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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Summary of the geology, mineral resources, engineering geology characteristics, and environmental geochemistry of east-central Utah

Part A. Geology and Mineral resources

Part B. Some engineering geologic problems of the east-central Utah coal-mining region

Part C. Some probable geochemical impacts of coal development in east-central Utah

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature

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PART A. GEOLOGY AND MINERAL RESOURCES

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INTRODUCTION

Location and extent of area

The area described herein is irregularly shaped and encompasses about 26,000 square kilometers. It includes the Henry Mountains, Emery, Wasatch Plateau, Book Cliffs, and Sego coal fields in most of Carbon and Emery Counties, the east edge of San Pete and Sevier Counties, the south edge of Uintah County, northern Grand County, central Wayne County, and a part of northern Garfield County (fig. A1).

Topography

The central Utah area is a part of the Colorado Plateaus physiographic province. It is characterized by high plateaus bounded by steep cliffs cut by deep canyons, by precipitous rock ridges, by rock pinnacles and monuments, and by isolated mountain peaks. These are described briefly below.

At the north edge of the area is the Roan (or Tavaputs) Plateau, which is divided into east and west parts by the canyon of the south-flowing Green River (called Desolation Canyon to the north and Gray Canyon to the south). The plateau is bounded on the south by the precipitous Book Cliffs. Elevations on the plateau reach nearly 3,140 m above sea level west of the Green River and 2,900 m east of the river. The plateau is dissected by deep canyons that contain streams tributary to the Green River or that flow generally southward across the Book Cliffs.

At the west edge of the area is the Wasatch Plateau, which is bounded on the east by high cliffs similar to the Book Cliffs. Elevations on the higher drainage divides of the Wasatch Plateau range between about 2,900 m and 3,445 m above sea level.

At the southern end of the area are the north-northwest-trending Henry Mountains, which are characterized by high domal peaks several miles apart separated by broad dissected saddle areas. Mount Ellen, the northernmost and highest peak, is 3,540 m above sea level. In the central part of the area is the north-northeast-trending San Rafael Swell, an uplifted area about 40 km wide and 113 km long marked by bare rock ridges, pinnacles, and narrow

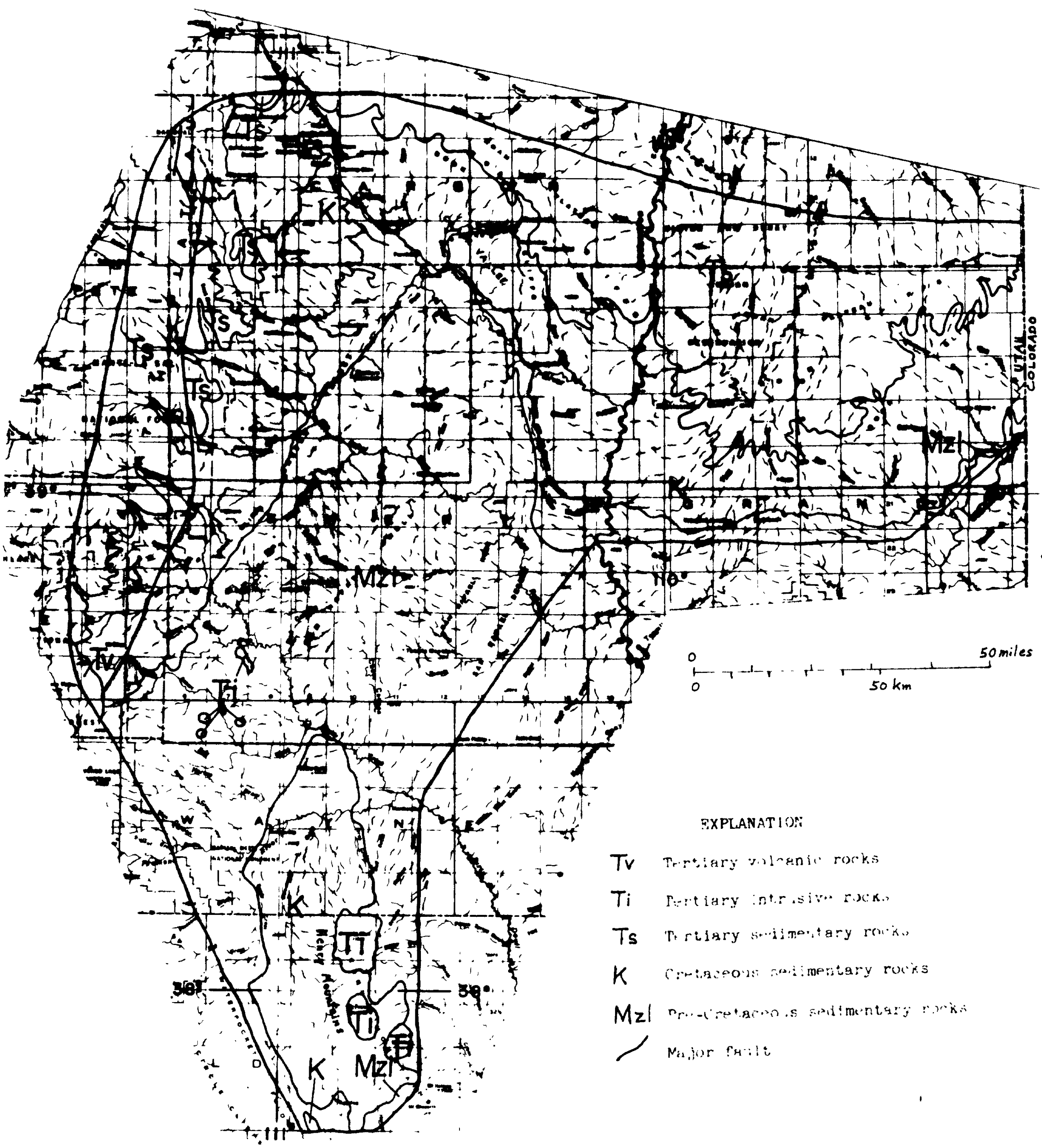

Figure A1. - Generalized geologic map of east-central Utah. (U.S. Geological Survey base) rock canyons. Elevations within the swell are as great as 2,336 m above sea level on Cedar Mountain and local relief within the swell area is in places as great as 450 m.

Between the San Rafael Swell and the Wasatch Plateau is the broad Castle Valley and between the swell and the western Book Cliffs is the narrower, rather featureless Clark Valley. Elevations in these valley areas range from about 1,200 m above sea level in the eastern part of the area to about 1,800 m in the western part.

GEOLOGIC FRAMEWORK

Different parts of the east-central Utah area have undergone varying degrees of upwarping or downwarping and normal faulting during the course of geologic history. The resultant changes in elevation along with changes in the direction and degree of continental tilting during geologic time had some major effects on the kinds of rocks that formed and underlie the report region. The nature and variations of these rocks, whether exposed or in the subsurface, are described from oldest to youngest very briefly.

Precambrian rocks

So far as is known, all of the Precambrian rocks underlying the report area are metamorphic and igneous crystalline rocks. Rocks of these types can be virtually eliminated as possible reservoirs for oil and gas, and because of their depth of burial (from perhaps 100 m on the extreme east to about 8 km or more on the extreme west) they offer little prospect of containing discoverable economic mineral deposits.

Younger Precambrian sedimentary rocks that have been only moderately altered are known to lie above the crystalline basement in northern and western Utah and in northern Arizona, beyond the limits of the report region, but so far as is known do not underlie the report region itself (Christiansen, 1963; Hedge, 1972).

Cambrian System

Cambrian rocks probably underlie all of the report area except on the Uncompahgre uplift (figs. A2, A3), from which they were eroded during Pennsylvanian time. Rocks of the system thicken from about 300 m on the east to more than 600 m on the extreme west. They are composed of orthoquartzite at the base overlain by limestones, dolomites, and shales (Lochman-Balk, 1972).

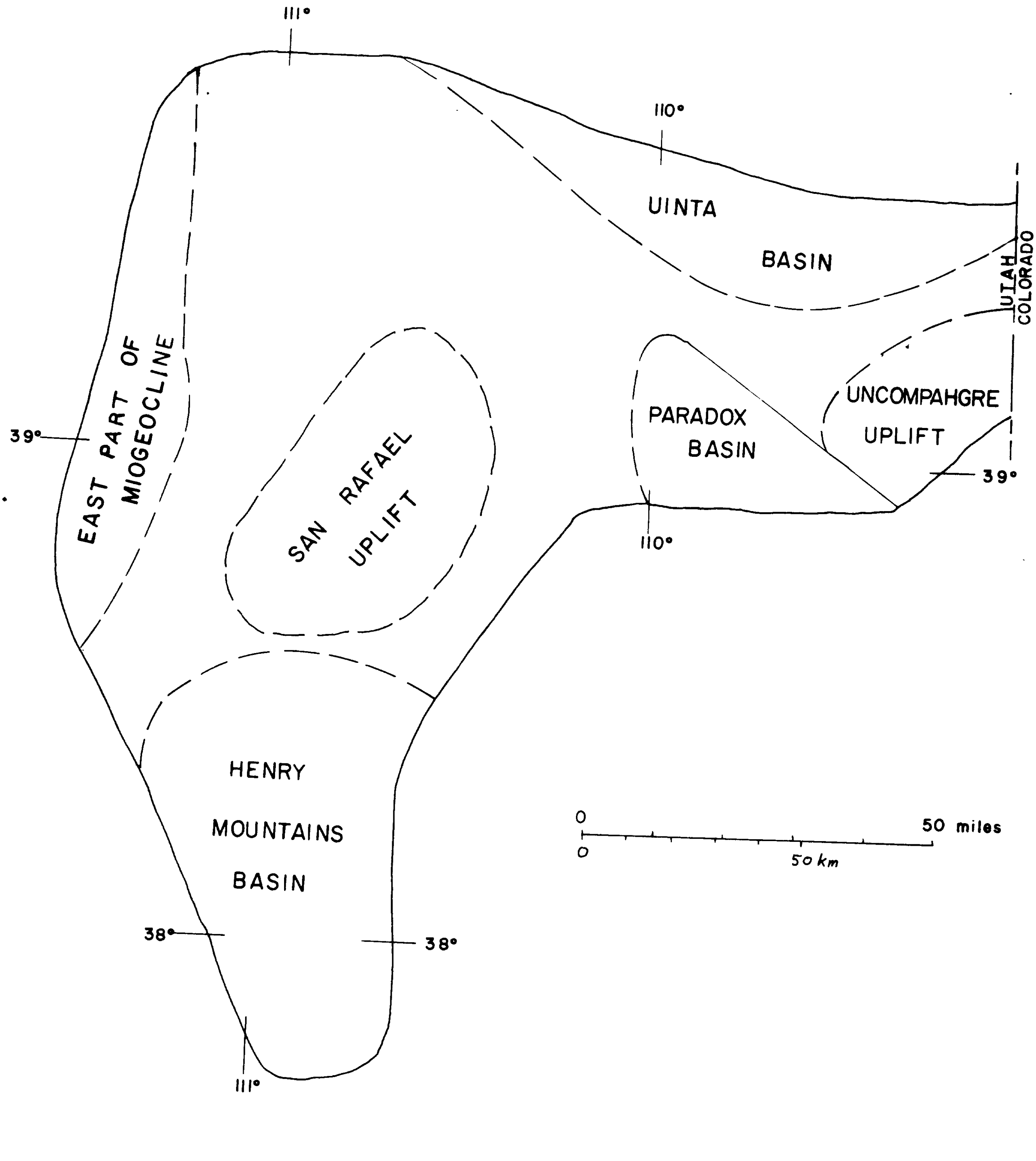

Figure A2. - Tectonic elements of east-central Utah.

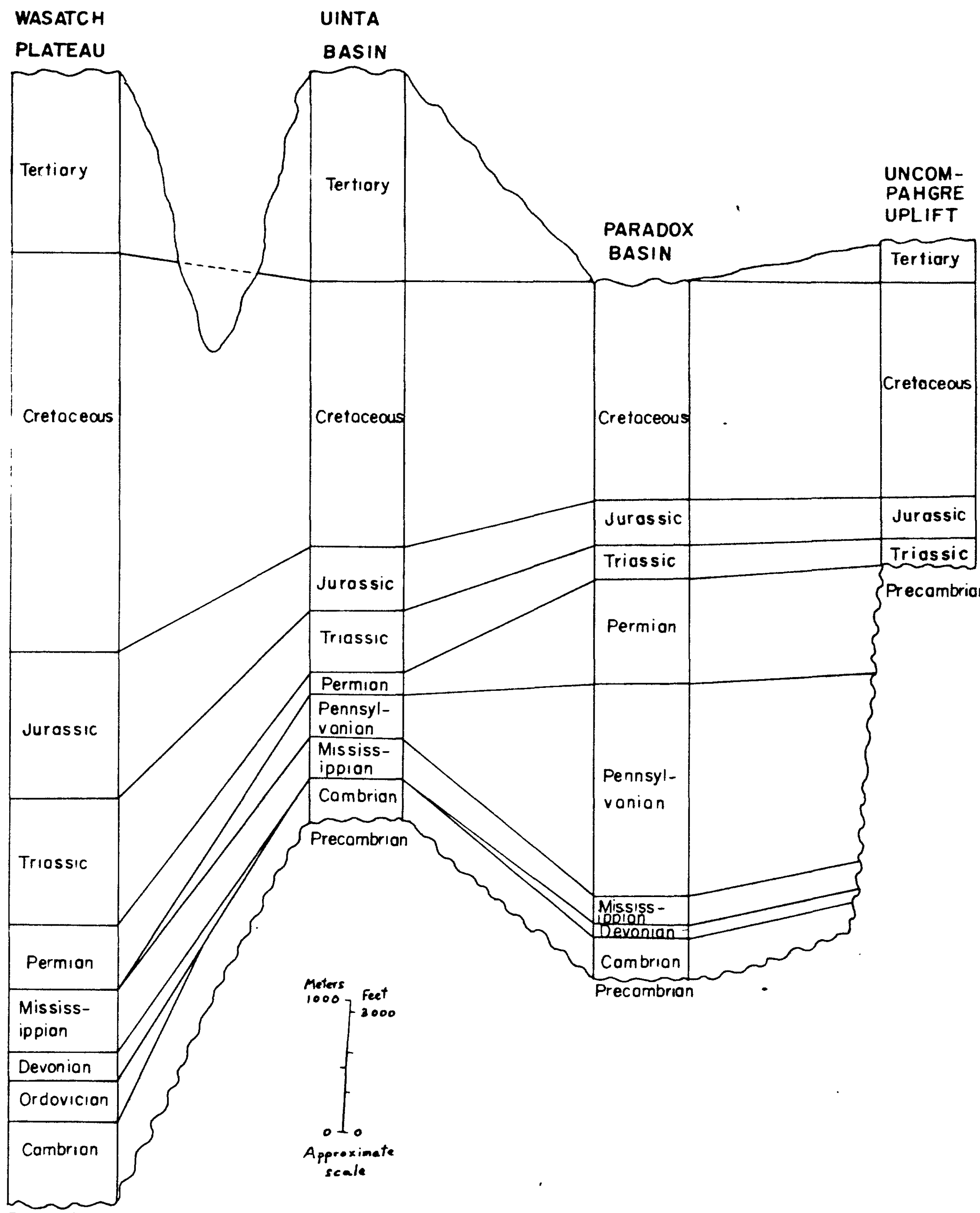

Figure A3. - Diagram showing relative thickness of Phanerozoic systems in parts of east-central Utah.

Ordovician System

Ordovician rocks are not known in most of the report area except in the extreme western part where dolomite of Ordovician age may reach a thickness of about 450 m (Foster, 1972).

Silurian System

Silurian rocks, although present in western Utah, are unknown in the subsurface of the report area (Gibbs, 1972).

Devonian System

Devonian rocks, consisting mostly of limestone and dolomite, underlie most of the report area at depth (Baars, 1972). The system is absent on the Uncompahgre uplift and in part of the Uinta Basin (figs. A2, A3), but otherwise thickens generally westward to about 200 m at the extreme west edge of the area.

Mississippian System

Mississippian rocks are present in the subsurface beneath all of the report area except on the Uncompahgre uplift (Craig, 1972). The system consists largely of limestone and shale that thicken from about 180 m in the Paradox basin (fig. A2) to more than 900 m at the northwest edge of the area (fig. A3).

Pennsylvanian System

Pennsylvanian rocks are the oldest rocks exposed in the report region but crop out only very locally in the east-central part of the San Rafael Swell (Baker, 1946). In the subsurface, rocks of the system are as much as 1,800 m thick in the Paradox basin (figs. A2, A3) but are absent on the adjacent Uncompahgre uplift (Mallory, 1972). They thin from the Paradox basin westward to a wedge edge near the west boundary of the report area. In the Paradox basin the Pennsylvanian System includes great thicknesses of salt, anhydrite, and other evaporites; elsewhere it consists largely of limestone and sandy limestone.

Permian System

Permian rocks crop out extensively on the San Rafael Swell, but not at any other place in the report area. They occur in the subsurface throughout the area, except on the Uncompahgre uplift (figs. A2, A3), and probably have a maximum thickness of more than 600 m near the southern end of the area (Rascoe and Baars, 1972). The rocks of the system are mostly sandstone, siltstone, and shale with some limestone near the top.

Triassic System

Triassic rocks are exposed in the San Rafael Swell and underlie younger rocks over the remainder of the report area (MacLachlan, 1972). They thicken from about 150 m at the eastern edge of the area to 1,050 m or more on the western edge. The rocks are almost entirely siltstone, shale, sandstone, and conglomerate.

Jurassic System

Jurassic strata are exposed in a broad belt surrounding the San Rafael Swell and in an adjoining belt surrounding the Henry Mountains basin (fig. A2). They occur in the subsurface beneath Cretaceous rocks throughout the remainder of the area and thicken from about 150 m at the east edge of the area to possibly as much as 1,200 m at the northwest edge (Peterson, 1972). The rocks are sandstone, mudstone, and siltstone to the east, but include much limestone and dolomite at the west edge.

Cretaceous System

Rocks of the Cretaceous System are exposed in a continuous broad outcrop belt that includes the Book Cliffs and the cliffs forming the east side of the Wasatch Plateau. They crop out in much of the Henry Mountains basin (fig. A2), and underlie the Cenozoic rocks in the Wasatch and Roan Plateaus (fig. A1). Throughout most of the region the Cretaceous strata are from 1,050 to 1,500 m thick, but thicken to 3,000 m or more at the extreme northwest margin of the region under the Wasatch Plateau (McGookey and others, 1972). Most of the system is a rather complexly intertonguing sequence of marine and nonmarine rocks with nonmarine rocks dominant at the far west and marine rocks dominant to the east. The marine rocks are mostly shale and subordinately, sandstone; the nonmarine rocks include a wide variety of clastic rocks, and contain all the economic and potentially economic coal beds of the region. The coal-bearing rock units are described in more detail in the section on coal.

Cenozoic rocks

Cenozoic rocks of the report area include up to more than 1,000 m of sedimentary rocks of continental origin on the Wasatch and Roan Plateaus, volcanic rocks on the Fish Lake Plateau (south of the Wasatch Plateau), and intrusive igneous rocks in the Henry Mountains basin and elsewhere (fig. A1). The Cenozoic is also represented by Holocene gravel deposits, alluvium, and dune sands.

MINERAL RESOURCES

Coal

Five important coal fields are contained within the east-central Utah area, as defined herein. They are, from south to northwest to northeast, the Henry Mountains, Emery, Wasatch Plateau, Book Cliffs, and Sego coal fields. Their locations are shown on figure A4. The geology and coal resources of these coal fields have been described by Doelling (1972a-e), and this report represents little more than an attempt to summarize the most important data contained in Doelling's reports.

The coal resource estimates presented here recognize four categories of coal resource. The categories, listed in decreasing degree of geologic assurance, are defined by the U.S. Geological Survey as follows:

Measured.--Resources are computed from dimensions revealed in outcrops, trenches, mine workings, and drill holes. The points of observation and measurement are so closely spaced and the thickness and extent of coals are so well defined that the tonnage is judged to be accurate within 20 percent of true tonnage. Although the spacing of the points of observation necessary to demonstrate continuity of the coal differs from region to region according to the character of the coal beds, the points of observation are no greater than 0.8 km apart. Measured coal is projected to extend as a 0.4-km-wide belt from the outcrop or points of observation or measurement.

Indicated.--Resources are computed partly from specified measurements and partly from projection of visible data for a reasonable distance on the basis of geologic evidence. The points of observation are 0.8 km to 2.4 km apart. Indicated coal is projected to extend as a 0.8-km-wide belt that lies more than 0.4 km from the outcrop or points of observation or measurement.

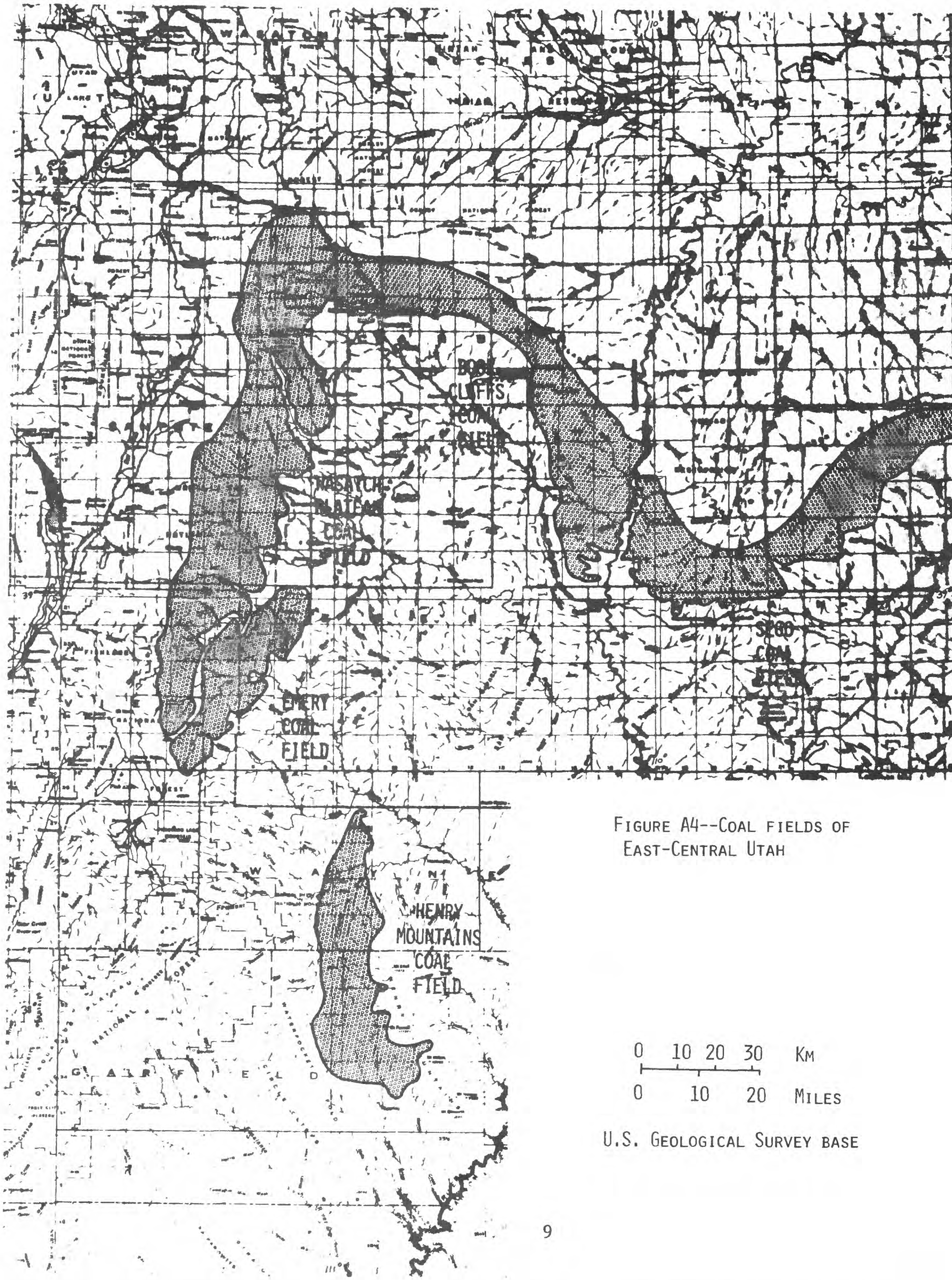

FIGURE A4--COAL FIELDS OF EAST-CENTRAL UTAH

0 10 20 30 KM
0 10 20 MILES

U.S. GEOLOGICAL SURVEY BASE

Inferred.--Quantitative estimates of inferred resources are based largely on broad knowledge of the geologic character of the bed or region and where few measurements of bed thickness are available. The estimates are based primarily on an assumed continuation from measured and inferred coal for which there is geologic evidence. The points of observation are 2.4 km to 9.6 km apart. Inferred coal is projected to extend as a 3.6-km-wide belt that lies more than 1.2 km from the outcrop or points of observation or measurement.

Hypothetical resources.--Quantitative hypothetical resource estimates are based on a broad knowledge of the geologic character of a coal bed or region. Measurements of coal thickness are more than 9.6 km apart. The assumption of continuity of a coal bed is supported only by geologic evidence.

Henry Mountains coal field

Geologic setting

Coal-bearing rocks of Cretaceous age in the Henry Mountains region, Wayne and Garfield Counties, occupy the center of a north-south-trending structural basin located immediately to the west of the Henry Mountains (figs. A4, A5). The Henry Mountains basin is limited to the north by the San Rafael Swell, to the west by the Circle Cliffs uplift, and to the east by the Monument upwarp. The coal field has a length of 72 km and a width of as much as 29 km. Coal-bearing rocks underlie an area of approximately 1,165 square km. (Doelling, 1972a).

Status of information

The geology of the Henry Mountains region was first studied by Gilbert in 1875 and 1876. Gilbert's report (1877) is considered a classic in the North American geological literature. The area was restudied and the geology described in considerable detail by Hunt, Averitt, and Miller (1953). Gregory and Moore (1931), Smith and others (1963), and Davidson (1967) described parts of the Waterpocket Fold, near the western boundary of the Henry Mountains coal field. Cretaceous rocks have been described by Lawyer (1972) and by Peterson and Ryder (1975). Information bearing on coal resources has been very ably summarized by Doelling (1972a).

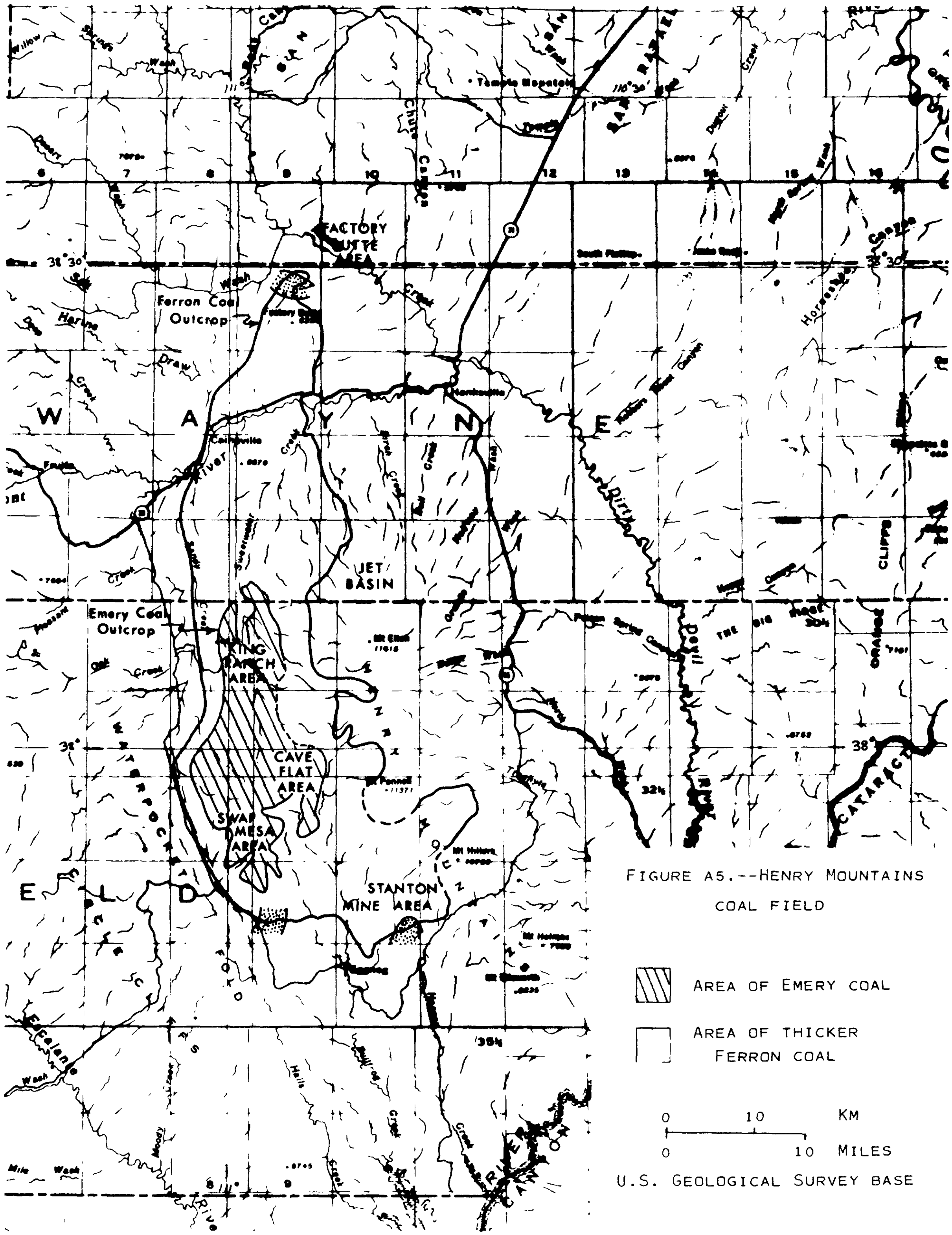

FIGURE A5.--HENRY MOUNTAINS COAL FIELD

Coal-bearing rock units

Coal in the Henry Mountains region is contained entirely within rocks of Cretaceous age. The coal-bearing units, in ascending order, are the Dakota Sandstone and the Ferron and "Emery" Sandstone Members of the Mancos Shale.

Dakota Sandstone.--The Dakota Sandstone averages about 10.7 m in thickness in the Henry Mountains region, attaining a maximum measured thickness of 28 m (Hunt and others, 1953; Peterson and Ryder, 1975). The Dakota is overlain by dark-gray marine shale of the Tununk Shale Member of the Mancos Shale (fig. A6). In many areas, the Dakota is absent and the Tununk Shale Member rests directly upon rocks assigned by various authors to the Cretaceous Cedar Mountain Formation and Jurassic Morrison Formation.

The Dakota Sandstone is a heterogeneous formation that may generally be divided into two parts. The lower part rests unconformably on the Cedar Mountain Formation or Morrison Formation. It contains lenticular beds of sandstone, which are locally pebbly to conglomeratic, and black to gray, locally bentonitic and carbonaceous mudstone and shale, and coal. Petrified wood is common in the Dakota near Hanksville, near the northeastern part of the coal field (Lawyer, 1972). In Jet Basin, north of Mount Ellen, logs and other plant debris have been "jetified," resulting in an unusual type of coal referred to as "jet." A lustrous, tough, firmly compact variety of coal that breaks with a conchoidal fracture, the jet coal of Jet Basin was once mined from small pits for production of jewelry (Travers and Kolvoord, 1968). Rock types and sedimentary structures indicate that the lower unit of the Dakota Sandstone was deposited in fluvial-channel, natural-levee, flood-basin, crevasse-splay, and swamp environments (Lawyer, 1972; Peterson and Ryder, 1975).

The upper unit of the Dakota Sandstone contains one or more ledge-forming beds of sandstone that are locally fossiliferous and laterally more continuous than are sandstone beds in the lower unit. Sedimentary structures and fossils suggest that the upper unit accumulated in a shallow marine, barrier-island or beach environment (Lawyer, 1972). Fossils indicate an early Late Cretaceous (late Cenomanian) age. The Dakota Sandstone thus records the transition from nonmarine to marine conditions as the Interior Cretaceous seaway spread westward across south-central Utah.

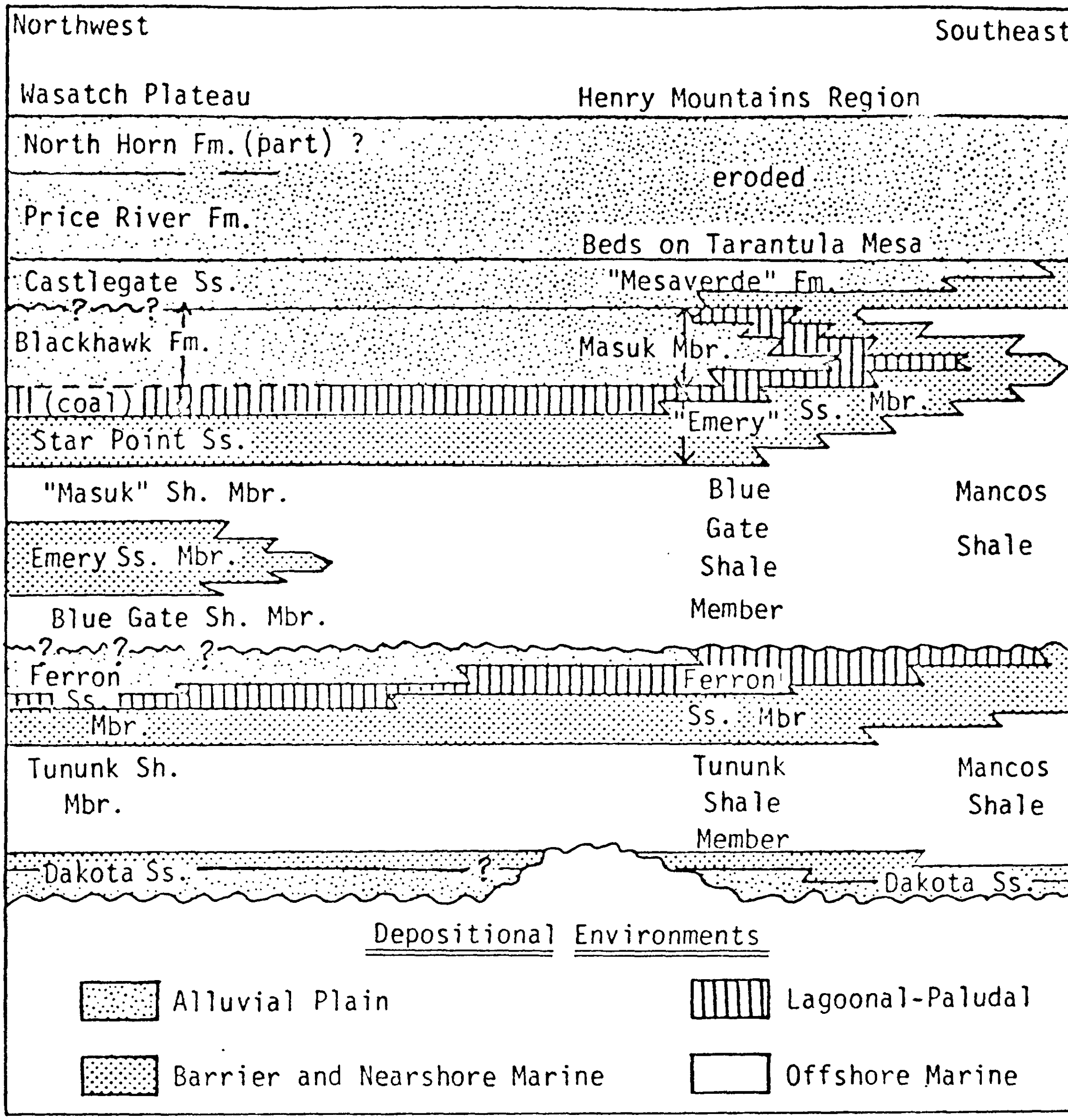

FIGURE A6.--GENERALIZED CROSS SECTION SHOWING CORRELATION OF STRATIGRAPHIC UNITS OF THE WASATCH PLATEAU AND THE HENRY MOUNTAINS REGION, UTAH (FROM PETERSON AND RYDER, 1975). NOT TO SCALE

Ferron Sandstone Member.--The Ferron Sandstone Member of the Mancos Shale weathers to conspicuous cliffs or ridges between the broad valleys formed on the Tununk and Blue Gate Shale Members, which, respectively, underlie and overlie the Ferron. The Ferron Sandstone Member ranges in thickness from 62 m to 117 m in the Henry Mountains region, averaging about 93 m (Peterson and Ryder, 1975).

Like the Dakota, the Ferron is divided into lower and upper units. The lower unit, 40 to 93 m thick (Peterson and Ryder, 1975) consists of cliff-forming, very fine to medium-grained sandstone that locally contains thin beds or lenses of coarse-grained sandstone, gray siltstone, and dark-gray silty shale. The contact with the underlying Tununk Shale Member is gradational. The upper unit, 4.6 to 62 m thick (Peterson and Ryder, 1975), contains lenticular beds of very fine to coarse-grained sandstone, gray mudstone, dark-brown to black carbonaceous mudstone, and coal. Coal is most commonly found near the top of the unit. The contact with the overlying Blue Gate Shale Member is sharp and, at least in the southern part of the Henry Mountains basin, unconformable. Thinning of the upper unit of the Ferron southward along the western margin of the basin suggests that a considerable thickness of sediment was eroded prior to deposition of the Blue Gate.

The Ferron Sandstone Member records a general eastward progradation of the western shoreline of the Interior Cretaceous seaway. The lower unit records progressively shallower marine conditions as the shoreline moved eastward by addition of land-derived sand and silt. The more heterogeneous upper unit accumulated in a variety of nonmarine depositional environments, including low-lying coastal swamps in which the organic material that now forms the coal beds accumulated. Fossils collected from the lower unit of the Ferron by Peterson and Ryder (1975) indicate a Late Cretaceous (middle Turonian) age. Nonmarine deposition of the upper unit of the Ferron was followed by a return to the open marine conditions recorded by the offshore-marine Blue Gate Shale Member.

"Emery" Sandstone Member.--The "Emery" Sandstone Member is exposed in the interior part of the Henry Mountains basin, where it forms prominent cliffs above the valley formed by the Blue Gate Shale Member. Beds in the Henry Mountains region that are presently assigned to the "Emery" Sandstone Member were originally named the Blue Gate Sandstone by Gilbert (1877).

Spieker and Reeside (1925) correlated Gilbert's Blue Gate Sandstone with the Emery Sandstone Member in its type area in Castle Valley. On the basis of this correlation, Hunt and Miller (1946) applied the name Emery to the unit in the Henry Mountains region. Peterson and Ryder (1975) have recently demonstrated that the correlation is incorrect, the "Emery" Sandstone Member of the Henry Mountains region being equivalent to the Star Point Sandstone of the Mesaverde Group in the Wasatch Plateau. Following the usage of Peterson and Ryder, the name "Emery" is enclosed in quotation marks in this report.

The "Emery" Sandstone Member averages about 109 m in thickness in the Henry Mountains region, ranging between 91 and 122 m (Peterson and Ryder, 1975). Fossils diagnostic of age have not been found in the "Emery." Correlation with the Star Point Sandstone indicates a Late Cretaceous (late Campanian) age.

The sequence of rock types in the "Emery" Sandstone Member is essentially identical to that in the Ferron and it, too, is divided into lower and upper units. The lower, cliff-forming, marine sandstone unit ranges in thickness from 54 to 94 m, averaging about 75 m (Peterson and Ryder, 1975). Its contact with the underlying Blue Gate Shale Member is gradational. The upper unit, distinguished by lenticularity of sandstone beds and by the presence of carbonaceous mudstone and coal, averages about 33 m in thickness. The range in measured thickness is 28 and 37 m (Peterson and Ryder, 1975). The upper unit of the "Emery" is the most important coal-bearing unit in the Henry Mountains region and contains the thickest reported coal beds.

Like the Ferron, the "Emery" Sandstone Member records general eastward progradation of the western shoreline of the Interior Cretaceous seaway. The "Emery" is conformably overlain by nonmarine mudstone and sandstone of the Masuk Member.

Coal beds and mines

Coal beds occur in the Dakota Sandstone and in the upper units of the Ferron and "Emery" Sandstone Members of the Mancos Shale. Small quantities of coal have been mined from these units at several localities; however, there are at present no active mines in the Henry Mountains coal field.

Though reaching 4.3 m in thickness at one locality (Hunt and others, 1953), coal beds of the Dakota Sandstone are extremely lenticular and are usually very thin. Dakota coal is considered to be of negligible economic importance.

Coal beds occur near the top of the Ferron Sandstone Member, reaching thicknesses of 1.2 m or more in three areas. They are, from north to south, the Factory Butte, Swap Mesa, and Stanton mine areas (fig. A5). Only rarely is there more than a single coal bed of minable thickness at any given locality, though the coal beds are split in many places by partings of siltstone or shale. A coal bed 2.1 m thick is present at the Factory Butte coal mine, where several tons of coal were mined each year for local use between about 1900 and the 1950's (Hunt and others, 1953; Doelling, 1972a). The coal is of minable thickness beneath an area of slightly more than 10.4 square km. A Ferron coal bed in the Swap Mesa area is more than 1.2 m thick over an area of about 9.1 square km, the maximum reported thickness being about 1.8 m (Doelling, 1972a). The rock overburden above the coal beds in both the Factory Butte and Swap Mesa areas is thin and coal could be removed by strip mining. A coal bed 1.2 to 1.8 m thick underlies an area of about 2.6 square km in the vicinity of the old Stanton mines at the southern margin of the Henry Mountains coal field. These mines produced a small amount of coal as fuel for gold dredges operating on the Colorado River between 1895 and 1900 (Doelling, 1972a).

Coal beds in the "Emery" Sandstone Member generally range from 0.6 to 1.8 m in thickness. The maximum reported thickness is 4.0 m (Peterson and Ryder, 1975). As is the case for the Ferron, only one coal bed of minable thickness may be expected at any given locality. According to Doelling (1972a), coal is present in 90 percent of the "Emery" outcrop areas. The thickest coal is in the King Ranch and Cave Flat areas where small amounts of "Emery" coal were mined for local consumption during the late 1940's at two localities west of Mt. Ellen.

Resources

The coal resources of the Henry Mountains coal field have been estimated by Doelling (1972a), and are presented in table A1. The estimates are based almost entirely on measurements of coal at the outcrop, drill-hole control being very sparse and, in most areas, nonexistent. Because of the great distance of the Henry Mountains region from established markets and rail lines, its relative inaccessibility, and the fact that most of the coal is in thin beds, the coal field has never been thoroughly evaluated. More drill-hole data will be necessary to prove the extent and value of the coal.

Table A1.--Coal resources of the Henry Mountains coal field (in millions of short tons)

[Data from Doelling (1972a); 1 short ton = 0.907 tonnes]

Quadrangle	Measured and indicated I and II	Inferred resource III	Hypothetical resource IV	Total coal	Beds 4 ft thick excluding hypothetical resource
Caineville-steamboat Point[1]	0.8	-	104.5	105.3	0.8
Cow Flat,[2]					
Mt. Hillers NW[3]	17.4	-	41.9	59.3	4.2
Factory Butte NE[4]	22.8	-	45.0	67.8	22.8
Mt. Ellen NE-SE[5]	-	-	-	-	-
Mt. Ellen NW-SW[5]	77.4	55.2	50.1	182.7	81.9
Mt. Pennell NE-NW[6]	50.1	63.8	120.4	234.3	45.0
Notom NE-SE	48.8	-	52.2	101.0	48.8
Wagon Box Mesa NE-Cave Point[7]	34.4	-	105.4	139.8	27.4
Totals	251.7	119.0	519.5	890.2	230.9

[1]Steamboat Point quadrangle is the south-central part of the U.S. Geological Survey's Factory Butte 15-minute quadrangle; the Caineville quadrangle combines parts of the Fruita and Factory Butte U.S. Geological Survey 15-minute quadrangles.

[2]Parts of the Mt. Hillers and Mt. Pennell 15-minute quadrangles of the U.S. Geological Survey.

[3]Northwestern quarter of the Mt. Hillers 15-minute quadrangle of the U.S. Geological Survey.

[4]Northeastern quarter of the Factory Butte 15-minute quadrangle of the U.S. Geological Survey.

[5]7.5 x 15-minute area formed by combining the designated quarters of the Mt. Ellen 15-minute quadrangle of the U.S. Geological Survey.

[6]15 x 7.5-minute area formed by combining the northeastern and northwestern quarters of the Mt. Pennell 15-minute quadrangle of the U.S. Geological Survey.

[7]Parts of the Wagon Box Mesa and Mt. Pennell 15-minute quadrangles of the U.S. Geological Survey.

The amount of coal in the Henry Mountains coal field contained in beds 0.3 m or more thick is estimated to be 807.6 million tonnes. The minable portion (measured, indicated, and inferred coal in beds 1.2 m or more in thickness) amounts to 209.5 million tonnes. Of this minable coal, 170.0 million tonnes is in the "Emery" Sandstone Member, 38.1 million tonnes in the Ferron Sandstone Member, and 1.4 million tonnes in the Dakota Sandstone.

Emery coal field

Geologic setting

Coal-bearing rocks of the Emery coal field, referred to by some (for instance, Maurer, 1966) as the Castle Valley coal field, are exposed along a northeast-southwest-trending outcrop belt in eastern Sevier and western Emery Counties (figs. A4, A7). The field is located on the western flank of the San Rafael Swell. Strata consistently dip 2^{0}-4^{0} NW. The eastern boundary of the coal field is defined by prominent southeast-facing cliffs known, from southwest to northeast, as the Limestone Cliffs, Coal Cliffs, and Molen Reef. The cliffs are formed by resistant sandstone units of the Ferron Sandstone Member. The Coal Cliffs and Molen Reef also define the eastern boundary of Castle Valley, which contains the northern part of the Emery coal field. The western limit of the field is drawn at the position where the thickness of overburden above the coal beds reaches 915 m, and is approximated by the front of the Wasatch Plateau. The coal beds thin and pinch out to the north, becoming unimportant near the settlement of Moore. The field is limited to the south by covering of the coal-bearing strata by volcanic rocks of the Fish Lake Plateau. The Emery coal field is about 56 km long and as much as 13 km wide. It includes an area of some 544 square km.

Status of information

The only comprehensive study of the Emery coal field was completed by Lupton (1916) during 1911 and 1912. Doelling (1972b) reviewed Lupton's data and added additional information on coal resources. The stratigraphy and depositional history of rocks in the area of the Emery coal field are described in papers by Katich (1953, 1954), Davis (1954), Cotter (1971, 1975a, 1975b), Hale (1972), and Cleavinger (1974). Gray, Patalski, and Schapiro (1966) discussed, in a very general way, the correlation of coal zones within the field by palynomorph biostratigraphy.

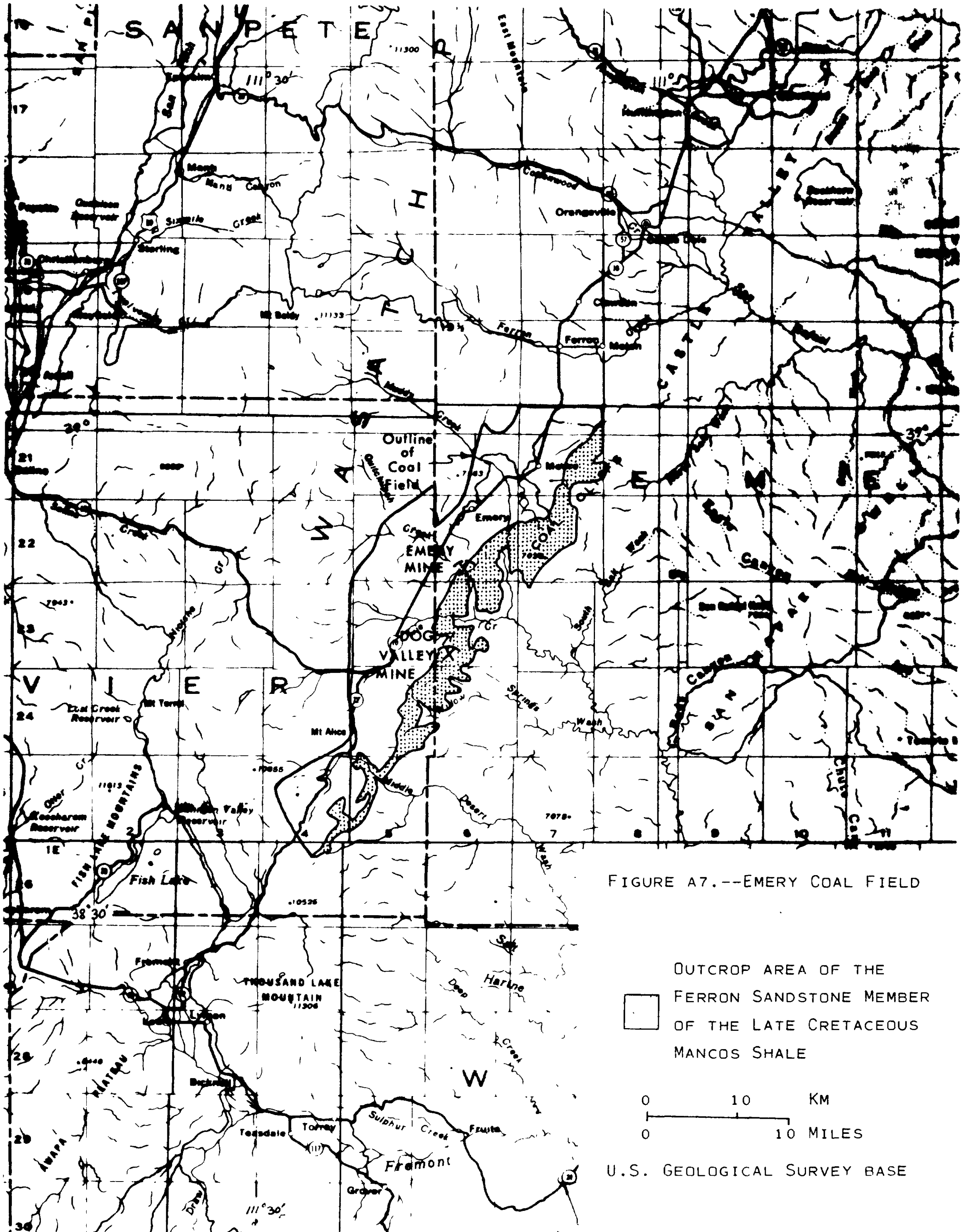

FIGURE A7.--EMERY COAL FIELD

Coal-bearing rock units

Coal of the Emery coal field is contained entirely within the Ferron Sandstone Member of the Mancos Shale. The Dakota Sandstone locally contains thin, lenticular beds of coal, but these are of no economic importance.

The Ferron Sandstone Member in the Emery field is a lateral equivalent of the Ferron in the Henry Mountains region (fig. A6), the two having been deposited during the same eastward migration of the western shoreline of the Interior Cretaceous seaway during Late Cretaceous (middle and late Turonian) time. The Ferron thins northward from a maximum thickness of about 245 m at Last Chance Creek, near the southern end of the Emery coal field (Lupton, 1916; Hale, 1972), to about 49 m at Dry Wash, east of Moore (Cotter, 1975b).

As in the Henry Mountains region, the Ferron Sandstone Member in the Emery coal field is divisible into lower and upper units. The lower unit consists of two or more thick, cliff-forming, very fine to medium-grained sandstones and averages about 30 m in thickness. It conformably overlies the Tununk Shale Member. The contact between the two is gradational. Sedimentary and biogenic structures indicate that the sandstones of the lower unit were deposited in shallow marine environments. The upper unit of the Ferron contains lenticular, very fine to coarse-grained sandstone, gray siltstone, carbonaceous siltstone and shale, and many beds of coal. These sediments accumulated in a variety of marginal-marine and nonmarine environments. The contact between the upper unit and the overlying Blue Gate Shale Member is everywhere sharp, but does not appear to be unconformable as it is in the southern part of the Henry Mountains basin.

The simple bipartite division of the Ferron becomes inapplicable in the area southeast of Emery, near the northern limit of the coal field. Here, marine and nonmarine lithologies interfinger in a complex way, marine rocks becoming increasingly dominant to the northeast. The Ferron Sandstone Member is mapped northward from the Emery coal field to Price, and hence eastward around the north end of the San Rafael Swell (Hintze and Stokes, 1964). The Ferron Sandstone in the northern part of Castle Valley, however, is stratigraphically lower than the Ferron of the Emery field (Cotter, 1975c). The environmental history of the two units is unrelated. The Ferron in the northern part of Castle Valley contains no coal on the outcrop, though coal has been reported from a drill hole near Price (Doelling, 1972b).

Coal beds

Coal beds are present through the entire thickness of the upper unit of the Ferron Sandstone. They have been traced and measured throughout the coal field by Lupton (1916). In the southern and central parts of the field, the coal beds are extremely lenticular, undergoing dramatic changes in thickness over short distances. Coal beds are somewhat more persistent and predictable in the northern part of the field (Doelling, 1972b).

Thirteen coal beds, designated in ascending order by the letters A through M, have been described (Lupton, 1916; Doelling, 1972b). Three coal groups are recognized: beds A through E comprise the lower coal group; F and G the middle coal group; and H through L the upper coal group. The M bed occurs at the top of the Ferron, immediately beneath the contact with the Blue Gate Shale Member.

Coal beds in the Ferron are locally thick, the maximum reported thickness being 6.7 m. Thicknesses of 3.0 m or more are common. A detailed description of the variations in the thicknesses of the coal beds would require many pages, and is beyond the scope of this report. This information may be found in the reports by Lupton (1916) and Doelling (1972b). Most of the coal in the Ferron Sandstone Member can be recovered only by underground mining methods. Thick coal beds occur near the top of the Ferron southeast of Emery, in the northern part of the coal field, and in the vicinity of Paradise Lake, near the south end of the field. These beds could be mined by strip mining.

Mines

At least 11 mines and prospects have been opened in the Ferron Sandstone Member in the Emery coal field (Doelling, 1972b). All but two have been abandoned for at least 25 years. The first mine on record in the field, and one of the two mines presently active, is the Emery mine now owned by the Consolidation Coal Co. Formerly known as the Browning Mine, it has been producing coal from the I bed since 1881. Production for 1975 was 68,717 tonnes. The Dog Valley mine of the Western States Coal Corp. is the other active mine. It, too, produces from the I bed and was opened in about 1930.

It produced 7,818 tonnes of coal in 1975. Coal from the Emery and Dog Valley mines is trucked distances of about 80 km to Price and Salina, respectively. Doelling (1972b) estimated that a total of 1.5 million tonnes of coal had been produced from the Emery coal field. The two active mines account for 90 percent of the total.

Resources

Lupton's (1916) estimate of the coal resources of the Emery coal field was brought up to date by Doelling (1972b). Doelling's figures are presented here. The estimate is based on a large number of coal sections measured on the outcrop, plus data from numerous drill holes. For the field as a whole, measured and indicated coal resources total 687.3 million tonnes, inferred resources are 610.4 million tonnes, and hypothetical resources are 575.6 million tonnes. The total original coal resources of the Emery coal field are estimated to be 1,873.2 million tonnes. Compared to these figures, the 1.5 million tonnes figure for coal that has been produced from the field is insignificant. The coal resources of specific 7.5-minute quadrangles are summarized in table A2.

Wasatch Plateau coal field

Geologic setting

The Wasatch Plateau coal field lies on the eastern side of the Wasatch Plateau and includes parts of Utah, Carbon, Emery, Sanpete, and Sevier Counties. The field is elongate in a north-south direction, ranging in width from 11.3 to 32.2 km, and having a length of about 145 km. It has an area of 2,850 square km (figs. A4 and A8). The eastern boundary of the coal field is defined by conspicuous, generally east-facing cliffs held up by resistant rock units of the Mesaverde Group, and thus corresponds to the eastern boundary of the Wasatch Plateau. Like the Emery coal field, the Wasatch Plateau field is limited to the south by the covering of the coal-bearing strata by Tertiary volcanic rocks of the Fish Lake Plateau. The western boundary of the field conforms closely to the drainage divide of the Wasatch Plateau. On the northeast, the Wasatch Plateau field is contiguous with the Book Cliffs coal field, the boundary between the two being arbitrarily drawn at the easternmost fault of the North Gordon fault system. U.S. Highway 6-50 and the main line of the Denver and Rio Grande Western Railroad, which follow the Price River Canyon from Price to Soldier Summit, define the northern limit of the coal field.

Table A2.--Original coal resources Emery coal field (in short tons)

[Data from Doelling (1972b); 1 short ton = 0.907 tonnes]

U.S. Geological Survey 7.5-minute quadrangle	Class I and II (measured and indicated)	Class III (inferred)
Walker Flat	209,200,000	289,200,000
Emery East	150,702,000	181,931,000
Emery 1 NE	-	-
Willow Springs	131,813,000	49,950,000
Johns Peak	72,000,000	98,200,000
Geyser Peak	34,840,000	-
Mesa Butte	78,000,000	-
Class total	676,555,000	619,281,000
	Total Coal	1,295,836,000

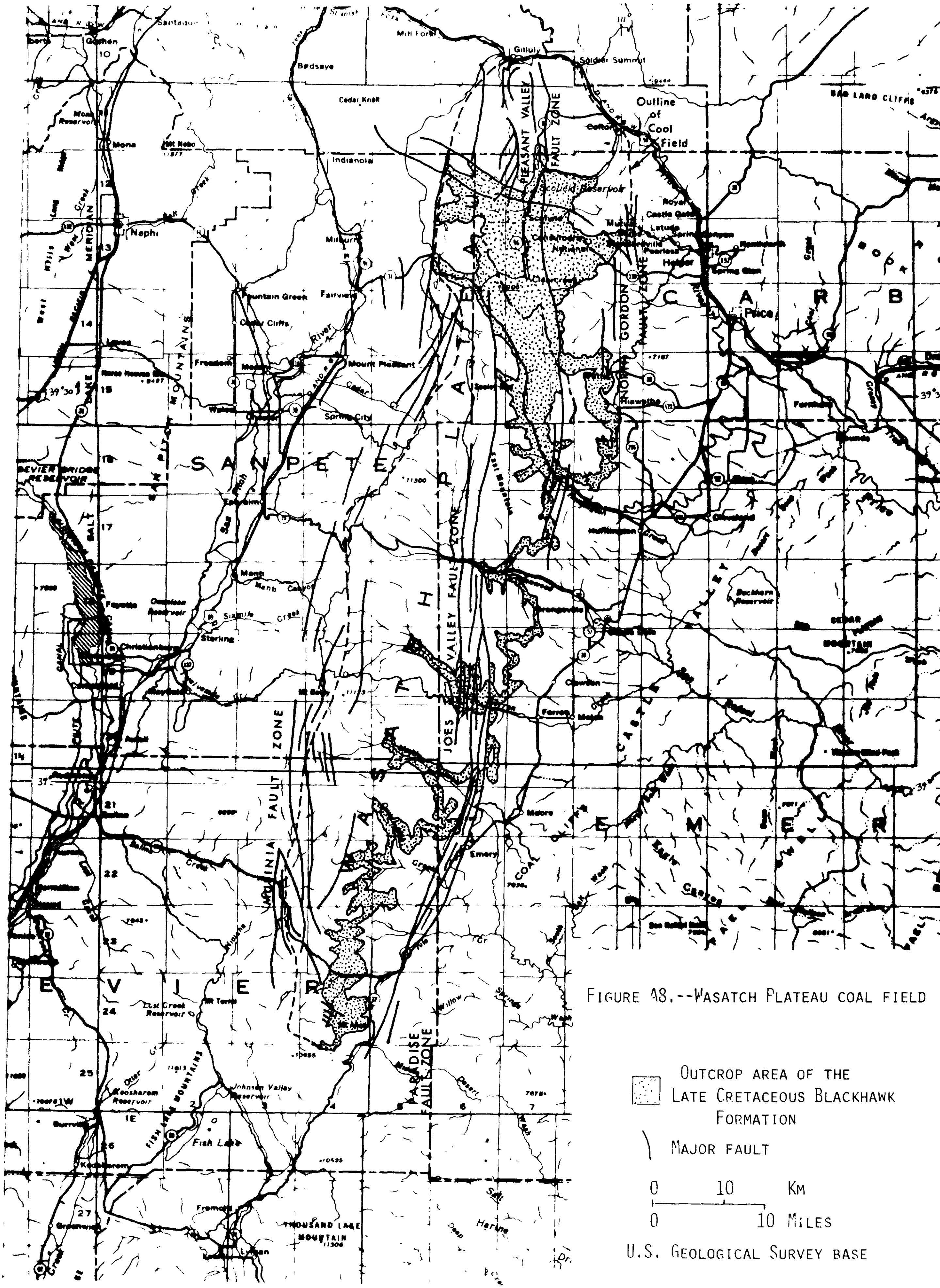

Figure 48.--Wasatch Plateau coal field

Status of information

Spieker (1931) completed a detailed study of the Wasatch Plateau coal field during the summers of 1921-1924, and his remains the definitive report on the geology and coal resources of the field. The report contains excellent geologic maps. Spieker's findings have been summarized, and to some extent updated, by Doelling (1972c). Papers by Spieker and Reeside (1925) and Katich (1954) have also described the stratigraphy of the area.

Coal-bearing rock units

Coal of the Wasatch Plateau coal field is contained entirely within gently westward dipping strata of the Upper Cretaceous Blackhawk Formation. Ranging in thickness between 213 and 305 m, the Blackhawk consists of sandstone, shale, carbonaceous shale, and coal, and generally forms slopes and small ledges between the prominent cliffs produced by the overlying Castlegate Sandstone and the underlying Star Point Sandstone. In the northern part of the field, sandstone comprises about two-thirds of the thickness of the formation (Spieker, 1931). The proportion of sandstone increases to the south, resulting in better exposure of the formation in the southern part of the field. The thicker coal beds are in the lower 76 to 107 m of the Blackhawk Formation. Thin coal beds are locally present throughout its thickness.

Genetically, the Blackhawk is closely related to the underlying Star Point Sandstone. The Star Point, 61 to 137 m thick, consists of several cliff-forming units of fine- to medium-grained sandstone separated by nonresistant, platy sandstone and dark-gray shale similar to that of the Mancos Shale. Its basal contact with the "Masuk" Shale Member of the Mancos Shale is gradational. The contact between the Blackhawk and the Star Point is sharp, but conformable, and is directly below or very close to the overlying Hiawatha coal bed in much of the field. The Star Point Sandstone was deposited in shallow-marine environments and records general eastward progradation of the western shoreline of the Interior Cretaceous seaway during Late Cretaceous (Campanian) time (Spieker, 1931). The Blackhawk accumulated in nonmarine environments marginal to the shoreline. The Star Point Sandstone and the Blackhawk Formation are thus analogous in terms of environmental history, and possibly correlate (Peterson and Ryder, 1975) with the "Emery" Sandstone and Masuk Shale Members, respectively, of the Mancos Shale in the Henry

Mountains region (fig. A6). They are likewise genetically analogous to the lower and upper units of the Ferron Sandstone Member in the Emery and Henry Mountains coal fields.

The Blackhawk Formation is disconformably overlain by the cliff-forming Castlegate Sandstone. The Castlegate, 46 to 122 m thick, consists of coarse sandstone with lenses of conglomerate; it is the result of deposition of sediment in fluvial and floodplain environments (Katich, 1954).

Faults

Faults cut and displace the coal-bearing strata of the Wasatch Plateau coal field, and are of importance because of the difficulties that they cause during mining of coal. The faults occur in definite zones separated by broader areas within which the strata are relatively undisturbed. The important fault zones have been named by Spieker (1931) and Spieker and Baker (1928), and are labelled on figure A8. They are, from southwest to northeast, the Musinia, Joes Valley, Pleasant Valley, and North Gordon fault zones. With the exception of the North Gordon fault zone, which consists of a series of faults with diverse trends, each of the fault zones consists of a north-south-trending graben--a down-dropped prism of the earth's crust--within which much fracturing has occurred. The faults that bound the grabens have the greatest displacements. Data for the fault zones are summarized in table A3.

Coal beds

The Blackhawk Formation contains many beds of coal, 23 of which have been named (Doelling, 1972c). The important beds occur in the lower third of the formation. The coal beds are lenticular, being well developed and of minable thicknesses beneath limited areas. Table A4 lists the coal beds and the areas in which they are of importance. Areas of the Wasatch Plateau coal field, as defined by Doelling (1972c), are shown on figure A9.

The Hiawatha bed, which occurs at the base of the Blackhawk Formation, is the most important coal bed of the Wasatch Plateau coal field, having the greatest areal extent (fig. A10). It has its maximum thickness in the Hiawatha area, where thicknesses of as much as 8.5 m have been mined (Doelling, 1972c).

Table A3.--Fault zones of the Wasatch Plateau coal field

[After Doelling, 1972c]

Fault	Miles[1]			Greatest displacement (feet[2])
	Known length on plateau	Average width	Average distances from next zone east	
Musinia	50	2	12	2,500
Joes Valley	75	2	5	2,500+
Pleasant Valley	35	4	6	1,500
North Gordon	22	4	-	800

[1]1 mile = 1.609 km.

[2]1 foot = 0.3048 m.

Table A4.--Coal beds of the Wasatch Plateau coal field and areas of their importance

[Figure A9 gives locations of areas]

Coal bed or zone	Area of importance
Bear Canyon bed	Cottonwood-Huntington Canyon
Upper Bear Canyon bed	Huntington Canyon
Blind Canyon bed	Huntington and Cottonwood Canyon
Bob Wright coal zone	Gordon Creek and Pleasant Valley
Candland bed	Huntington Canyon
Castlegate "A" bed	Pleasant Valley, Gordon Creek, Huntington Canyon
Cottonwood bed	Cottonwood Canyon
Fourth bed	Huntington Canyon
Gordon bed	Gordon Creek
Haley bed	Pleasant Valley
Hiawatha bed	All areas, except Pleasant Valley
Ivie bed	South
Muddy No. 1 bed	Flagstaff Peak
Muddy No. 2 bed	South
Second bed	Hiawatha
Slide Hollow bed	Flagstaff Peak
Tank bed	Hiawatha
Third bed	Huntington Canyon
Union Pacific bed	Pleasant Valley
Upper bed of Grimes Wash	Cottonwood Canyon
Upper Hiawatha bed	Cottonwood Canyon, Flagstaff Peak, South
Upper Ivie bed	South
Wattis bed	Hiawatha

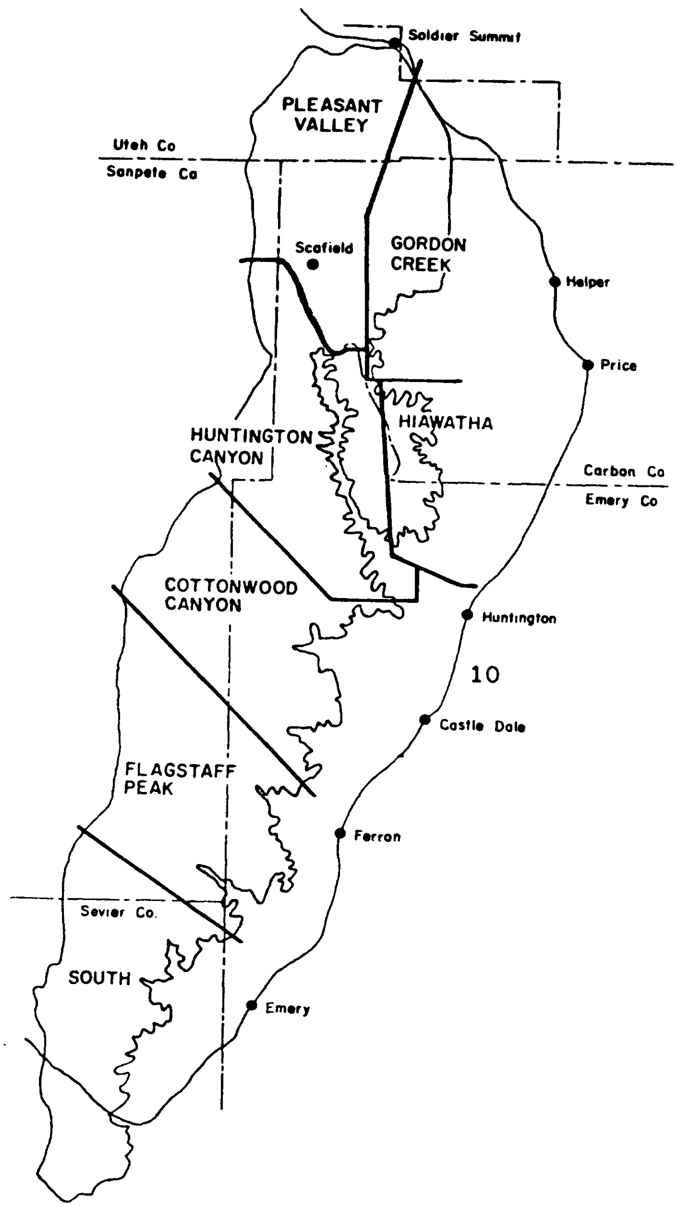

FIGURE A9.-- DESIGNATED AREAS OF THE WASATCH PLATEAU COAL FIELD. (FROM DOELLING, 1972C.) REFER TO FIGURES A4 AND A11 FOR LOCATION OF AREA.

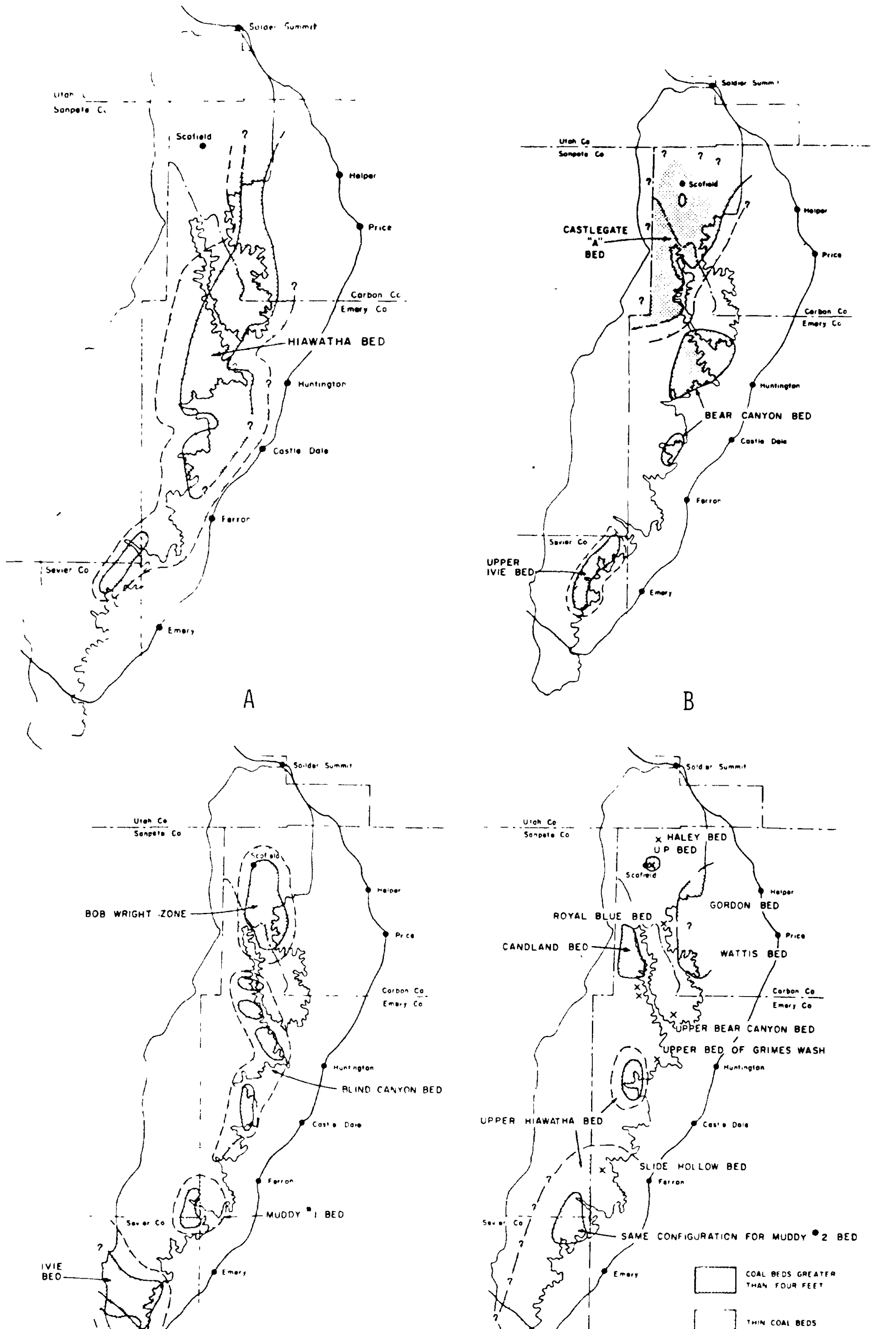

FIGURE A10.--AREAS OF IMPORTANCE OF THE HIAWATHA COAL BED (A); THE CASTLEGATE "A", BEAR CANYON, AND UPPER IVIE COAL BEDS (B); THE BOB WRIGHT ZONE AND BLIND CANYON, MUDDY NO. 1, AND IVIE COAL BEDS (C); AND THE HALEY, U.P., ROYAL BLUE, GORDON, CANDLAND, WATTIS, UPPER BEAR CANYON, UPPER GRIMES WASH, UPPER HIAWATHA, SLIDE HOLLOW, AND MUDDY NO. 2 COAL BEDS (D), WASATCH PLATEAU COAL FIELD. (FROM DOELLING, 1972C.) REFER TO FIGURES A4 AND A11 FOR LOCATION OF AREA.

The Castlegate "A" bed is present in the northern part of the Wasatch Plateau coal field, and is second in importance. It is as much as 5.8 m thick, occurring 49 to 64 m above the base of the Blackhawk. Third in importance are the Ivie and Upper Ivie beds of the South area. They are stratigraphically about 24 to 30 m above the base of the Blackhawk and reach respective thicknesses of about 3.4 and 4.0 m. The areas of importance of these and other coal beds are shown on figure A10.

Mines

Coal mining began in the Wasatch Plateau coal field in 1875, the first mine having been opened in Huntington Canyon. The first large mine that operated in the field, the Utah or Mud Creek mine of the Utah Fuel Co., was opened in 1878 in Pleasant Valley, about 4.8 km south of Scofield (fig. A9). Between 1878 and 1909, all of the coal shipped from the Wasatch Plateau coal field was mined in Pleasant Valley. The first mines on the east front of the plateau were established near Hiawatha and Mohrland in 1909 and 1910. Coal mining gradually spread through the entire Wasatch Plateau coal field--Doelling (1972c) records 92 mines--but has been most intense in the northern part. This reflects proximity of the northern part of the field to the main line of the Denver and Rio Grande Western Railroad, and the fact that coal beds are generally thickest in this area. Doelling (1972c) estimates that, as of 1969, 90.7 million tonnes of coal has been produced from the field, 80 percent of this total coming from the Pleasant Valley and Hiawatha areas.

At present, 10 mines are active in the Wasatch Plateau coal field. Their locations are shown on figure A11. Production figures for these mines are summarized in table A5.

Resources

Spieker (1931) calculated the coal resources of the Wasatch Plateau coal field. His data have been modified by Doelling (1972c) to fit 7.5-minute quadrangles, and Doelling's figures are presented in this report (table A6). Unfortunately, Spieker did not distinguish between measured, indicated, inferred, and hypothetical resources--only total resources were calculated. Doelling (1972c) estimated that the total coal resources in the Wasatch Plateau coal field, as a whole, are 9,314 million tonnes. Of this amount, 5,787 million tonnes are the sum of measured, indicated, and inferred resource categories. The remaining 3,527 million tonnes are hypothetical resources.

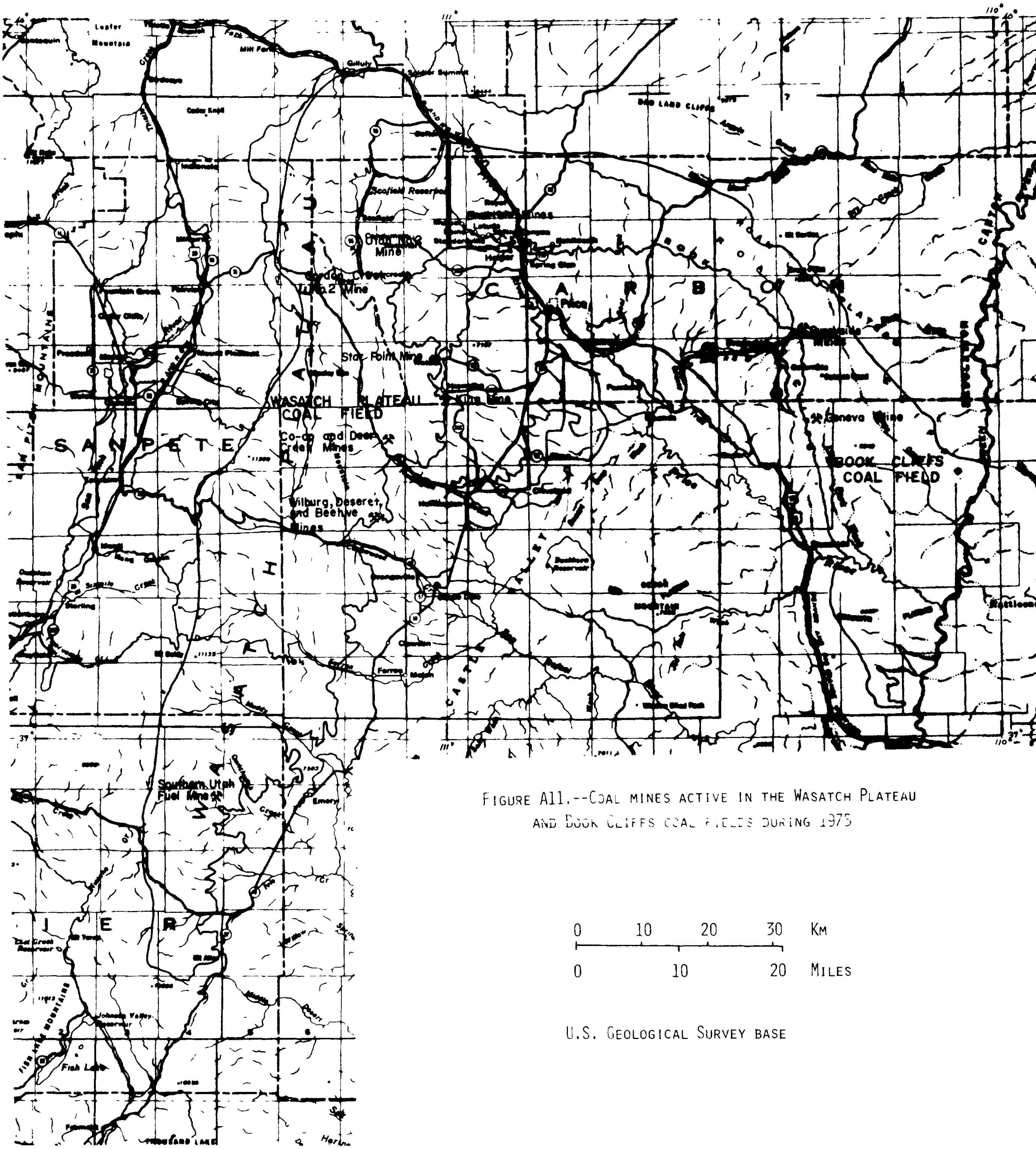

FIGURE A11.--COAL MINES ACTIVE IN THE WASATCH PLATEAU AND BOOK CLIFFS COAL FIELDS DURING 1975

0 10 20 30 KM

0 10 20 MILES

U.S. GEOLOGICAL SURVEY BASE

Table A5.--1975 production figures for coal mines of the Wasatch Plateau coal field, in short tons

[Data supplied by H. H. Doelling, Utah Geol. and Mineral Survey. Locations of mines are shown in figure A11. 1 short ton = 0.907 tonnes]

Beehive Mine	584,356
Co-op Mine	66,000
Deer Creek Mine	1,046,141
Deseret Mine	530,509
Gordon Creek No. 2	258,614
King Mine	529,228
Southern Utah Fuel Mine	827,462
Star Point Mine	435,754
Utah No. 2 Mine	193,398
Wilberg Mine	90,333
Total	4,561,795

Table A6.--Original coal resources and estimated production, Wasatch Plateau coal field (in short tons, in beds averaging 4 feet or more thick under less than 3,000 feet of cover)

[Data from Doelling (1972c); 1 short ton = 0.907 tonnes]

U.S. Geological Survey 7.5-minute quadrangle	Resource	Estimated production ending January 1, 1970
Emery West	164,896,000	164,000
Acord Lakes	491,256,000	1,106,600
Old Woman Plateau	300,393,000	1,000±
Castle Dale NW[1]	377,725,500	8,000
Castle Dale SW[1]	24,321,600	<1,000
Johns Peak	134,481,600	<1,000[1]
Ferron Canyon	57,664,800	<1,000
Flagstaff Peak	392,154,500	40,000
Hiawatha NE[2]	466,054,740	51,776,000
Hiawatha NW[2]	764,426,920	232,500
Hiawatha SE[2]	110,165,420	4,040,300
Hiawatha SW[2]	538,048,020	96,000
Scofield NE[3]	608,784,120	5,400,000
Scofield NW[3]	594,727,740	28,300,000
Scofield SE[3]	302,598,000	8,077,600
Scofield SW[3]	461,930,940	230,000
Soldier Summit SE[4]	462,342,600	6,000
Other areas	126,880,000	-
	6,378,851,700	99,481,000

[1]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[4]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

Because thick coal beds of the Blackhawk Formation seldom occur beneath thin overburden, most of the coal in the Wasatch Plateau coal field may be recovered only by underground mining or in situ recovery techniques.

Book Cliffs coal field

Geologic setting

The Book Cliffs of east-central Utah are formed by resistant sandstones of the Upper Cretaceous Mesaverde Group. They define the southern limit of the Uinta Basin. The 113-km-long stretch of the Book Cliffs that extends from Spring Canyon, where the Book Cliffs join the Wasatch Plateau, to the Green River are included in the Book Cliffs coal field. The coal field has an arcuate shape, curving around the northward-plunging nose of the San Rafael Swell (figs. A4, A12). Dip of the coal-bearing strata is generally 4^{o}-6^{o}, being to the north in the northwestern part of the field and to the northeast in the southeastern part.

As defined by Doelling (1972d), the Book Cliffs coal field encompasses an area of 1,670 square km, including parts of Utah, Duchesne, Carbon, and Emery Counties. The curving, northeastern boundary of the field has been placed a little beyond the line of 914 m of overburden thickness, a distance of 8 to 24 km northward to eastward from the exposures of the coal-bearing strata in the south- to west-facing Book Cliffs. The field is contiguous with the Wasatch Plateau coal field on the west, and with the Sego coal field on the east. Its western and eastern boundaries are drawn respectively at the easternmost fault of the North Gordon fault zone and at the Green River.

Status of information

The geology of the Book Cliffs coal field has been studied in considerable detail. The important coal beds and their relationships to enclosing stratigraphic units were described by Clark (1928) and Fisher (1936). Clark studied the northwestern part of the field; Fisher the southeastern part. The stratigraphy and environmental history of the region has been described by Spieker (1949), Young (1955, 1957, 1966), and Fisher, Erdmann, and Reeside (1960). Doelling (1972d) summarized the work of all of these authors. Detailed work in the Sunnyside area has been done by geologists of the U.S. Geological Survey. (See references listed in Maberry, 1971.)

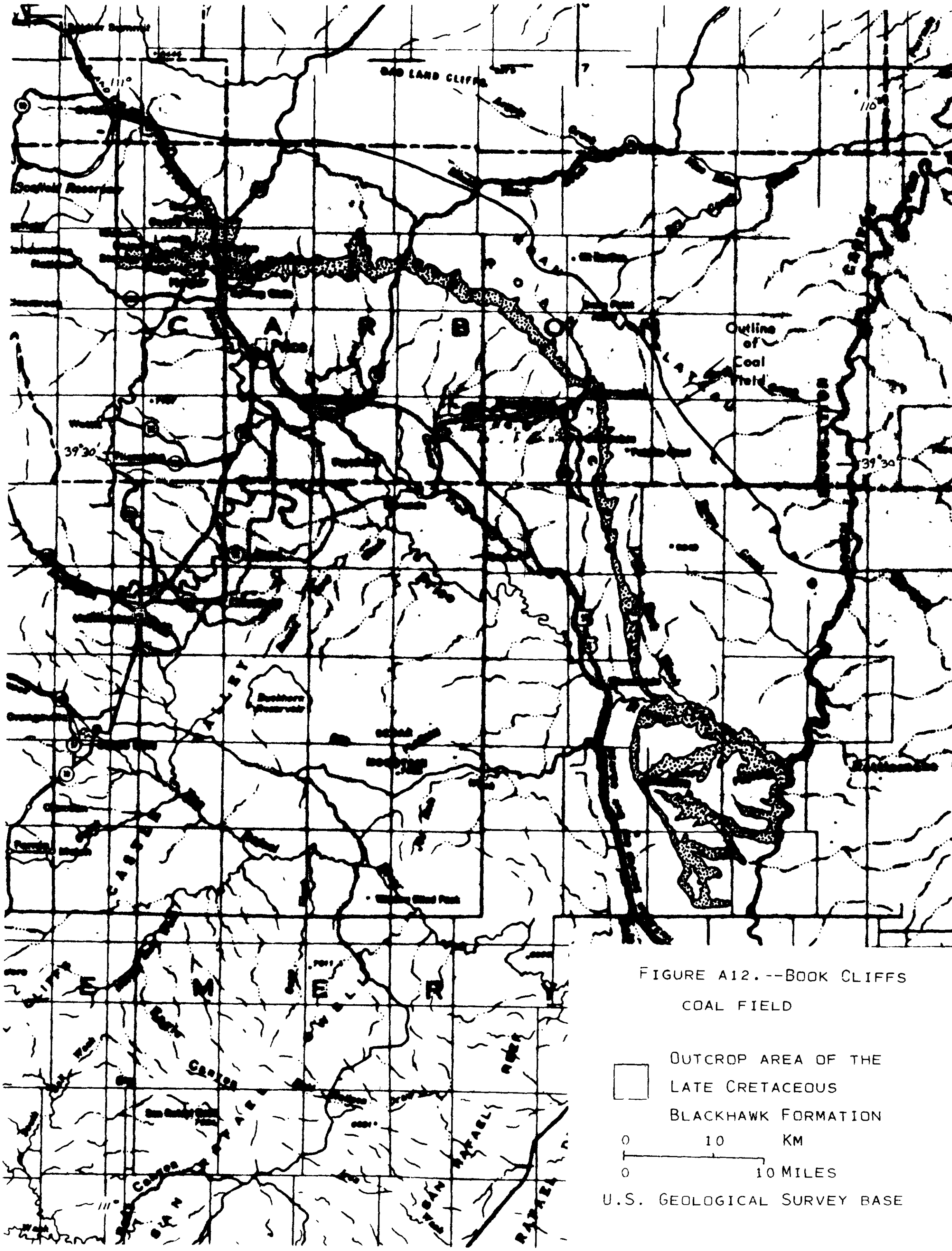

FIGURE A12.--BOOK CLIFFS COAL FIELD

OUTCROP AREA OF THE LATE CRETACEOUS BLACKHAWK FORMATION

0 10 KM

0 10 MILES

U.S. GEOLOGICAL SURVEY BASE

Coal-bearing rock units

The Blackhawk Formation of the Mesaverde Group contains all of the coal beds that are of economic value in the Book Cliffs coal field. In this respect, the Book Cliffs coal field resembles the Wasatch Plateau coal field. In both, the Blackhawk consists of sandstone, shale, carbonaceous shale, and coal. Because the two coal fields are situated with their long axes at nearly right angles, however, the stratigraphic relationships displayed by the Blackhawk and adjacent formations along the outcrop belts are quite different.

The outcrop belt of the Blackhawk Formation along the eastern edge of the Wasatch Plateau coal field essentially parallels the western paleoshoreline of the Interior Cretaceous seaway. Thus movements of the shoreline are reflected by uniform change in rock type along the entire outcrop. The Late Cretaceous (Campanian) eastward regression of the Interior Cretaceous seaway that resulted in deposition of the Star Point Sandstone, Blackhawk Formation, and Castlegate Sandstone was not continuous, but consisted of many minor transgressions and regressions, eastward regression predominating. The exposures of the Blackhawk in the Book Cliffs, oriented perpendicular to the ancient shoreline, reveal these many fluctuations of the shoreline position in cross section. Accordingly, the Blackhawk Formation undergoes marked, large-scale facies changes in relatively short distances. The situation is depicted on figure A13. Tongues of shallow marine sandstone, each of which records progradation of the shoreline, thin eastward, eventually pinching out into the marine Mancos Shale. Successive sandstone tongues rise stratigraphically to the east. The same is true of the coal beds, which accumulated landward of the beaches on which the sands were deposited. The economically important coal beds in the northwestern part of the Book Cliffs coal field are older and stratigraphically lower than are those of the southeastern part of the field. In this manner, the Blackhawk Formation thins from a maximum of 396 m near Castlegate, at the western edge of the field, to a maximum of 145 m at the south end of the Beckwith Plateau (fig. A12) by interfingering of its lower part with the Mancos Shale (Doelling, 1972d). The complex stratigraphic relationships briefly described here have been discussed in detail by Young (1955).

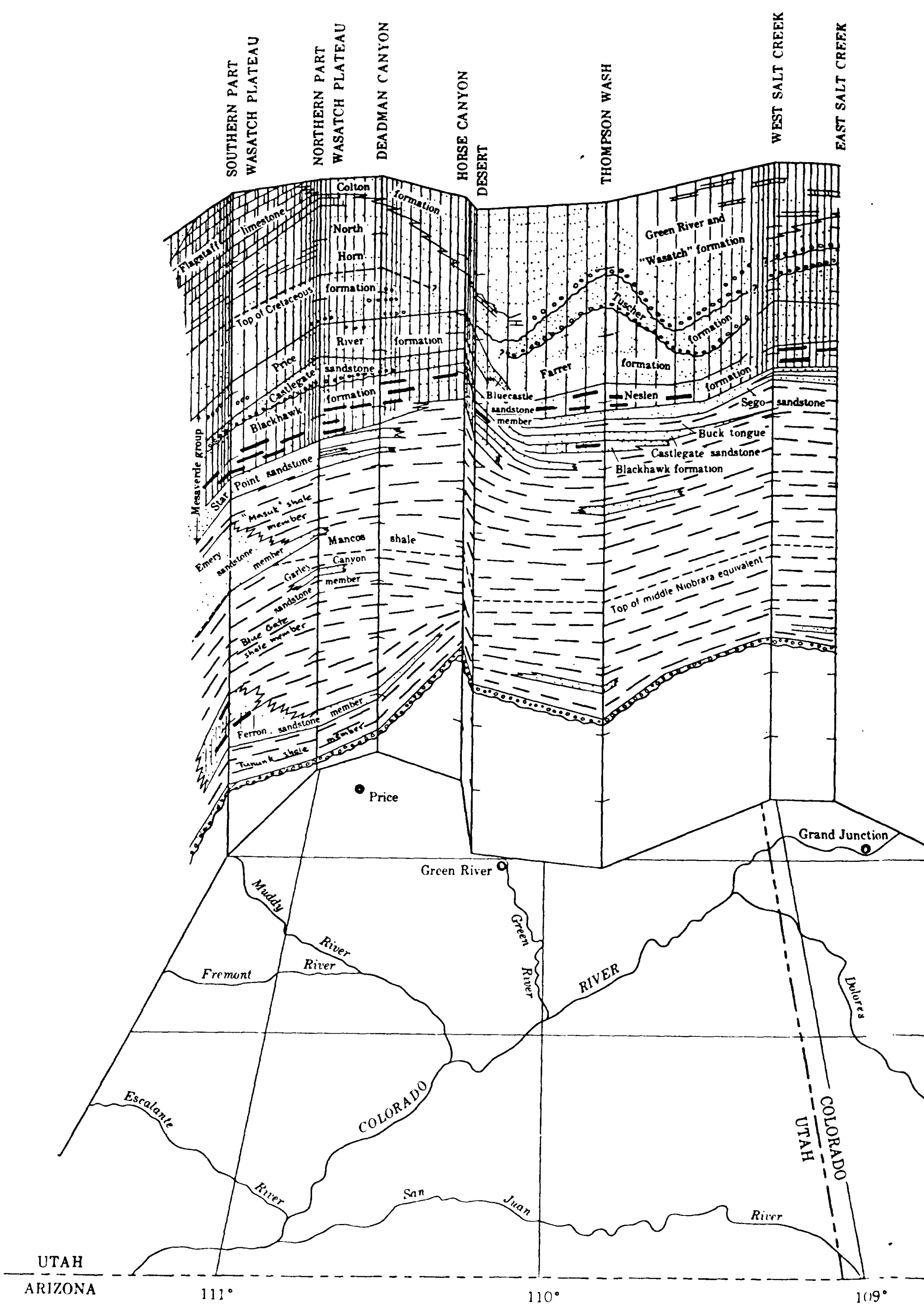

FIGURE A13.--CROSS SECTION SHOWING CORRELATION OF STRATIGRAPHIC UNITS OF THE WASATCH PLATEAU AND BOOK CLIFFS, UTAH. (MODIFIED FROM FISHER, ERDMANN, AND REESIDE, 1960.)

Coal beds

Coal beds of the Blackhawk Formation in the Book Cliffs coal field are lenticular, reaching minable thicknesses (1.2 m) beneath limited areas. The important coal beds, listed in descending stratigraphic order, are related to their areas of importance in table A7. Areas of the Book Cliffs coal field, as designated by Doelling (1972d), plus the areas of greatest extent and thickness of the important coal beds, are shown graphically on figure A14.

The most important coal bed of the Book Cliffs coal field is the Lower Sunnyside bed. It has the greatest areal distribution of any coal bed in the field, and in the Sunnyside area it is locally 5.5 m thick. Of particular significance is the fact that Sunnyside coal, when blended with 15 to 20 percent of low- to medium-volatile coals from other sources, produces a metallurgical-grade coke.

Mines

Production of coal from the Book Cliffs coal field began in 1889, with the opening of the Castle Gate mine. Because of its location on the main line of the Denver and Rio Grande Western Railroad, its proximity to western markets, and the high quality of the coal mined there, the Castle Gate area underwent rapid development. It was found that the coal could be used to produce a low-grade coke, and by 1900 more than 200 2.4-m beehive coking ovens were in operation in the Castle Gate area.

Coking coal was discovered in the Sunnyside area in 1898. Coal from the Sunnyside area was originally hauled to the coking ovens at Castle Gate, but because of the superior quality of the coke produced, operations quickly shifted to Sunnyside. By 1919, more than 800 3.6- to 4.0-m beehive ovens were producing coke at the Sunnyside coke plant, making it the largest beehive operation in the United States.

Until the last few years, the Book Cliffs coal field remained the single most important coal field in the State of Utah, accounting for about 75 percent of annual production. Maximum production of 5.4 million tonnes annually was achieved during the 1910's and early 1920's, and again during the late 1940's and early 1950's. Doelling (1972d) estimated that a total of 189.2 million tonnes of coal have been produced from the field.

Mining activity centered in the Castle Gate and Sunnyside areas during the development of the Book Cliffs coal field, and this situation remains the same today. Doelling (1972d) recorded 63 mines and prospects that have been

Table A7.--Coal beds of the Book Cliffs coal field and areas of importance

[From Doelling (1972d); figure 14 gives location of areas]

Coal bed or zone	Area of importance
Beckwith zone	Woodside
Upper Sunnyside bed	Sunnyside
Lower Sunnyside bed	Sunnyside
Rock Canyon bed	Soldier Canyon and Sunnyside
Fish Creek bed	Soldier Canyon
Gilson bed	Soldier Canyon
Kenilworth bed	Castlegate
Castlegate zone	Castlegate
Spring Canyon zone	Castlegate

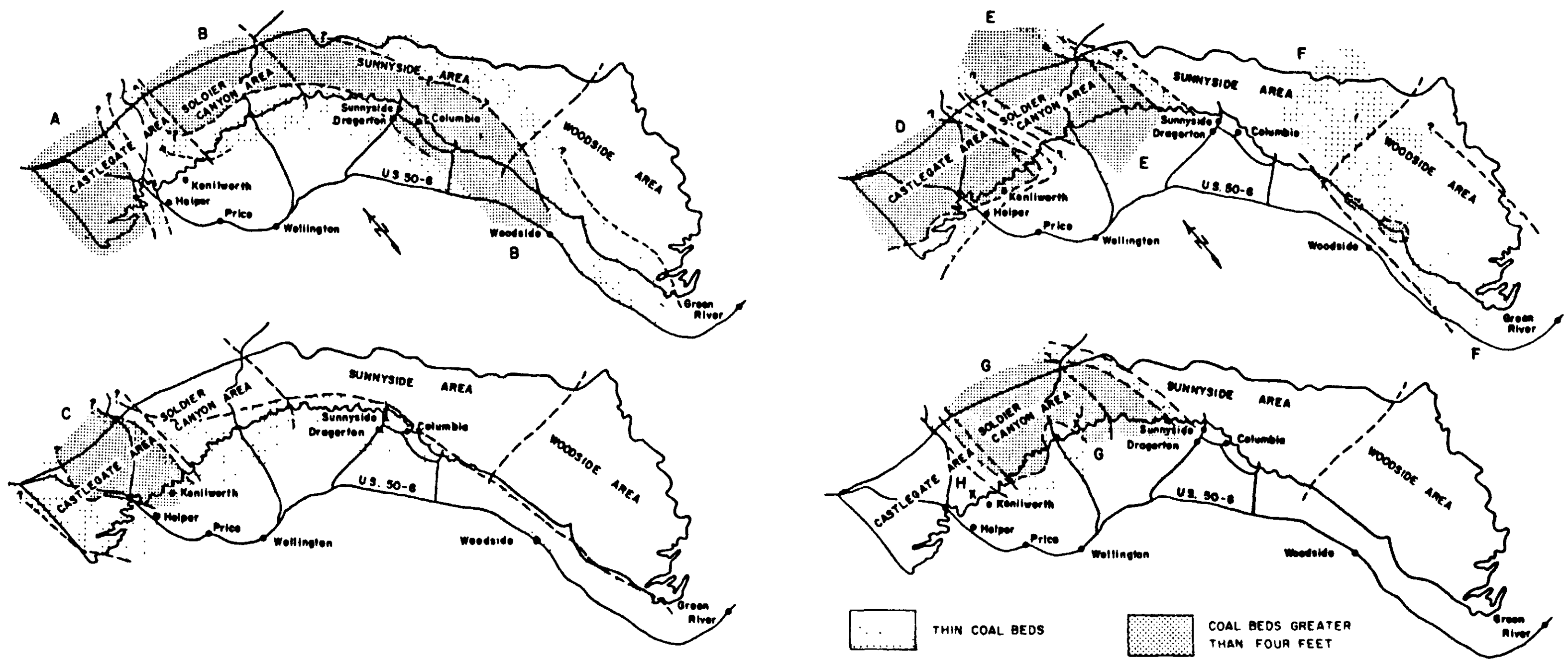

FIGURE A14. AREAS OF IMPORTANCE OF THE SPRING CANYON (A), SUNNYSIDE (B), KENILWORTH (C), CASTLEGATE (D), ROCK CANYON (E), BECKWITH (F), GILSON (G), ROYAL BLUE (H), AND FISH CREEK (J) COAL BEDS, BOOK CLIFFS COAL FIELD. (FROM DOELLING, L972D.)

opened in the field. At present, seven mines are active and producing coal. The mines and their production figures for 1975 are listed in table A8. The locations of the mines are shown on figure A11. Much of the coal from the field is being shipped by unit train to steel plants at Fontana, Calif., and Provo, Utah.

Resources

The coal resources of the Book Cliffs coal field were calculated by Clark (1928) and Fisher (1936). Their figures were updated and modified to fit specific quadrangles by Doelling (1972d), whose figures are summarized in table A9. The resource estimates were not broken down into measured, indicated, and inferred categories. Doelling (1972d) calculated that the total of measured, indicated, and inferred coal resources for the entire field is 3,328 million tonnes. Hypothetical resources are 240 million tonnes. The small proportion of hypothetical resources reflects the fact that outcrop, mine, and drill-hole data bearing on the thickness of the coal beds are fairly complete. All coal beds of the Book Cliffs coal field must be underground mined. The amount of coal that has been produced from the field, about 191 million tonnes, is small when compared to the resources that remain. It must be borne in mind, however, that the production figure represents the most easily mined coal--that which occurs in thick beds beneath shallower overburden cover. Future mining will necessarily take place in areas where overburden thicknesses and pressures are great.

Sego coal field

Geologic setting

The Sego coal field of east-central Utah follows, and lies immediately north of, the Book Cliffs between the Green River and the Utah-Colorado State line. As defined by Doelling (1972e), the field is approximately 105 km long, has a maximum width of 9.6 km, and includes an area of about 1,010 square km (figs. A4, A15). The dip of the coal-bearing strata is gentle, generally between 2^{o} and 4^{o} to the north and northeast. The western boundary of the field, along which the Sego coal field is contiguous with the Book Cliffs coal field, is drawn at the Green River. The eastern boundary is the Utah-Colorado State line.

Table A8.--1975 production figures for coal mines (fig. 11) of the Book Cliffs coal field, in short tons

[Data supplied by H. H. Doelling, Utah Geological and Mineral Survey; 1 short ton = 0.907 tonnes]

Mine	Tonnage
Braztah No. 3 Mine	318,841
No. 4 Mine	154,765
No. 5 Mine	34,101
Geneva	674,148
Sunnyside Nos. 1, 2, 3 Mines	1,059,521 (most from No. 1)
Total	2,241,376

Table A9.--Coal resources of the Book Cliffs coal field (in millions of short tons)

[Data from Doelling (1972d); 1 short ton = 0.907 tonnes]

7.5 quadrangle	Original tonnage	Recoverable (rounded)	Production to 1970	Recoverable remaining
Castlegate-Kyune[1]	935	258	53.0	205.0
Castlegate-Matts Summit[2]	717	236	65.0	171.0
Wellington-Minnie Maud W[3]	336	134	2.5	131.5
Wellington NE[4]	530	185	2.6	182.4
Sunnyside NW[5]	272	136	<0.1	136.0
Sunnyside SW[5]	123	55	13.0	42.0
Sunnyside SE[5]	359	143	39.0	104.0
Woodside NE[6]	399	160	33.5	126.5
Woodside SE[6]	72	36	-	36.0
Totals	3,743	1,343	208.6	1,134.4

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

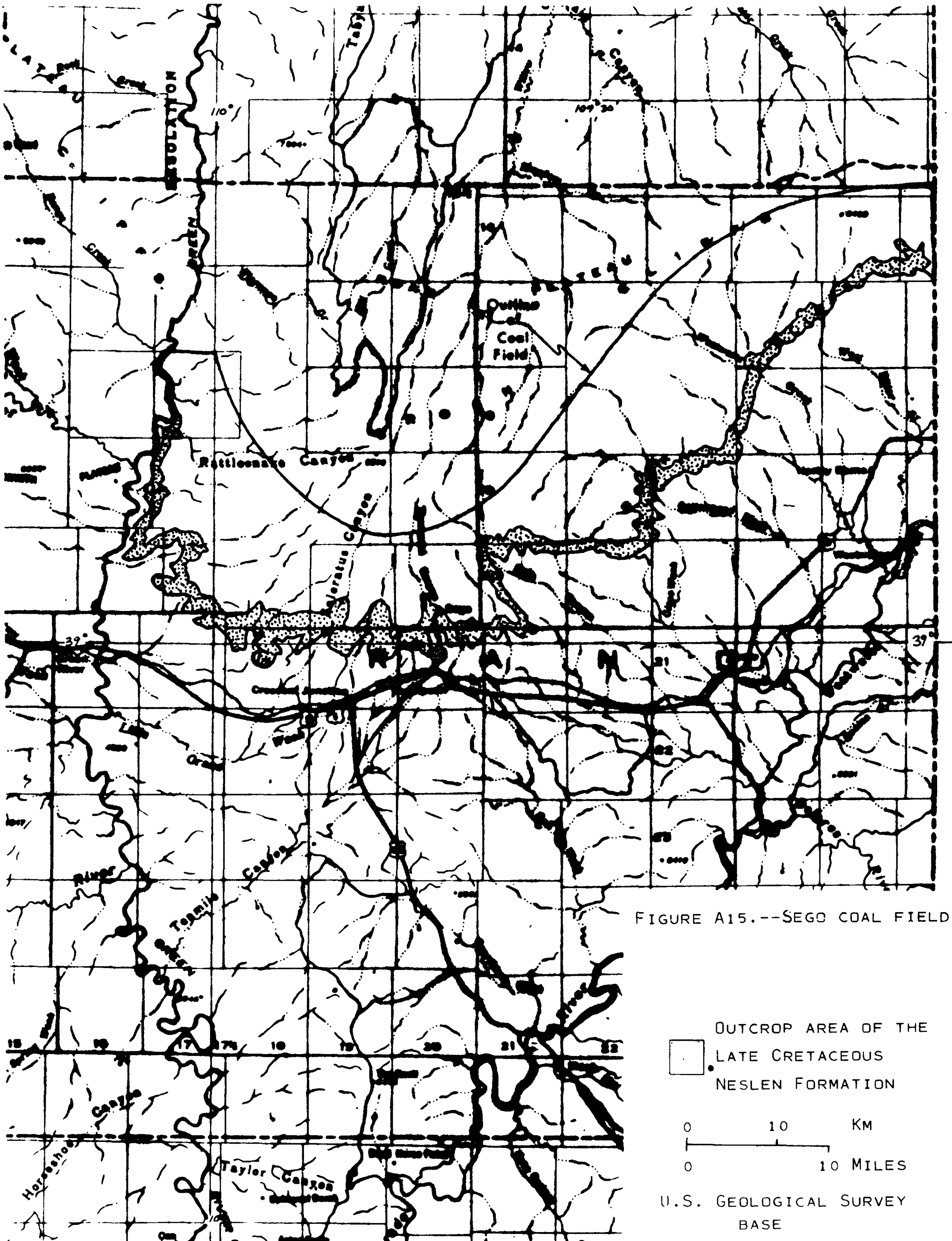

FIGURE A15.--SEGO COAL FIELD

Status of information

Geologic investigations of the coal resources of the Sego coal field were carried out by Clark (1914) and Fisher (1936). Clark's study concerned only the Sego and Thompson Canyon areas, in the western part of the field. Spieker (1949), Young (1955, 1957, 1966), and Fisher, Erdmann, and Reeside (1960) thoroughly described the stratigraphy, paleontology, and environmental history of the area. The geology of the Sego coal field was summarized by Doelling (1972e).

Coal-bearing rock units

Within the Sego coal field, coal beds have been reported in the Blackhawk Formation, which is recognizable only in the westernmost part of the field, the Castlegate Sandstone, and the Neslen and Farrer Formations. Only the coal beds of the Neslen Formation are thick and continuous enough to be of economic importance.

The Neslen Formation, 76 to 125 m thick, (Doelling, 1972e), consists of fine- to medium-grained sandstone, siltstone, shale, and coal. The formation produces a steep slope with many sandstone ledges above the vertical cliff formed by the underlying Sego Sandstone. The Sego Sandstone consists of fine- to medium-grained, calcareous sandstone and averages 61 m in thickness. The Sego grades downward into, and is in transitional contact with, marine shale of the Buck Tongue of the Mancos Shale. The upper part of the Buck Tongue, the Sego Sandstone, and the Neslen Formation record deposition of sediment in offshore marine, nearshore marine, and marginal marine-lagoonal environments, respectively, and accumulated during eastward progradation of the western shoreline of the Interior Cretaceous seaway during Late Cretaceous (Campanian) time (fig. A13). The Neslen Formation is conformably overlain by the nonmarine Farrer Formation. Ranging from 122 to 335 m in thickness, the Farrer is lithologically much like the Neslen, but contains a greater percentage of sandstone and lacks important beds of coal.

Coal beds

Thin, lenticular beds of coal occur locally throughout the thickness of the Neslen Formation. The thicker coal beds, however, occur in four laterally traceable coal zones. These are, in descending stratigraphic order, the Carbonera, Chesterfield, Ballard, and Palisade coal zones. The Chesterfield and Ballard zones are the most important. Both have their greatest thickness of coal in the area between Nash and Thompson Canyons, north and northeast of Thompson, where they contain coal beds that average 1.2 to 1.8 m in thickness (Doelling, 1972e).

Mines

Mining of coal in the Sego coal field began in 1900, when a Mr. Ballard opened a mine in a coal bed in what is now called the Ballard coal zone in Sego Canyon. Coal from the mine was hauled about 9.6 km by wagon to Thompson and the Denver and Rio Grande Western Railroad. The Ballard property was purchased by the American Fuel Co. in 1912. The company built a branch line from the railroad at Thompson and established the town of Neslen, later to be known as Sego, near the mine. Coal was subsequently mined from the Ballard, Palisade, and Chesterfield coal zones from a total of 10 portals. The Chesterfield coal zone proved to be the most important, and supported all production after 1915. The mines became the property of the Chesterfield Coal Co. in 1925, and production continued until 1953, when the mines were shut down. There has been no production of coal from the Sego coal field since that time. Doelling (1972e) states that when operations ceased, a total of 2,364,000 tonnes of coal had been removed from the area of Thompson and Sego Canyons. Several small mines operated intermittently in the field until 1953, producing small amounts of coal for local consumption. Total production from these small mines was about 3,266 tonnes.

Resources

Most of the coal resources of the Sego coal field occur in the western part of the field, particularly in the Thompson and Sego Canyons area. The coal resources of the Sego coal field have been estimated by Fisher (1936) and by Doelling (1972e). Doelling's resource estimates, by quadrangle, are tabulated in table A10. The total coal resources (including measured, indicated, and inferred categories) that occur in beds 0.46 m or more in thickness is estimated to be 458 million metric tons. Of this amount, 266.3 million tonnes are in beds 1.2 m or more in thickness. The distribution of coal resources among the four recognized coal zones is shown in table A11.

Table A10.--Original coal resources (in millions of short tons) of the Sego coal field

[Data from Doelling (1972e); 1 short ton = 0.907 tonnes]

Quadrangle (7.5-minute)	Measured and estimated I and II	Inferred III	Total coal	Beds 4 feet (1.22 m) or more
Colorado line[1]	-	-	-	-
Cottonwood Creek[2]	-	-	-	-
Floy Canyon SE and Floy Canyon SW[3]	16.9	17.9	34.8	17.9
Gunnison Butte East[4]	-	-	-	-
Sego Canyon SE[5]	15.8	52.9	68.7	61.9
Sego Canyon SW[5]	238.4	155.3	393.7	205.9
West Bitter Creek[6]	-	-	-	-
Westwater Creek North[7]	-	7.9	7.9	7.9
Westwater Creek South[8]	-	-	-	-
Totals	271.1	234.0	505.1	293.6

[1]Includes parts of Rat Hole Ridge and Jim Canyon 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Includes parts of Flume Canyon and Cisco Springs 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Includes the southeastern and southwestern quarters, respectively, of the Floy Canyon 15-minute quadrangle of the U.S. Geological Survey.

[4]Includes part of the Gunnison Butte 15-minute quadrangle of the U.S. Geological Survey.

[5]Includes the southeastern and southwestern quarters, respectively, of the Sego Canyon 15-minute quadrangle of the U.S. Geological Survey.

[6]Includes parts of Bryson Canyon and San Arroyo Ridge 7.5-minute quadrangles of the U.S. Geological Survey.

[7]Includes parts of the Dry Canyon and Antone Canyon 7.5-minute quadrangles of the U.S. Geological Survey.

[8]Includes parts of the Antone Canyon and Danish Flat 7.5-minute quadrangles of the U.S. Geological Survey.

Table A11.--Distribution of resource to zones in the Sego coal field (in millions of short tons)

[From Doelling (1972e); 1 short ton = 0.907 tonnes]

	>4-foot (>1.2-m) beds	<4-foot (<1.2-m) beds
Carbonera zone	7.9	-
Chesterfield zone	116.3	69.3
Ballard zone	93.3	89.4
Palisade zone	76.1	44.8
Other beds	-	8.0
Totals	293.6	211.5

Coal quality and composition

Coal in the Henry Mountains, Emery, Wasatch Plateau, Book Cliffs, and Sego fields ranges in rank from high-volatile C bituminous to high-volatile A bituminous coal and the heat value on an as-received basis ranges from 7,045 to 14,220 Btu/lb (3,915 to 7,900 kcal/kg). Most of the coal is agglomerating and some of the coal (Book Cliffs field, Sunnyside area) is used for coking (Doelling, 1972d).

Most of the coal is classed as low to medium ash and as low-sulfur coal, containing 6 to 12 percent ash and 0.6 to 1.0 percent sulfur. Within a given field little difference in quality among coal beds is noted, although locally beds higher in ash and/or sulfur content do occur (Doelling, 1972b).

Many proximate analyses are available of the coal from each of the fields, but the number of detailed trace element analyses on which to base a summary are sufficient only for coal from the Wasatch Plateau and Book Cliffs fields. The limited number of complete analyses of coal from the Henry Mountains, Emery, and Sego fields (two, one, and one, respectively) precludes any meaningful summary at this time.

Henry Mountains field

Sixteen analyses of coal for the entire Henry Mountains coal field indicate the quality of coal, but many more analyses are necessary to give an accurate picture. Of the sixteen, thirteen are from coal beds in the "Emery" Sandstone Member, two from the Ferron Sandstone Member of the Mancos Shale, and one is from the Dakota Sandstone. The averages of the proximate analyses are compared in table A12 (Doelling, 1972a).

Emery field

Forty-seven proximate analyses summarized in table A13 indicate the quality of coal in the Emery field. Most of these samples were from outcrops or abandoned prospects, and the presence of splits and impurities in many beds probably explains the differences noted in ash, sulfur, and Btu/lb values (Doelling, 1972b).

Table A12.--Average proximate analyses of coal, Henry Mountains coal field

[From Doelling, 1972a]

	As received, percent		
	"Emery" coal	Ferron coal	Dakota coal
Moisture	9.8	5.0	5.8
Volatile matter	36.5	35.3	58.2
Fixed carbon	43.9	42.9	34.2
Ash	9.4	15.3	1.7
Sulfur	0.87	2.85	2.92
Btu/lb	11,253	11,575	13,478

Table A13.--Average proximate analyses of coal, Emery coal field

[from Doelling, 1972b, table 2]

	No. analyses	As-received, percent	
		Average	Range
Moisture	47	7.4	2.3 - 23.6
Volatile matter	46	37.7	32.3 - 43.9
Fixed carbon	46	44.8	32.9 - 52.2
Ash	47	8.5	4.0 - 23.6
Sulfur	46	0.95	0.31 - 4.66
Btu/lb	44	11,450	7,823 - 12,970

Wasatch Plateau field

More than 900 proximate analyses show little difference in quality among coal beds throughout the field. These analyses are discussed in Doelling (1972c), from which the following summary statements and tables are taken.

(1) The moisture content of 914 samples from the entire field ranges from 0.7 to 14.5 percent and averages 6.1 percent (table A14). The coal with the lowest moisture content (commonly less than 5 percent) is located in the West Hiawatha quadrangles. Moisture content increases to the north and south from this area.

(2) Based on 733 analyses, the average volatile matter content of the coal in the field is 42.0 percent (table A15). The coal with the highest average content of volatile matter comes from the Hiawatha quadrangles.

(3) Based on 773 analyses, the fixed carbon content of coal averages 45.4 percent (table A16).

(4) The analyses of more than 800 samples indicate that the average ash content in Wasatch Plateau coal is 6.5 percent (table A17). No regional trend in percent of ash is apparent.

(5) The sulfur content of 722 Wasatch Plateau coal samples averages 0.6 percent (table A18).

(6) The average Btu/lb of 788 samples from the field is 12,590 (6,995 kcal/kg) with a range from 10,250 to 13,690 (5,695 to 7,605 kcal/kg) (table A19). The coal with the higher values lies in the Hiawatha quadrangles.

In summary, the Wasatch Plateau field coal has the following average characteristics, as-received: moisture, 6.1 percent; volatile matter, 42.0 percent; fixed carbon, 45.4 percent; ash, 6.5 percent; sulfur, 0.6 percent; and Btu/lb, 12,590 (6,995 kcal/kg) (Doelling, 1972c).

According to the American Society for Testing and Materials Classification, the coal is generally a high-volatile B bituminous coal. The coal is noncoking.

The composition of ash of Wasatch Plateau field coal and the concentrations of trace elements in the coal are given in table A20. For comparison, similar information is given in table A21 for 295 Rocky Mountain province coal samples.

Table A14.--Moisture content of coal, Wasatch Plateau coal field

[From Doelling, 1972c]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Soldier Summit SE[1]	0	-	-
Scofield NE[2]	47	6.9	3.2-12.6
Scofield NW[2]	93	7.5	2.8-14.5
Scofield SE[2]	49	6.5	2.7-11.1
Scofield SW[2]	22	7.2	4.9-11.0
Hiawatha NE[3]	386	5.6	0.7-11.0
Hiawatha NW[3]	41	4.9	3.1- 6.8
Hiawatha SE[3]	154	5.2	1.2-11.4
Hiawatha SW[3]	27	4.7	1.5-13.2
Castle Dale NW[4]	3	7.7	6.4- 9.8
Ferron Canyon	0	-	-
Castle Dale SW[4]	0	-	-
Flagstaff Peak	1	8.4	8.4
Emery West	7	8.3	7.0-12.9
Acord Lakes	12	8.7	5.6-10.4
Old Woman Plateau	0	-	-
Johns Peak	2	13.4	12.9-13.9
Wasatch Plateau field	844	6.1	0.7-14.5

[1]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[4]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

Table A15.--Volatile matter content of coal, Wasatch Plateau coal field

[From Doelling, 1972c]

Quadrangle (7.5-minute)	No. of samples	As received, percent	
		Average	Range
Soldier Summit SE[1]	0	-	-
Scofield NE[2]	40	41.6	37.3-44.4
Scofield SW[2]	86	41.3	35.3-54.3
Scofield SE[2]	44	40.8	37.3-43.6
Scofield SW[2]	18	41.8	37.7-45.1
Hiawatha NE[3]	372	42.4	36.3-46.4
Hiawatha NW[3]	35	43.4	40.4-46.0
Hiawatha SE[3]	140	42.1	37.4-45.6
Hiawatha SW[3]	16	41.6	37.9-43.7
Castle Dale NW[4]	3	38.8	34.4-41.0
Ferron Canyon	0	-	-
Castle Dale SW[4]	0	-	-
Flagstaff Peak	1	39.1	39.1
Acord Lakes NE	5	38.1	37.5-38.6
Acord Lakes NW	11	38.3	36.2-40.6
Acord Lakes SW	0	-	-
Emery 3 NW	2	36.2	35.2-37.2
Wasatch Plateau field	773	42.0	34.4-54.3

[1]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[4]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

Table A16.--Fixed carbon content of coal, as received, Wasatch Plateau coal field

[From Doelling, 1972c]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Soldier Summit SE[1]	0	-	-
Scofield NE[2]	40	44.7	39.7-49.1
Scofield NW[2]	86	44.9	28.3-53.5
Scofield SE[2]	44	46.0	39.8-48.9
Scofield SW[2]	18	45.9	42.8-48.0
Hiawatha NE[3]	372	45.6	38.3-51.2
Hiawatha NW[3]	35	45.7	43.5-51.1
Hiawatha SE[3]	140	44.8	35.1-48.4
Hiawatha SW[3]	16	46.4	43.2-48.7
Castle Dale NW[4]	3	49.5	47.0-54.4
Ferron Canyon	0	-	-
Castle Dale SW[4]	0	-	-
Flagstaff Peak	1	45.2	45.2
Acord Lakes NE	5	48.6	45.3-46.4
Acord Lakes NW	11	46.6	43.3-50.4
Acord Lakes SW	0	-	-
Emery 3 NW	2	43.8	43.6-43.9
Wasatch Plateau field	773	45.4	28.3-54.4

[1]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[4]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

Table A17.--Ash content of coal, as received, Wasatch Plateau coal field

[From Doelling, 1972c]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Soldier Summit SE[1]	0	-	-
Scofield NE[2]	45	6.4	2.9-11.5
Scofield NW[2]	91	6.1	3.1-13.5
Scofield SE[2]	46	6.3	2.6- 9.8
Scofield SW[2]	22	5.0	2.8-11.2
Hiawatha NE[3]	375	6.3	3.3-12.4
Hiawatha NW[3]	41	6.0	2.8-10.7
Hiawatha SE[3]	147	7.6	4.0-18.3
Hiawatha SW[3]	20	6.5	4.2- 8.8
Castle Dale NW[4]	3	4.3	1.4- 6.3
Ferron Canyon	0	-	-
Castle Dale SW[4]	0	-	-
Flagstaff Peak	1	7.3	7.3
Acord Lakes NE	7	8.0	5.4-10.0
Acord Lakes NW	12	6.5	5.9- 7.1
Acord Lakes SW	0	-	-
Emery 3 NW	2	6.7	6.0- 7.3
Wasatch Plateau field	812	6.5	1.4-18.3

[1]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[4]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

Table A18.--Sulfur content of coal, as received, Wasatch Plateau coal field
[From Doelling, 1972c]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Soldier Summit SE[1]	0	-	-
Scofield NE[2]	34	0.53	0.39-1.60
Scofield NW[2]	70	0.60	0.40-1.10
Scofield SE[2]	34	0.85	0.59-1.20
Scofield SW[2]	21	0.62	0.31-1.60
Hiawatha NE[3]	344	0.61	0.29-1.10
Hiawatha NW[3]	40	0.55	0.23-0.80
Hiawatha SE[3]	136	0.57	0.31-1.50
Hiawatha SW[3]	18	0.57	0.38-0.70
Castle Dale NW[4]	3	0.77	0.60-0.90
Ferron Canyon	0	-	-
Castle Dale SW[4]	0	-	-
Flagstaff Peak	1	0.47	0.47
Acord Lakes NE	7	0.42	0.40-0.50
Acord Lakes NW	12	0.46	0.30-0.60
Acord Lakes SW	0	-	-
Emery 3 NW	2	0.60	0.60
Wasatch Plateau field	722	0.60	0.23-1.60

[1]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[4]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

Table A19.--Calorific value of coal, as received, Wasatch Plateau coal field

[From Doelling, 1972c]

Quadrangle (7.5-minute)	No. of samples	Btu/lb Average	Range
Soldier Summit SE[1]	0	-	-
Scofield NE[2]	43	12,216	10,550-13,078
Scofield NW[2]	81	12,095	10,250-13,650
Scofield SE[2]	45	12,286	11,206-12,860
Scofield SW[2]	15	12,459	11,640-13,350
Hiawatha NE[3]	380	12,718	10,840-13,600
Hiawatha NW[3]	35	13,080	12,290-13,690
Hiawatha SE[3]	144	12,704	10,800-13,353
Hiawatha SW[3]	23	12,905	11,376-13,452
Castle Dale NW[4]	3	12,363	12,200-12,400
Ferron Canyon	0	-	-
Castle Dale SW[4]	0	-	-
Flagstaff Peak	1	11,922	11,922
Acord Lakes NE	5	11,674	11,570-11,770
Acord Lakes NW	11	11,770	11,390-12,260
Acord Lakes SW	0	-	-
Emery 3 NW	2	10,570	10,540-10,600
Wasatch Plateau field	788	12,589	10,250-13,690

[1]Southeastern quarter of the Soldier Summit 15-minute quadrangle of the U.S. Geological Survey.

[2]Designated quarters of the Scofield 15-minute quadrangle of the U.S. Geological Survey.

[3]Designated quarters of the Hiawatha 15-minute quadrangle of the U.S. Geological Survey.

[4]Designated quarters of the Castle Dale 15-minute quadrangle of the U.S. Geological Survey.

Table A20.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of 7 additional trace elements in 48 Wasatch Plateau field coal samples

[Samples collected by Utah Geological and Mineral Survey, Salt Lake City, Utah; analyses by U.S. Geological Survey. All samples were ashed at 525°C; L, less than value shown.]

Major and minor oxides in ash (percent)

Oxide	Average (arithmetic mean)	Range Minimum	Range Maximum
(Ash)	11.4	1.8	36.6
SiO_2	53	21	84
Al_2O_3	16	6.2	29
CaO	6.1	.86	25
MgO	1.05	.42	2.53
Na_2O	3.64	.11	8.41
K_2O	.75	.062	2.2
Fe_2O_3	3.9	.83	12
MnO	.010	.003	.026
TiO_2	.92	.42	1.7
SO_3	4.2	.66	10

Trace elements in ash (ppm)

Element	Average (arithmetic mean)	Range Minimum	Range Maximum
B	1,000	200	3,000
Ba	700	70	3,000
Be	15	3 L	50
Cd	.9	1.0L	2.0
Co	15	10 L	50
Cr	100	30	200
Cu	95	32	266
Ga	30	10	70
Li	111	15	288
Mo	10	7 L	20
Nb	20	20 L	50
Ni	50	10	200
Pb	55	25 L	195
Sc	20	10 L	50
Sr	1,000	100	5,000
V	100	70	300
Y	70	30	300
Yb	7	3	15
Zn	84	19	237
Zr	200	100	500

Trace elements in whole coal (ppm)

Element	Average (arithmetic mean)	Range Minimum	Range Maximum
As	1.0	0.5 L	3
F	70	20 L	240
Hg	.05	.01	.21
Sb	.3	.1 L	.7
Se	1.7	.8	5.7
Th	1.7	3.0 L	5.2
U	1.3	.2	3.5

Table A21.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of 7 additional trace elements in 295 Rocky Mountain province coal samples (From Hatch and Swanson, 1976)

[All analyses by U.S. Geological Survey. All samples were ashed at 525°C; L, less than value shown]

Major and minor oxides in ash (percent)			
Oxide	Average (arithmetic mean)	Range: Minimum	Range: Maximum
(Ash)	13.3	1.8	88.2
SiO_2	46	15	79
Al_2O_3	21	4.3	35
CaO	8.9	.21	35
MgO	1.63	.22	7.1
Na_2O	1.39	.08	8.6
K_2O	.65	.05	3.0
Fe_2O_3	7.6	1.1	26
MnO	.049	.004	.55
TiO_2	.89	.02 L	1.8
SO_3	8.4	.10 L	29
Trace elements in ash (ppm)			
Element	Average (arithmetic mean)	Range: Minimum	Range: Maximum
B	500	70	3,000
Ba	2,000	70	10,000
Be	5	.1L	15
Cd	.7	.5L	4
Co	15	10 L	50
Cr	30	10	150
Cu	87	22	1,260
Ga	30	10	50
Li	88	10 L	328
Mo	15	5 L	70
Nb	7	20 L	50
Ni	20	10 L	70
Pb	45	20 L	195
Sc	15	7	30
Sr	700	150	3,000
V	100	50	300
Y	50	20	150
Yb	5	2	15
Zn	77	13	1,820
Zr	200	50	500
Trace elements in whole coal (ppm)			
Element	Average (arithmetic mean)	Range: Minimum	Range: Maximum
As	2	1 L	50
F	95	20 L	920
Hg	.08	.01	1.48
Sb	.4	.05L	5.2
Se	1.6	.1 L	5.7
Th	4.2	1.7	34.8
U	1.9	.1	23.8

A comparison of the average concentrations of oxides and elements in tables A20 and A21 shows that Na_2O, B, Be, Cr, Nb, and Ni concentrations are higher by a factor of two or more in the Wasatch Plateau field coal ash, while Fe_2O_3, MnO, SO_3, and Ba are higher by a factor of two or more in the Rocky Mountain coal ash. As and Th are higher by a factor of two or more in Rocky Mountain coal. The other oxide and element concentrations are about the same in both sets of samples.

Book Cliffs field

Nearly 1,300 proximate analyses of coal from this field are available to determine the quality of coal. Most of these samples (875) are from the Castlegate area. No major differences mark the coal throughout the field. The only differences noted in quality between individual beds are that locally a bed may have a higher ash and/or sulfur content than its neighboring beds. The proximate analyses were discussed by Doelling (1972d), and the following summary statements and tables are taken from his report.

(1) The moisture content of 1,287 coal samples averages 4.6 percent, ranging from 0.6 to 24.5 percent (table A22). The large number of analyses from the Castlegate area influences the average only slightly; a better estimated moisture value for the nine quadrangles is 4.8 percent.

(2) The average percentage of volatile matter in the coal is 41.2 percent (table A23), but the average is influenced by the large number of samples from the Castlegate area. Probably a more accurate figure would be 39.4 percent. Volatile matter is highest in the Castlegate-Kyune quadrangle, gradually decreasing east-southeast toward the Sunnyside area.

(3) The average fixed-carbon content of coal in the field of 47.4 percent (table A24) is also biased by the large number of analyses from the Castlegate area. A 49.1-percent average is more indicative of the entire field. The fixed-carbon content is lowest in the Castlegate area and increases east-southeast across the Soldier Canyon and Sunnyside areas.

(4) The average ash content of the coal in the quadrangles (table A25) fluctuates between 6 and 8 percent and is influenced by the presence of partings common in the Spring Canyon area, Coal Canyon area north of Wellington, and in the Rock Canyon area.

Table A22.--Moisture content of coal, as received, Book Cliffs coal field

[From Doelling, 1972d]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Castlegate-Kyune[1]	563	4.1	0.6-24.5
Castlegate-Matts Summit[2]	312	4.7	2.5-10.4
Wellington-Minnie Maud W[3]	136	4.8	2.2- 8.4
Wellington NE[4]	97	4.9	3.1- 8.5
Sunnyside NW[5]	6	5.2	3.1- 7.9
Sunnyside SW[5]	1	4.3	4.3
Sunnyside SE[5]	61	5.1	3.1-15.2
Woodside NE[6]	110	5.5	1.9- 9.8
Woodside SE[6]	1	4.8	4.8
No analyses for remaining quadrangles.			
Book Cliffs coal field	1,287	4.6-(4.8)	0.6-24.5

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

Table A23.--Volatile matter content of coal, as received, Book Cliffs coal field

[From Doelling, 1972d]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Castlegate-Kyune[1]	514	43.2	31.4-48.5
Castlegate-Matts Summit[2]	306	41.7	35.7-64.3
Wellington-Minnie Maud W[3]	124	38.6	30.9-45.7
Wellington NE[4]	94	38.6	37.4-40.1
Sunnyside NW[5]	6	38.8	37.2-40.0
Sunnyside SW[5]	1	37.8	37.8
Sunnyside SE[5]	56	38.1	33.9-42.9
Woodside NE[6]	96	37.5	16.4-44.7
Woodside SE[6]	1	33.6	33.6
No analyses for remaining quadrangles.			
Book Cliffs coal field	1,198	41.2-(39.4)	16.4-64.3

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

Table A24.--Fixed carbon content of coal, as received, Book Cliffs coal field

[From Doelling, 1972d]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Castlegate-Kyune[1]	513	45.9	33.9-52.9
Castlegate-Matts Summit[2]	306	47.2	28.3-52.1
Wellington-Minnie Maud W[3]	124	48.7	44.0-52.6
Wellington NE[4]	94	50.1	45.2-52.9
Sunnyside NW[5]	6	49.0	48.4-49.7
Sunnyside SW[5]	1	51.0	51.0
Sunnyside SE[5]	56	50.6	44.8-54.2
Woodside NE[6]	96	50.1	41.6-74.3
Woodside SE[6]	1	50.2	50.2
No analyses for remaining quadrangles.			
Book Cliffs coal field	1,197	47.4 (49.1)	28.3-74.3

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

Table A25.--Ash content of coal, as received, Book Cliffs coal field

[From Doelling, 1972d]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Castlegate-Kyune[1]	534	6.8	4.3-13.2
Castlegate-Matts Summit[2]	311	6.3	3.8-12.7
Wellington-Minnie Maud W[3]	128	7.5	3.4-12.6
Wellington NE[4]	97	6.4	3.7-11.5
Sunnyside NW[5]	6	7.0	5.2- 7.9
Sunnyside SW[5]	1	6.9	6.9
Sunnyside SE[5]	61	6.3	4.2-11.9
Woodside NE[6]	99	6.7	3.8-10.7
Woodside SE[6]	1	11.4	11.4
No analyses for remaining quadrangles.			
Book Cliffs coal field	1,238	6.9	3.4-13.2

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

(5) The average sulfur content of the coal of 0.58 percent is biased by the large number of analyses of coal from the west part of the field--a more accurate figure would be 0.85 percent (table A26). The coal in both the Castlegate and Wellington quadrangles have relatively low sulfur contents, but the content fluctuates greatly in the Sunnyside and Woodside quadrangles. The coal from these areas is generally washed to reduce the sulfur content to meet requirements for metallurgical-grade coal.

(6) The Btu/lb is generally between 12,500 and 13,000 (6,950 and 7,220 kcal/kg) on an as-received basis (table A27), with no major difference in the coal among beds or on a regional basis.

Using figures presumed more typical for the field as a whole, rather than the averages calculated, the Book Cliffs coal has the following characteristics: moisture, 4.8 percent; volatile matter, 39.4 percent; fixed carbon, 49.1 percent; ash, 6.7 percent; sulfur, 0.85 percent; and Btu/lb, 12,760 (7,090 kcal/kg).

According to the ASTM system, the coal of the Book Cliffs coal field is classified as high-volatile B bituminous coal. The coal in the Sunnyside area is a coking coal, but must be blended with 15 to 20 percent of low- or medium-volatile coals from other sources to achieve a product of metallurgical grade. The Castlegate area produced coke in the early days but its coke-making industry succumbed to the higher quality product produced in the Sunnyside area before 1910.

The composition of ash of Book Cliffs field coal and the concentrations of trace elements in the coal are given in table A28.

A comparison of the average concentrations of oxides and elements in table A28 with those for Rocky Mountain coals (table A21) shows that MnO, B, Li, Nb, and Sr concentrations are higher by a factor of two or more in the Book Cliffs field coal ash, while SO_3 and Ba are higher by a factor of two or more in Rocky Mountain coal ash. As, Hg, Sb, and U are higher by a factor of two or more in Rocky Mountain coal. The other oxide and element concentrations are about the same in both sets of samples.

Sego field

Twenty-seven proximate analyses of coal are available for the Sego coal field, of which two-thirds are from one of the ten quadrangles included in the field. Five of these ten quadrangles are not represented by any samples. With these inadequacies noted, the averages are listed in table A29 (from Doelling, 1972e).

Table A26.--Sulfur content of coal, as received, Book Cliffs coal field

[From Doelling, 1972d]

Quadrangle (7.5-minute)	No. of samples	Percent	
		Average	Range
Castlegate-Kyune[1]	489	0.59	0.2- 2.1
Castlegate-Matts Summit[2]	295	0.44	0.1- 0.8
Wellington-Minnie Maud W[3]	110	0.49	0.3- 1.0
Wellington NE[4]	96	0.49	0.3- 0.8
Sunnyside NW[5]	6	1.82	1.0- 2.4
Sunnyside SW[5]	1	0.67	0.67
Sunnyside SE[5]	60	1.02	0.5- 3.0
Woodside NE[6]	91	0.70	0.5- 1.1
Woodside SE[6]	1	1.15	1.15
No analyses for remaining quandrangles.			
Book Cliffs coal field	1,149	0.58 (0.85)	0.1- 3.0

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

Table A27.--Btu/lb content of coal, as received, Book Cliffs coal field

[From Doelling, 1972d]

Quadrangle (7.5-minute)	No. of samples	Btu/lb	
		Average	Range
Castlegate-Kyune[1]	551	12,863	7,045-13,530
Castlegate-Matts Summit[2]	303	12,755	11,840-13,370
Wellington-Minnie Maud W[3]	132	12,451	11,700-13,000
Wellington NE[4]	93	12,645	11,390-13,390
Sunnyside NW[5]	6	12,512	11,880-12,940
Sunnyside SW[5]	1	13,197	13,197
Sunnyside SE[5]	51	12,906	9,530-13,660
Woodside NE[6]	105	12,664	10,860-14,220
No analyses for remaining quadrangles.			
Book Cliffs coal field	1,242	12,762	7,045-14,220

[1]Parts of the Castlegate 15-minute and Kyune 7.5-minute quadrangles of the U.S. Geological Survey.

[2]Parts of the Castlegate 15-minute and Matts Summit 7.5-minute quadrangles of the U.S. Geological Survey.

[3]Parts of the Wellington 15-minute and Minnie Maud Creek West 7.5-minute quadrangles of the U.S. Geological Survey.

[4]Northeastern quarter of the Wellington 15-minute quadrangle of the U.S. Geological Survey.

[5]Designated quarters of the Sunnyside 15-minute quadrangle of the U.S. Geological Survey.

[6]Designated quarters of the Woodside 15-minute quadrangle of the U.S. Geological Survey.

Table A28.--Average (arithmetic mean) composition and observed range of 10 major and minor oxides and 20 trace elements in coal ash, and contents of 7 additional trace elements in 8 Book Cliffs field coal samples. (U.S. Geological Survey data)

[All samples were ashed at 525°C; L, less than value shown]

Major and minor oxides in ash (percent)

Oxide	Average (arithmetic mean)	Range	
		Minimum	Maximum
(Ash)	8.75	6.0	12.4
SiO_2	47	38	62
Al_2O_3	19	13	25
CaO	8.4	2.5	15
MgO	1.64	.71	2.65
Na_2O	1.83	.79	3.51
K_2O	.37	.05	.77
Fe_2O_3	5.9	1.5	19
MnO	.13	.003	.39
TiO_2	1.1	.67	1.5
SO_3	4.0	1.7	5.9

Trace elements in ash (ppm)

Element	Average (arithmetic mean)	Range	
		Minimum	Maximum
B	1,000	700	1,500
Ba	1,000	300	2,000
Be	7	3 L	7
Cd	1.0	1.0L	1.0
Co	10	10 L	15
Cr	50	30	70
Cu	59	22	95
Ga	30	20	30
Li	187	63	328
Mo	10	7 L	15
Nb	20	20	30
Ni	20	15	30
Pb	44	30	60
Sc	15	15	30
Sr	1,500	500	3,000
V	70	70	100
Y	50	30	70
Yb	5	3	5
Zn	72	42	88
Zr	300	200	300

Trace elements in whole coal (ppm)

Element	Average (arithmetic mean)	Range	
		Minimum	Maximum
As	0.6	0.5	1.0
F	54	20	110
Hg	.03	.01	.04
Sb	.2	.2	.3
Se	1.9	1.5	2.4
Th	2.6	3.0 L	3.9
U	.7	.3	.9

Table A29.--Average proximate coal analysis of coal from the Sego coal field, as received

[From Doelling, 1972e, table 2]

	No. of samples	Percent	
		Average	Range
Moisture	27	9.1	5.2 -20.0
Volatile matter	23	34.7	28.7 -42.2
Fixed carbon	23	46.8	38.4 -52.6
Ash	27	11.1	4.2 -19.0
Sulfur	27	0.60	0.37- 1.0
Btu/lb	18	10,940	9,000-12,150

Oil and gas

Petroleum production in east-central Utah was initiated in 1924, with discovery of the Farnham dome field (table A30) in south-central Carbon County, Utah. Since that time, production in east-central Utah has been established from about 145 wells in 20 fields to 1976 (fig. A16). Production is mainly concentrated in the southern Uinta Basin, on the Uncompahgre Uplift, and in the northern Paradox basin. Minor production comes from the east side of the Wasatch Plateau area (figs. A16, A17). Formations that have produced oil and gas in east-central Utah include the following (fig. A18):

Tertiary	Wasatch
Cretaceous	Price River, Mancos, Dakota, Cedar Mountain
Jurassic	Morrison, Navajo, Entrada
Triassic	Moenkopi
Permian	Kaibab

Depth of production is as shallow as 150-210 m at Ferron field and Harley dome to nearly 3,350 m at Gordon Creek (table A30). The following section of the report is a brief summary of selected oil and gas fields in east-central Utah (Crawford, 1963; Preston, 1961; Stowe, 1972).

Summary of selected petroleum fields in east-central Utah

San Arroyo field

San Arroyo field, located along the Book Cliffs escarpment in east-central Utah, is on the structural and topographic boundary between the Uinta Basin and the Grand Valley, Colo., area. Regional dip is northwest into the Uinta Basin. Production at San Arroyo is from sandstone reservoirs in the Dakota, Morrison, and Entrada Formations. The Dakota reservoirs consist of a lower sandstone of fluviatile origin and an upper nearshore marine sandstone, probably deposited during the latest transgression of the Early Cretaceous sea. The Entrada consists of crossbedded white to brownish-red, fine-grained sandstone of eolian origin. Dakota production is both stratigraphically and structurally controlled, and Entrada production is controlled by structure. The San Arroyo structure is a northwest-southeast-trending asymmetrical, doubly plunging anticline with about 90 m of closure on the Entrada Formation. The Entrada is about 70 m thick in this area.

Table A30.—Production data of oil and gas fields of east-central Utah.

Field	Year discovered	Age and Formation of reservoir	Gas or oil	Type of trap	Cumulative production (to month and year)	Ultimate recovery	No. prod. wells (past and present)	Av. depth prod. unit (
Bar-X	1948	Cretaceous-Dakota, Cedar Mountain; Jurassic-Morrison, Entrada	Oil & gas	Stratigraphic	50,164,053 MCF 2/ (7/76)	———	13	3,000
Blaze Canyon	1975	Jurassic-Entrada	Oil		9,486 BO 3/ (1/76)	99,486 BO	———	———
Book Cliffs	1961	Cretaceous-Dakota	Gas	Structural & stratigraphic	346,219 MCF (7/76)	———	1	———
Bull Canyon	1972	Jurassic-Entrada	Oil	Stratigraphic	10,561, BO (7/76)	———	5	———
Cisco Dome	1925	Cretaceous-Dakota, Cedar Mountain; Jurassic-Morrison	Gas	Stratigraphic	3,149,948 MCF	10,000 MMCF	16	2,100
Cisco Springs	1955	Jurassic-Morrison	Oil & gas	Stratigraphic	12,379 BO 68,583 MCF (7/76)	———	1	1,775
Clear Creek	1951	Cretaceous-Mancos	Gas	Structural & stratigraphic	135,445,840 MCF (7/76)	168,000 MMCF (1961)	16	4,700
Farnham Dome	1924	Jurassic-Navajo	Gas	Stratigraphic	1,945,646 MCF (7/76)	———	5	3,000
Fence Canyon	1967	Cretaceous-Dakota, Cedar Mountain; Jurassic-Morrison	Gas	Stratigraphic	3,537,006·MCF (7/76)	———	4	8,175 8,450
Ferron	1957	Cretaceous-Mancos; Permian-Kaibab	Oil & gas	Stratigraphic & structural	38,470 BO 7,555,923 MCF (7/76)	23,000 MMCF (1961)	7	810
Flat Canyon	1953	Cretaceous-Mancos, Dakota	Gas	Stratigraphic & structural	917,444 MCF (9/74)	———	4	5,900 7,020
Flat Rock	1963	Paleocene-Wasatch	Oil & gas	Stratigraphic	35,674 BO 159 MCF (9/74)	———	5	———
Gordon Creek	1948	Cretaceous-Mancos; Triassic-Moenkopi	Gas	Structural	Plugged & abandoned	———	3	3,500 10,900
Grassy Trail	1961	Triassic-Moenkopi	Oil	Stratigraphic	131,014, BO (7/76)	———	3	3,900
Harley Dome	1926	Jurassic-Morrison, Entrada	Gas	Stratigraphic	———	———	4	500-600
Last Chance	1947	Triassic-Moenkopi	Gas	Stratigraphic	6,500 MCF	———	3	2,625
Miller Creek	No Report							
San Arroyo	1962	Cretaceous-Price River, Dakota, Cedar Mountain; Jurassic-Morrison, Entrada	Oil & gas	Stratigraphic & structural	95,477 BO 58,451,471 MCF (1974)	———	30	(Price River) 900 (Dakota) 4,400 (Morrison) 5,200 (Entrada) 5,700
Segundo Canyon	1962	Cretaceous-Dakota, Cedar Mountain	Oil & gas	Stratigraphic	704 BO 888,684 (7/76)	———	2	———
Westwater	1957	Cretaceous-Price River, Dakota Jurassic-Morrison, Entrada	Oil & gas	Stratigraphic & structural	9,867 BO 27,053,886 MCF	43,925 MCF		(Price River) 900 (Dakota) 4,400 (Morrison) 5,200 (Entrada) 5,700

1/ 1 ft = 0.30 x m.

2/ 1 MCF = 28.32 m^3.

3/ 1 BO = approximately 1/7 metric tons oil.

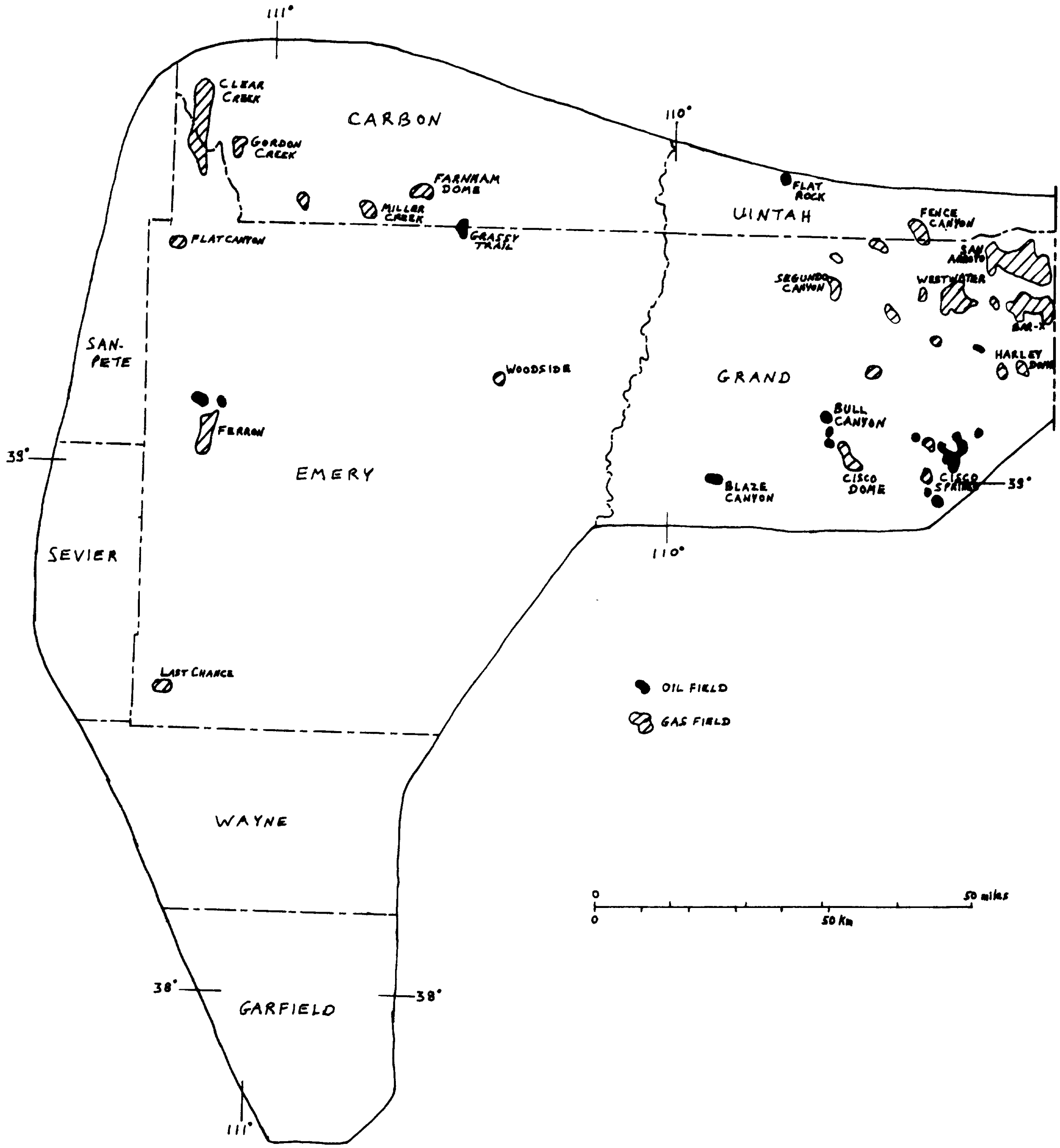

Figure A16.- Map showing oil and gas fields in east-central Utah.

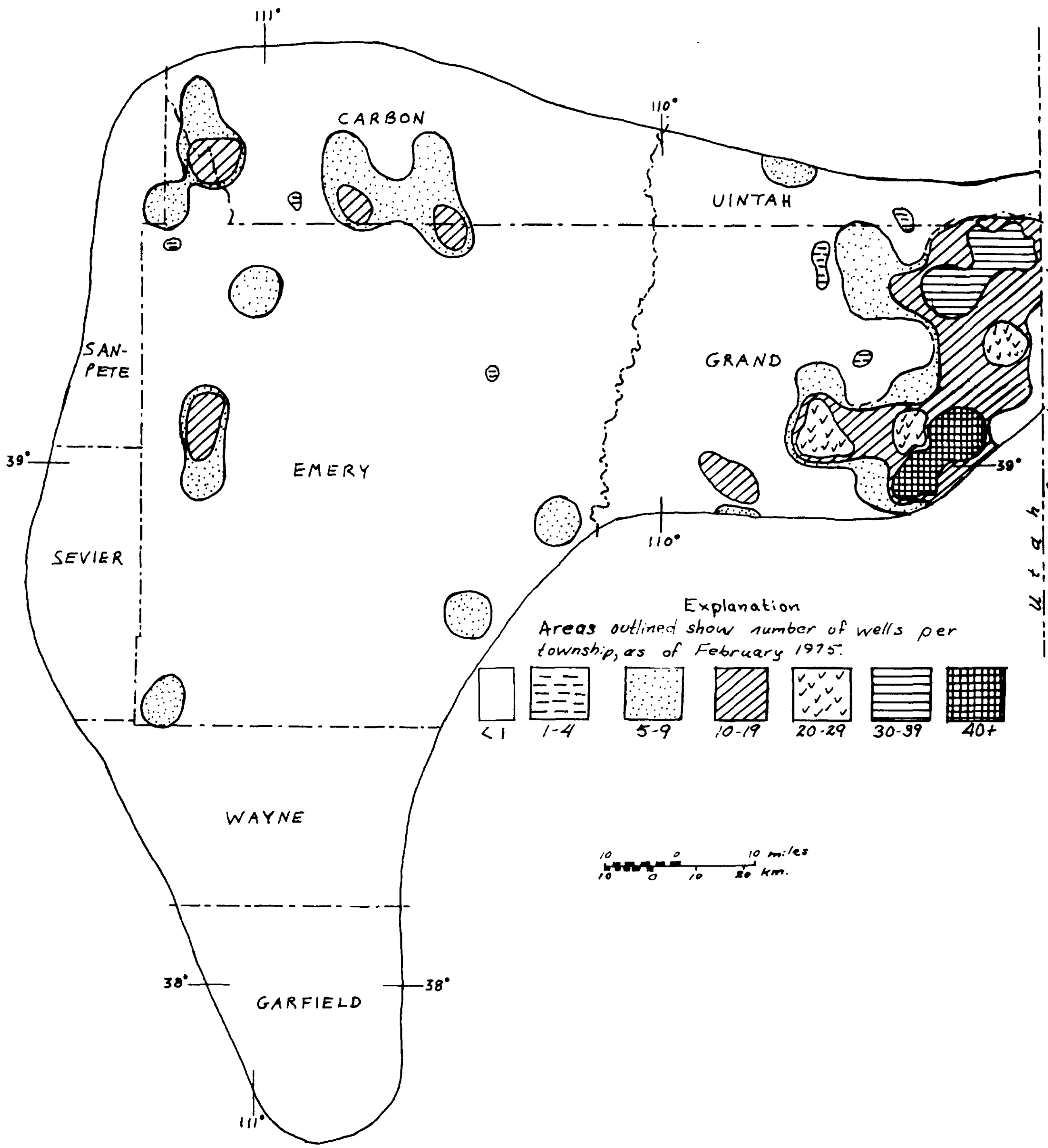

Figure A17. - Map showing density of drilling for oil and gas in east-central Utah.

Age: Era	Age: Period	Age: Epoch	San Rafael Swell and Wasatch Plateau	Southern part of Uinta basin	Paradox basin and Uncompahgre uplift
CENOZOIC	Quaternary		Unconsolidated deposits	Unconsolidated deposits	Unconsolidated deposits
CENOZOIC	Tertiary	Oligocene to Pliocene	(Absent)	(Absent)	(Absent)
CENOZOIC	Tertiary	Paleocene and Eocene	Green River Fm. Colton Fm. Flagstaff Ls.	Green River Fm. Wasatch Fm. (OG)	Green River Fm. Wasatch Fm.
MESOZOIC	Cretaceous	Late	North Horn Fm. Price River Fm. (OG) Blackhawk Fm. Star Point Ss. Mancos Sh. (G) Dakota Ss. (G)	North Horn Fm. Price River Fm. Blackhawk Fm. Mancos Sh. Dakota Ss. (OG)	Tuscher Fm. Price River Fm. Mancos Sh. Dakota Ss. (G)
MESOZOIC	Cretaceous	Early	Cedar Mountain Fm. (G)	Cedar Mountain Fm. (G)	Burro Canyon Fm.
MESOZOIC	Jurassic	Late	Morrison Fm. (OG) Summerville Fm. Curtis Fm. Entrada Ss. (OG) Carmel Fm.	Morrison Fm. (OG) Summerville Fm. Curtis Fm. Entrada Ss. (OG) Carmel Fm.	Morrison Fm. (G) Summerville Fm. Curtis Fm. Entrada Ss. (OG) Carmel Fm.
MESOZOIC	Jurassic	Early	Navajo Ss. (G) Kayenta Fm.	Navajo Ss. (Absent?)	Navajo Ss. Kayenta Fm.
MESOZOIC	Triassic	Late	Wingate Ss. Chinle Fm.	(Absent?) Chinle Fm.	Wingate Ss. Chinle Fm.
MESOZOIC	Triassic	Early	Moenkopi Fm. (O)	Moenkopi Fm.	Moenkopi Fm.
PALEOZOIC	Permian	Late	(Absent)	(Absent?)	(Absent)
PALEOZOIC	Permian	Early	Kaibab Ls. (OG) Coconino Ss.	Cutler Fm.?	Cutler Fm. Rico Fm.
PALEOZOIC	Cambrian to Pennsylvanian		Many older non-producing formations	Many older non-producing formations	Many older non-producing formations

(O) Oil-producing formation; (G) Gas-producing formation
(OG) Oil- and gas-producing formation

Figure A18. - Stratigraphic correlation chart showing formations that produce oil and gas in east-central Utah.

Bar-X field

Bar-X field produces from sands in the Upper Cretaceous Dakota, Lower Cretaceous Buckhorn Member of the Cedar Mountain Formation, and the Upper Jurassic Salt Wash Member of the Morrison Formation, and the Entrada Sandstone. All sandstones are lenticular and discontinuous except for the Entrada which is a blanket sandstone. Drill data in the area indicate that almost every porous and permeable sandstone within the Dakota, Cedar Mountain, and Morrison can be expected to yield gas. Oil is produced from one well in the Morrison at Bar-X.

Westwater field

Westwater field is located on the southeast edge of the Uinta Basin. Reservoirs at Westwater consist of sandstones in the Price River, Dakota, Morrison, and Entrada Formations. With the exception of the Entrada and the uppermost part of the Castlegate Sandstone Member of the Price River Formation, all sandstones are lenticular and discontinuous. From the standpoint of porosity, the Entrada forms the best reservoir; it is of eolian origin, and in cores is highly friable. The upper part of the Castlegate forms a blanket sandstone 3 to 5.5 m thick. Sandstones in the Dakota and Morrison are quite restricted in lateral extent, which probably reflects deposition in local channels. Westwater field is located on a westward-plunging anticlinal nose. Several small local faults have been mapped at the surface, but, except for faults in the shallow Castlegate Sandstone Member, these faults probably do not affect the reservoirs.

Book Cliffs and Fence Canyon fields

Reservoirs at the Book Cliffs and Fence Canyon fields are located on the north plunge of the Uncompahgre uplift and the south edge of the Uinta Basin, respectively. Production in these fields is from dominantly continental strata in the Upper Cretaceous Dakota Formation, Lower Cretaceous Cedar Mountain Formation, and Upper Jurassic Morrison Formation. These formations consist of porous lenticular sandstones interbedded with, and commonly enclosed by, impervious shale. Most sandstones are fluviatile in origin. Abrupt porosity changes both laterally and vertically are important factors controlling the oil and gas accumulation; anticlinal control and faulting are of lesser importance.

Harley dome field

Natural gas containing helium was found in early drilling at Harley dome. As a result of this discovery, the area was set aside as a helium reserve by the U.S. Government. In October 1955, a well drilled on a northern extension of the Harley dome structure showed a potential for 3,050 MCFGPD (86,375 m^3GPD) from a sandstone in the Brushy Basin Member of the Morrison Formation. Production in the field is located on a northwest-plunging anticlinal nose, but seems to be restricted to and controlled by discontinuous sandstone bodies.

Flatrock field

Flatrock field produces oil from stratigraphic traps in the fluviatile red-bed sequence of the Wasatch Formation. This sequence consists of lenticular sandstones interbedded with shales. The Wasatch Formation, undivided in this area, is time equivalent to the basal Green River, Colton, and Flagstaff Formations to the southwest of the basin, to part of the North Horn Formation to the west and possibly the Tuscher Formation to the southeast. Age of the Wasatch here is mostly Paleocene and Eocene but probably also latest Cretaceous age. The largest percentage of gas production to date in the southern Uinta Basin is from stratigraphic traps in the Wasatch Formation.

Segundo Canyon field

Segundo Canyon produces oil and gas from the Lower Cretaceous Cedar Mountain Formation. The reservoirs are in dominantly fluvial strata consisting of porous and lenticular sandstones and conglomerates interbedded with shale. Facies changes of the sandstone reservoir rocks to shale appear to control oil and gas accumulations more than does structure.

Cisco Dome and Bull Canyon fields

Cisco Dome field, located on an anticlinal structure on the southwest edge of the northern part of the Uncompahgre uplift, produced natural gas from the Dakota and Cedar Mountain Formations between 1925 and 1929. Initial flows of wells averaged 4,000 MCFGPD (about 115,000 m^3GPD). This gas was high in distillate and was used for carbon black production. Drilling ceased between 1936-1955 and then additional drilling resumed, and gas is again being produced. Bull Canyon, a relatively new discovery (1972), at the northernmost end of Cisco Dome anticline, produces oil from the Late Jurassic Entrada Formation. The area is considered favorable for additional discoveries of hydrocarbons from lenticular sands in up-dip positions on the flanks of the Cisco Dome anticline.

Cisco Springs field

Cisco Springs field, located on the northwest-plunging nose of the Cottonwood anticline of the northern Uncompahgre uplift, produced gas from a lenticular sandstone in the Brushy Basin Member of the Morrison Formation. Tests of the producing well in this field showed 73.5 m of green oil in the Dakota Formation, but failed to produce oil in commercial quantities, and was completed as a gas well for 2.8 MCFGPD (79 m^3GPD) in the Morrison. Future drilling objectives in this field will be the lenticular channel sandstones in the Cretaceous Dakota Group-Cedar Mountain Formation.

Blaze Canyon field

No published data are currently available on Blaze Canyon in the northern Paradox basin, but preliminary data indicate that the field produces oil from the Late Jurassic Entrada Formation on a north or northwest-plunging faulted anticline.

Clear Creek field

The Clear Creek gas field, located on the Clear Creek-Monument Butte fold just east of the Wasatch Plateau, produces from the Ferron Sandstone Member of Late Cretaceous age. The Ferron Sandstone Member is a regressive marine sand with characteristically low permeability and porosity, but in this area complex faulting has provided natural fracturing and pay-zone communication across the field, thereby enhancing reservoir character. The trapping mechanism is an elongate fault closure on an older structure, which was rejuvenated during Laramide time. The gas-water contact, at about 1,200 m depth, defines the limits of the field.

Ferron field

Ferron field, located in Castle Valley on the west flank of the San Rafael uplift, is situated on a pronounced 10 1/2-km-long anticlinal structure called Ferron anticline. Gas accumulation occurs in lenticular sandstones of the Ferron Sandstone Member of the Mancos Shale that were deposited in nearshore marine environments in response to oscillations in sea level. The sands thicken southward and westward across the north-south-trending structure. Discovery of Ferron field was made in a well which flowed 4,700 MCFGPD (133,000 m^3GPD) between 191.4 and 231.0 m depth. Additional deeper exploration in shelf-type sandstones of both Mesozoic and Paleozoic age is considered of importance in this area.

Flat Canyon field

Flat Canyon field is located on the Flat Canyon anticline, near the middle of the north-south-trending edge of the Wasatch Plateau. High-angle faulting to the northeast and southwest defines the limits of the northeast-trending Flat Canyon anticline. Gas accumulations of similar quality occur in both the Ferron Sandstone Member of the Mancos Shale and in the Dakota Sandstone of Late Cretaceous age. This fact, together with multiple pay zones and structural entrapment, seems to indicate a common hydrocarbon source bed for the gas in both sandstones.

Gordon Creek field

The Gordon Creek field is located on the highest structural closure of the Gordon Creek anticline, a subsidiary fold on the larger Clear Creek-Monument Butte uplift. The northwest-trending axis of the anticlinal structure is broken by a large north-south graben fault zone; production is to the west of this zone. Hydrocarbon gas accumulations at Gordon Creek are in littoral and deltaic facies of theUpper Cretaceous Ferron Sandstone Member. Carbon dioxide gas is also produced from fine-grained, dense marine limestones of the Triassic Moenkopi Formation (Sinbad Member). This gas is probably in fractures in the limestone, as cores of the limestone itself exhibit little porosity.

Last Chance field

Last Chance field, located on the western flank of the Henry Mountains basin, has produced gas along the axis of the Last Chance anticline. Accumulation of the gas is in three or four fine-grained sandstone beds 3 to 9 m thick in the lower part of the Triassic Moenkopi Formation. These sandstones, probably lenticular, were deposited on the shallow eastern shelf of the Cordilleran miogeosyncline. Oil shows are also found in limestone of the Sinbad Member of the Moenkopi Formation as well as in the Permian Kaibab Formation and in older formations in the Paleozoic. At present, Last Chance field is abandoned as noncommercial. Future development depends upon ascertaining the stratigraphic and structural relations that control accumulation.

Future exploration trends

Oil and gas production in east-central Utah has been mainly concentrated in the easternmost part, which includes the southern Uinta Basin-northern Uncompahgre uplift and the eastern part of the region of the San Rafael uplift near the Colorado-Utah border (fig. A17). Entrapment of hydrocarbons in this area is primarily stratigraphically controlled, although some accumulations are on anticlinal structures. Most production in the area comes from the Tertiary-Upper Cretaceous(?) Wasatch; the Upper Cretaceous Castlegate and Dakota Sandstones; the Lower Cretaceous Cedar Mountain Formation; the Salt Wash and Brushy Basin Members of the Morrison Formation; and from other Jurassic formations. Reservoirs in these units are mainly in local porous and permeable sandstone lenses deposited in fluvial and nearshore marine environments. Other sandstone reservoirs are present in the Entrada Formation of Jurassic age, which locally contains excellent porosity and permeability. Traps for hydrocarbons in the Entrada, however, are mostly dependent upon structure, the unit being a widespread blanket sand of eolian origin over most of the region.

The only current production in the northern part of the Paradox basin of east-central Utah is from the Blaze Canyon field, discovered in 1975. This field produces oil from the Entrada Formation. Preliminary data on the field indicate that the trap is located on a north- or northwest-plunging anticline.

Oil and gas production in the northern part of the east-central Utah region east of the Wasatch Plateau (fig. A17) is mainly from the Ferron Sandstone Member and Dakota Group of Cretaceous age, which were deposited in littoral marine and deltaic environments. Additional production comes from fractured limestone in the Moenkopi Formation of Triassic age. Entrapment of hydrocarbons in this region is dominantly structurally controlled, on anticlines and in fault traps. Faulting in the area not only controlled formation of traps, but also enhanced reservoir quality by providing natural fracturing and pay-zone communication in fields where gas is typically found in low-permeability and low-porosity sandstones (for example, in the Ferron Sandstone Member at Clear Creek field). Gas is produced farther south on the west flank of the San Rafael uplift from the Ferron Sandstone Member at Ferron field, but in this area entrapment is in lenticular marine and deltaic sandstones on an anticlinal structure. At Last Chance field (abandoned) on the northwest flank of the Henry Mountains basin, gas was found in three or four fine-grained sandstone beds in the lower part of the Moenkopi Formation of Triassic age. These sands were deposited on the shallow eastern shelf of the Cordilleran miogeosyncline. Oil shows have been encountered in the east-central Utah region in Devonian, Mississippian, Pennsylvanian, Permian (Coconino and Kaibab), and Triassic (Chinle) formations.

The data on production and potential production in east-central Utah (table A30) suggest that future exploration for oil and gas will significantly increase the resources in this region. Many of the fields are not now in full production and others have been shut-in, awaiting increased prices for oil and gas ,and improved drilling, completion, and recovery technology. Additionally, other potentially productive areas still exist within the region that are largely unexplored at the present time. These include the areas to the north and west of the Cretaceous-Jurassic outcrop belt in parts of Uintah, Grand, Carbon, and Emery Counties, where excellent potential still exists for gas production from stratigraphic traps in Cretaceous and Jurassic rocks of the southern Uinta Basin and northern Uncompahgre uplift, and from structural traps east of the Wasatch Plateau. Moderately good production potential also exists in the central part of the region around the flanks of the San Rafael uplift and the Henry Mountains basin for stratigraphic accumulations in Cretaceous and older Mesozoic and Paleozoic rocks. Low potential for fluid oil and gas production exists on the San Rafael uplift itself or within the Henry Mountains basin because erosion has removed rocks younger than Permian on the San Rafael uplift and because the Henry Mountains basin contains no significant untested structural closures.

Some areas overlain by coal beds in the Book Cliffs, Sego, and Wasatch Plateau coal fields offer excellent potential for future discovery of hydrocarbon accumulations. Production of hydrocarbons and coal mining could take place at the same time, only with careful coordination of activities.

Nonpetroleum gases

Helium

Helium gas has been discovered in wells drilled on the Woodside anticline near the northeast end of the San Rafael Swell (Osmond, 1956) and on Harley dome just south of the Book Cliffs near the Colorado-Utah State line (Keebler, 1956). Tracts at both localities have been set aside as Federal helium reserves administered by the U.S. Bureau of Mines (fig. A19), but no helium has been produced. The helium in the Woodside anticline was apparently encountered in Permian rocks in an interval between 951 and 965 m below the surface. The helium at Harley dome was encountered less than 150 m below the surface in an interval about 30 m thick in the Morrison Formation of Jurassic age. The surface rocks in these two reserves are stratigraphically below coal-bearing strata of the Book Cliffs so no conflict with potential coal development will exist.

Carbon dioxide

Carbon dioxide gas has been encountered in wells drilled on Farnham dome, in San Arroyo gas field, and on the Woodside, Ferron, and Gordon Creek anticlines (fig. A16) (Utah Geol. and Mineral Survey, 1976). The carbon dioxide from Farnham dome has been produced since 1953 and piped to a dry ice manufacturing plant in the town of Wellington. There may be increased demand for the gas in the future for use in the "CO_2-miscible-flood" process of secondary recovery in oil fields. Most of the carbon dioxide known in east-central Utah underlies areas in which the surface rocks are stratigraphically below coal-bearing rocks, so production of carbon dioxide from those areas could have no influence on coal production.

Oil shale

Oil shale is a fine-grained sedimentary rock that is rich in degraded and decomposed organic matter. When heated sufficiently it will yield a product similar to liquid petroleum, called shale oil. Such rock is present in the Green River Formation in the higher parts of the Roan (or Tavaputs) Plateau on both sides of the Green River along the northern edge of the report area. Cashion (1967) calculated indicated and inferred potential reserves of tens of billions of barrels of shale oil in the Uinta Basin, but only a minute fraction of 1 percent of this total is in the report area, and that is in relatively thin, low-grade beds not likely to be exploited for several decades. Even if it were deemed desirable to utilize this resource at some time in the future, the Green River Formation is, both stratigraphically and by elevation, so far above the coal-bearing formations that its removal would have no effect upon coal mining in the region.

Bituminous sandstone

Bituminous sandstone is sandstone whose pore spaces are partly or completely filled with asphaltic or bituminous material. Such sandstone is abundant in two distinct areas along the north edge of the report area. One of these areas is about 6 1/2 to 13 km north of the town of Sunnyside in northeastern Carbon County, and the other area is along the Uintah and Grand County line, about 24 km west of the Colorado and Utah State boundary (fig. A19).

The bituminous sandstone near Sunnyside is within a zone about 300 m thick in the upper part of the Wasatch Formation and the lower part of the Green River Formation (Holmes and others, 1948). This crushed asphaltic sandstone was once utilized as paving material but apparently has not been mined since about 1945 (Cashion, 1964). Holmes, Page, and Averitt (1948) estimated that more than 700 million barrels of asphaltic petroleum could be extracted from sandstone in this area. The bituminous sandstone in the area near the Uintah and Grand County line is in the Green River Formation in a zone about 105 m thick (Cashion, 1967). These have not been mined to date, nor have any reserve estimates of recoverable petroleum been made, but the characteristics of the sandstones and their combined oils have been the subject of recent investigations by the U.S. Bureau of Mines and the Utah Geological and Mineral Survey (Johnson and others, 1975).

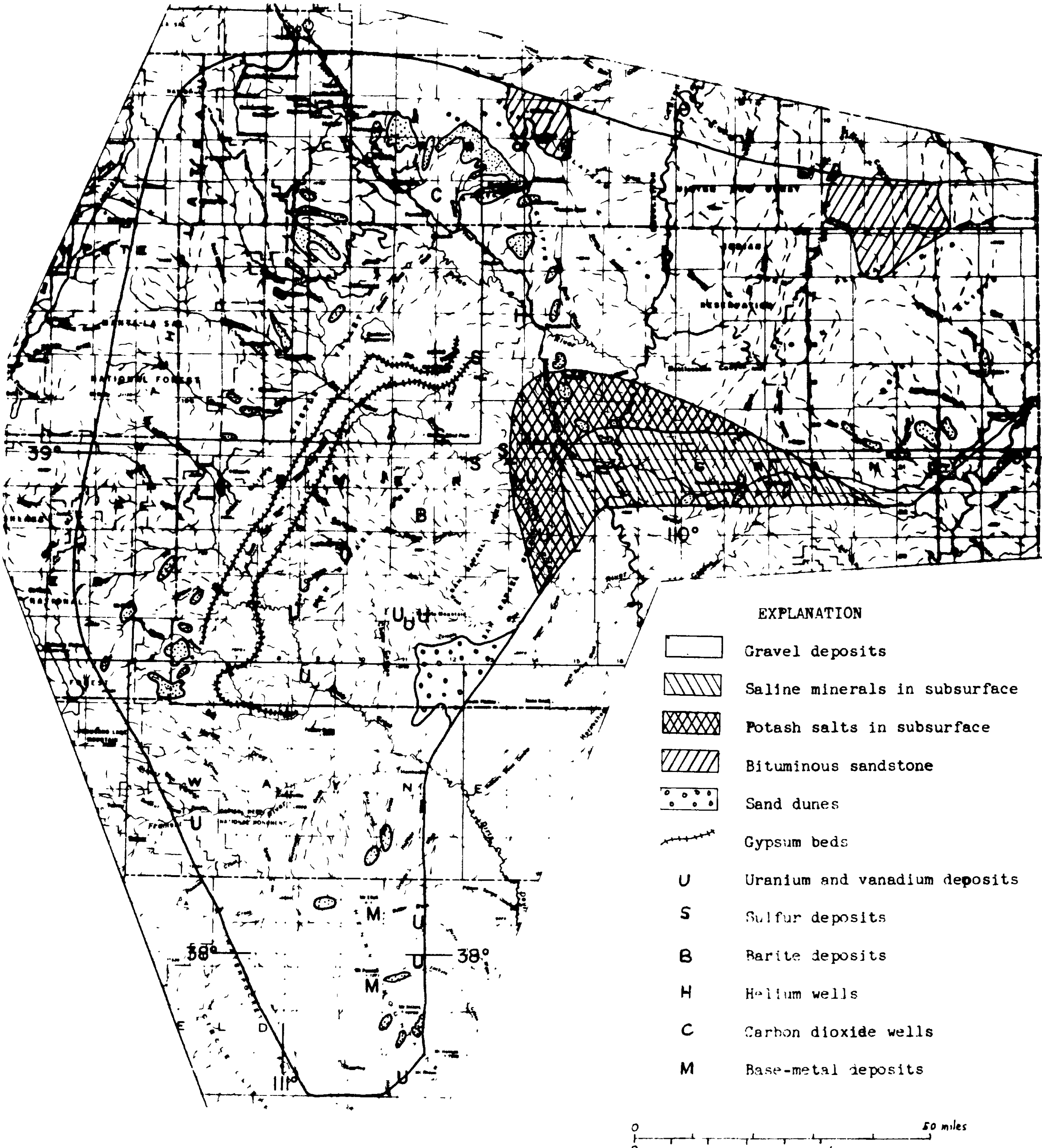

Figure A19. - Map showing some mineral deposits of east-central Utah.

The bituminous sandstone units are far enough above the coal-bearing rocks in both areas that their exploitation would have no effect on coal mining.

Uranium and vanadium

Numerous uranium deposits of varying size and grade have been found in the report area, but none of economic value have been found in the principal coal-bearing formations. Most of the important uranium deposits known to date in the area are vanadiferous deposits in the Chinle Formation of Triassic age and in the Morrison Formation of Jurassic age (Hilpert, 1964).

The largest and greatest concentration of uranium-vanadium deposits in the Chinle Formation is between Temple Mountain and Muddy Creek in the south part of the San Rafael Swell (fig. A19), and this area offers the greatest possibliity for future discoveries in the Chinle (Finch, 1945; Johnson, 1959b).

The largest and greatest number of uranium-vanadium deposits in the Morrison Formation are along and near the San Rafael River 19 to 24 km west and southwest of the town of Green River, and in an elongate area on the east side of the Henry Mountains (Hilpert, 1964; Johnson 1959b) (fig. A19). These areas seem to offer the greatest prospect for future discoveries. Small deposits have been found in the Morrison Formation at other places around the San Rafael Swell (Johnson, 1959a, 1959b). The deposits of the Morrison tend to be richer in vanadium and poorer in uranium than those of the Chinle Formation (Finch, 1959; Fischer and Vine, 1964).

Mining of uranium-vanadium ores in east-central Utah began on a small scale in the first decade of this century, but was intermittent until 1948. The greatest production was in the decade 1948-1957. The known deposits have not been depleted and some deposits probably remain undiscovered. None of the deposits or potential deposits described above are within the limits of a coal field, and their exploitation would have no effect on coal mining in the region.

Base metals

Minor amounts of gold, silver, and copper have been produced from quartz veins in intrusive rocks of the Henry Mountains. The last known production was from old dumps in Bromide basin in 1969 (Doelling, 1975). The working of these and other similar deposits would have little or no effect on coal mining in the Henry Mountains coal field.

Clays

The term clay used without qualifying adjectives includes a broad range of fine-grained earthy materials that vary widely in composition, physical properties, and uses. Most clay is of little or no economic value and is of no interest in this discussion. Some common types of clay are of limited value, and are usually extracted only from pits very close to where they are needed. Some other types of clay, however, are of sufficient value to warrant transport for hundreds or even thousands of miles from their source.

Among clays of limited value are the so-called common clays and shales used in making brick, tile, and related products. The demand for these has been so low in east-central Utah that little work has been done on them, though it may be assumed that there should be no shortage of such clays in the Cretaceous rocks of the region, particularly in the Mancos Shale (Hyatt and Cutler, 1953).

Bentonite is the only one of the more valuable clays known in the report region. It occurs in thin beds in the Dakota Sandstone and Mancos Shale in the Henry Mountains area (Hunt and others, 1953) and near the town of Green River (Patterson, 1964). No economic extraction of bentonite is known from the region to date, however.

The locations of clays mentioned above are far enough from potentially economic coal beds that the exploitation of the clays would have little effect on coal mining. Whether or not any clays closely associated with coal beds are potentially valuable is not known.

Construction materials

Demand for, and, therefore, production of construction materials in the central Utah region has been minimal because of low population density. Should the population of the region increase substantially, the local demands for sand and gravel, and perhaps other construction materials, would probably increase proportionately.

Gravel.--Gravel that is suitable for most ballast and aggregate needs is locally present in abundance near the surfaces of the many remnants of terraces and pediments that lie below and south of the Book Cliffs and the east-facing escarpment of the Wasatch Plateau (Clark, 1928; Spieker, 1931; Fisher, 1936) (fig. A19). Similar gravel is also common around the margins of the Henry Mountains (Hunt, 1953).

Sand.--There is a great abundance of well-sorted dune sand in the extensive dunes in the San Rafael Desert on the southeast side of the San Rafael Swell near the margin of the report area (Baker, 1946; Hunt, 1953; Williams and Hackman, 1971) (fig. A19). Fairly pure unconsolidated quartz sand is apparently scarce in the northern and western parts of the region, but probably could be obtained by screening the unconsolidated gravels mentioned in the preceding paragraph.

Gypsum.--Bedded gypsum, some of which is of fairly high quality, occurs in the Carmel and Summerville Formations of Jurassic age along the west side of the San Rafael Swell (Withington, 1964) (fig. A19). Lupton (1916) described one bed that was locally as much as 12 m thick, and Gilluly (1929) reported that 2-m-thick beds are common.

All of the above construction materials, except a very small percentage of the gravel, are far removed from coal-bearing rocks and their exploitation would have no effect on coal mining. On the other hand, large population increases brought about by greatly increased coal production could make some of these deposits of great use and value.

Other minerals

Sulfur.--Several small deposits of native sulfur occur in and near the San Rafael River, 22 1/2 to about 32 km west of the town of Green River; one such deposit is at Cedar Mountain, about 24 km north of the deposits near the San Rafael River (Mount, 1964) (fig. A19). Most of these deposits are associated with modern springs. Because of the abundance of sulfur available from larger deposits and as byproducts of smelter operations and petroleum refineries, none of the deposits in east-central Utah have been worked, and are not likely to be for many decades.

Saline minerals.--Great thicknesses of rock salt and other evaporite minerals are present at depth in the Paradox Member of the Hermosa Formation of Pennsylvanian age in the Paradox basin (figs. A2, A19). The town of Green River is near the northwest end of this elongate basin. The salt sequence wedges out within about 32 km to the north, west, and south of Green River, but thickens to 900 m or more within 32 km to the east before suddenly wedging out in that direction (Pierce and Rich, 1962). Potash salts are associated with the rock salt in part of the Paradox basin (fig. A19).

An inevitable increase in demand for potash fertilizers will undoubtedly stimulate interest in exploration for, and development of, potash within the study area, but coal-bearing strata are not near the potentially workable salt and potash deposits.

Barite.--Barite, a heavy, soft mineral that is much in demand as a base for drilling muds, has been mined in Emery County on the San Rafael Swell (Brobst, 1964) (fig. A19). Details concerning the size and geologic nature of the deposit have apparently never been published. The latest certain production was about 1961.

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PART B

SOME ENGINEERING GEOLOGIC PROBLEMS OF THE EAST-CENTRAL UTAH COAL MINING REGION

By

FRANK W. OSTERWALD and C. RICHARD DUNRUD

UNDERGROUND COAL MINING

Coal has been mined from east-central Utah since 1874 (Morton, 1877). East-central Utah is one of the major sources of bituminous coal in the Western United States, although geologic and topographic conditions combine to produce many difficult mining situations. Most coal beds crop out near the base of steep cliffs in the Book Cliffs and in the Wasatch Plateau. Other coal beds, particularly in the Clear Creek and Scofield areas, about 20 mi (32 km) northwest of Price, Utah (fig. A 1), are mined from down-faulted blocks within a major zone of north-trending, nearly vertical faults. Although dips of the coal-bearing strata in most of the region are low, so that changes of overburden thickness due to structural changes are minor, variations in overburden thickness range from 0 to 2,700 ft (0-820 m) in presently active mines as a result of the steep cliff-and-canyon or mountainous topography. These large topographic variations cause corresponding variations in the amount of stress on the coal and the roof rock and floor rock in the mines. Mining conditions in the east-central Utah region tend to become more difficult beneath overburden thicker than 1,500 ft (450 m).

Most of the economically valuable coal beds in the region were deposited in regressive sedimentary sequences (Osterwald and others, 1971, p. 7-8; Maberry, 1971, p. 1), so that most mines have strong sandstone floors and weaker shale or siltstone roofs. Locally, the coal is thinned or removed completely by sandstone-filled channels in the rocks above the coal beds, creating "wants" or "washouts" (Spieker, 1931, p. 63-64). Tightly cemented sandstone roof rocks make stable mine roofs if the channels are broad as compared to their thickness but may fail to collapse as mining is completed, causing dangerously high stress concentrations, resulting in violent failures (bumps and rock bursts), in nearby mine workings (Osterwald and Dunrud, 1965, p. 173). Sandstone beneath the coals generally makes good mine floors, but where a few feet of soft or plastic mudstone separates the coal from the sandstone it may be difficult to operate modern automatic longwall support and mining machinery efficiently.

In underground mines in the Sunnyside, Utah, area, a type of carbonaceous siltstone commonly occurs above the coal that appears massive and strong when first exposed during mining. When subjected to lateral shear stresses, however, this siltstone becomes brittle and breaks into innumerable small chips (Osterwald and Dunrud, 1965, p. 172-173). It also breaks into innumerable small rectangular prisms when wetted. Failures of the rock can cause massive roof falls and violent bumps in and around mine openings.

Extraction of coal in many previously mined areas is not complete. Some large areas are underlain by old mine workings that contain numerous pillars, which probably are highly stressed. In areas characterized by very gentle dips and varying strike, mining produced a complicated pattern of workings wherein large blocks of coal are surrounded by areas containing numerous pillars. Other factors also may cause miners to leave large pillars. Some of these factors may be economic, such as a change in plans by management, but some are also geologic, such as changes in composition of the coal, increased thickness of included beds of rock, or a change in lithology of the roof rocks.

Miners tend to avoid mining the coal near faults where possible. Stress due to mining is concentrated along faults, resulting in hazardous mining conditions. Because these hazardous conditions are avoided in mining, erratic mining patterns result (Osterwald and Dunrud, 1965, p. 169-171). Large inflows of water have been encountered in some workings extended across faults in the major north-trending belt (Osterwald and others, 1971, p. 8).

Bumps, known locally as "bounces" (sudden, sometimes catastrophic releases of stress stored in coal or rock), are a major hazard to underground coal mining in the east-central Utah region. Many miners have been killed by bumps in east-central Utah, much time has been lost repairing damage to mine workings and equipment, and much coal has been lost forever when mine sections prone to bump were abandoned. Mine faces that bump continuously during mining are common in the region, particularly near Sunnyside (Clark, 1928, p. 80). Such small bumps actually are beneficial to some degree, because they make mining easier and reduce the need for blasting; they are hazardous, however, because unwary personnel have been injured or even killed by flying coal from small bumps.

A close relationship between the directions of mine workings, the orientations of joints, cleavages, and fracture zones in coal, and the degree of hazard from bumps was noted at Sunnyside, Utah (Osterwald and Brodsky, 1960). Where fractures intersect room-and-pillar mine workings at angles of less than about 30°, only small amounts of stress are concentrated in ribs and faces; and failures, although numerous, are of small intensity. Where fractures intersect room-and-pillar mine workings at angles greater than 30°, large amounts of stress are concentrated, and failures may be violent. Longwall mining, however, creates an entirely different stress field, wherein fractures nearly parallel to a longwall face make caving of the roof easy and greatly reduce stress concentrations ahead of the face.

Stability of underground mine openings in east-central Utah, as well as the incidence of bumps, is in part controlled by directional sedimentary structures (such as trace fossils and crossbedding) in the rocks above and below the coal (Maberry, 1971, p. 1). Where such structures are oriented at large angles to mine workings, coal can slip easily along bedding planes into the openings and stress is continually relieved. Where friction is high between coal and its enclosing rocks, stress accumulates to high levels, and may lead to explosive failures in coal, roof, or floor. High friction along bedding planes may be due to sedimentary structures that are oriented at small angles to the workings, or to coarse-grained rocks above and below the coal.

Concentrations of methane (natural gas) constitute a major explosion hazard in coal mining. Early miners at Sunnyside, Utah, noticed that considerable gas was released from the coal during mining (Taff, 1906).

Additional amounts of gas are added to mine atmospheres from sandstones in mine roofs and floors. Large amounts of methane flowed into the Sunnyside No. 3 mine in 1966 from a sandstone-filled channel above the coal. The concentration of gas was high enough to cause evacuation of personnel from the mine.

Locally in the east-central Utah region more than one coal bed is minable. To minimize hazards to miners and to increase recovery of coal resources, plans for underground mines should provide for systematic extraction of all economically minable coal beds. This can be done either by carefully coordinating sequences of workings in different beds so that workings in lower beds are alined with workings in upper beds, by complete removal of upper beds before extracting coal from lower beds, by leaving enough pillars in lower beds to prevent collapse of roofs into lower workings, or by some combination of these procedures.

Underground coal mining in east-central Utah is hazardous. The fatality rate in Utah per million man-hours of employment in the industry in 1941 was the highest in the United States (Adams and Geyer, 1944, p. 6). Two hundred men were killed at Scofield in 1900, and 171 at Castle Gate in 1924 in mine-gas explosions (Adams and Geyer, 1944, p. 120). Twenty-three miners died in a gas explosion in the Sunnyside No. 1 mine in 1948 (Harrington and others, 1950, p. 28). Over the years, many other miners were killed by numerous small explosions or by falls of faces and ribs (including bumps). The total number of fatalities in Utah coal mines probably exceeds 500, and may exceed 1,000.

COAL MINE SUBSIDENCE

Coal mine subsidence, the most damaging aspect of underground mining from an environmental viewpoint, can be defined as all the deformation within the overburden and at the surface that is caused by underground mining. It includes the apparent local upward movement of strata that sometimes occurs above solid coal mine boundaries or large barrier pillars, which may be caused by downwarping of overburden into mine cavities. It also includes the downwarping itself; the associated horizontally directed tensile, compressive, and shear strains produced by flexure of strata; and the compressive strain induced by compression arches (Dunrud, 1976, p. 2).

Mining in east-central Utah is controlled by geologic and topographic conditions in at least two ways. First, the mountainous cliff-and-canyon topography requires that nearly all the coal be mined by underground methods. The overburden generally is thick, but it varies greatly in thickness over short distances. Most of the rocks comprising the overburden are strong sandstones alternating with mudstones of Late Cretaceous age. The cost of mining by surface methods would be higher for a given quantity of material than for mining, for example, the weaker Tertiary rocks in the Powder River Basin of Wyoming and Montana, although the Utah coal is higher in value and contains more heat value, or Btu, per ton than the Tertiary coal. Second, the rugged topography and the faults and numerous joints, and the steep slopes, may change the effects of surface subsidence as compared to mining beneath similar thicknesses at uniform depths, even though the amount of ground subsidence may be comparable in the two situations. This discussion is restricted to the more important surface effects of underground coal mining because only a very small area is considered amenable to current surface mining methods.

The most damaging aspect of coal mine subsidence is differential settlement. Differential settlement is caused by the overburden settling into the mine cavities while the strata above the unmined coal do not settle, rise slightly, or settle only a little (fig. B 1). This differential settlement commonly produces a trough above the mine workings. The maximum depth of the subsidence trough commonly is 50 to 90 percent of the thickness of the coal mined, depending on geologic, topographic, and mining conditions (fig. B-2). The area covered by the subsidence trough commonly is somewhat larger than the actual mined-out area. The angle made by a straight line drawn between the limit of surface settlement and the limit of mine cavities producing the subsidence, referenced to the vertical or the horizontal, is called the angle of draw, or limit angle (θ and ϕ in fig. B-1) (Natl. Coal Board, 1966, fig. 1.1). This angle varies with geology, topography, and mining procedures but commonly ranges between 25° and 45° from the vertical in foreign countries (Zwartendyk, 1971, p. 142-143). The angle varies between 10° and 25° from the vertical in room-and-pillar mining in the Somerset, Colo., area (Dunrud, 1976), where very rugged terrain is underlain by moderately strong rocks of the Mesaverde Group, of Late Cretaceous age, comprised of competent, lenticular sandstones and mudstones. The limit angle ranges between 15° and 26° from the vertical above a longwall mining panel in the Raton, N. Mex., area in rugged terrain underlain by Paleocene rocks composed of mudstones and lenticular sandstones (Gentry and Abel, 1976).

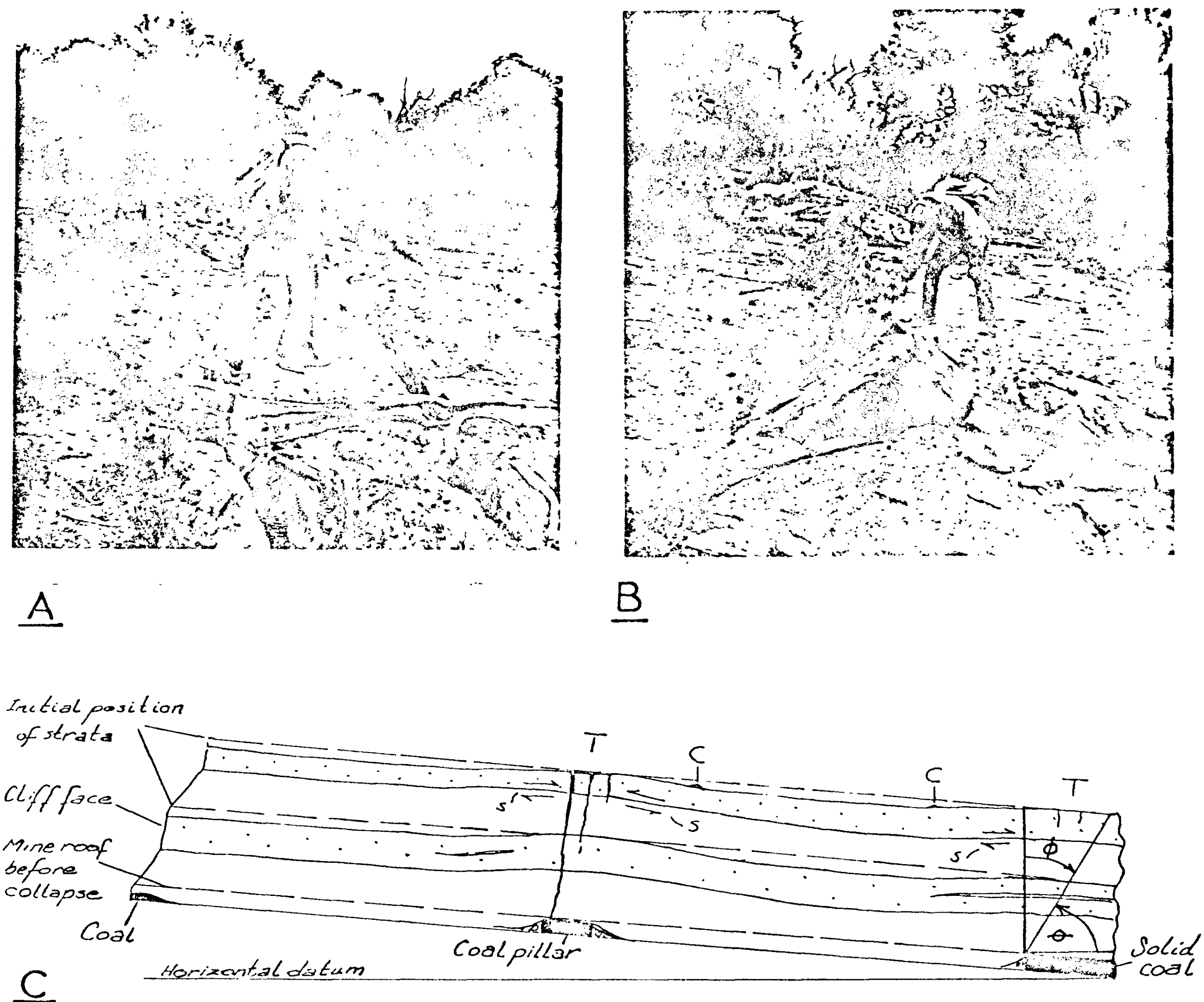

Figure B 1.--Subsidence effects caused by coal mining in the Book Cliffs area near Sunnyside, Utah (modified from Dunrud, 1976). The tensile (T), compressive (C), and shear (S) stresses are produced by differential settlement of the overburden into mine cavities. The angle of draw or limit angle is referenced either to the vertical (ϕ) or to the horizontal (θ). The thickness of the coal bed and the amount of subsidence are exaggerated for clarity. Examples of tensile and compressive failure are shown in B 1a and B 1b, respectively. The overburden above the mine void on the right behaves as a plate composed of different materials in contact and is supported on two sides, which causes the shear stress along the lithologic boundaries. The overburden above the mine near the cliff behaves as a plate supported on one side by a coal pillar and a restraining tensile force in the overburden (a cantilever) because the coal was mined too close to the outcrop. Failure of the cantilevered part of the overburden produces wide extension cracks above the barrier pillar that commonly are many hundreds of feet deep. These tensile stresses produced by settlement into the mine cavity on the right add to the extension produced by the cantilever failure.

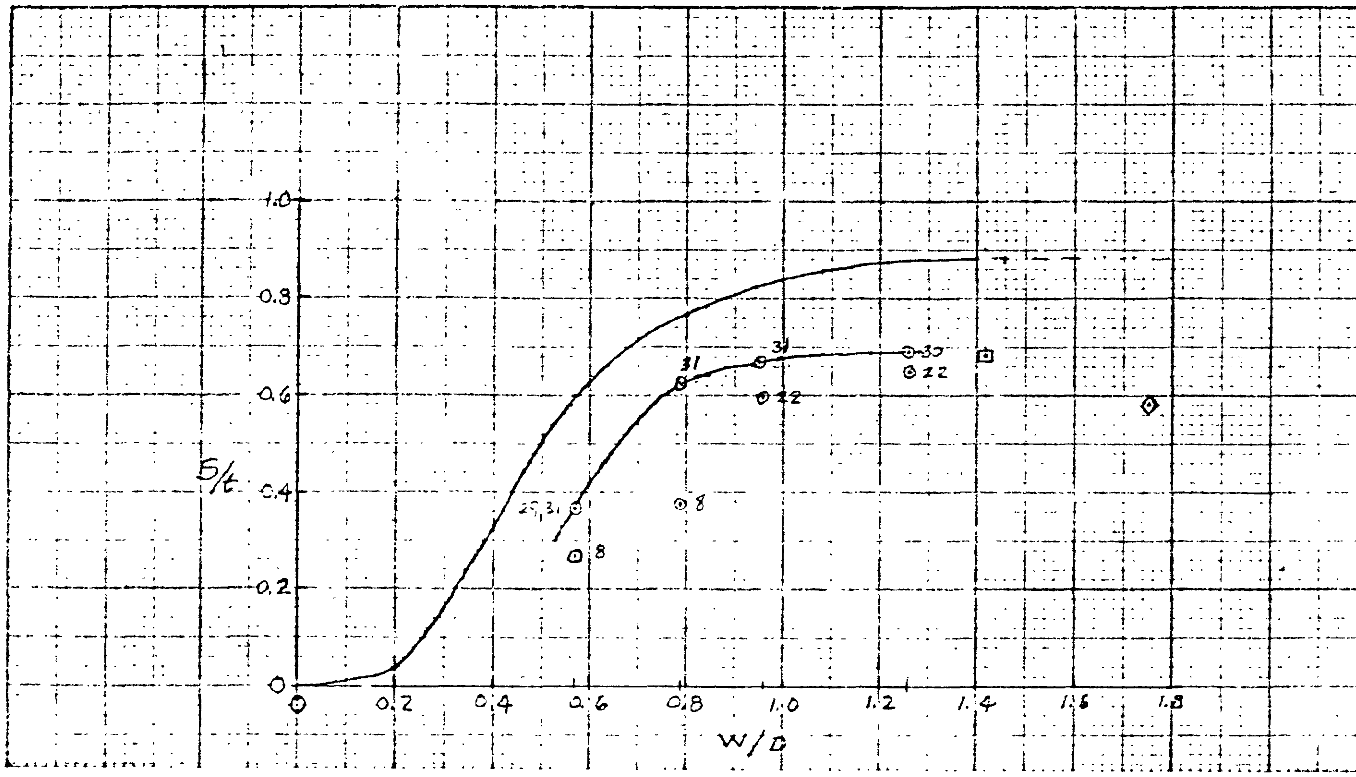

Figure B-2.--Graph showing the ratio of maximum subsidence (S) to thickness of coal mined (t) (subsidence ratio) versus the ratio of mining panel width (W) to overburden depth (D) for selected mining areas in the United Kingdom, Somerset, Colo., and Raton, N. Mex. The solid curve at left is from Wardell (1972, p. 206), derived from surface measurements in the United Kingdom above caved longwall panels greater than 1.40 D in length, in strata dipping less than 15°. The circled data points are from USGS measurements in the very rugged terrain near Somerset, Colo., above two caved room-and-pillar mining panels; extraction progressed toward deeper overburden beneath a high ridge underlain by moderately strong Mesaverde Group sandstones and mudstones of Cretaceous age; the subsidence values are corrected to 1.40 D by use of the National Coal Board (1966, fig. 2.2) correction graph. Circled points beneath the curve from Somerset show the subsidence value when mining ended in each panel. The points in squares and diamonds are from measurements made by the Colorado School of Mines (Gentry and Abel, 1976) in rugged topography above caved longwall workings; the square shows the subsidence ratio when mining progressed toward shallower overburden, and the diamond shows the subsidence ratio when mining progressed toward deeper overburden. Note that surface subsidence was about 10 percent greater when mining progressed from deeper to shallower overburden than when mining was from shallower to deeper overburden.

Differential settlement that produces the trough geometry tends to cause horizontal strain and deformation. At the margins of the trough, the surface commonly is subjected to tensile stresses because the ground is bowed upward (positive curvature) (fig. B 1a). These tensilt stresses commonly produce tensile strains and open cracks, particularly where bedrock joints or faults parallel the direction of mining. Tensile stresses and associated extension and cracking commonly are increased or even doubled above coal barrier pillars that separate two mining panels. Inward from the margins of the trough, the ground surface tends to bow downward (negative curvature). This produces high compressive stresses and strains that can bulge and buckle thick, strong, massive sandstone beds (fig. B 1b).

Effects of topography and geology

Topographic effects on subsidence were also noted in the Raton, N. Mex., area (Gentry and Abel, 1976). Vertical settlement was as much as 10 percent less when a longwall face, which was parallel to canyon-and-ridge topography, retreated from beneath a canyon toward a ridge than it was when the longwall face progressed from a ridge toward a canyon (figs. B 2, B 3). Topographic effects on horizontal movement were much more striking. The horizontal component of movement commonly was as much as or more than the vertical component of movement, and in the direction of mining, when the longwall face moved from beneath a ridge toward a canyon, whereas the horizontal component commonly either was nearly zero or was in a direction opposite to the direction of movement of the face when the face moved from beneath a canyon toward a ridge.

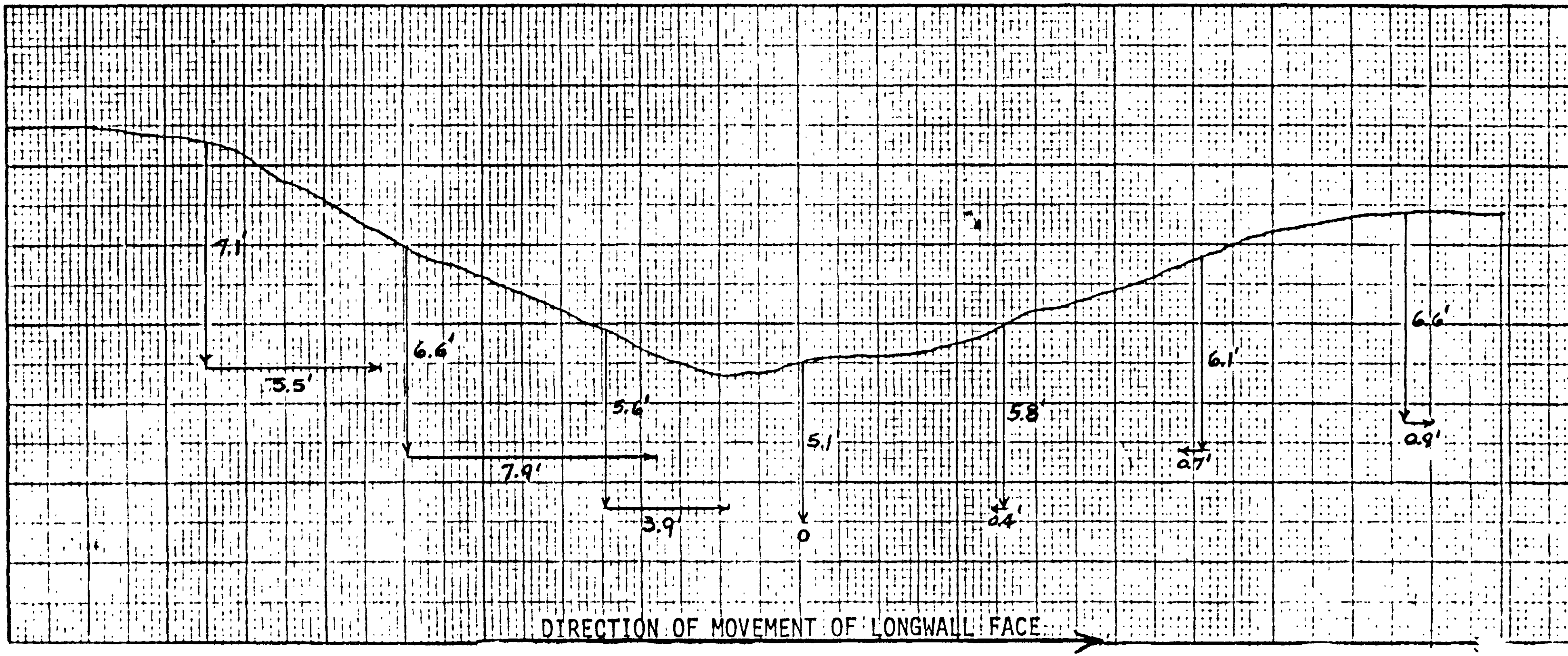

Figure B-3.--Profile along a centerline of a longwall panel in the Raton, N. Mex., area showing surface relief and the vertical and horizontal components of surface movement (modified from Gentry and Abel, 1977). Note that when the direction of movement of the longwall face is in the downslope direction of the ground surface the horizontal component of surface movement is much greater and the vertical component is as much as 10 percent more than they are when face movement is in the upslope direction with respect to the ground surface. Longwall face is oriented perpendicular to the profile; direction of movement is parallel to profile.

In other words, with a longwall face oriented parallel to a slope contour and the direction of movement of the face parallel to the downslope direction, both the vertical and horizontal components of subsidence are increased, whereas when the direction of face movement is in the upslope direction, both the vertical and horizontal components of subsidence are decreased. The mining direction of room-and-pillar mining at Somerset has been only in a direction toward deeper overburden in the subsidence study area, so that comparative information is not available. Gentry and Abel (1976) also found that the vertical component of subsidence beneath draws was much less than that measured beneath ridges (fig. B 3); the horizontal component also was small as compared to that measured beneath ridges. This might be attributed to the subjection of canyons to greater lateral confinement than uniform overburden because of adjacent ridges, which could cause stable compression arches to form above mine workings and thereby reduce subsidence.

The effects of cliff-and-canyon topography on subsidence in the Sunnyside area of Utah are striking, especially where coal is mined near cliffs (fig. B 1). The overburden has no lateral support near the cliffs; consequently, any mining activity near the cliffs that produces settlement of the overburden at the cliff face tends to cause the overburden to behave as a cantilever--a rock mass supported by coal on one side, inward from the cliff, and a restraining force. Rocks, particularly jointed rocks, are weak in tension. Failure of the overburden as a cantilever tends to produce large open cracks that follow joints. Cracks such as these have been observed to extend as much as 950 ft (290 m) below the surface (Dunrud, 1976; fig. B 1a). All surface drainage is, of course, diverted underground by open cracks (as in fig. B 1a), and any underground waterflow also is interrupted and often diverted to the mine workings. In more uniform overburden with lateral support, cracks and bulges produced in subsidence troughs commonly are much shallower and less extensive than those produced by cantilever failure.

Rockfalls and small landslides are common when coal is mined beneath cliff outcrops or steep canyons. Large-scale landslides could occur, however, where bedrock dips toward the cliff outcrop instead of away from it, as shown in figure B 1. If the dip is sufficient to overcome frictional resistance along the coal bed, the overburden can fail as a cantilever, become detached, and slide as a block along the coal; the effects could have very serious mining and environmental consequences.

Effects of mining

Mining methods, together with topography and geology, also control the time at which initial subsidence occurs as well as the rate and amount of surface subsidence. Subsidence development curves for selected caved longwall mining panels in the United Kingdom and near Raton, N. Mex., and caved room-and-pillar mining near Somerset, Colo., are shown in figure B 4. They show that (1) the surface commonly subsides farther ahead of a retreating longwall face in the United Kingdom than in the rugged terrain in the Raton, N. Mex., area; (2) the surface commonly has subsided nearly 20 percent of the total amount when the face is directly beneath the measuring station in the United Kingdom, whereas the surface has subsided only about 5 percent in the Raton, N. Mex., area when the face is beneath the measuring station; and (3) the overburden subsides more quickly, completely, and apparently more predictably above longwall mining panels than is the

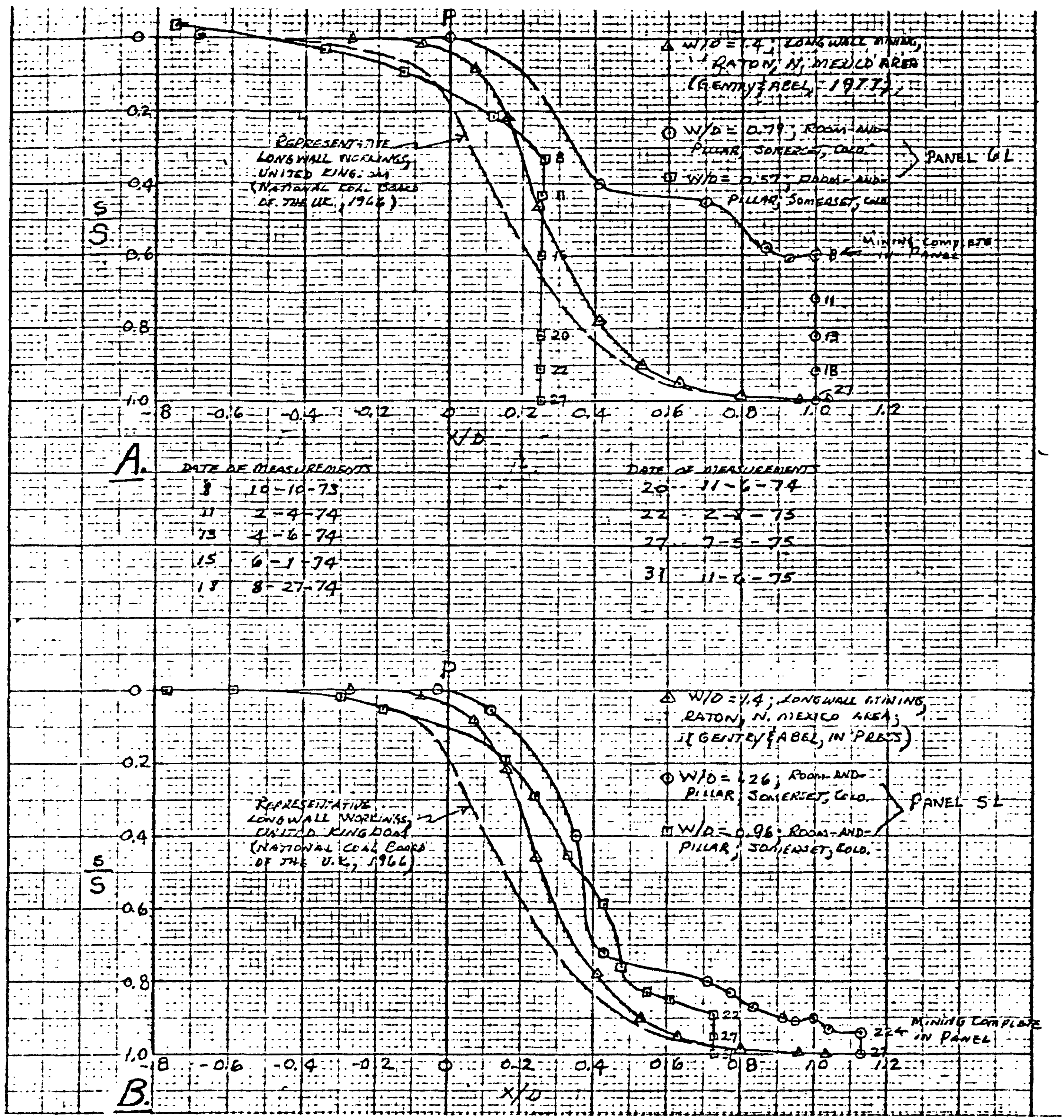

Figure B 4.--Subsidence development curves for caved longwall workings in the United Kingdom and in the Raton, N. Mex., area and for caved room-and-pillar workings near Somerset, Colo. The curves are a plot of the ratio of surface subsidence measured (s) to the maximum surface subsidence (S) versus the ratio of the position of face or pillar line distance (X) to the overburden depth (D) at the point where the subsidence was measured (P). The circled points in a and b are USGS measurements from surface bench marks near the initial position of the pillar retreat lines, the points enclosed by squares are USGS measurements from bench marks near the final position of the pillar retreat lines; and the points enclosed by triangles are subsidence measurements made by the Colorado School of Mines in the Raton, N. Mex., area (Gentry and Abel, 1976).

case above the room-and-pillar mining panels. In addition, subsidence measuring stations near the initial positions of pillar retreat lines (the curves defined by the circled points in figs. B-4a, b) were not subsiding when the pillar retreat lines were beneath the stations (positions x/o = 0 in figs. B-4a, b), whereas the stations near the final positions of the pillar retreat lines had settled 10 to 15 percent of the total amount when the pillar retreat lines were directly beneath these stations.

The rate of subsidence with respect to position of the longwall face is greater in the rugged terrain near Raton, N. Mex., than in the gently rolling to hilly terrain common in Great Britain (fig. B-4). This also infers that the slope, curvature, and surface strain also are greater than those in typical areas in the United Kingdom. Indeed, surface compressive and tensile strains of as much as 22,000 and 21,000 μin/in were measured near a canyon where longwall mining was retreating in a direction parallel to the downslope direction of the surface (Gentry and Abel, 1976). These strains are nearly twice the amount predicted by the National Coal Board (1966) of the United Kingdom (about 13,000 μin/in) for subsidence amount and overburden depth. The rate of subsidence was even steeper above the 5L room-and-pillar mining panel near Somerset, Colo. (fig. B-4b), with the direction of mining upslope to the surface topography. The surface strain, therefore, should be greater; however, surface strains tend to be erratic and undefinable in jointed bedrock because of the presence of surface cracks.

Subsidence above the 5L room-and-pillar mining panel in the Somerset area, where the panel width-to-depth ratio was about 1:1.25, tended to follow the amount and rate of subsidence measured above longwall mining panels much more closely than that above panel 6L, where the ratio of W/D was about 0.6:0.8 (fig. B 4). Also, the residual subsidence, after mining was completed, was much less in panel 5L than that in panel 6L, probably because a compression arch is present above panel 6L (Dunrud, 1976). Subsidence appears to have been complete about 9 months after mining was finished in panel 5L, whereas subsidence may not have been complete in panel 6L for about 21 months after mining was completed. Measurements are continuing to determine whether or not subsidence is complete above these and other room-and-pillar mining panels in the Somerset area.

Summary

Subsidence resulting from coal mining can damage the ground surface as well as other coal or mineral deposits or fluid-bearing rocks between the surface and the coal bed being mined. The effects of topography, geology, and mining procedure on subsidence type, rate, and amount are significant. The obvious remedy to subsidence seems to be to either (1) mine the coal completely in a uniform manner over a large enough area so that the overburden settles uniformly and the tensile, compressive, and shear stress effects of differential settlement are minimized; or (2) leave enough coal in the ground to support the overburden uniformly until mining is completed, and later on, perhaps, extract the remaining coal by another means, assuming that the coal pillars left behind will remain competent and not lose strength through exposure to air or water.

Both these options are fraught with problems that depend on specific geologic and topographic conditions in the area to be mined. The overburden may be too thick or too variable in thickness to implement a mining plan that would extract the coal completely over an area extensive enough to minimize the effects of differential settlement, or the coal deposit may comprise more than one vertically superposed bed, thus complicating complete extraction. It also may be difficult to implement a uniform mining plan involving partial extraction and secondary recovery in the rugged terrain of east-central Utah because (1) variable overburden load would dictate variable pillar dimensions, and (2) secondary recovery procedures, such as in-place gasification, might burn out of control if air were available via subsidence cracks caused by voids created during the burning.

It is obvious that the best and most efficient mining activity is one that incorporates geologic and topographic information as well as mining experience into the mining plan. This means that site-specific geological and geotechnical investigations should be conducted early in the mine planning stage.

NATURAL AND MANMADE EARTHQUAKES

Seismicity in east-central Utah is derived from two major sources: normal low- to intermediate-magnitude earthquakes along active faults of the Wasatch Plateau and the Wasatch Front, and tremors resulting from the sudden release of pent-up, mine-induced stresses. In addition, small natural earthquakes occur occasionally in the San Rafael Swell and in the Book Cliffs.

Most seismicity in the region probably originates in room-and-pillar coal mining areas. More than 50,000 tremors having Richter magnitudes of as much as 4.5 have been recorded in a single year in the Sunnyside, Utah, area (Barnes and others, 1969). These tremors occurred as much as 8,000 ft (2,400 m) below the mines and within 8,000 ft (2,400 m) laterally from mine workings. The number of these tremors fluctuates daily in response to mining work cycles (Osterwald and others, 1971, p. 15-16, 19; Dunrud and others, 1973). Most seismicity related to release of stresses induced by longwall mining is restricted to mine barriers and to pillars left behind in long haulageways.

Seismicity resulting from underground mining activities is causing large accumulations of talus at several localities, particularly along the front of the Book Cliffs, north and south of Sunnyside, Utah. A striking example of such a talus accumulation, consisting of angular boulders--many of which are of huge size, is clearly visible along a cliff face 2 1/2 mi (4 km) north of East Carbon City, Utah. This talus began to accumulate in 1959.

FOUNDATION CONDITIONS

Large parts of east-central Utah, particularly the Clark Valley-Castle Valley area surrounding the San Rafael Swell, are underlain by Mancos Shale. The Mancos contains considerable amounts of clays that swell when wetted and also of salts such as complex sodium sulfates that undergo hydration and dehydration (swelling and contraction) with humidity changes. These swelling clays and salts cause much differential movement of building foundations unless such conditions are taken into account for engineering designs. They also cause highway surfaces on the Mancos to become uneven and eventually to break up if the roadways are not carefully designed.

Although seemingly soft and easily able to absorb water, the Mancos has much mixed-layer clay that allows water only slight penetration below the surface and forces much of the precipitation to run off. During heavy rains, surfaces on the Mancos Shale are impassible to vehicles, owing to mud, but the rocks may be dry a few inches down.

LANDSLIDES

Some parts of the east-central Utah region are particularly susceptible to landsliding. Quaternary deposits of dark-gray to light-reddish-brown clay, silt, and sand containing large amounts of black organic material are widespread on slopes above 7,200 ft (2,200 m) in elevation. These deposits also contain variable amounts of locally derived angular rock fragments. Locally, masses of this material were disturbed by landsliding in Pleistocene time and large areas are covered by landslide debris, particularly where the bedrock is the North Horn Formation or Colton Formation. Some of these slides are currently active, and most masses of these Quaternary deposits are easily made unstable by excavations for roads and other structures.

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PART B. SOME PROBABLE GEOCHEMICAL IMPACTS OF COAL DEVELOPMENT IN EAST-CENTRAL UTAH

by

Jon J. Connor

SYNOPSIS

Coal based energy development in east-central Utah is expected to impact the geochemical landscape most importantly by changing the chemistry of vegetation. Examples of such impact observed to date in other coal-bearing areas of the western United States, include altered copper/molybdenum ratios in sweetclover growing on spoil banks, slightly increased concentration of cadmium, cobalt, flourine, uranium, and zinc in crested wheatgrass growing on reclaimed spoils, and elevated concentration of selenium, uranium, and perhaps flourine in native vegetation growing within 5 to 10 km of coal-fired electric-generating plants. Lowered copper/molybdenum ratios might induce molybdenosis in ruminants, and cadmium, selenium, and flourine are known poisons. In general, whereas natural scientists can define an "excessive" trace element level in natural materials, medical scientists are the only ones capable of assessing a "health hazard" based on such levels.

With the exception of work in coal chemistry (see Swanson and others, 1976), no formal studies in environmental geochemistry have as yet been directed to the area of east-central Utah (fig. C1). Some miscellaneous samples of landscape materials from the area have been analyzed and are available in upbublished files of the U.G. Geological Survey, but few are of materials likely to be involved in coal development and fewer still were collected for purposes of establishing geochemical norms or baselines. Limited data on sandstone and shale of lower Eocene age are given in table C1 along with summaries of similar materials in other parts of the western U.S. Crustal averages for the two most common rock materials associated with coal (shale and sandstone) are also included for comparison. Table C1 is useful primarily as a guide to the geochemical diversity to be expected in a natural landscape and can be used, with caution, as a rough guide to background concentrations in the area.

Central to the problem of the expected geochemical impact of coal development is the chemistry of coal itself. For most trace or minor elements, the gross composition of coal is similar to that of shale (see Swanson and others, 1976). The potential environmental impact of this chemistry, however, must be viewed as large because such elements can be easily released into the environment by weathering or burning.

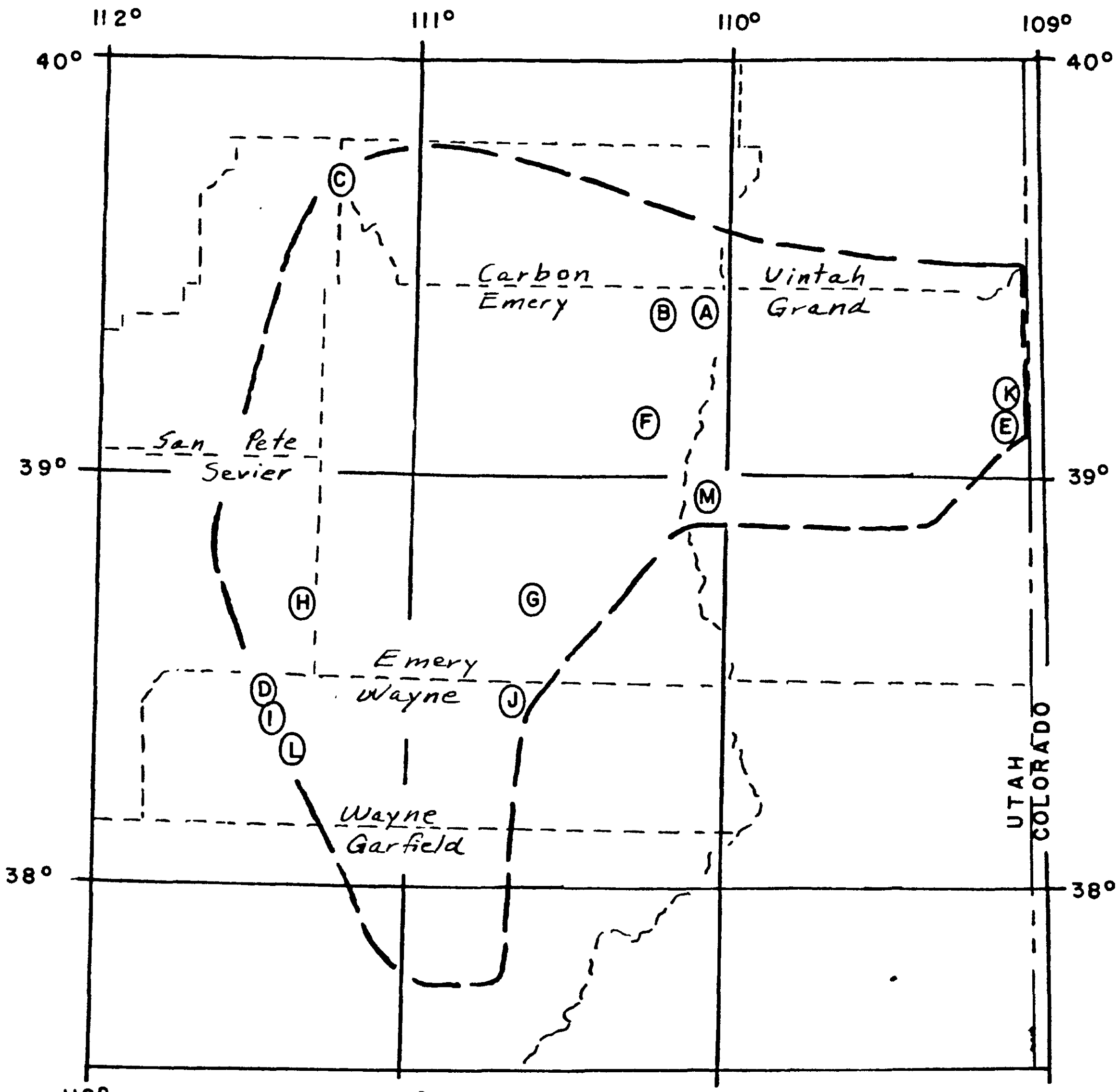

Figure C1.--Index map showing location of east-central Utah area (heavy dashed line) and sample localities used in compiling parts of Table C1 (lettered circles).

Table C1.--Geochemical summary of landscape materials

[Element concentrations given in parts per million except where noted as percent (%) or parts per billion (ppb); leaders (--) indicate insufficient data]

Identification of material and sources of data

(1) Average (median) of up to four samples of Lower Eocene mudstone and shale from Locality A (fig. C1). Taken from unpublished files of the U.S. Geological Survey.

(2) Average (median) of up to six samples of Lower Eocene mudstone and shale from Locality B (fig. C1). Taken from unpublished files of the U.S. Geological Survey.

(3) Crustal average for shale. Taken from Turekian and Wedepohl (1961).

(4) Average (geometric mean) of six samples of Lower Eocene sandstone from Locality C (fig. C1). Taken from Vine and Tourtelot (1973).

(5) Average (geometric mean) of six samples of Lower Eocene sandstone from Locality B (fig. C1). Taken from Vine and Tourtelot (1973).

(6) Average (geometric mean) of six samples of Lower Eocene sandstone from Locality D (fig. C1). Taken from Vine and Tourtelot (1973).

(7) Crustal average for sandstone. Taken from Turekian and Wedepohl (1961).

(8) Average (median) of up to six samples of B-horizon soil from Localities E-J (fig. C1). Taken from unpublished files of U.S. Geological Survey.

(9) Average (geometric mean) of B-horizon soil in the western United States. Taken from Shacklette, Boerngen, and Turner (1971), Shacklette, Boerngen and Bowles (1971), Shacklette and others (1973), and Shacklette and others (1974).

 (FOLLOW BY PAGE 120-A)

(10) One sample of grass (*Orizopsis hymenoides*) from Locality K (fig. C1). Taken from unpublished files of the U.S. Geological Survey.

(11) One sample of Juniper stems (*Juniperus osteosperma*) from Locality L (fig. C1). Taken from unpublished files of the U.S. Geological Survey.

(12) Average of two samples of saltbush stems (*Atriplex corrugata* and *A. nuttali*) from Locality M (fig. C1). Taken from unpublished files of the U.S. Geological Survey.

(13) Average of typical concentrations for sagebrush stems (*Artemisia tridentata*) from the Powder River and the Green River Basins, Wyoming. Taken from Connor, Keith, and Anderson (1976) and Anderson and Keith (1976).

Element	Shale			Sandstone				Soil		Plant ash			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Aluminum, % --	6.0	6.9	8.0	4.1	5.5	0.97	2.5	3.0	5.4	0.7	0.7	3.3	2.2
Antimony -----	--	--	1.5	--	--	--	< .1	--	--	--	--	--	--
Arsenic ------	--	--	13	--	--	--	1	--	6.1	--	--	--	.15
Barium -------	500	520	580	1,500	740	420	< 100	500	560	200	500	400	400
Beryllium ----	1.5	< 1	3	--	--	--	< 1	< 1.5	.6	--	--	--	--
Boron --------	20	< 25	100	--	19	--	35	40	< 20	70	300	130	270
Bromine ------	--	--	4	--	--	--	1	--	--	--	--	--	--
Cadmium ------	--	--	.3	--	--	--	< .1	--	< 1	--	--	--	4.2
Calcium, % ---	5	6.3	2.2	5.9	3.1	7.1	3.9	6	1.8	5	> 10	11	9.1
Cerium -------	--	--	59	--	--	--	92	--	74	--	--	--	--
Cesium -------	--	--	5	--	--	--	< 1	--	--	--	--	--	--
Chlorine -----	--	--	180	--	--	--	10	--	--	--	--	--	--
Chromium -----	50	64	90	24	37	6.3	35	40	38	10	15	23	17
Cobalt -------	5	12	19	9.7	9.4	3.2	.3	6	8	--	--	--	1.9
Copper -------	40	41	45	16	24	8.3	< 10	25	21	100	100	35	110
Dysprosium ---	--	--	4.6	--	--	--	7.2	--	--	--	--	--	--

 (FOLLOWED BY PAGE 120-c)

Element	Shale			Sandstone				Soil		Plant ash			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Erbium -----	--	--	2.5	--	--	--	4.0	--	--	--	--	--	--
European ----	--	--	1	--	--	--	1.6	--	--	--	--	--	--
Fluorine ----	--	--	740	--	--	--	270	400	250	--	--	--	15/
Gadolinium --	--	--	6.4	--	--	--	10	--	--	--	--	--	--
Gallium -----	15	21	19	13	14	--	12	13	18	< 7	--	< 7	< 10
Germanium ---	--	--	1.6	--	--	--	.8	--	--	--	--	--	--
Gold, ppb ---	--	--	< 10	--	--	--	< 10	--	--	--	--	--	--
Hafnium -----	--	--	2.8	--	--	--	3.9	--	--	--	--	--	--
Holmium -----	--	--	1.2	--	--	--	2	--	--	--	--	--	--
Indium ------	--	--	.1	--	--	--	< .1	--	--	--	--	--	--
Iodine ------	--	--	2.2	--	--	--	1.7	--	--	--	4/	--	--
Iron, % -----	2	3.1	4.7	.77	1.7	.26	.98	1.8	2	.3	.7	1.5	.68
Lanthanum ---	40	57	92	--	17	--	30	< 30	35	--	--	--	--
Lead --------	20	24	20	8.5	18	--	7	15	18	150	70	< 20	53
Lithium -----	--	--	66	--	--	--	15	15	23	--	--	23	12
Lutetium ----	--	--	.7	--	--	--	1.2	--	--	--	--	--	--

Element	Shale			Sandstone				Soil		Plant ash			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Magnesium, %	1.0	1.8	1.5	1.3	1.1	0.89	0.7	1.0	0.78	1.5	7.0	2.5	1.5
Manganese ----	500	680	850	440	380	160	< 100	250	390	500	300	500	480
Mercury, ppb	--	--	400	--	--	--	30	< 20	55	--	--	--	19/
Molybdenum ---	--	--	2.6	--	--	--	.2	--	--	10	15	< 7	9.9
Neodymium ----	--	--	24	--	--	--	37	--	36	--	--	--	--
Nickel -------	13	30	68	12	19	4.1	2	13	16	50	10	10	13
Niobium ------	--	--	11	--	--	--	< .1	< 15	11	--	--	--	--
Phosphorus, %	--	.08	.07	.06	.07	.04	.02	< .1	.03	1.5	2.0	.24	2.7
Potassium, % -	2	1.8	2.7	.6	1.7	.43	1.1	2	1.7	> 10	> 10	2.9	23
Praseodymium -	--	--	5.6	--	--	--	8.8	--	--	--	--	--	--
Rubidium -----	--	--	140	--	--	--	60	65	--	--	--	--	--
Samarium -----	--	--	6.4	--	--	--	10	--	--	--	--	--	--
Scandium -----	8.5	15	13	--	--	--	1	6	9	--	--	--	--
Selenium -----	--	--	.6	--	--	--	.05	< 1	.25	--	--	--	.29/
Silicon, % ---	>10	22	7.3	31	30	33	37	> 10	--	--	--	--	8.6
Silver -------	--	--	.07	--	--	--	< .1	--	--	--	--	--	--

Element	Shale			Sandstone				Soil		Plant ash			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Sodium, % ---	2.5	2.6	0.96	0.53	1.8	0.1	0.33	0.7	1.0	0.14	0.56	12.0	0.21
Strontium ---	150	280	300	180	250	730	20	180	210	1,000	7,000	2,000	480
Sulfur ------	--	--	2,400	--	--	--	240	--	--	--	--	--	1,500_/
Tantalum ----	--	--	.8	--	--	--	< .1	--	--	--	--	--	--
Terbium -----	--	--	1	--	--	--	1.6	--	--	--	--	--	--
Thallium ----	--	--	1.4	--	--	--	.82	--	--	--	--	--	--
Thorium -----	--	--	12	10	8.9	2.7	1.7	5.8	--	--	--	--	--
Thulium ------	--	--	.2	--	--	--	.3	--	--	--	--	--	--
Tin ---------	--	--	6	--	--	--	< 1	--	--	--	--	--	--
Titanium, % -	.15	.28	.46	.11	.19	.05	.15	.11	.21	.03	.05	.18	.10
Tungsten ----	--	--	1.8	--	--	--	1.6	--	--	--	--	--	--
Uranium -----	--	--	3.7	3.2	2.2	2.8	.45	2.3	--	--	--	--	.67
Vanadium ----	85	120	130	48	84	12	20	70	66	30	20	50	29
Ytterbium ---	1.5	--	2.6	--	--	--	4	2.5	3	--	--	--	--
Yttrium -----	15	25	26	18	8.8	6.4	40	18	25	--	--	--	--
Zinc --------	--	--	95	--	--	--	16	44	51	--	--	--	350
Zirconium ---	100	120	160	140	150	120	220	130	170	< 20	20	190	58

_/ Measured in dry material.

Numerous investigators have looked at the probable partitioning of elements during coal combustion and the expected amount of stack emissions at a number of powerplants. Kaakinen and others (1974) found in a study of inlet and outlet streams in a Colorado powerplant that of 12 elements, all could be properly accounted or in terms of mass balance except for selenium (some 60 percent of the mass unaccounted for) and mercury (nearly 100 percent unaccounted for). These masses presumably escaped through the stack. The U.S. Environmental Protection Agency (1975) states that mercury as well as sulfur and chlorine exists in powerplants as a gas. Gordon and Tourangeau (1975) give estimates of the tons per year of fluoride and of the oxides of sulfur and nitrogen emitted in 12 TVA powerplants. These data suggest that about 20 tons of fluoride, 40,000 tons of the nitrogen oxides and about 80,000 tons of sulfur dioxide are emitted for each million ton of coal burned in these plants. The U.S. Environmental Protection Agency (1975) lists 19 trace elements as being enriched in the flue gas of three powerplants they studied. They are antimony, arsenic, boron, cadmium, chlorine, chromium, cobalt, copper, fluorine, lead, mercury, molybdenum, nickel, selenium, silver, sulfur, uranium, vanadium, and zinc.

Theoretically, of course, all naturally occurring elements will exist in the stack gas in at least some concentration levels, however small. More important, in an environmental context, is not whether or not an element can be measured in the emissions, but whether or not its effects can be observed in the local environment. Connor, Keith, and Anderson (1976), Connor, Anderson, Keith, and Boerngen (1976), and Gough and Erdman (1976) found exponentially decreasing concentrations of a variety of elements in lichen, grass, or sagebrush going away from two western powerplants, including nine which must be regarded as possible stack emittents. These are copper, fluorine, lead, nickel, selenium, strontium, sulfur, vanadium, and zinc.

Emitted trace elements appear to excape in or on flyash particles too small to be effectively trapped in the stack. Natusch and others (1974) found the highest concentrations of lead, titanium, antimony, cadmium, selenium, arsenic, nickel, chromium, zinc, and sulfur in the finer sizes of flyash from eight U.S. powerplants. Further, there is a tendency for many elements to concentrate on the surface of the flyash particle (Linton and others, 1976) presumably as condensates during the temperature drop from combustion to emission.

Some elements are emitted largely in the gaseous state, particularly the oxides of sulfur, nitrogen, and carbon, but also included here, to some extent, are probably hydrofluoric acid and elemental selenium, mercury, antimony, arsenic, cadmium, and molybdenum (Vaughn and others, 1975). Most attention seems to be focused on the potential for "acid rain" resulting from hydrolysis of sulfur dioxide in the atmosphere. Gordon and Tourangeau (1975) and Gordon and others (1976) found that fluorine concentrations in pine trees are indirectly related to percentage of healthy needles and that needle retention is substantially reduced in polluted areas. Tingey and others (1976) found that four hours exposure to 1-2 ppm sulfur dioxide resulted in slight to severe foliar injury to grass and sagebrush.

Finally, geochemical effects of power generation need not necessarily reflect only stack emissions. A sagebrush traverse north of the Jim Bridger Powerplant in western Wyoming indicated appreciable accumulations in sagebrush of iron, titanium, nickel, silicon, fluorine, and selenium as well as increased ash contents. All of these effects were measured before any of the generating units were fully operational, and they tended to be greatest within 1 to 3 kilometers of the plant. They probably reflect either a construction impact (windborne dust) or natural (substrate) fluctuations, or both (Anderson and Keith, 1976).

Probably the greatest concern over powerplant siting focuses on potential injury to man. It is a subject area that deserves careful and continued attention because the probable effects, if any, are likely to be long-term and chronic. The pathway for trace-element emissions from burned coal to man is complex, and data necessary for determining long-term health effects in man is generally insufficient. Vaughn and others (1975), in a detailed review of the subject, conclude that "it seems quite unlikely that any direct effects on health would result. Depending on their emission rates, cadmium, mercury, molybdenum, and tungsten may pose some threat to environmental quality for coal plants operating without efficient ash recovery devices."

By far, one of the greatest environmental impacts of a powerplant is the amount of waste material generated during coal combustion and stack scrubbing or precipitation. Because of the included shale or shale-like material contained in coal, the resulting ash will tend to have a chemical composition similar to shale, at least for the major elements. However, the bulk chemistry of such material is less important than the chemical mobility exhibited by the contained elements. Dreesen and others (1976) investigated the leachability of flyash at a New Mexico powerplant and found that few trace elements are readily leachable except in fairly strong acids. Molybdenum is a notable exception to this generalization, and boron, calcium, molybdenum, and strontium seem to be moderately well mobilized in weak HNO_3. Both molybdenum and boron are environmentally sensitive elements.

A very serious problem in coal development involves strip-mine reclamation. Mineral, as well as chemical, changes will result in the substrate if natural soil is replaced by or intermixed with overburden rock. Probably the most important result of such substitution arises from exposure of previously buried material to weathering, with the attendant possibility of chemical release of "foreign" substances into the surficial landscape. The most highly reactive materials occurring at the surface of overturned materials are expected to be fragments of coal or other highly carbonaceous strata, and the pyrite commonly found in both coal and sandstone. The bulk of such overturned material, however, will most likely be a mixture of fine-grained fragments of shale, siltstone, and claystone. The mineralogy of such a mixture would, no doubt, be rather simple, consisting largely of quartz and clay minerals with more or less feldspar and carbonate minerals.

As a geologic system, a stripped area can be viewed as a porous, unsorted matrix of largely ordinary fine-grained silicate minerals through which are dispersed "nuggets" of chemically reactive limestone, coal, and pyrite. Top-dressing of a reclaimed area adds an additional geochemical complication, but the important feature of the entire mass is that it is in chemical disequilibrium with its surroundings. Chemical change in this mass through time (weathering) works to restore the system to equilibrium with its new surroundings.

Again, the potential geochemical impact focuses on the chemical mobility exhibited by the contained elements. Problems in the humid eastern U.S. are dominated by acid-mine drainage, which results from rapid oxidation and dissolution of contained pyrite. The acid conditions so produced appear to be potent mobilizers of most of the transition elements. In the western U.S., where surface runoff is sparse, concern focuses more on disruption of underground water supplies through changes in quantity or flow direction although potential problems in element mobilization cannot be discounted.

Van Voast and others (1975) noted that manganese and nitrate appear to be strongly enriched in spoil water at one location compared to that in typical ground water in the Northern Powder River Basin, but calcium, magnesium, potassium, silica, chlorine, sulfate, total dissolved solids, and specific conductance were also substantially elevated. The elevation in sulfate suggests oxidation of pyrite in the spoils. Little is known of trace-element mobilization during weathering of coal-mine spoils, although there appears to be a general tendency for many trace metals to be more soluble in acid oxidizing solutions.

Much of the work in strip-mine reclamation is directed to insuring that such areas be returned to at least as productive a status (in terms of crops or grass) as before mining. The potential impact on vegetative cover is suggested in an examination of the copper/molybdenum ratio in sweetclover (<u>Melilotus officinalis</u> or <u>M</u>. <u>alba</u>) growing on these materials from strip-mine spoils in the Northern Great Plains (table C2). This ratio is seen to rarely exceed three or four in clover from eight such areas, some of which are reclaimed, and compares with "optimal" ratio in forage of about five to seven (Erdman and Ebens, 1976a). A browse diet formed largely of such a plant might induce symptoms of a copper/molybdenum imbalance in ruminants.

Table C2.--Copper and molybdenum in sweetclover (*Melilotus* spp.), and pH in spoil materials from eight coal mines in the Northern Great Plains

[Geometric mean (GM) concentrations and observed ranges expressed as parts per million in dry material; arithmetic mean (AM) of pH expressed in standard units; GD, geometric deviation; SD, standard deviation; mines listed in order of increasing Cu:mo ratios]

Mines, or baseline data	Sweetclover, above ground parts									Mine spoils		
	Copper			Molybdenum			Cu:Mo ratio			pH		
	GM	GD	Observed range	GM	GD	Observed range	GM	GD	Observed range	AM	SD	Observed range
Big Sky -------	8.2	1.16	6.5-9.8	13.0	1.23	10-20	0.61	1.21	0.44-0.75	7.6	0.53	6.5-8.5
Utility -------	6.9	1.14	5.3-9.0	11	1.33	6.4-18	.62	1.29	.43-1.0	7.8	1.30	4.4-9.0
Velva ---------	7.2	1.18	5.9-9.5	7.9	1.25	5.3-12	.92	1.27	.63-1.4	7.8	.40	7.0-8.5
Savage --------	5.9	1.27	4.1-9.3	6.4	1.30	4.8-10	.92	1.47	.50-1.9	8.2	.49	7.0-8.5
Kincaid -------	9.0	1.20	6.7-13	6.5	1.84	2.8-18	1.4	1.70	.65-2.8	7.8	.71	7.1-9.4
Beulah --------	5.5	1.14	4.4-6.7	2.6	1.60	1.2-8.3	2.1	1.60	.63-3.8	7.0	.69	6.2-8.7
Dave Johnston -	7.0	1.19	5.2-9.5	3.1	2.18	1.5-14	2.3	2.34	.47-6.5	6.2	1.59	4.0-8.5
Welch ---------	8.1	1.27	5.6-11	3.4	1.68	1.9-9.5	2.4	1.77	1.2-5.0	6.6	.96	5.4-7.8
Baseline data 2/	7.6	1.66	2.8-21 1/	2.1	2.57	.32-14 1/	3.6	2.35	.65-20 1/	7.2	.46	6.3-8.1 1/

1/ Ranges given for baseline data are not the "observed" ranges, but the expected central 95-percent ranges as described in the text.

2/ Sweetclover baseline based on eight samples collected throughout the United States; pH baseline based on 64 A-horizon soil samples collected across the Powder River Basin (Tidball and Ebens, 1976).

An additional impact has been observed in crested wheatgrass (*Agropyron desertorum* and *A. cirstatum*) at the southern edge of the Powder River Basin (table C3). Expected concentrations (geometric means) of cadmium, cobalt, flourine, uranium, and zinc are elevated in wheatgrass growing on reclaimed spoil materials when compared to controls.

The most difficult aspect of impact assessment on the trace-element character of the landscape, however, is that of assessing the broad-scaled regional effects. This is so because, while changes in trace-element concentrations far from mines or powerplants will almost certainly be very small, the fear exists that such changes may still pose a potential hazard to plant, animal, or human health. Table C4 lists some trace-element toxicities in plants and animals reported in the literature (see Gough and Shacklette, 1976, for a more complete list). Overall, though, the exact roles played by many trace elements in living tissue remain unclear or unknown, and the relation of the local geochemical environment on health or disease is even less well known. (See also Hopps and Cannon, 1972, and Cannon and Hopps, 1971.) Moreover, such assessment must be an interdisciplinary one. While it is the role of the natural scientist to determine the relative magnitude of man's contributions to the geochemical environment, it is the role of the medical scientist to determine what, if any, health hazard may ensue from that contribution.

Table C3.--Statistical analysis of element concentrations in the ash of crested wheatgrass from topsoil borrow areas and from reclaimed spoil areas at the Dave Johnston Mine, southern Powder River Basin, Wyoming

[Concentrations expressed as parts per million, except for Ca, Na, K, P, S, Si, and ash, which are in percent; *, component of variance tested to be significant at the 0.05 probability level; ratio, number of samples in which element was detected to total number of samples analyzed.]

Element or ash	Analysis of variance				Summary statistics							
	Total log10 variance	Natural variance[1/]		Variance due to analytical error	Topsoil borrow areas				Reclaimed spoil areas			
		Between areas	Among samples within areas		Ratio	Geometric mean	Geometric deviation	Observed range	Ratio	Geometric mean	Geometric deviation	Observed range
Ca------	0.0046	<1	95*	5	20:20	4.1	1.11	3.6-5.2	20:20	3.9	1.21	2.6-5.3
Cd------	.0702	27*	<1	73	20:20	.86	1.90	.2-2	20:20	1.4	1.40	.6-2
Co------	.0991	35*	13	52	10:20	.72	1.76	<1-2	15:20	1.5	2.59	<1-8
F[2/]-----	.0240	30*	61*	9	20:20	4.5	1.17	3-6	20:20	6.2	1.46	3-10
Hg[2/]----	.0138	<1	18	82	20:20	.011	1.33	.01-.02	20:20	.011	1.29	.01-.02
K-------	.0148	<1	96*	4	20:20	18	1.23	13-24	20:20	20	1.38	9.8-30
Li------	.1081	15	83*	2	20:20	13	2.02	4-30	20:20	22	1.93	8-65
Na------	.0661	<1	87*	13	15:20	.27	2.32	<.2-.8	18:20	.37	1.67	<.2-.8
P-------	.0267	55*	29*	16	20:20	2.1	1.16	1.8-2.4	20:20	1.4	1.38	.6-2.4
S, total[2/]	.0203	<1	97*	3	20:20	.17	1.29	.10-.27	20:20	.18	1.45	.09-.33
Se[2/]----	.0710	<1	91*	9	20:20	.23	1.91	.10-.60	20:20	.27	1.73	.10-.70
Si------	.0138	15	65*	20	20:20	20	1.22	14-26	20:20	16	1.33	9.4-26
U-------	.2165	39*	54*	7	9:20	.25	2.41	<.4-1.2	19:20	1.0	3.02	<.4-10
Zn------	.0199	59*	39*	2	20:20	310	1.20	220-460	20:20	440	1.25	300-580
Ash-----	.0035	<1	94*	6	20:20	6.3	1.15	5.3-8.0	20:20	6.0	1.14	2.6-5.3

1/Expressed as percent of the total variance

2/Analyses determined on dry material, not ash; therefore expressed on dry-weight basis.

Table C4.--Some reported trace-element toxicities in plants and animals (adapted from summaries compiled by Gough and Shacklette, 1976, and by R. C. Severson and L. P. Gough, written commun., 1976)

Element	In plants	In animals
Cadmium	Growth reduction when nutrient solution contained 0.2 ppm (beets, beans, turnips), 5 ppm (tomato, barley), and 9 ppm (cabbage).	Reduced growth in sheep with 30-60 ppm in diet for 191 days; toxic to rats at 45 ppm in diet for 6 months or 0.5 mg Cd^{++} in 10g/day dry weight diet; 16 mg Cd^{++} in 10g/day dry weight diet lethal to rats.
Cobalt	Toxic to crops at 0.1 ppm in culture solution. Sudan grass (containing 19-32 ppm in dry weight) showed toxic effects when grown in soil to which 2,000 pounds/acre had been added.	1 mg/kg of body weight per day toxic to cattle.
Fluorine	Reduced growth at 30-300 ppm (dry weight?) of plant tissue; yield reduction in citrus at leaf levels (dry weight?) of 200 ppm.	Normal performance may be affected if dietary dry matter contains 40 ppm (beef or dairy heifers), 60 ppm (horses), 100 ppm (finishing cattle), 300 ppm (broiler chickens), and 400 ppm (breeding hens and turkeys).
Zinc	Toxic(?) to corn, soybeans, wheat, barley, and oats at leaf levels of 150 ppm (ash weight?); toxic to citrus at leaf levels of 200 ppm (ash weight?); decreased yields of navy beans at levels above 50 ppm in the bean (ash weight?).	Growth depression and anemia in rats at dietary levels of 5,000 ppm, lethal at 10,000 ppm; growth depression in weanling pigs at dietary levels of more than 1,000 ppm; mortality at 4,000-8,000 ppm; reduced gains in lambs at dietary levels of 1,000-1,500 ppm; reduced gains in steers at dietary levels of 900 ppm; 150 mg Zn^{++} in 10g/day dry weight diet lethal to rats.
Selenium	Chlorosis of wheat leaves at leaf levels less than 250 ppm (dry weight?) if content of leaf sulfur "low".	Growth rates depressed at dietary levels greater than 4-5 ppm; selenosis in young pigs within 2-3 weeks at dietary levels of 10-15 ppm. Dietary levels of 5-10 ppm in rats and dogs induce chronic poisoning.

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