Text to Accompany:

Open-File Report 79-817

1979

COAL RESOURCE AND COAL DEVELOPMENT POTENTIAL MAPS OF THE CRAIG NW QUADRANGLE, MOFFAT COUNTY, COLORADO

[Report includes 7 plates]

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

By

DAMES & MOORE

DENVER, COLORADO

This report has not been edited for conformity with U.S. Geological Survey editorial standards or stratigraphic nomenclature.

CONTENTS

ILLUSTRATIONS

TABLES

INTRODUCTION

Purpose

This text is to be used in conjunction with Coal Resource Occurrence and Coal Development Potential Maps of the Craig NW quadrangle, Moffat County, Colorado. This report was compiled to support the land-planning work of the Bureau of Land Management (BLM) and to provide a systematic coal resource inventory of Federal coal lands in Known Recoverable Coal Resource Areas (KRCRA's) in the western United States. This investigation was undertaken by Dames & Moore, Denver, Colorado, at the request of the United States Geological Survey under contract number 14-08-0001-15789. The resource information gathered for this report is in response to the Federal Coal Leasing Amendments Act of 1975 (P.L. 94-377). Published and unpublished public information was used as the data base for this study. No new drilling or field mapping was performed as part of this study, nor was any confidential data used.

Location

The Craig NW quadrangle is located in the central part of Moffat county in northwestern Colorado, approximately 12 miles (19 km) northwest of the town of Craig. With the exception of several ranches, the quadrangle is unpopulated.

Accessibility

U.S. Highway 40 passes east-west approximately 8 miles (13 km) south of the Craig NW quadrangle. Several light-duty, all-weather roads intersect U.S. Highway 40 just west of the town of Craig providing access to the Craig NW quadrangle from the south. The remainder of the quadrangle is served by a network of unimproved dirt roads and trails.

Railway service for the Craig NW quadrangle is provided by the Denver & Rio Grand Western Railroad from Denver to the railhead at

Craig. The rail line follows U.S. Highway 40, extending from the southeastern corner of the Craig quadrangle to its terminus at Craig. The rail line is the major transportation route for coal shipped eastward from northwestern Colorado.

Physiography

The Craig NW quadrangle lies in the southern part of the Wyoming Basin physiographic province as defined by Howard and Williams (1972). The quadrangle is approximately 14 miles (23 km) north-northwest of the Williams Fork Mountains and 50 miles (80 km) west of the Continental Divide.

Approximately 600 feet (183 m) of relief is present in the Craig NW quadrangle. Altitudes range from 7,312 feet (2,229 m) in the northwestern corner of the quadrangle, to approximately 6,710 feet (2,045 m) along the southwestern corner of the quadrangle. The landscape within this quadrangle is dominated by moderate to gentle slopes along intermittent stream valleys. Local ponds and marsh areas are scattered throughout the lowlands in stream valleys.

In general, the Craig NW quadrangle is drained by a dendritic pattern of numerous intermittent creeks and streams that flow mainly in response to snowmelt in the spring. North Fork Big Gulch and Big Gulch are the primary intermittent streams and provide most of the drainage from the Craig NW quadrangle, flowing southwesterly into Lay Creek which eventually empties into the Yampa River.

Climate and Vegetation

The climate of northwestern Colorado is semiarid. Clear, sunny days prevail in the Craig NW area with daily temperatures varying from 0° to 35°F (-18° to 2°C) in January to 42° to 80°F (6° to 27°C) in July. Annual precipitation in the area averages approximately 14 inches (36 cm), most of which occurs as snowfall during the winter months.

However, rainfall from thundershowers during the summer months also contributes to the total. Moderate and gusty winds blow generally from the west and southwest, although wind directions may be modified by local topography (U.S. Bureau of Land Management, 1977).

Principal types of vegetation in the quadrangle include sagebrush, small semiarid shrubs, and scattered trees, mostly juniper and pinyon varieties. Some grasslands in the quadrangle are used for grazing livestock (U.S. Bureau of Land Management, 1977).

Land Status

The Craig NW quadrangle lies on the north-central boundary of the Yampa Known Recoverable Coal Resource Area (KRCRA). Approximately 20 percent of the quadrangle lies within the KRCRA boundary as shown on plate 2. The Federal government owns the coal rights for all of the land within the KRCRA boundary and no coal leases, prospecting permits, licenses or preference right lease applications are located within the KRCRA in this quadrangle.

GENERAL GEOLOGY

Previous Work

The first geologic description of the general area in which the Craig NW quadrangle is located was published by Emmons (1877) as part of the Survey of the Fortieth Parallel. C. A. White compiled topographic and geologic maps of northwestern Colorado (1878 and 1889) and was the first geologist to note the extensive coal deposits in the Yampa area. The decision to build a railroad into the region stimulated several coal investigations including those by Hewett (1889), Hills (1893), and Storrs (1902). A more recent geologic investigation in the region to the east of this quadrangle was carried out by and Bass and others (1955). The most recent and comprehensive geologic map of the Craig NW area is by Tweto (1976).

Stratigraphy

The rocks which crop out in the Craig NW quadrangle are Tertiary in age and include the Fort Union, Wasatch, Green River, and Browns Park Formations. These four formations unconformably overlie Upper Cretaceous sedimentary rocks that extend several thousand feet into the subsurface.

The highest stratigraphic unit of Cretaceous age is the Lance Formation. This formation consists of light-colored fine-grained sandstone interbedded with gray shale and local coals (Bass and others, 1955), and is approximately 1,000 feet (305 m) thick as indicated in two oil and gas test holes drilled in the southeast quarter of the quadrangle. Only the upper 870 feet (265 m) of the Lance Formation is shown in the composite columnar section on plate 3, which diagrammatically represents the section to a depth of approximately 3,800 feet (1,158 m) in the vicinity of the hole drilled in sec. 17, T. 8 N., R. 91 W.

The Fort Union Formation of Paleocene age unconformably overlies the Lance Formation and crops out in the southwestern part of the quadrangle (Tweto, 1976). This formation is approximately 1,250 feet (383 m) thick and is composed of medium- to coarse-grained brown sandstone interbedded with light-gray to dark gray silty shale and lenticular coals. An arkosic conglomerate occurs at the base of the formation above the unconformity (Bass and others, 1955).

The Wasatch Formation of Eocene age unconformably overlies the Fort Union Formation and crops out over approximately 75 percent of this quadrangle (Tweto, 1976). From the limited information available in two oil and gas wells, the Wasatch Formation is believed to be approximately 2,050 feet (623 m) thick in the southern half of the Craig NW quadrangle. This formation consists of interbedded coarse brown sandstones, light-gray shales, sandy shales, gray siltstones and conglomerate (Bass and others, 1955). The Wasatch Formation is not known to contain coal in the Yampa KRCRA. However, coals have been identified in the formation in Wyoming, approximately 30 miles (51 km) north of the Craig NW quadrangle.

The Eocene-age Tipton Tongue member of the Green River Formation is exposed in the northwestern corner of the Craig NW quadrangle and is estimated by Tweto (1976) to range in thickness from approximately 50 to 300 feet (15 to 91 m). In general, the member consists of interbedded brown to gray sandstone and intertongues with the Eocene-age Wasatch Formation (Fisher, 1962).

A layer of the Miocene-age Browns Park Formation lies unconformably on the Cretaceous- and Tertiary-age rocks in the lower south-central part of the quadrangle (Tweto, 1976). This formation is approximately 160 feet (49 m) thick and contains light-colored, loosely consolidated sandstone and a basal conglomerate consisting essentially of eroded Pre-Cambrian materials (Cary, 1955).

The Upper Cretaceous-age rocks in the Yampa KRCRA area accumulated close to the western edge of a Late Cretaceous-age epeirogenic seaway which covered part of the western interior of North America (O'Boyle, 1955). Several transgressive-regressive cycles resulted in the deposition of a series of marine, near-shore marine, and non-marine sediments in the Craig NW area.

A large rise in sea level caused a landward movement of the shoreline, which resulted in the end of deposition of the near-shore and continental sediments of the Mesaverde Group. After this rise in sea level, the marine Lewis Shale was deposited in an off-shore marine environment in the Craig NW quadrangle area (Ryer, 1977).

Final regression of the Cretaceous sea resulted from regional uplift west of the Yampa Basin area. As the sea retreated to the northeast, the

Fox Hills Sandstone was deposited over the Lewis Shale in a littoral and near-shore environment. Following the regression of the Cretaceous sea, broad areas of estuarine, marsh, lagonnal, and coastal swamp environment resulted in deposits of carbonaceous shales, mudstones, and thin coal beds, characteristic of the Lance Formation (O'Boyle, 1955).

After a period of erosion, the Paleocene-age Fort Union Formation was deposited on the edge of the Larimide uplift after the final recession of the Cretaceous sea (Rizma, 1955). The formation consists of thick conglomerate and sandstone beds which were deposited in fluvial and lacustrine environments. The thin sandstone, shale and coal beds of the Fort Union Formation are typical of deposits formed in fluvial, lacustrine and swamp environments (Ritzma, 1955).

Fluvial and lacustrine sediments were alternately deposited during the different stages of the Eocene Epoch. The Wasatch Formation is predominantly a fluvial deposit (Picard and McGrew, 1955), while the Tipton Tongue of the Green River Formation is predominantly a lacustrine deposit (Fisher, 1962).

During the Miocene, the Browns Park Formation blanketed the Craig NW quadrangle area. The Browns Park Formation is postulated to have been deposited during a transition from a temperate climate to one of aridity (Carey, 1955).

Structure

The Yampa KRCRA lies in the southern extension of the Washakie/Sand Wash structural basin of south-central Wyoming. The basin is bordered on the east by the Park Range, approximately 40 miles (64 km) east of the Craig NW quadrangle, and on the southwest by the Axial Basin Anticline, approximately 17 miles (27 km) southwest of the quadrangle. Beds in the Craig NW quadrangle generally dip northwest. Two northwest-trending faults, shown on plate 1, offset Tertiary-age rocks in the southwest corner of the quadrangle (Tweto, 1976).

COAL GEOLOGY

Several coal beds of the Lance and Fort Union Formations have been identified in one well drilled by Sinclair Oil and Gas Company in the southwestern corner of the Craig NW quadrangle (plate 1). The Lance and Fort Union coals tend to be thin, lenticular and of limited areal extent. These coal beds have not been formally named, but the coal bed greater than the Reserve Base thickness of 5.0 feet (1.5 m) is numbered with a bracketed number for identification purposes in this quadrangle only.

Lance Coal Beds

Coal beds in the Lance Formation occur in the subsurface within the KRCRA boundary but are at depths greater than 3,000 feet (914 m) as indicated by the geophysical logs of the two oil and gas wells drilled in the southern part of the quadrangle. These coals are shown diagrammatically in the composite columnar section on plate 3. In general, coal beds in the Lance Formation are thin, lenticular and of subbituminous rank in the Yampa KRCRA (Bass and others, 1955).

Fort Union Coal Beds

Coal beds in the Fort Union Formation do not crop out in the Craig NW quadrangle, but have been penetrated in the oil and gas well drilled in sec. 17, T. 8 N., R. 91 W. One coal bed, the FU[1] coal bed, is 6.0 feet (1.8 m) thick and has been correlated with Fort Union coal beds penetrated in two oil and gas wells drilled in the southwest quarter of the adjacent Craig NE quadrangle. The FU[1] coal bed measures 4 and 5 feet (1.2 and 1.5 m) thick in these two drill holes. Based on the structural trend of the FU[1] coal bed projected from the adjacent Craig NE quadrangle, and the elevation of penetration in this quadrangle, the coal bed appears to dip between 2° and 3° to the north.

No chemical analyses are known to be available for the Fort Union coal beds identified in this quadrangle. However, a chemical analysis of Fort Union coal from the Seick mine in the adjacent Pine Ridge quadrangle to the south (Fieldner and others, 1937) is shown in table 1 and indicates that the coal ranks subbituminous B on a moist, mineral-matter-free basis (ASTM, 1977). According to Bass and others (1955), Fort Union coals in the Yampa KRCRA area are characteristically subbituminous in rank.

COAL RESOURCES

Data from drill hole measurements in the Craig NW and Craig NE quadrangles (plate 1) were used to construct isopach and structure contour maps of the FU[1] coal bed. The source of each indexed data point shown on plate 1 is listed in table 3.

Coal resources of the FU]1] coal bed were calculated using data from the coal isopach map (plate 4) and from the areal distribution and identified resources (ADIR) map (plate 6). The coal-bed acreage (measured by planimeter), multiplied by the average thickness of the coal bed times a conversion factor of 1,770 short tons of coal per acre-foot (13,018 metric tons per hectare-meter) for subbituminous coal yields the coal resources in short tons of coal for the isopached coal bed. Reserve Base and Reserve tonnages for the FU[1] coal bed are shown on plate 6 and are rounded to the nearest 10,000 short tons (9,072 metric tons).

Reserve Base tonnages are calculated for coal beds that lie less than 3,000 feet (914 m) below the ground surface and exceed 5.0 feet (1.5 m) in thickness. These criteria differ somewhat from that used in calculating Reserve Base and Reserve tonnages as described in U.S. Geological Survey Bulletin 1450-B, which calls for a maximum depth of 1,000 feet (305 m) for subbituminous coal. Total Reserve Base tonnages per Federal section are shown on plate 2 and total approximately 3.94 million short tons (3.57 million metric tons) for all Federal land within the KRCRA boundaries in this quadrangle. Reserve Base tonnages in the various development potential categories for subsurface mining methods are shown in table 2.

Dames & Moore has not made any determination of economic recoverability for any of the coal beds described in this report.

COAL DEVELOPMENT POTENTIAL

Coal development potential areas are drawn so as to coincide with the boundaries of the smallest legal land subdivisions shown on plate 2. In sections or parts of sections where no land subdivisions have been surveyed by the BLM, approximate 40-acre (16-ha) parcels have been used to show the limits of the high, moderate, or low development potentials. A constraint imposed by the BLM specifies that the highest development potential affecting any portion of a 40-acre (16-ha) lot, tract, or parcel be applied to that entire lot, tract, or parcel. For example, if 5 acres (2 ha) within a parcel meet criteria for a high development potential, 25 acres (10 ha) a moderate development potential, and 10 acres (4 ha) a low development potential, then the entire 40 acres (16 ha) are assigned a high development potential.

Development Potential for Surface Mining Methods

Areas where the coal beds of Reserve Base thickness are overlain by 200 feet (61 m) or less of overburden were considered to have potential for surface mining and can be assigned a high, moderate, or low development potential based on the mining ratio (cubic yards of overburden per ton of recoverable coal). The formula used to calculate mining ratios for surface mining of coal as follows:

$$MR = \frac{t_o\ (cf)}{t_c\ (rf)}$$

where MR = mining ratio

t_o = thickness of overburden in feet

t_c = thickness of coal in feet

rf = recovery factor (85 percent for this quadrangle)

cf = conversion factor to yield MR value in terms of cubic yards of overburden per short tons of recoverable coal:

0.911 for subbituminous coal

0.896 for bituminous coal

Note: To convert mining ratio to cubic meters of overburden per metric ton of recoverable coal, multiply MR by 0.8428.

Areas of high, moderate, and low development potential for surface mining methods are defined as areas underlain by coal beds having less than 200 feet (61 m) of overburden and having respective mining-ratio values of 0 to 10, 10 to 15, and greater than 15. These mining ratio values for each development potential category are based on economic and technological criteria and were provided by the U.S. Geological Survey.

No areas with high, moderate, or low development potential for surface mining methods have been identified in the Craig NW quadrangle. An unknown development potential has been assigned to those areas where coal data is either absent or does not comply with the development potential criteria established for surface mining methods by the U.S. Geological Survey. All Federal coal land within the KRCRA in the Craig NW quadrangle is classified as having unknown development potential for surface mining methods.

Development Potential for Subsurface and In-Situ Mining Methods

The coal development potential for subsurface mining methods is shown on plate 7. Areas of high, moderate, and low development potential are defined as areas underlain by coal beds of Reserve Base thickness which dip at 15° or less that occur at depths ranging from 200 to 1,000 feet (61 to 305 m), 1,000 to 2,000 feet (305 to 610 m), and 2,000 to 3,000 feet (610 to 914 m), respectively. Coal beds lying between 200 and 3,000 feet (61 and 914 m) below the ground surface, dipping greater that 15°, are subject to in-situ mining methods.

Approximately 10 percent of the Federal land within the KRCRA in the Craig NW quadrangle has been classified as having known development potential for conventional subsurface mining methods and 100 percent of this area is rated as having low development potential. The remaining Federal land is classified as having unknown development potential, implying that no known coal in beds 5 feet (1.5 m) or more thick occur between 200 and 3,000 feet (61 m and 914 m) below the ground surface but that coal-bearing units are present.

Because the coal beds in the quadrangle have dips less than 15°, the development potential for in-situ mining methods is rated as unknown.

Table 1 -- Chemical Analysis of Coal in the Craig NW Quadrangle, Moffat County, Colorado

Location	COAL BED NAME	Form of Analysis	Proximate				Ultimate					Heating Value	
			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	Btu/Lb
SE¼ NE¼ sec. 2, T. 7 N., R. 92 W., Seick Mine, Pine Ridge quadrangle (Fieldner and others, 1937)	Fort Union undifferentiated	A	23.3	29.6	40.0	7.1	0.7	5.8	54.0	0.7	31.7	4,928	8,870

Form of Analysis: A, as received

Note: To convert Btu/pound to kilojoules/kilogram, multiply by 2.326

Table 2. -- Coal Reserve Base data for subsurface mining methods for Federal coal lands (in short tons) in the Craig NW quadrangle, Moffat County, Colorado

Coal Bed or Zone	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Fort Union 1	0	0	3,940,000	3,940,000
Total			3,940,000	3,940,000

Note: To convert short tons to metric tons, multiply by 0.9072.

Table 3. -- Sources of data used on plate 1

Plate 1 Index Number	Source	Data Base
1	Sinclair Oil and Gas Co.	Clara Sturman Estate No. 1
2	Mountain Fuel Supply Co.	Cottonwood Gulch No. 2

SELECTED REFERENCES

American Society for Testing and Materials, 1977, Standard specification for classification of coals by rank, in Gaseous fuels; coal and coke; atmospheric analysis: ASTM Standard Specification D 388-77, pt. 26, p. 214-218.

Bass, N.W., Eby, J. B., and Campbell, M. R., 1955, Geology and mineral fuels of parts of Routt and Moffat Counties, Colorado: U.S. Geological Survey Bulletin 1027-D, p. 143-250.

Carey, B. D., Jr., 1955, A Review of the Browns Park Formation, in Guidebook to the geology of northwest Colorado: Intermountain Association of Petroleum Geologists and Rocky Mountain Association of Geologists, p. 47-49.

Emmons, S. F., 1877, Valleys of the Upper Yampa and Little Snake Rivers, in Hague, Arnold and Emmons, S. F., Descriptive Geology: U.S. Geological Exploration of the Fortieth Parallel, Section IX, p. 181-189.

Fenneman, N. M., and Gale, H. S., 1906, The Yampa coal field, Routt County, Colorado: U.S. Geological Survey Bulletin 297, 96 p.

Fieldner, A. C., Cooper, H. M., Abernethy, R. F., 1937, Analyses of Colorado coals: U.S. Bureau of Mines Technical Paper 574, p. 106-107.

Fisher, C. K., 1962, Modern stratigraphic logging and its application to subsurface exploration, in Exploration for oil and gas in northwestern Colorado, Rocky Mountain Association of Geologists Guidebook, 1962: p. 57-71.

Gale, H. S., 1910, Coal fields of northwestern Colorado and northeastern Utah: U.S. Geological Survey Bulletin 415, 265 p.

Greer, W. J., 1959, North Craig field, Moffat County, Colorado, in Washakie, Sand Wash and Piceance Basins, Symposium on Cretaceous rocks of Colorado and adjacent areas, Rocky Mountain Association of Geologists Guidebook, 11th Annual Field Conference, 1959: p. 81-84.

Hancock, E. T., 1925, Geology and coal resources of the Axial and Monument Butte quadrangles, Moffat County: U.S. Geological Survey Bulletin 757, 134 p.

Hancock, E.T., and Eby, J.B., 1930, Geology and coal resources of the Meeker quadrangle, Moffat and Rio Blanco Counties, Colorado: U.S. Geological Survey Bulletin 812, p. 209.

Selected References--Continued

Hewett, G. C., 1889, The northwestern Colorado coal region: American Institute of Mining Engineers Transactions, v. 17, p. 375-380.

Hills, R. C., 1893, Coal fields of Colorado, in Mineral resources of the United States, calendar year 1892: U.S. Geological Survey, p. 319-365.

Hornbaker, A. L., Holt, R. D., and Murray, K. D., 1975, Summary of coal resources in Colorado: Colorado Geological Survey Special Publication No. 9, 17 p.

Howard, A. D., and Williams, J. W., 1972, Physiography, in Geologic Atlas of the Rocky Mountain Region (W. W. Mallory, ed.): Rocky Mountain Association of Geologists, p. 30.

Konishe, Kenji, 1959, Upper Cretaceous surface stratigraphy, Axial Basin and Williams Fork area, Moffat and Routt Counties, Colorado; in Washakie, Sand Wash, and Piceance Basins, Symposium on Cretaceous rocks of Colorado and adjacent areas, Rocky Mountain Association of Geologists Guidebook, 11th Annual Field Conference, 1959: p. 67-73.

Kucera, R. E., 1959, Cretaceous stratigraphy of the Yampa district, northwest Colorado, in Washakie, Sand Wash, and Piceance Basins, Symposium on Cretaceous rocks of Colorado and adjacent areas, Rocky Mountain Association of Geologists Guidebook, 11th Annual Field Conference, 1959: p 37-45.

Masters, C. D., 1967, Use of sedimentary structures in determination of depositional environments, Mesaverde Formation, Williams Fork Mountains, Colorado: American Association of Petroleum Geologists Bulletin, v. 51, no. 10, p. 2033-2046.

______ 1959, Correlation of the post-Mancos Upper Cretaceous sediments of the Sand Wash and Piceance Basins, in Washakie, Sand Wash, and Piceance Basins, Symposium on Cretaceous rocks of Colorado and adjacent areas, Rocky Mountain Association of Geologists Guidebook, 11th Annual Field Conference, 1959: p. 78-80.

McGookey, D. P., (Compiler), 1972, Cretaceous systems, in Geologic Atlas of the Rocky Mountain region (W. W. Mallory, ed.): Rocky Mountain Association of Geologists, p. 190-228.

O'Boyle, C. C., 1955, The Cretaceous Rocks of Northwest Colorado, in Guidebook to the Geology of Northwest Colorado: Intermountain Association of Petroleum Geologists and Rocky Mountain Association of Geologists, p. 32-35.

Selected References--Continued

Picard, M. D. and McGrew, P. O., 1955, Correlation of Cenozoic Deposits of Northwestern Colorado, *in* Guidebook to the Geology of Northwest Colorado: Intermountain Association of Petroleum Geologists and Rocky Mountain Association of Geologists, p. 50-52.

Powell, J. W., 1876, Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, *in* U.S. Geologic and Geographic Survey of the Territories (Powell): 218 p.

Reeside, J. B., Jr., 1957, Paleoecology of the Cretaceous seas of the western interior: Geological Society of America Memoir 67, v. 2, p. 505-542.

Ritzma, H. R., 1955, Early Cenozoic History of the Sand Wash Basin, Northwest Colorado, *in* Guidebook to the Geology of Northwest Colorado: Intermountain Association of Petroleum Geologists and Rocky Mountain Association of Geologists, p. 36-40.

Ryer, T. A., 1977, Geology and coal resources of the Foidel Creek EMRIA site and surrounding area, Routt County, Colorado: U.S. Geological Survey Open-File Report 77-303.

Storrs, L. S., 1902, The Rocky Mountain coal field study: U.S. Geological Survey Annual Report 22, Pt. 3, p. 415-471.

Tweto, Ogden, 1976, Geologic map of the Craig 1° x 2° quadrangle, northwest Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-972.

U.S. Bureau of Land Management, 1977, Description of the environment, chapter II, *in* Final environmental statement on northwest Colorado coal: p. 1-125, appendix B, foldout 9.

White, C. A., 1878, Report on the geology of a portion of northwestern Colorado, *in* U.S. Geologic and Geographic Survey of the Territories (Hayden), 10th Annual Report, 1878: p. 1-60, pl. 2.

______ 1889, The geology and physiography of a portion of northwestern Colorado and adjacent parts of Utah and Wyoming: U.S. Geological Survey, 9th Annual Report, p. 677-712, pl. 18.