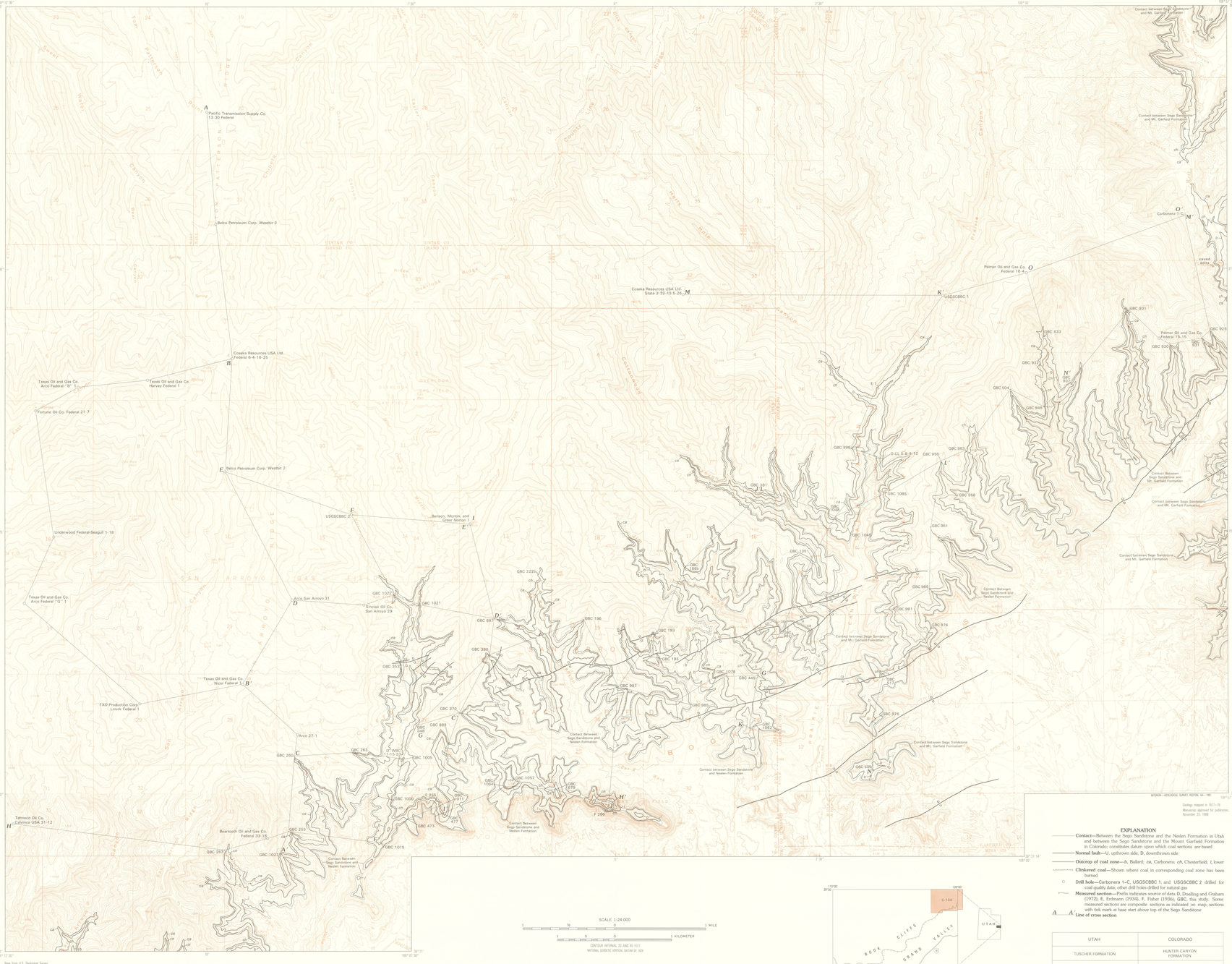

DISCUSSION

The Book Cliffs coal field extends diagonally across the Westwater 30′ × 60′ quadrangle from the southwest to the northeast. The coal field is named for the Book Cliffs, a prominent, generally southwest-facing escarpment that is underlain by Upper Cretaceous and Tertiary rocks. The study area covered by this report is the northeastern part of the Westwater 30′ × 60′ quadrangle and includes all or parts of the Bar X Wash, Bryson Canyon, Carbonera, Jim Canyon, and San Arroyo Ridge 7 1/2-minute quadrangles.

STRATIGRAPHY OF COAL-BEARING ROCKS AND ADJACENT STRATA

Most coal in the study area occurs in the Upper Cretaceous Neslen Formation in Utah and, to its stratigraphic equivalent, the lower part of the Mount Garfield Formation in Colorado. Minor coal beds occur in strata above the Neslen. According to H.W. Roehler (oral commun., 1980), the Neslen, lower Mount Garfield, and adjacent strata are typical examples of strand-plain sedimentation. These strand-plain deposits are, in ascending order, the Sego Sandstone (lower, middle, and upper strand-plain environment); the Neslen Formation in Utah and the lower Mount Garfield Formation in Colorado (mostly paludal environment); the Buck Tongue of the Mancos Shale (marine environment); the Sunnyside Member (coastal plain environment); and the Tuscher Formation in Utah and the Hunter Canyon Formation in Colorado (alluvial environment). All of these formations are exposed in the Book Cliffs of Colorado and Utah (Erdmann, 1934, p. 32–33; Fisher, 1936, p. 15–20) and the stratigraphic nomenclature in the study area is shown on figure 1.

The Sego Sandstone is composed of several persistent littoral marine sandstone tongues that are interbedded with beds of silty sandy shale. The sandstone tongues grade into the shale underlying them and have abrupt, distinct tops. In the study area, the Sego Sandstone occurs as two distinct tongues separated by the Anchor Mine Tongue of the marine Mancos Shale.

Sandstone beds of the Sego are composed of very fine to medium-grained quartz, and minor amounts of hardened feldspar and opaque mineral grains. The sandstones are commonly crossbedded or cross laminated and range from brown to very light gray. The Sego Sandstone overlies the Buck Tongue of the Mancos Shale. The thickness of the Sego Sandstone is about 200 ft (61 m) in the area of this report.

The Neslen Formation and the lower part of the Mount Garfield Formation are composed of shale, silty sandy shale, and sandstone. The shale is commonly carbonaceous; however, in many places it is noncarbonaceous and greenish gray. Coal beds occur throughout these formations but the greatest number of beds and the thickest beds are concentrated in the lower part of the formations. Erdmann (1934, p. 36) described the coals of the Neslen and the lower part of the Mount Garfield. Most of the sandstone is very fine grained, cross laminated, and brown to very light gray. The sandstone bodies are pod shaped to blanket lenticular and are believed to be products of distributary streams. The Sulphur Canyon Sandstone Member of the Neslen Formation (Fisher, 1936, p. 18) is present in the southwestern part of the study area extending east to the canyon of Bitter Creek. A coarse siltstone body, similar to the Sulphur Canyon and possibly genetically related to it, occurs in the general area of Bar X and Jim Canyons.

The approximate location of the contact between the Neslen and Mount Garfield Formations and the underlying Sego Sandstone is generally distinct; however, in some places the exact boundary is difficult to locate. The thickness of the Neslen Formation and the lower part of the Mount Garfield is roughly 400–500 ft (122–152 m).

The Farrer Formation in Utah and its equivalent, the upper part of the Mount Garfield Formation in Colorado, are fluvial deposits and contain proportionately more and coarser sandstone than the Neslen Formation. The thickness of sandstone units increases progressively upward through the Farrer and upper part of the Mount Garfield into the overlying Tuscher Formation in Utah and the equivalent Hunter Canyon Formation in Colorado. Almost all of the shale in the formations above the Neslen in the study area is red to brown in color. In the Westwater canyon area, however, coal beds do occur sporadically in the Farrer and the upper part of the Mount Garfield. The contact of the Farrer and the upper part of the Mount Garfield with the underlying units is gradational and difficult to identify (Fisher, 1936, p. 17; Erdmann, 1934, p. 44).

METHODS OF INVESTIGATION AND CORRELATION

Coal zone correlations are present in cross sections *A–A′* through *O–O′*. Lines and letter designations of the respective cross sections are plotted on the map as are the locations and number of the measured sections and drill holes. The lines of section are aligned roughly north-south and east-west with minor exceptions. The cross sections intersect to obtain a more reliable basis for coal correlation.

Drill-hole and measured section data are from a variety of sources. The correlation of coal zones identified in some of the previous studies has been reinterpreted in some sections, although the names of coal zones are retained (except where discussed in the section on "Coal zones and coal beds"). Miscorrelation of coal zones is possible because of errors inherent in the methods employed in this study, including hand level and altimeter. Some difficulty in identifying the top of the Sego Sandstone was encountered and there may be a problem with its correlation in some sections.

A diligent search was made for all coal occurrences in measured sections and described other close examination, including digging trenches. Most of the measured sections extend no higher than the highest coal occurrence although the strata above the highest coal occurrence were examined to verify that the occurrence was indeed the highest. Some incomplete coal sections were measured on outlying knobs or ridges where strata of the upper part of the coal-bearing section are not present or where coal beds are burned and the ash of the burned coal could not be definitely located.

Subsurface information is from holes drilled to obtain coal quality data (Carbonera 1–C, USGSCBBC 1, and USGSCBBC 2), as well as from geophysical logs of natural gas drill holes which are identified by name on the map. Although the natural gas drill holes were drilled deeper than the Sego Sandstone, only data to the top of the Sego are shown on figure 2. The geophysical logs used in this report include combinations of the gamma ray, gamma ray, laterolog, neutron, spontaneous potential, and resistivity. These geophysical logs are only marginally useful for discerning coal and are subject to misinterpretation. The coal beds interpreted from geophysical logs are generally thicker than those in adjacent measured sections and impure coal and partings of shale, siltstone, and tonstein, common in or adjacent to coal beds, are not differentiated.

COAL ZONES AND COAL BEDS

Four coal zones delineated in the study area, in ascending order, are the lower, Ballard, Chesterfield, and Carbonera.

Lower is the informal name for a coal zone that is pervasive throughout the study area. It consists of 1–9 coal beds that occur from about 1 ft. (2.5 cm) above the top of the Sego Sandstone to about 50 ft (15 m) above it. Individual coal beds range in thickness from 0 in. to more than 7 ft (0 to 2.1 m). The base of the zone ranges from 8 in. to 31 ft (20 cm to 15.5 m). This zone includes the Palisade coal zone as used by Fisher (1936, p. 99) and Erdmann (1934, p. 81–83) in the study area; the name Palisade is not used in this report, however, because Young (1955, p. 190) observed that the coal zone in the study area is correlative with a coal zone stratigraphically lower than the Palisade in its type locality near Palisade, Colo. The lower coal zone may be correlative with the Anchor coal zone (Erdmann, 1934, p. 80–81; Young, 1955, p. 190).

The Ballard coal zone (Fisher, 1936, p. 18–19) consists of 1–4 coal beds ranging in thickness from less than 1 in. to more than 3 ft (2.5 cm to 1 m). The thickness of the zone ranges from 6 in. to about 17 ft (20 cm to 5 m). The base of the zone ranges from 123 to 189 ft (37–58 m) above the top of the Sego Sandstone. The Ballard is generally pervasive in the study area. The Ballard coal zone was defined by Fisher (1936, p. 18–19) Creek. A coarse siltstone body, similar to the Sulphur Canyon and possibly genetically related to it, occurs in the general area of Bar X and Jim Canyons.

The approximate location of the contact between the Neslen and Mount Garfield Formations and the underlying Sego Sandstone is generally distinct; however, in some places the exact boundary is difficult to locate. The thickness of the Neslen Formation and the lower part of the Mount Garfield is roughly 400–500 ft (122–152 m).

The Farrer Formation in Utah and its equivalent, the upper part of the Mount Garfield Formation in Colorado, are fluvial deposits and contain proportionately more and coarser sandstone than the Neslen Formation. The thickness of sandstone units increases progressively upward through the Farrer and upper part of the Mount Garfield into the overlying Tuscher Formation in Utah and the equivalent Hunter Canyon Formation in Colorado. Almost all of the shale in the formations above the Neslen in the study area is red to brown in color. In the Westwater canyon area, however, coal beds do occur sporadically in the Farrer and the upper part of the Mount Garfield. The contact of the Farrer and the upper part of the Mount Garfield with the underlying units is gradational and difficult to identify (Fisher, 1936, p. 17; Erdmann, 1934, p. 44).

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EXPLANATION

Contact—Between the Sego Sandstone and the Neslen Formation in Utah and between the Sego Sandstone and the Mount Garfield Formation in Colorado; constitutes datum upon which coal sections are based

Normal fault—*U*, upthrown side; *D*, downthrown side

Outcrop of coal zone—*b*, Ballard; *ca*, Carbonera; *ch*, Chesterfield; *l*, lower

Clinkered coal—Shown where coal in corresponding coal zone has been burned

Drill hole—Carbonera 1–C, USGSCBBC 1, and USGSCBBC 2 drilled for coal quality data; other drill holes drilled for natural gas

Measured section—Prefix indicates source of data: D, Doelling and Graham (1972); E, Erdmann (1934); F, Fisher (1936); GBC, this study. Some measured sections are composite sections as indicated on map; sections with tick mark at base start above top of the Sego Sandstone

A—A′ **Line of cross section**

UTAH	COLORADO
TUSCHER FORMATION	HUNTER CANYON FORMATION
FARRER FORMATION	UPPER PART OF THE MOUNT GARFIELD FORMATION
NESLEN FORMATION / SULPHUR CANYON SANDSTONE MEMBER	LOWER PART OF THE MOUNT GARFIELD FORMATION
SEGO SANDSTONE	
ANCHOR MINE TONGUE OF THE MANCOS SHALE	
SEGO SANDSTONE	
BUCK TONGUE OF THE MONCOS SHALE	

Figure 1. Diagram showing part of the Upper Cretaceous stratigraphic nomenclature used in the northeastern part and adjacent area of the Westwater 30′ × 60′ quadrangle, Colorado and Utah.

COAL RESOURCES

The U.S. Geological Survey generates coal resources calculations using the computer-based National Coal Resources Data System (NCRDS). The system can effectively compute coal resources of individual, noncomplex, persistent coal beds; however, due to the highly lenticular nature of the coal beds in the study area, their general thinness, and the abundance of interbedded noncoal materials, resource estimates were not calculated using NCRDS. Coal beds less than 14 in. (36 cm) thick are not included in coal resources, although they are included in measured sections and drill holes.

On the basis of his observation of the quality of the coal, Fisher (1936, p. 94, 97) believed that the Book Cliffs coal field, from just east of long 109° 52′ W. to about long 109° 00′ W., contained no coal resources. However, analyses of samples from coal drill holes USGSCBBC 1 and USGSCBBC 2 indicate that there are numerous coal beds 14 in. (36 cm) or more thick of relatively high apparent rank, and with an ash content of less than 25 weight percent on a moisture-free basis in the study area west of the Utah-Colorado border. Erdmann (1934, p. 96) estimates combined coal resources for the Palisade (lower), Carneo (Ballard), Carbonera, and local beds in T.7 S., R.104 W., an area just east of the Utah-Colorado border, to be 180 million short tons (163 million metric tons).

Coal has been mined in only one place in the study area, near the abandoned town of Carbonera. A total of 171,892 short tons (155,958 metric tons) were mined there as of 1922 (Erdmann, 1934, p. 96).

Most of the surface and mineral rights are federally owned, although some are state owned and very few are privately owned.

COAL ANALYSES

Selected coal analyses of samples obtained from the drill holes Carbonera 1–C, USGSCBBC 1, and USGSCBBC 2 are presented in tables 1–7. Analytical data are keyed by number to coal sections shown in cross sections *E–E′* and *M–M′*.

Coal and impure coal were visually determined in the measured sections and are probably reasonably accurate; however, some beds in the drill holes described as coal (as determined visually) are actually impure coal on the basis of analytical data.

Apparent coal rank is high-volatile B and high-volatile C bituminous and increases irregularly with depth. From east to west, coal of higher apparent rank occurs at a higher position in the stratigraphic section although at approximately the same structural level. It is unclear if the high-rank coal beds higher in the stratigraphic section have any relationship to the fact that rocks are in closer proximity to crystalline basement rocks in the plunging nose of the Uinconpahgre Plateau. In any case, it is assumed that coal rank increases northeastward where coal beds are depressed into the depths of the Uinta Basin.

Sulfur content in the coal samples averages about 0.7 percent and ash, on a moisture-free basis, averages about 13 percent. It is believed that these analytical data are a general reflection of coal quality in the study area.

Elsewhere in the study area the coal zone is located relative to the underlying Ballard coal zone.

The Carbonera coal zone (Erdmann, 1934, p. 96) consists of 1–6 coal beds ranging in thickness from 1 in. to more than 7 ft (2.5–213 cm). The Carbonera is the least pervasive of the four coal zones and is not present in many parts of the study area. Where present, it ranges in thickness from 2 1/2 in. to about 29 ft (6 cm to 9 m). The base of the zone is about 252–380 ft (77–116 m) above the top of the Sego Sandstone. Coal sections were measured as far east as long 108° 37′ 30″ W., to include data from the area of the Carbonera coal zone type locality. The Carbonera coal zone extends west from the type locality and includes coal beds that are positioned stratigraphically similar relative to the underlying Chesterfield coal zone.

In addition to coal beds that have been correlated with the four coal zones, other minor coal beds occur in the study area. These coal beds occur sporadically, cannot be correlated, and therefore are not considered to be coal zones. One to four coal beds occur between the lower and Ballard coal zones and range in thickness from 1 in. to more than 3 ft (2.5 cm to 1 m). One to six beds occur between the Ballard and Chesterfield coal zones and range in thickness from 1 in. to more than 5 ft (2.5 cm to 1.5 m). One to four coal beds occur between the Chesterfield and Carbonera coal zones, or between the Chesterfield coal zone and the estimated horizon of the Carbonera in measured sections where the Carbonera does not occur. One to eight coal beds occur above the Carbonera coal zone or above the estimated horizon of that zone. The beds range in thickness from 1 in. to more than 5 ft (2.5 cm to 1.5m). They occur from about 5 ft to about 250 ft (1.5–76 m) above the top of the Carbonera coal zone.

Table 1. *Proximate and ultimate analyses, Btu/lb, equilibrium moisture, moist, ash free Btu/lb, and apparent rank for selected coal samples from drill hole Carbonera 1–C*

[All analyses by Commercial Testing and Engineering Co. As rec'd, as received; eq. moist, equilibrium moisture; daf, dry, ash free; leaders (--) indicate no data]

Sample number (shown on M–M′)	From (ft)	From (in.)	To (ft)	To (in.)	Thickness (ft)	Thickness (in.)	Analysis basis	Proximate analysis: Moisture	Volatile matter	Fixed carbon	Ash	Btu/lb	Ultimate analysis: Carbon	Hydrogen	Nitrogen	Chlorine	Oxygen	Sulfur	Moist, ash free Btu/lb (calculated by Parr's sixth formula, 1928, p. 7–23)	Apparent rank
1	225	5	228	0	2	7	As rec'd	11.10	33.18	41.32	14.40	10,506	58.21	4.57	1.56	0.01	9.58	0.57	12,475	High-volatile C bituminous
							Eq moist	11.10	33.18	41.32	14.40	10,506	58.21	4.57	1.56	.01	9.58	.57		
							Moisture free	---	37.32	46.48	16.20	11,818	65.48	5.14	1.75	.01	10.78	.64		
							daf	---	44.53	55.47	---	14,103	78.14	6.13	2.09	.01	12.86	.76		
2	299	11	300	11	1	0	As rec'd	7.34	31.48	42.83	18.35	10,147	58.27	4.07	1.28	.01	10.25	.43	12,706	High-volatile C bituminous
							Eq moist	9.90	30.41	41.65	17.84	9,867	56.66	3.96	1.24	.01	9.97	.42		
							Moisture free	---	32.82	46.23	19.80	10,951	62.89	4.39	1.38	.01	11.07	.46		
							daf	---	42.36	57.64	---	13,655	78.43	5.47	1.72	.01	13.80	.57		
3	300	11	304	6	3	7	As rec'd	13.00	32.24	45.38	8.79	11,087	63.91	4.37	1.47	.02	9.80	.42	12,268	High-volatile C bituminous
							Eq moist	10.76	31.60	46.04	9.00	11,264	64.91	4.20	1.41	.02	9.42	.48		
							Moisture free	---	36.11	52.22	10.11	12,757	73.39	5.03	1.63	.02	10.34	.48		
							daf	---	41.91	58.09	---	14,192	80.53	5.60	1.81	.02	11.50	.53		
4	305	6	307	6	2	0	As rec'd	8.61	36.74	48.08	6.57	11,848	67.14	4.74	1.60	.00	10.77	.57	12,763	High-volatile C bituminous
							Eq moist	10.70	35.90	48.08	6.42	11,577	65.60	4.63	1.56	.00	10.77	.56		
							Moisture free	---	40.20	52.61	7.19	12,694	73.46