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Preliminary Results of Coal Exploratory Drilling in the Book Cliffs Coal Field, Grand County, Utah

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Preliminary Results of Coal Exploratory Drilling in the Book Cliffs Coal Field, Grand County, Utah

Abstract

Two holes, one of which was the completion of a hole that was started in 1979 and recessed during inclement winter months, were drilled in the Book Cliffs coal field of Grand County, Utah during 1980. The holes were drilled to provide coal core suitable for analysis and stratigraphic information about coal-bearing strata. Pilot-hole rotary drilling totaled 1,090 feet (332 m), which includes 575 feet (175 m) drilled in 1978. Cored intervals totaled 239.46 feet (73 m), which includes 50.21 feet (15 m) drilled in 1978. Mechanical and geophysical logs of the two holes were made. Most of the cored rock is from the coal-bearing Neslen Formation of Late Cretaceous age and almost all of it is carbonaceous to some degree; a small part of the core is from the Sego Sandstone. Lithologies of the rotaried intervals are shown on plate 1 and were interpreted from geophysical logs and cuttings.

Introduction

Holes at two sites, USGSCBBC 4 and USGSCBCB 5, were drilled in the Book Cliffs coal field, Grand County, Utah (fig. 1) during the period June 20 to July 4, 1979. Hole USGSCBBC 4 was rotary drilled and partly cored in an offset hole in 1978 and recessed during the winter and spring months. Additional core was obtained from intervals above and below those cored in 1978 from a new offset hole drilled in 1979. Pilot-hole rotary drilling totaled 1,090 feet (332m), which includes 575 feet (175 m) drilled in 1978. Cored intervals totaled 239.46 feet (73 m), which includes 50.21 feet drilled in 1978. Results of drilling in 1978 have been previously reported (Gualtieri, 1979).

The drill-hole data provide information about the coal resources and the regional stratigraphy of the coal-bearing rocks. Geophysical logs made of the coal-bearing rocks will further aid stratigraphic and coal studies. Methane-yield studies of the cored coal have been conducted by personnel of the Utah Geological and Mineral Survey.

Lithology of the rotary-drilled intervals of the holes (pl. 1) was interpreted from geophysical logs and cuttings; the lithology of hole BC-3-SC is extracted from the report of U.S. Geological Survey work done in the Sego Canyon area of the Book Cliffs coal field (Albee, 1979). It is included on plate 1 for correlation purposes. Formational boundaries and coal zones are tentatively identified. Results of chemical analyses of coals, their methane yield, and other data are not yet available.

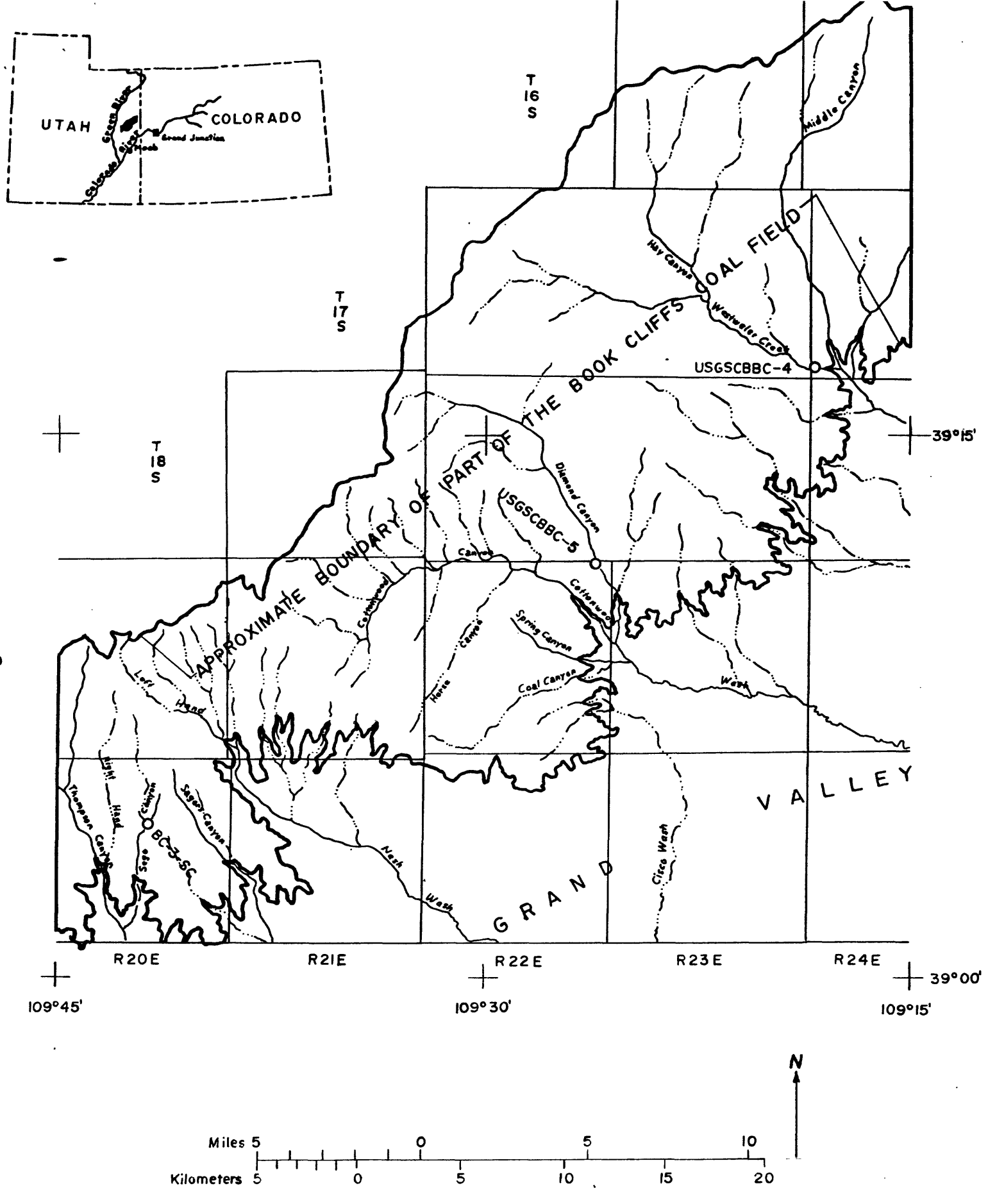

Figure 1.-- Part of the Book Cliffs coal field, Utah showing location of coal exploratory drill sites.

Geology

Coal-bearing rocks of the Book Cliffs coal field are of Late Cretaceous age. They crop out along the lower part of the Book Cliffs near the southern edge of the Uinta Basin. Most coal beds in the area are in the Neslen Formation of Late Cretaceous age and form four coal zones, which in ascending order are: Palisade, Ballard, Chesterfield, and Carbonera. The Ballard is only locally present; however, it is shown as continuous in plate 1. The Carbonera occurs only in the eastern part of the report area. Minor, nonextensive coal beds occur in the underlying Sego Sandstone and the overlying Farrer Formation. All three formations belong to the Mesaverde Group.

The Sego Sandstone is an eastward-prograding delta-front unit. It is mostly sandstone and also contains siltstone, shale, and minor coal. Locally the formation is mostly siltstone and shale. The overlying Neslen Formation was deposited in swampy fluvial and interfluvial areas of a coastal-plain environment. It consists of almost equal proportions of sandstone, siltstone, and shale, almost all of which are carbonaceous to some degree. All important coal beds in this part of the Book Cliffs coal field occur in the Neslen. The Farrer Formation was deposited in mostly nonswampy fluvial and interfluvial areas of a coastal-plain environment. It consists of sandstone, siltstone, and shale; sandstone is dominant. Most of the rock is noncarbonaceous. These formations total more than 1,000 feet (305 m) in thickness in the area where drilling took place.

The rocks in the area where drilling was conducted dip as much as about 10 degrees and they commonly dip 4 degrees or less. Anticlines and synclines of low to moderate structural amplitude occur in the area. Sparse high-angle east- and northwest-trending faults occur in the region and are rarely traceable for more than a few miles. Throw on the faults is commonly less than 100 feet (30 m).

Site Selection and Drilling Operations

Selection of sites drilled by the U.S. Geological Survey was based on four criteria: 1) the surface and mineral rights were to be federally owned; 2) access was to be by way of preexisting roads--no road building or site preparation was to be undertaken; 3) drill holes were to be spudded as near as possible to the top of the coal-bearing section; and 4) drill sites were to be located at intervals of 6 miles (10 km). The first two criteria were met; the third and fourth criteria could be only partially met. The holes were spudded considerably above the coal-bearing section, more than 300 feet (92 m) in the case of USGSCBBC 5. The interval between USGSCBBC 4 and USGSCBBC 5 is 9.3 miles (15 km).

A twin-hole method was used for the drilling; pilot holes were rotary drilled and geophysically and mechanically logged. The logs include focused density, natural gamma, apparent resistivity, caliper, and, in hole USGSCBBC 5, deviation. Coal-bearing intervals were identified on the logs of pilot holes and offset holes were drilled close to the pilot holes. In the offset holes noncoal-bearing intervals were rotary drilled and coal-bearing intervals were cored.

Pilot holes bottomed in the Sego Sandstone, the top of which is regarded as the most reliable and accessible marker for coal-hole correlation in this part of the Book Cliffs coal field.

Most coal beds were cored and have provided samples for proximate and ultimate analyses, trace element analysis, heating value determination, and methane yield. Methane-yield studies were done by the Utah Geological and Mineral Survey.

Description of drill sites and drilling

Drill hole USGSCBBC 4

The drill hole is near the canyon wall north of Westwater Creek in NW 1/4, SW 1/4, sec. 31, T. 17 S., R. 24 E. (Dry Canyon quadrangle), Grand County, Utah. Ground elevation is approximately 5,330 feet (1,625 m) above sea level. Drilling commenced November 21, 1978 and was recessed November 29, 1978. Core was obtained from three intervals in an offset hole drilled in 1978. A new offset hole was started June 20, 1979 and completed on June 23, 1979, and additional intervals were cored above and below intervals cored in 1978.

The rocks penetrated include most of the Neslen Formation and the upper part of the Sego Sandstone. The pilot hole was drilled to a depth of 575 feet (175 m). Seventeen cores, totaling 139.54 feet (42.53 m), were cut in the offset holes drilled in 1978 and 1979. Lithology of the core is described in table 1; the interpretation of the pilot hole, and the cored intervals are shown on plate 1; and the geophysical and mechanical logs are in the appendix.

Drill hole USGSCBBC 5

The drill hole is near the canyon wall west of the road in Diamond Canyon, in NE 1/4, NW 1/4, sec. 1, T. 19 S., R. 22 E. (Flume Canyon quadrangle), Grand County, Utah. Ground elevation is approximately 5,510 feet (1,680 m) above sea level. Drilling commenced June 23, 1979 and was completed July 4, 1979.

The rocks penetrated include most of the Neslen Formation and the upper part of the Sego Sandstone. The pilot hole was drilled to a depth of 515 feet (157 m). Eleven cores were cut in the offset hole totaling 89.92 feet (27.41 m). Lithology of the core is described in table 1, the interpretation of the pilot hole and the core intervals are shown on plate 1, and the geophysical and mechanical logs are in the appendix.

Drill hole BC-3-SC

The drill hole is located on the floor of Sego Canyon in NW 1/4, sec. 15, T. 20 S., R. 20 W. (Sego Canyon quadrangle), Grand County, Utah. Ground elevation is approximately 6,300 feet (1920 m) above sea level.

The rocks penetrated include part of the Farrer Formation, all of the Neslen Formation, and the upper part of the Sego Sandstone. The total depth of the hole is 1,002 feet (306 m); the upper 702 feet (214 m) was rotary drilled and the lower 300 feet (92 m) was totally cored. Drilling was conducted by the U.S. Geological Survey. For details see U.S. Geological Survey Open-File Report 79-738 (Albee, 1979).

References cited

Goddard, E. N., chm., and others, 1948, Rock-color chart: National Research Council; reprinted by Geological Society of America, 6 p.

Gualtieri, J. L., 1979, Preliminary results of coal exploratory drilling in the Book Cliffs coal region, Garfield County, Colorado, and Grand County, Utah: U.S. Geological Survey Open-File Report 79-999, 49 p.

Albee, Howard F., 1979, Geophysical and lithologic logs of four holes drilled in the Book Cliffs coal field, Sego Canyon quadrangle, Grand County, Utah: U.S. Geological Survey Open-File Report 79-738, 20 p.

Table 1.--Description of core from drilled holes (measured in feet and inches)

[Color designations from Goddard and others, 1948]

USGSCBBC 4

Cretaceous:

Neslen Formation:

		From	To	Thickness
1.	Rotary drilled	0′0"	148′0"	148′0"
2.	Shale, pale-yellowish-brown (10YR 6/2), obscurely laminated; contains wispy carbonaceous bodies and minor in-slumped sandstone in upper part	148′0"	148′2 3/16"	0′2 3/16"
3.	Shale, medium-light-gray (N6), slightly carbonaceous, obscurely to moderately well laminated; contains abundant carbonaceous films, flakes, and irregular bodies, and sparse slickened surfaces	148′2 3/16"	149′6"	1′3 13/16"
4.	Shale, silty in part, grayish-black (N2) to medium-dark-gray (N4), highly to moderately carbonaceous, obscurely laminated; contains abundant vitrain lenses in uppermost 4 inches and abundant carbonaceous films and flakes throughout. Unit disturbed in part, slumped and bioturbated in a few places	149′6"	151′10 1/8"	2′4 1/8"
5.	Siltstone, medium-dark-gray (N4), moderately to slightly carbonaceous; contains sparse to moderately abundant films and flakes. Unit disturbed, especially in lower part, contorted ghostly laminae evident and minor inclusions of irregular bodies of sandstone. Base in slump contact with underlying unit	151′10 1/8"	153′10 1/8"	2′0"
6.	Siltstone, silty shale, medium-dark-gray (N4), moderately carbonaceous, moderately well to distinctly laminated; contains abundant carbonaceous films and flakes. Unit bioturbated in basal part	153′10 1/8"	155′ 1/8"	1′2"
7.	Shale, dark-gray (N3), moderately carbonaceous, distinctly laminated; base in slump contact with underlying unit	155′1/8"	155′3 7/8"	0′3 3/4"

Neslen Formation--Continued

		From	To	Thickness
8.	Claystone, light-brownish-gray (5YR 6/1), kaolinitic, grainy; contains ragged lenticular bodies of carbonaceous shale. Base in slump contact with underlying unit	155′3 7/8"	155′5"	0′1 1/8"
9.	Coal, black (N1), vitrainous and attrital; cleat not apparent	155′5"	155′8"	0′3"
10.	Shale, grayish-black (N2), highly carbonaceous, contains abundant vitrain lenses	155′8"	156′4 1/2"	0′8 1/2"
11.	Coal, black (N1), vitrainous and attrital; cleat not apparent	156′4 1/2"	156′7"	0′2 1/2"
12.	Shale, medium-gray (N5), non-carbonaceous, unlaminated; contains several slickened surfaces	156′7"	157′10"	1′3"
13.	Shale and silty shale, medium-gray (N4), moderately to slightly carbonaceous; contains abundant carbonaceous films and flakes	157′10"	158′7"	0′9"
14.	Siltstone, medium-dark-gray (N4), slightly carbonaceous; contains abundant carbonaceous films and flakes	158′7"	159′1/2"	0′ 5 1/2"
15.	Sandstone and siltstone intermixed, bioturbated; laminae less disturbed and recognizable in lower part; sandstone, very fine grained, very light gray (N8); siltstone, medium-gray (N5), moderately to slightly carbonaceous. Unit contains abundant carbonaceous films and flakes; wispy carbonaceous bodies deposited in burrowed rock. Unit in slump contact with underlying unit	159′1/2"	161′1/2"	2′0"
16.	Shale, dark-gray (N3), moderately carbonaceous; contains abundant carbonaceous films and flakes	161′ 1/2"	162′6"	1′5 1/2"
17.	Rotary drilled	162′6"	183′0"	20′6"

Neslen Formation--Continued

		From	To	Thickness
18.	Sandstone, very fine grained, very light gray (N8), obscurely laminated; laminae inclined; contains abundant opaque mineral grains, sparse to numerous yellowish-gray, minute, ragged, flakes (clay mineral?), and sparse carbon-rich films	183'0"	186'1 1/2"	3'1 1/2"
19.	Siltstone, pale-yellowish-brown (10YR 6/2), very slightly carbonaceous, distinctly laminated; laminae inclined; contains abundant carbonaceous films and flakes, and numerous carbon-rich laminae	186'1 1/2"	186'5 1/2"	0'4"
20.	Sandstone, very fine grained, very light gray (N8), distinctly to obscurely laminated; laminae inclined; contains abundant opaque mineral grains, sparse siltstone laminae in uppermost 4 inches; abundant rounded to angular, pale-yellowish-brown and brownish-gray siltstone in basal 6 inches; sparse carbon-rich laminae, and numerous vitrain flakes in upper and basal parts	186'5 1/2"	191'8"	5'2 1/2"
21.	Siltstone and silty shale, medium-dark-gray (N4) to grayish-black (N2), moderately to highly carbonaceous, unlaminated; contains vitrain flakes	191'8"	193'2 1/2"	1'6 1/2"
22.	Coal, black (N1), vitrainous and attrital; contains vitrain lenses as thick as 1/4 inch and resin bodies as much as 1/4 inch long; cleat not apparent	193'2 1/2"	194'2 1/2"	1'0"
23.	Siltstone and shaly siltstone, medium-dark-gray (N4), moderately carbonaceous, unlaminated	194'2 1/2"	196'8 1/2"	2'6"
24.	Rotary drilled	196'8 1/2"	230'0"	33'3 1/2"
25.	Sandstone, very fine grained, very light gray (N8), obscurely laminated; contains abundant opaque mineral grains, sparse carbon-rich laminae, and sparse to abundant angular to rounded, pale-yellowish-brown and brownish-gray siltstone bodies in lower part	230'0"	233'11"	3'11"

Neslen Formation--Continued

		From	To	Thickness
26.	Coal, black (N1), vitrainous and attrital; contains vitrain lenses as thick as 1/4 inch; cleat not apparent. Coal fractured; fractures inclined	233'11"	234'7"	0'8"
27.	Shale, silty, grayish-black (N2), highly carbonaceous; contains abundant vitrain lenses, some as thick as 1/4 inch	234'7"	235'11"	1'4"
28.	Coal, black (N1), vitrainous and attrital; contains vitrain lenses as thick as 1/2 inch, and sparse resin bodies; cleat well developed, spaced 1 inch or more. Sparse pyrite on cleat faces	235'11"	239'11 1/2"	4'0 1/2"
29.	Siltstone, grayish-black (N2) and dark-gray (N3), highly carbonaceous, unlaminated; contains abundant carbonaceous films throughout; abundant vitrain lenses in uppermost 4 inches	239'11 1/2"	242'2"	2'2 1/2"
30.	Siltstone, medium-light-gray (N6), very slightly carbonaceous; contains numerous carbonaceous films and flakes	242'2"	245'0"	2'10"
31.	Rotary drilled	245'0"	273'0"	28'0"
32.	Siltstone and sandstone, interlaminated, slumped and bioturbated in few parts; siltstone, medium-dark-gray (N4), moderately carbonaceous; sandstone, very fine grained, very light gray (N8). Unit dominantly siltstone	273'0"	276'3 1/2"	3'3 1/2"
33.	Coal, black (N1), vitrainous and attrital; contains vitrain lenses as thick as 1/4 inch, and sparse pyrite in one part; cleat not apparent. Coal fractured; fractures inclined; contains 1/4-inch-thick claystone lens in middle part	276'3 1/2"	278'6"	2'2 1/2"
34.	Siltstone, grayish-black (N2), highly carbonaceous; contains abundant vitrain lenses, some as thick as 1/8 inch, and numerous filmy bodies of pyrite	278'6"	278'8"	0'2"

Neslen Formation--Continued

		From	To	Thickness
35.	Siltstone and sandstone, interlaminated and intermixed, bioturbated; silt-stone, medium-dark-gray (N4), moderately carbonaceous; sandstone, very fine grained, very light gray (N8). Unit contains numerous carbonaceous films and flakes	278'8"	283'11"	5'3"
36.	Siltstone, medium-dark-gray (N4), moderately carbonaceous; contains very minor, very fine grained, very light gray, intermixed, bioturbated sandstone, sparse carbonaceous films, and abundant casts of flat pelecypods in upper part	283'11"	289'1"	5'2"
37.	Siltstone and shaley siltstone, dark-gray (N3) and grayish-black (N2), highly carbonaceous, obscurely laminated; contains vitrain lenses in uppermost and basal parts, and very sparse sandstone laminae in lower part	289'1"	290'8 1/2"	1'7 1/2"
38.	Coal, black (N1), vitrainous and attrital; contains vitrain lenses commonly 1/16 inch thick; cleat well developed; sparse pyrite on cleat faces	290'8 1/2"	291'6 1/4"	0'9 3/4"
39.	Siltstone, grayish-black (N2) and brownish-black (5YR 2/1), highly carbonaceous; contains sparse vitrain lenses, and numerous bioturbated and slumped sandstone lenses and laminae in lower part	291'6 1/4"	292'5 1/4"	0'11"
40.	Sandstone, very fine grained, very light gray (N8) and light-gray (N7); contains minor interlaminated, highly carbonaceous siltstone	292'5 1/4"	294'6"	2'3/4"
41.	Rotary drilled	294'6"	338'0"	43'6"

Neslen Formation--Continued

	From	To	Thickness
42. Sandstone, very fine grained, very light gray (N8), distinctly laminated in most parts; laminae flat to moderately inclined, many carbon rich. Unit bioturbated in parts; wispy carbonaceous bodies deposited in burrowed rock. Contact with underlying unit undulous	338′0"	343′9 5/8"	5′9 5/8"
43. Siltstone, grayish-black (N2), highly carbonaceous, laminated	343′9 5/8"	344′0"	0′2 3/8"
44. Coal, black (N1), vitrainous and attrital	344′0"	345′11 1/2"	1′11 1/2"
45. Siltstone, grayish-black (N2), highly carbonaceous, indistinctly laminated; contains several vitrain lenses, thickest 1/8 inch, and pyrite lens 1 inch long	345′11 1/2"	346′3"	0′3 1/2"
46. Sandstone, very fine grained, very light gray (N8), laminated; laminae become more distinct downward; moderately bioturbated in lower part; contains abundant carbon-rich laminae in lower part	346′3"	350′3"	4′0"
47. Siltstone and minor sandstone, intermixed, highly bioturbated; siltstone, dark-gray (N3); moderately to highly carbonaceous; sandstone, very fine grained, very light gray (N8). Unit gradational with underlying one	350′3"	352′2"	1′11"
48. Sandstone and minor siltstone, interlaminated and intermixed, bioturbated, slumped in most parts; sandstone, very fine grained, very light gray (N8); siltstone, medium-dark-gray (N4), moderately carbonaceous	352′2"	353′10 1/2"	1′8 1/2"
49. Sandstone, very fine grained, very light gray (N8), distinctly cross-laminated and slightly bioturbated in lower part	353′10 1/2"	354′7"	0′8 1/2"

Neslen Formation--Continued

		From	To	Thickness
50.	Sandstone and siltstone, interlaminated and bioturbated; sandstone, very fine grained, very light gray (N8); siltstone, medium-dark-gray (N4), moderately carbonaceous. Proportion of sandstone decreases downward. Unit more bioturbated in lower part, and gradational with underlying unit	354′7"	358′8 1/4"	4′1 1/4"
51.	Siltstone and minor sandstone, interlaminated and intermixed, bioturbated; siltstone, dark-gray (N3), moderately carbonaceous; sandstone, very fine grained, very light gray (N8). Proportion of sandstone decreases downward. Unit gradational with underlying one	358′8 1/4"	360′2 3/8"	1′6 1/8"
52.	Shale, dark-gray (N3), moderately to highly carbonaceous, unlaminated to obscurely laminated	360′2 3/8"	361′9"	1′6 5/8"
53.	Coal, black (N1), vitrainous and attrital; contains sparse resin bodies	361′9"	364′3"	2′6"
54.	Shale, dark-gray (N3), moderately to highly carbonaceous, obscurely laminated. Basal contact undulous	364′3"	364′7 1/2"	0′4 1/2"
55.	Shale, silty, and minor sandstone, interlaminated, slightly bioturbated and slumped, microfaulted in parts; shale, dark-gray (N3), moderately to highly carbonaceous; sandstone, very fine grained, very light gray (N8). Basal contact abrupt	364′7 1/2"	365′4 1/2"	0′9"
56.	Sandstone and minor silty shale, interlaminated, bioturbated, slumped, and microfaulted; sandstone, very fine grained, very light gray (N8); shale, dark-gray (N3), moderately to highly carbonaceous	365′4 1/2"	366′0"	0′7 1/2"
57.	Rotary drilled	366′0"	398′0"	32′0"
58.	Siltstone, shaly, medium-dark-gray (N4) to brownish-gray (5YR 4/1), moderately carbonaceous, obscurely laminated; contains sparse to abundant carbonaceous films, flakes, and vitrain lenses; some vitrain lenses as thick as 1/8 inch	398′0"	403′5 1/2"	5′5 1/2"

Neslen Formation--Continued

		From	To	Thickness
59.	Shale, medium-dark-gray (N4) to dark-gray (N3), moderately to highly carbonaceous; contains very abundant vitrain; pyrite on fracture surface	403'5 1/2"	403'6 1/2"	0'1"
60.	Coal, black (N1), vitrainous and attrital, slightly impure in parts	403'6 1/2"	405'1"	1'6 1/2"
61.	Siltstone, medium-gray (N5) to medium-dark-gray (N4) and brownish-gray (5YR 4/1), moderately carbonaceous, obscurely laminated; contains moderate quantities of carbonaceous films and flakes; vitrain lens 1/4 inch thick in uppermost part. Base in slump contact with underlying unit	405'1"	407'11 1/2"	2'10 1/2"
62.	Sandstone, very fine grained, very light gray (N8), cross laminated, slumped, bioturbated in parts; contains minor siltstone in upper part, very minor siltstone in lower part, sparse carbonaceous films and flakes throughout	407'11 1/2"	410'1 5/8"	2'2 1/8"
63.	Siltstone, medium-gray (N5), slightly carbonaceous, unlaminated, probably bioturbated. Base in slump contact with underlying unit	410'1 5/8"	411'7 1/8"	1'5 1/2"
64.	Sandstone, fine grained, very light gray (N8), laminated, slump folded, contorted, slightly limy in parts; contains very minor siltstone. Basal contact abrupt	411'7 1/8"	413'3 1/8"	1'8"
65.	Siltstone, shaly, dark-gray (N3), moderately to highly carbonaceous, unlaminated, probably bioturbated and slumped; contains abundant carbonaceous films and flakes throughout and abundant vitrain lenses in lower part	413'3 1/8"	415'9 3/8"	2'6 1/4"
66.	Siltstone, shaly, grayish-black (N2), highly carbonaceous; contains abundant vitrain lenses	415'9 3/8"	415'10 7/8"	0'1 1/2"

Neslen Formation--Continued

		From	To	Thickness
67.	Siltstone, medium-gray (N5) to medium-dark-gray (N4), slightly to moderately carbonaceous; contains moderate quantities of carbonaceous films and flakes throughout, and minor contorted infolded bodies of sandstone in basal part. Basal contact slightly undulous, abrupt	415'10 7/8"	418'3 3/4"	2'4 7/8"
68.	Siltstone and sandstone, intermixed, slump contorted; siltstone, medium-gray (N5), slightly carbonaceous; sandstone, very fine grained, very light gray (N8). Unit contains abundant carbonaceous films and flakes	418'3 3/4"	418'9 3/4"	0'6"
69.	Shale, silty, grayish-black (N2), highly carbonaceous, unlaminated	418'9 3/4"	419'2 1/2"	0'4 3/4"
70.	Coal, black (N1), impure; contains much highly carbonaceous shale, abundant irregular bodies of resin	419'2 1/2"	419'8 1/4"	0'5 3/4"
71.	Claystone, brownish-gray (5YR 4/1), very pale orange (10YR 8/2) in 3/4-inch sequence near base, kaolinitic; contains abundant carbonaceous films and flakes in uppermost part. Unit visibly grainy only in uppermost part	419'8 1/4"	420'4 1/4"	0'8"
72.	Siltstone, medium-gray (N5) to dark-gray (N4), slightly to moderately carbonaceous, mostly unlaminated, probably bioturbated; contains slightly disturbed to contorted sandstone laminae in lower part, sparse vitrain lenses in upper part, and sparse to abundant carbonaceous films and flakes throughout, some oriented at high angles. Base in slump contact with underlying unit	420'4 1/4"	423'4 1/2"	3' 1/4"
73.	Siltstone, medium-gray (N5) to pale-yellowish-brown (10YR 6/2), slightly carbonaceous, unlaminated to obscurely laminated. Base in slump contact with underlying unit	423'4 1/2"	424'1"	0'8 1/2"

Neslen Formation--Continued

		From	To	Thickness
74.	Shale and claystone, dark-yellowish-brown (10YR 4/2) to brownish-gray (5YR 4/1), interlaminated and intermixed, probably bioturbated and slumped; contains abundant carbonaceous films and flakes in upper part, none in lower parts. Claystone fraction grainy, kaolinitic. Base in slump contact with underlying unit	424'1"	424'7 1/2"	0'6 1/2"
75.	Shale, dark-yellowish-brown (10YR 4/2), noncarbonaceous, obscurely laminated, gradational with underlying unit	424'7 1/2"	425'4"	0'8 1/2"
76.	Shale, dark-gray (N3), moderately carbonaceous; contains sparse carbonaceous films and flakes	425'4"	425'9 1/2"	0'5 1/2"
77.	Coal, black (N1), vitrainous and attrital; contains abundant resin bodies	425'9 1/2"	426'6"	0'8 1/2"
78.	Shale, dark-gray (N3) to grayish-black (N2), moderately to highly carbonaceous; contains abundant vitrain lenses, some as thick as 1/4 inch	426'6"	430'1 1/4"	3'7 1/4"
79.	Coal, black (N1), vitrainous and attrital	430'1 1/4"	432'2 1/2"	2'1 1/4"
80.	Shale, grayish-black (N2), highly carbonaceous; contains abundant vitrain lenses, some as thick as 1/8 inch. Base gradational with underlying unit	432'2 1/2"	433'5"	1'2 1/2"
81.	Siltstone, shaly, dark-gray (N3), moderately carbonaceous, unlaminated to obscurely laminated, probably bioturbated; contains abundant carbonaceous films and flakes, some disturbed sandstone laminae in lower part. Base in slump contact with underlying unit	433'5"	434'3 3/8"	0'10 3/8"
82.	Sandstone and siltstone, interlaminated and intermixed, slumped and contorted; sandstone, very fine grained, very light gray (N8); siltstone, dark-gray (N3), moderately carbonaceous	434'3 3/8"	435'2 1/8"	0'10 3/4"

Neslen Formation--Continued

		From	To	Thickness
83.	Siltstone, dark-gray (N3), moderately carbonaceous; contains minor interlaminated and disturbed sandstone in the the middle part, and sparse vitrain lenses	435'2 1/8"	435'4"	0'1 7/8"
84.	Rotary drilled	435'4"	477'0"	41'8"

Sego Sandstone (contact in rotaried interval):

85.	Sandstone, fine- to medium-grained, very light gray (N8) to pinkish-gray (5 YR 8/1), obscurely to distinctly laminated; contains abundant orangish-brown and dark opaque clasts, abundant carbon-rich and shaly laminae in parts; laminae disturbed. Base in slump contact with underlying unit	477'0"	480'2 1/2"	3'2 1/2"
86.	Sandstone and siltstone, interlaminated and intermixed, slumped, contorted, and microfaulted; sandstone, very fine grained, very light gray (N8); siltstone, brownish-gray (5YR 4/1) to dark-gray (N3). Carbonaceous films associated with siltstone	480'2 1/2"	481'0"	0'9 1/2"

Sego Sandstone--Continued

		From	To	Thickness
87.	Sandstone, medium-grained, very light gray (N8), laminated; contains sparse to abundant orangish-brown and dark opaque clasts, laminae of brownish-gray siltstone, and vitrain lenses in basal part	481'0"	481'4 3/4"	0'4 3/4"
88.	Coal, black (N1), vitrainous and attrital, impure in basal part	481'4 3/4"	482'1 3/4"	0'9"
89.	Shale, dark-gray (N3) to grayish-black (N2), highly carbonaceous; contains abundant carbonaceous films and flakes	482'1 3/4"	482'10 5/8"	0'8 7/8"
90.	Sandstone and siltstone, intermixed, highly bioturbated; sandstone, very fine grained, very light gray (N8); siltstone, dark-gray (N3), moderately to highly carbonaceous	482'10 5/8"	484'8 1/8"	1'9 1/2"
91.	Sandstone and siltstone, interlaminated, slightly bioturbated; sandstone, very fine- to fine-grained, very light gray (N8); siltstone, brownish-gray (5YR 4/1) to dark-gray (N3), moderately to highly carbonaceous	484'8 1/8"	484'11 1/8"	0'3"
92.	Sandstone, fine-grained, very light gray (N8),obscurely laminated; contains sparse to abundant orangish-brown and dark clasts, and sparse wispy carbon-rich laminae	484'11 1/8"	486'6"	1'6 7/8"

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Cretaceous:

Neslen Formation:

1.	Rotary drilled	0'0"	300'0"	300'0"
2.	Sandstone, fine-grained, very light gray (N8), unlaminated; contains sparse to abundant dark opaque clasts, and very abundant to sparse angular to rounded (rip up) fragments of shale and silty shale ranging from a fraction of an inch to 3 inches long. Most shale fragments medium-gray, moderately carbonaceous, laminated and(or) bioturbated; some fragments grayish-brown to moderate-brown, and structureless	300'0"	310'1 1/4"	10'1 1/4"
3.	Shale, silty, dark-gray (N3), moderately to highly carbonaceous; contains abundant vitrain lenses, commonly 1/16 inch thick	310'1 1/4"	310'5 3/4"	0'4 1/2"
4.	Coal, black (N1), vitrainous and attrital	310'5 3/4"	310'11 3/4"	0'6"
5.	Coal, grayish-black (N2), impure, pyritic	310'11 3/4"	311'2"	0'2 1/4"
6.	Coal, black (N1), vitrainous and attrital	311'2"	313'7 3/4"	2'5 3/4"
7.	Coal, grayish-black (N2), impure	313'7 3/4"	313'8 1/4"	0'1/2"
8.	Coal, black (N1), vitrainous and attrital	313'8 1/4"	314'6"	0'9 3/4"
9.	Shale, silty, dark-gray (N3), highly carbonaceous; contains abundant vitrain lenses, as thick as 1/8 inch, and a paper-thin pyrite lamina	314'6"	314'7 1/4"	0'1 1/4"
10.	Shale, silty, medium-dark-gray (N4) to brownish-gray (5YR 4/1), moderately carbonaceous, obscurely laminated; contains sparse to abundant carbonaceous films and flakes throughout, and sandy laminae in lower part	314'7 1/4"	320'7 3/4"	6' 1/2"
11.	Shale, silty, dark-gray (N3) to grayish-black (N2), moderately to highly carbonaceous, obscurely laminated; contains abundant vitrain lenses, some as thick as 1/8 inch; no vitrain lenses in basal foot	320'7 3/4"	326'3 1/2"	5'7 3/4"

Neslen Formation--Continued

		From	To	Thickness
12.	Shale, silty, medium-dark-gray (N4) to dark-gray (N3), moderately carbonaceous, obscurely to distinctly laminated, bioturbated in parts; contains sparse to abundant carbonaceous films and flakes, and very sparse vitrain lenses mostly in upper part, and sparse sandstone laminae in lower part. Minute pyrite grains on parting about 1/2 inch above base	326′3 1/2"	329′8"	3′4 1/2"
13.	Coal, black (N1), vitrainous and attrital	329′8"	331′7"	1′11"
14.	Siltstone, medium-dark-gray (N4), moderately to highly carbonaceous; contains abundant carbonaceous films, flakes, and vitrain lenses; some vitrain lenses as much as 1/8 inch thick; pyrite grains and scale, mostly associated with vitrain	331′7"	331′10 3/4"	0′3 3/4"
15.	Sandstone, and siltstone, interlaminated and intermixed; laminae much disturbed, bioturbated; sandstone, very fine, very light gray (N8); siltstone, very light gray (N8), mostly noncarbonaceous. Unit in part contains sparse to abundant interlaminae of dark-gray carbonaceous silty shale	331′10 3/4"	335′6"	3′7 1/4"
16.	Rotary drilled	335′6"	347′0"	11′6"
17.	Shale, medium-dark-gray (N4), slightly carbonaceous	347′0"	347′8"	0′8"
18.	Siltstone and sandstone, intermixed, highly bioturbated; proportion of lithologies differs throughout unit; siltstone, medium-dark-gray (N4), moderately carbonaceous; sandstone, very fine grained, very light gray (N8); contains sparse carbonaceous films, flakes, and vitrain lenses; several vitrain lenses in basal inch; one as thick as 1/4 inch	347′8"	350′8 1/2"	3′1/2"

Neslen Formation--Continued

		From	To	Thickness
19.	Coal, black (N1), vitrainous and attrital	350′8 1/2"	351′3"	0′6 1/2"
20.	Coal, dark-gray (N2), impure; contains sparse vitrain lenses and abundant pyrite grains	351′3"	351′4 1/2"	0′1 1/2"
21.	Coal, black (N1), vitrainous and attrital	351′4 1/2"	352′9 1/2"	1′5"
22.	Shale, silty, dark-gray (N3), moderately to highly carbonaceous; contains abundant carbonaceous films and flakes, and pyrite grains	352′9 1/2"	353′0"	0′2 1/2"
23.	Rotary drilled	353′0"	420′0"	67′0"
24.	Siltstone and minor sandstone, intermixed, bioturbated; laminae contorted, obscure: siltstone medium-gray (N5), slightly to moderately carbonaceous; sandstone, very fine grained, very light gray (N8); contains sparse carbonaceous films and flakes	420′0"	421′10 1/4"	1′10 1/4"
25.	Sandstone and minor siltstone, intermixed, bioturbated and slumped; laminae obscure; sandstone, very fine grained, very light gray (N8); siltstone, medium-gray (N5), slightly carbonaceous	421′10 1/4"	422′4 3/4"	0′6 1/2"
26.	Siltstone and sandstone, interlaminated and intermixed, bioturbated, slumped, and microfaulted; siltstone, medium-gray (N5), slightly to moderately carbonaceous; sandstone, very fine grained, very light gray (N8). Proportion of lithologies differs throughout unit. Unit contains sparse carbonaceous films and flakes	422′4 3/4"	426′7"	4′2 1/4"
27.	Coal, black (N1), vitrainous and attrital	426′7"	427′7 1/2"	1′ 1/2"
28.	Shale, grayish-black (N2), highly carbonaceous, contains abundant vitrain lenses in uppermost inch; pyrite and translucent mineral (not calcite) deposited as scale on slickened surface. Basal contact gradational	427′7 1/2"	427′10 1/4"	0′2 3/4"

Neslen Formation--Continued

		From	To	Thickness
29.	Claystone, light-brownish-gray (5YR 6/1), grainy, kaolinitic; contains carbonaceous shale parting. Basal contact abrupt	427′10 1/4"	428′3/4"	0′2 1/2"
30.	Shale, dark-gray (N3) to grayish-black (N2), highly carbonaceous; contains abundant vitrain lenses, some as thick as 1/4 inch, mostly in upper part, and abundant carbonaceous films and flakes in lower part. Basal contact gradational	428′3/4"	429′3/4"	1′0"
31.	Shale, silty, dark-gray (N3), moderately carbonaceous, obscurely laminated; contains sparse to abundant carbonaceous films and flakes, and very sparse vitrain lenses	429′3/4"	432′8 1/2"	3′7 3/4"
32.	Siltstone and minor sandstone, interlaminated and intermixed, bioturbated; siltstone, brownish-gray (5YR 4/1), slightly to moderately carbonaceous; sandstone, very fine grained, very light gray (N8). Siltstone contains sparse carbonaceous films and flakes. Abundant vitrain lenses and flakes in lowermost 5 inches, commonly 1/16 inch thick. Proportion of sandstone increases downward	432′8 1/2"	435′3 1/2"	2′7"
33.	Coal, black (N1), vitrainous and attrital	435′3 1/2"	436′11"	1′7 1/2"
34.	Shale, silty, dark-gray (N3), highly carbonaceous; contains abundant vitrain lenses averaging about 1/16 inch thick	436′11"	437′1 3/4"	0′2 3/4"
35.	Coal, black (N1), vitrainous	437′1 3/4"	437′2"	0′ 1/4"
36.	Siltstone, shaley, dark-gray (N3), moderately carbonaceous, obscurely laminated; contains sparse vitrain lenses and sparse to abundant carbonaceous films and flakes. Some vitrain lenses inclined	437′2"	438′2 1/4"	1′ 1/4"

Neslen Formation--Continued

		From	To	Thickness
37.	Sandstone and siltstone, intermixed, (mostly slumped and microfaulted, bioturbated in parts); sandstone, very fine grained, very light gray (N8); siltstone, dark-gray (N3), moderately carbonaceous; contains sparse carbonaceous films and flakes	438′2 1/4"	440′2 3/4"	2′ 1/2"
38.	Shale, silty, grayish-black (N2), highly carbonaceous; contains several vitrain lenses, some as thick as 1/8 inch, and several sandstone laminae	440′2 3/4"	440′7 1/4"	0′4 1/2"
39.	Coal, black (N1), vitrainous	440′7 1/4"	440′7 3/4"	0′ 1/2"
40.	Shale, silty, grayish-black (N2), highly carbonaceous; contains abundant vitrain lenses, commonly about 1/16 inch thick	440′7 3/4"	441′1 3/4"	0′6"
41.	Coal, black (N1), vitrainous and attrital, impure in parts	441′1 3/4"	441′5 3/4"	0′4"
42.	Shale, silty, grayish-black (N2), highly carbonaceous; contains very abundant vitrain lenses; one lens 3/4 inch thick	441′5 3/4"	442′ 3/4"	0′7"
43.	Shale, silty, dark-gray (N3), moderately carbonaceous	442′3/4"	442′3 1/2"	0′2 3/4"
44.	Coal, black (N1), vitrainous	442′3 1/2"	442′4"	0′ 1/2"
45.	Siltstone, shaly, dark-gray (N3), moderately carbonaceous; contains abundant carbonaceous films and flakes, several vitrain lenses,some inclined; pyrite body 1 inch long near top of unit	442′4"	444′5"	2′1"
46.	Rotary drilled	444′5"	458′0"	13′7"
47.	Sandstone and siltstone, interlaminated and intermixed, slightly to highly bioturbated; sandstone, very fine grained, very light gray (N8); siltstone, medium-gray (N5), slightly carbonaceous. Proportion of sandstone increases downward	458′0"	459′7 3/4"	1′7 3/4"

Neslen Formation--Continued

		From	To	Thickness
48.	Siltstone, shaly, medium-gray (N5), slightly carbonaceous; obscurely laminated; contains a few sandstone laminae in lower part	459'7 3/4"	459'11 1/4"	0'3 1/2"
49.	Sandstone and siltstone, interlaminated and slightly bioturbated; sandstone, very fine grained, very light gray (N8); siltstone, medium-dark-gray (N4), grayish-orange (10YR 7/4) in one part, slightly to moderately carbonaceous. Siltstone contains abundant carbonaceous films and flakes. Several undulous vitrain lenses, as much as 1/4 inch thick, occur in lower part of unit	459'11 1/4"	461'2 1/4"	1'3"
50.	Coal, black (N1), vitrainous and attrital, impure in basal 2 inches; cleat poorly developed; contains sparse pyrite scale	461'2 1/4"	462' 3/4"	0'10 1/2"
51.	Shale, silty, dark-gray (N3), moderately to highly carbonaceous; contains abundant carbonaceous films and flakes, and vitrain lenses	462'3/4"	463'7"	1'6 1/4"
52.	Siltstone, sandy, brownish-gray (5YR 4/1), moderately carbonaceous; contains abundant carbonaceous films and flakes; contains several vitrain lenses, as much as 1/8 inch thick. Unit may be homogeneously bioturbated	463'7"	464'1 1/2"	0'6 1/2"
53.	Sandstone and siltstone, interlaminated, interbedded, and intermixed (bioturbated, slumped, and microfaulted); sandstone, very fine grained, very light gray (N8); siltstone, medium dark gray (N4), slightly to moderately carbonaceous; contains sparse carbonaceous films and flakes	464'1 1/2"	466'4"	2'2 1/2"
54.	Shale, silty, medium-gray (N5), slightly to moderately carbonaceous; contains abundant carbonaceous films and flakes, several slickened surfaces	466'4"	467'0"	0'8"
55.	Shale, dark-gray (N3), moderately to highly carbonaceous, contains abundant carbonaceous films and flakes, and abundant vitrain lenses	467'0"	467'8 1/2"	0'8 1/2"

Neslen Formation--Continued

		From	To	Thickness
56.	Coal, black (N1), vitrainous and attrital; impure in lowermost 1/2 inch	467'8 1/2"	468'8 1/2"	1'0"
57.	Shale, silty, grayish-black (N2), highly carbonaceous; contains sparse to abundant carbonaceous films and flakes, and several vitrain lenses in upper part	468'8 1/2"	469'6 1/2"	0'10"
58.	Siltstone and minor sandstone, interlaminated and interlensing, bioturbated; siltstone, brownish-black (5YR 2/1), moderately to highly carbonaceous; sandstone, very fine grained, very light gray (N8). Proportion of sandstone increases downward	469'6 1/2"	470'4 3/4"	0'10 1/4"
59.	Sandstone and siltstone, interlaminated, bioturbated in part; sandstone, very fine grained, very light gray (N8); siltstone, medium-dark-gray (N4) and dark-gray (N3), moderately carbonaceous; contains sparse films, flakes and vitrain lenses	470'4 3/4"	471'10 1/2"	1'5 3/4"
60.	Sandstone and minor siltstone, interlaminated; sandstone, fine-grained, very light gray (N8); contains abundant carbonaceous films and vitrain lenses; siltstone, pale-yellowish-brown (10 YR 6/2), mostly noncarbonaceous; contains sparse carbonaceous films and flakes	471'10 1/2"	478'10 1/2"	7'0"
61.	Coal, black (N1), vitrainous and attrital; slightly impure in basal part; cleat poorly developed; contains sparse resin bodies and vitrain lenses as thick as 1/4 inch	478'10 1/2"	479'9"	0'10 1/2"
62.	Siltstone, shaly, medium-dark-gray (N4), slightly to moderately carbonaceous, obscurely laminated; contains sparse carbonaceous films and flakes, and very sparse vitrain lenses and bodies	479'9"	482'0"	2'3"