8)	--	2.63	None
COS3-32	0.0	7.6	91.5	0.9	0.0	76.7 (18.3)	--	2.63	None
COS3-33	5.9	6.5	85.9	1.7	67.9 (16.2)	65.4 (15.6)	0.873	2.33	None
COS3-34	0.0	8.6	90.6	0.8	0.0	86.7 (20.7)	--	2.63	None
COS3-35	0.0	9.9	88.8	1.3	0.0	99.3 (23.7)	--	2.63	None
COS3-36	12.8	7.4	76.2	3.6	146.2 (34.9)	74.2 (17.7)	0.880	2.04	None
COS3-37	9.0	5.8	82.0	3.2	103.1 (24.6)	58.2 (13.9)	0.874	2.20	None
COS3-38	0.4	11.1	87.5	1.0	4.2 (1.0)	111.5 (26.6)	--	2.61	None
COS3-39	8.6	8.4	79.9	3.1	98.0 (23.4)	84.2 (20.1)	0.885	2.22	None
COS3-40	5.2	9.0	81.5	4.3	57.8 (13.8)	90.5 (21.6)	0.895	2.37	None
COS3-41	2.5	8.7	83.3	5.5	28.5 (6.8)	87.6 (20.9)	0.874	2.49	None
COS3-42	0.0	8.0	90.9	1.1	0.0	80.0 (19.1)	--	2.63	None
COS3-43	0.0	14.1	84.5	1.4	0.0	141.6 (33.8)	--	2.63	None

Table 6.--Oil shale assays by modified Fischer retort method.--Continued

Sample number	Yield of product: Weight percent: Oil	Weight percent: Water	Weight percent: Spent shale	Weight percent: Gas & loss	liters/metric ton (gallons/short ton): Oil	liters/metric ton (gallons/short ton): Water	Specific gravity: Oil[1/]	Specific gravity: Oil Shale[2/]	Tendency of spent shale to coke
Elko Formation, member 1:									
E-16-77	0.8	7.0	90.4	1.8	8.4 (2.0)	70.4 (16.8)	--	--	None
E-17-77	0.0	6.3	92.5	1.2	Trace	63.7 (15.2)	--	--	None
E-18-77	0.0	3.1	96.6	0.3	0.0	31.0 (7.4)	--	--	None
E-19-77	0.0	5.6	93.5	0.9	Trace	56.1 (13.4)	--	--	None
Conglomerate, sandstone, and shale:									
E- 2-77	0.2	2.6	96.0	1.2	2.5 (0.6)	26.0 (6.2)	--	--	None

1/Specific gravity of oil estimated as 0.920 for rocks yielding less than 25.1 L/metric ton (6.0 gal/short ton).

2/Specific gravity of member 2 oil shale derived from oil yield-specific gravity relationships for oil shale from Phil Core Hole and Cathedral Bluffs area, Colorado (Smith, 1956, table 11).

Shale Oil Resource Calculation

Table 6 shows assays of oil shale samples collected from the conglomerate, sandstone, and shale unit and from the Elko Formation. The sample from the conglomerate, sandstone, and shale unit was collected from a surface outcrop, and was thought to represent the richest beds within the unit. Because the sample yielded only 2.5 L/t (0.6 gal/short ton) the unit is assumed to contain no significant amount of oil, and data for this unit are not used to calculate the total shale oil resource. Similarly, the four samples collected from member 1 of the Elko Formation, which were thought to be representative of the richest beds of the unit, yielded only up to 8.4 L/t (2.0 gal/short ton), so member 1 is also assumed to contain no significant amount of oil, and data for this unit are not used to calculate the total shale oil resource. Two samples from member 4 of the Elko Formation were collected from surface outcrops of the richest beds, and yielded 21.8 and 42.7 L/t (5.2 and 10.2 gal/short ton). As the samples are not necessarily representative of member 4 shales and the relative amount of shale within the unit is not known, data for this unit are not used to calculate the total shale oil resource.

A preliminary estimate for shale oil resources near Elko of approximately 30,292,000 m^3 (190,841,000 barrels) is calculated from data for members 2 and 3 of the Elko Formation (table 6). Samples from member 2 were collected from two trench locations; only oil yields from trench COS-4 are used in the calculation, however, because these samples are less weathered than those from trench COS-3. Samples were collected both from 30-cm-thick (1-ft-thick) intervals, and selectively from richer beds, regardless of thickness. Oil yield ranges up to 258.5 L/t (61.7 gal/short ton) for the richest 30-cm-thick (1-ft-thick) interval (table 6). The richest single bed yields 358.2 L/t (85.5 gal/short ton) over a 20-cm-thick (8-in-thick) interval. The sampled interval in trench COS-4 yields an average of 31.8 L/t (7.6 gal/short ton). Ten samples were collected from surface outcrops of member 3 (table 6). Because significant lithologic variations do not occur in this unit, and because the samples were collected systematically from all strata rather than selectively from the richest beds, the average oil yield of the samples is assumed to be representative of the entire unit. Individual yields range up to 72.1 L/t (17.2 gal/short ton); the samples average 21.4 L/t (5.1 gal/ short ton; table 6).

Oil yields are determined analytically on a weight basis by the Fischer assay and cannot be used directly to calculate the oil yields of shale obtained by mining and compositing a series of beds on a volume basis (Smith, 1956). The oil yield determined by assay must be converted to a volume basis by considering the specific gravity of the oil shale, which has not been determined for the Elko oil shale. An approximation of the oil yield-specific gravity relationship for Elko shale, however, may be obtained by using data calculated for part of the Green River Formation in Colorado (Smith, 1956; Stanfield and others, 1957).

To calculate the average oil yield per unit volume of samples collected in trench COS-4, each sample from a 30-cm-thick (1-ft-thick) interval was assigned a specific gravity based upon the sample's assayed oil yield. The specific gravities were obtained from Smith (1956, table 11), and are shown in table 6. Specific gravities for all samples were added, and an arithmetic average was computed. This average specific gravity, 2.48, was used to reconvert to oil yield per unit weight (Smith, 1956, table 11), and corresponds to an oil yield of 31.8 L/t (7.6 gal/short ton). The average specific gravity and the oil yield per unit weight, in turn, was used to calculate the amount of oil shale per unit volume. On the basis of 28.3 kg (62.3 lb) as the weight of 0.028 m^3 (1 ft^3) of water at 15.6°C (60°F) in air, the following formula was used to calculate oil shale per unit volume:

weight of water (in Kg/m^3)@ 15.6°C ×
specific gravity of shale

The amount of oil shale per unit volume for samples collected in trench COS-4 is 2,478.2 kg/m^3 (154.5 lb/ft^3). The oil shale per unit volume is related to the oil shale per unit weight by the following formula:

$$\frac{1{,}000 \text{ kg/t}}{\text{oil shale per unit volume (in Kg/m}^3\text{)}}$$

The amount of oil shale per unit weight for samples collected in trench COS-4 is 0.40 m^3/t (12.8 ft^3/short ton). The oil shale per unit weight and the oil yield per unit weight are used to calculate the oil yield per unit volume:

$$\underset{\text{(in L/m}^3\text{)}}{\text{oil yield per unit volume}} = \frac{\text{oil yield per unit weight (in L/Kg)}}{\text{oil shale per unit weight (in m}^3\text{/Kg)}}$$

The oil yield per unit volume for samples collected in trench COS-4 is 79.5 L/m^3 (0.594 gal/ft^3). The total volume of oil in the 16.8-m-thick (55-ft-thick) section sampled in trench COS-4, calculated for the estimated area of outcrop and subcrop of member 2 of the Elko Formation, is approximately 9,151,000 m^3 (57,655,000 barrels), according to the formula:

$$\text{area} \times \text{secant of dip} \times \text{thickness} \times \text{oil yield per unit volume} \times 0.001\ m^3/L$$

The weight of shale obtained by mining one hectare of the 16.8-m-thick (55-ft-thick) section is 416,338 t (183,189 short tons/acre):

$$\frac{\text{thickness} \times \text{shale per unit volume} \times 10{,}000\ m^2/ha}{1{,}000\ kg/t}$$

The oil yield for this block of shale is 13,240 m^3/ha (33,365 barrels/acre):

$$\text{oil yield/ha} = \text{weight of shale/ha} \times \text{oil yield per unit weight} \times 0.0001\ m^3/L$$

Similar calculations are performed for member 3 of the Elko Formation. The results of the calculations are shown in table 7.

Comparison of Oil Shale From the Elko and Green River Formations

The estimates calculated represent an initial approximation of the total in-place shale oil resources near Elko, disregarding minimum thickness and yield necessary for the deposit to be of economic value. Oil shale deposits currently are considered valuable if the deposit

Table 7.--Oil shale resources of members 2 and 3 of the Elko Formation near Elko, Nevada.

	Member 2	Member 3
Thickness[1] m (ft)	16.8 (55)	120.0 (400)
Area m^2 (ft^2)	6,227,000 (66,960,000)	2,724,000 (29,294,000)
Average dip degrees	25	25
Secant of dip	1.10	1.10
Average specific gravity of oil shale[2]	2.48	--
Oil yield per unit weight[3] L/t (gal/short ton)	31.8 (7.6)	21.4 (5.1)
Oil shale per unit weight m^3/t (ft^3/short ton)	.40 (12.8)	.40 (12.8)
Oil yield per unit volume L/m^3 (gal/ft^3)	79.5 (.594)	53.5 (.400)
Weight of shale per unit area t/ha (short ton/acre)	416,338 (183,189)	3,033,000 (1,353,000)

Table 7.--Oil shale resources of Members 2 and 3 of the Elko Formation near Elko, Nevada

	Member 2	Member 3
Oil yield per unit area...................... m^3/ha (barrels/acre)	13,240 (33,365)	64,927 (165,266)
Total volume of oil.......................... m^3 (barrels)	9,151,000 (57,655,000)	21,140,000 (133,185,000)

1/ Thickness of member 2 is equal to the total thickness of beds sampled in trench COS-4, and is not equal to the total thickness of the member.

2/ Average specific gravity of member 3 is not calculated because samples from member 3 were not collected systematically.

3/ Oil yield per unit weight for member 3 is the arithmetic average of the yields for samples E-3-77 through E-12-77 of table 6.

yields at least 62.9 L/t (15 gal/short ton) over a minimum thickness a minimum thickness of 4.6 m (15 ft; Culbertson and Pitman, 1973, p. 500). Oil shale in member 2 of the Elko Formation exceeds this criterion. The richest 4.6-m-thick (15-ft-thick) interval in trench COS-4 (samples COS4-7 through COS4-21; table 6) yields 71.6 L/t (17.1 gal/short ton). A 7.9-m-thick (26-ft-thick) section from trench COS-4 (samples COS4-7 through COS4-33; table 6) yields in excess of 62.9 L/t (15 gal/short ton).

As the Green River Formation contains the largest known oil shale deposits in the United States, a comparison of Green River and Elko oil shale resources is of interest. The Green River Formation of Colorado Tract C-a contains at least 150 m (495 ft) of oil shale that averages 125 L/t (30 gal/short ton). The total in-place shale oil resource in beds 3 m thick (10 ft thick) or more averages about 392,600 m^3/ha (1,000,000 barrels/acre), and the total in-place shale oil resource amounts to approximately 810 million m^3 (5.09 billion barrels; U.S. Department of the Interior, 1973, v. III, p. II-46 to II-48). The richest intervals at Tract C-a are the Mahogany-rich interval, which is 15 to 20 m thick (50 to 65 ft thick) with an average yield of about 130 L/t (31 gal/short ton), the R-4 interval, which is 30 to 50 m thick (100 to 160 ft thick) with an average yield of about 135 L/t (32 gal/short ton), and the R-5 interval, which is 45 to 65 m thick (150 to 210 ft thick) with an average yield of about 121 L/t (29 gal/short ton; Gulf Oil Corp. and Standard Oil, Co. 1974, p. 53; Murray, 1974, p. 132).

In oil shale leasing tracts along Kinney Rim on the western edge of the Washakie Basin in Wyoming, 64 to 88 m (210 to 290 ft) of oil shale in the Laney Member of the Green River Formation averages 62.9 L/t (15 gal/short ton). This represents more than 93,600 m^3/ha (240,000 barrels/acre; Trudell and others, 1973).

Although preliminary calculations indicate that oil shale near Elko has less potential than oil shale in the Green River Formation, several factors tend to affect the data. Of primary importance is the method of sample collection. Samples from the conglomerate, sandstone, and shale unit, and from members 1, 3, and 4 of the Elko Formation were collected from surface outcrops and are probably weathered to a large degree, as indicated by water contents as high as 8.3 weight percent (table 6). Weathering drastically reduces oil yield. For example, yields of surface samples collected from the Washakie Basin, Wyoming, were found to be 17 to 69 percent lower than average yields from cores (Trudell and others, 1973). A sample of weathered shale from the Mahogany bed of the Uinta Basin, Utah, assayed 53.7 L/t (12.8 gal/short ton), whereas an unweathered sample of the bed assayed 190.6 L/t (45.5 gal/short ton; Guthrie, 1938, p. 99). Although trench samples lessen the likelihood that weathering has affected oil yields, this is still not a completely reliable method. Samples from member 2 of the Elko Formation were collected from trenches, yet the effects of weathering were still noted. Water content of rock ranges up to 14.1 percent by weight, sulfides in the shale have been partly oxidized to sulfates, and biotite phenocrysts in interbedded tuff are almost completely weathered.

This suggests that assayed oil yields of Elko samples are less than might be expected from fresh samples. A constant factor for upgrading assayed oil yields cannot be applied because of great variations in the weathering of oil shale beds (Cashion, 1964, p. 211).

Inaccuracies in the calculated oil resources near Elko also are introduced when oil yields assayed on a weight basis are converted to those on a volume basis. Such a conversion is dependent upon the specific gravity of the shale (Smith, 1969). Because the specific gravity of Elko shale is not known, the specific gravity of Green River shale was used. Variations in mineral composition, organic content, conversion of organic material to oil, and differences of oil gravity between Elko and Green River shales affect the utility of applying Green River data to calculate Elko oil shale yields. Mineral density is particularly sensitive to changes in amounts of pyrite and analcime (Smith, 1969, p. 5). Because Elko shale contains little of those minerals, the effect of mineral composition is assumed to be quite small. Similarly, as organic matter in an oil shale deposit tends to be homogenous, significant changes in organic density in a single deposit are unlikely (Smith, 1969, p. 6). Density of organic material of both Elko and Green River shales is assumed to be similar as a result of similarities in depositional environment. In relating oil shale density to oil yield, a much more significant variable is how much of the organic material will convert to oil (Smith, 1969, p. 7). Because Elko and Green River shales have similar conversion fractions, 58 percent for Elko shales and 66 percent for Green River shales from the Mahogany Zone, this factor can also be ignored (Smith, 1966, p. 168). Shale oil specific gravities for Elko and Green River oils are similar, 0.880 for Elko shales and 0.920 for Green River shales from the Mahogany Zone, thus the effect of this factor is also assumed to be small (Smith, 1963, p. 809). Therefore, the principal limitation on an accurate estimate of the total in-place shale oil resources near Elko is the use of samples collected at or near the surface.

CONCLUSION

The Elko Formation of Eocene and Oligocene(?) age and unnamed lithostratigraphic units of Eocene and probable Eocene age are exposed near Elko, Nevada, unconformably overlying the Mississippian and Pennsylvanian Diamond Peak Formation. This stratigraphic sequence records a change, during the Mesozoic, from marine deposition largely by sediment gravity flows to nonmarine sedimentation.

For a period of about 6 m.y., from the initial deposition of the conglomerate, sandstone, and shale unit approximately 43 m.y. ago, through the deposition of the upper part of the Elko Formation approximately 37 m.y. ago, lacustrine sedimentation took place in the Elko region. These lake beds contain oil shale, and were deposited slightly later than the well-known oil shale of the Green River Formation of Utah, Colorado, and Wyoming. Oil shale from the Elko Formation yields up to 358 L/metric ton (85.5 gal/short ton), and contains at least 30 million m^3 (191 million barrels) of oil.

Gradual transgression of the lake shore near Elko is recorded by the succession of marginal lacustrine and fluvial rocks that accumulated as sediment adjacent to the lake. These rocks grade upward into carbonate flat, mudflat, interdeltaic and deltaic rocks of lake margin origin, and finally to shale rich in organic matter deposited in an open-lacustrine environment.

A period of volcanism commenced during deposition of member 4 of the Elko Formation and may have led to the eventual destruction of the lake system. Following a period of deformation in the early Oligocene, volcanism intensified, as indicated by the Indian Well Formation and the andesite unit. After a pause in volcanic activity, during which the siltstone and sandstone unit was deposited later in the Oligocene, Basin and Range block faulting started. Isolated basins, in which the Humboldt Formation was deposited, formed in Miocene time.

Deposits similar to the oil shale near Elko are extant over a wide area of northeast Nevada in a region extending about 155 km in a north-south direction and about 125 km in an east-west direction. It is still uncertain whether all these rocks were deposited in a single large basin or whether irregular topography created several lakes. The large minimum thickness of the Elko Formation in both the Carlin-Pinon Range and Elko areas suggests, however, that the lake basin of deposition must have been of regional scale. If the Elko Formation in both the Elko and the Carlin-Pinon Range areas is indicative of relatively nearshore deposits of a single lake, then offshore, open-lacustrine deposition might have occurred farther east. If the rocks were formed in a series of adjacent, smaller lakes, offshore open-lacustrine sediment might not have been deposited to any significant degree. Two periods of Tertiary deformation and subsequent erosion have left only isolated remnants of Eocene and Oligocene lacustrine deposits.

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