UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TEXT TO ACCOMPANY:

COAL RESOURCE OCCURRENCE

AND

COAL DEVELOPMENT POTENTIAL

MAPS

OF THE

ARVADA QUADRANGLE,

SHERIDAN COUNTY, WYOMING

BY

INTRASEARCH INC.

ENGLEWOOD, COLORADO

OPEN FILE REPORT 79-166
1980

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

MAPS | PLATES

TABLE OF CONTENTS (continued)

CONVERSION TABLE

TO CONVERT	MULTIPLY BY	TO OBTAIN
inches	2.54	centimeters (cm)
feet	0.3048	meters (m)
miles	1.609	kilometers (km)
acres	0.40469	hectares (ha)
tons (short)	0.9072	metric tons (t)
cubic yards/ton	0.8428	cubic meters/ metric ton
acre-feet	0.12335	hectare-meters
British thermal units/pound (Btu/lb)	2.326	kilojoules/kilogram (kj/kg)
British thermal units/pound (Btu/lb)	0.55556	kilocalories/kilogram (kcal/kg)
Fahrenheit	5/9 (F-32)	Celsius

I. Introduction

This report and accompanying maps set forth the Coal Resource Occurrence (CRO) and Coal Development Potential (CDP) of coal beds within the Arvada Quadrangle, Sheridan County, Wyoming. This CRO and CDP map series includes 45 plates (U. S. Geological Survey Open-File Report 79-166). The project is compiled by IntraSearch Inc., 5351 South Roslyn Street, Englewood, Colorado, under KRCRA Eastern Powder River Basin, Wyoming, Contract Number 14-08-0001-17180. This contract is a part of a program to provide an inventory of unleased federal coal in Known Recoverable Coal Resource Areas (KRCRAs) in the western United States.

The Arvada Quadrangle is located in Sheridan County, in northeastern Wyoming. It encompasses all or parts of Townships 54 and 55 North, Ranges 77 and 78 West, and covers the area: 44°37'30" to 44°45' north latitude; 106°07'30" to 106°15' west longitude.

Main access to the Arvada Quadrangle is U. S. Highway 14-16 which angles east-to-west across the northern half of the area. Maintained gravel roads provide additional access to the area in the northwestern and southeastern areas. Minor roads and trails branch from these maintained roads, providing access to the more remote areas. Burlington Northern railroad trackage traverses the quadrangle from the northwestern quarter to the southeastern corner.

The Powder River meanders along the southeastern edge of the quadrangle, and flows northward immediately east of the quadrangle. Clear Creek, located in the extreme northwest corner of the area, drains northeastward into the Powder River approximately 10 miles (16 km) to the north of the Arvada Quadrangle. Elevations attain maximum heights of 4,560 feet (1,390 m) above sea level in the southwestern corner of the area, approximately 900 feet (274 m) above the Powder River valley floor to the east.

The 13 to 14 inches (33 to 36 cm) of annual precipitation falling in this semi-arid region accrue principally in the springtime. Summer and fall precipitation usually originates from thunderstorms, and infrequent snowfalls of 6 inches (15 cm) or less generally characterize winter precipitation. Although temperatures ranging from less than -25°F (-32°C) to more than 100°F (38°C) have been recorded near Arvada, Wyoming, average wintertime minimums and summertime maximums range from +5° to +15°F (-15° to -9°C) and 75° to 90°F (24° to 32°C), respectively.

Surface ownership is divided among fee, state, and federal categories with the state and federal surface generally leased to ranchers for grazing purposes. Details of surface ownership are available at the Sheridan County Courthouse in Sheridan, Wyoming. Details of mineral ownership on federal lands are available from the U. S. Bureau of Land Management in Cheyenne, Wyoming. Federal coal ownership is shown on plate 2 of the Coal Resource Occurrence maps. The non-federal coal ownership comprises both fee and state coal resources.

The Coal Resource Occurrence and Coal Development Potential program pertains to unleased federal coal and focuses upon the delineation of lignite, subbituminous coal, bituminous coal, and anthracite at the surface, and in the subsurface. In addition, the program identifies total tons of coal in place (resources), as well as recoverable tons (reserves). These coal tonnages are then categorized in measured, indicated, and inferred parts of identified resources, and hypothetical resources. Finally, recommendations are made regarding the potential for surface mining, underground mining, and in-situ gasification of the coal beds. This report evaluates the coal resources of all unleased federal coal beds in the quadrangle which are 5 feet (1.5 m) or greater in thickness and occur at depths down to 3,000 feet (914 m). No resources or reserves are computed for leased federal coal, state coal, fee coal, or lands encompassed by coal prospecting permits and preference-right lease applications.

Surface and subsurface geological and engineering extrapolations drawn from the current data base suggest the occurrence of approximately 7.0 billion tons (6.4 billion metric tons) of total, unleased federal coal-in-place resources in the Arvada Quadrangle.

The suite of maps that accompanies this report sets forth and portrays the coal resource and reserve occurrence in considerable detail. For the most part, this report supplements the cartographically displayed information with minimum verbal duplication of the CRO-CDP map data.

II. Geology

Regional. The thick, economic coal deposits of the Powder River Basin in northeastern Wyoming occur mostly in the Tongue River Member of the Fort Union Formation, and in the lower part of the overlying Wasatch Formation. Approximately 3,000 feet (914 m) of the Fort Union Formation, including the Tongue River, Lebo, and Tullock Members of Paleocene age, are unconformably overlain by approximately 700 feet (213 m) of the Wasatch Formation of Eocene age. These Tertiary formations lie in a structural basin flanked on the east by the Black Hills uplift, on the south by the Hartville and Casper Mountain uplifts, and on the west by the Casper Arch and the Big Horn Mountain uplift. The structural configuration of the Powder River Basin originated in Late Cretaceous time, with episodic uplift thereafter. The Cretaceous Cordillera was the dominant positive land form throughout the Rocky Mountain area at the close of Mesozoic time.

Outcrops of the Wasatch Formation and the Tongue River Member of the Fort Union Formation cover most of the areas of the major coal resource occurrence in the Powder River Basin. The Lebo Member of the Fort Union Formation is mapped at the surface northeast of Recluse, Wyoming. The Lebo Member is east of the principal coal outcrops and associated clinkers (McKay, 1974), and it presumably projects into the subsurface beneath much of the basin. One of the principal characteristics for separating the Lebo and Tullock Members (collectively referred to as the Ludlow Member east of Miles City, Montana) from the overlying Tongue River Member is the color differential between the lighter-colored upper portion and the somewhat darker lower portion (Brown, 1958). Although geologists are trying to develop criteria for subsurface recognition of the Lebo-Tullock and Tongue River-Lebo contacts through use of subsurface data from geophysical logs, no definitive guidelines are known to have been published. Hence, for subsurface mapping purposes, the Fort Union Formation is not divided into its member subdivisions for this study.

During the Paleocene epoch, the Powder River Basin tropical to subtropical depositional environment included broad, inland flood basins with extensive swamps, marshes, freshwater lakes, and a sluggish, but active, northeastward-discharging drainage system. These features were superimposed on an emerging sea floor, near base level. Much of the vast area where organic debris collected was within a reducing depositional environment. Localized uplifts began to disturb the near sea level terrain of northeastern Wyoming, following retreat of the Cretaceous seas. However, the extremely fine-grained characteristics of the Tongue River Member clastics suggest that areas of recurring uplift peripheral to the Powder River Basin were subdued during major coal deposit formation.

The uplift of areas surrounding the Powder River Basin created a structural basin of asymmetric character, with the steep west flank located on the eastern edge of the Big Horn Mountains. The axis of the Powder River Basin is difficult to specifically define, but it is thought to be located in the western part of the Basin, and to display a north-south configuration some 15 to 20 miles (24 to 32 km) east of Sheridan, Wyoming. Thus, the sedimentary section described in this report lies on the east flank of the Powder River Basin, with gentle dips of 2 degrees or less disrupted by surface structure thought to relate to tectonic adjustment and differential compaction.

Some coal beds in the Powder River Basin exceed 200 feet (61 m) in thickness. Deposition of these thick, in-situ coal beds requires a delicate balance between subsidence of the earth's crust and and in-filling of these areas by tremendous volumes of organic debris. These conditions, in concert with a favorable ground water table, non-oxidizing clear water, and a climate amenable to the luxuriant growth of vegetation produce a stabilized swamp critical to the deposition of coal beds.

Deposition of the unusually thick coal beds of the Powder River Basin may be partially attributable to short-distance water transportation of organic detritus into areas of crustal subsidence. Variations of coal bed thickness throughout the basin relate to changes in the depositional environment. Drill-hole data that indicate either the complete absence or extreme attenuation of a thick coal bed probably relate to location of the drill holes within the ancient stream channel system servicing this lowland area in Early Cenozoic time. Where thick coal beds thin rapidly from the depocenter of a favorable depositional environment, it is not unusual to encounter a synclinal structure over the maximum coal thickness due to the differential compaction between organic debris in the coal depocenter and fine-grained clastics in the adjacent areas.

The Wasatch Formation of Eocene age crops out over most of the central part of the Powder River Basin and exhibits a disconformable contact with the underlying Fort Union Formation. The contact has been placed at various horizons by different workers; however, for the purpose of this report, the contact is positioned near the top of the Roland coal bed as mapped by Olive (1957) in northwestern Campbell County, Wyoming. It is considered to disconformably descend in the stratigraphic column to the top of the Wyodak-Anderson coal bed (Roland coal bed of Taff, 1909) along the eastern boundary of the coal measures. No attempt is made to differentiate the Wasatch and Fort Union Formations on geophysical logs or in the subsurface mapping program for this project.

Although Wasatch and Fort Union lithologies are too similar to allow differentiation in some areas, most of the thicker coal beds occur in the Fort Union section on the east flank of the Powder River Basin. Furthermore, orogenic movements peripheral to the basin apparently increased in magnitude during Wasatch time causing the deposition of friable, coarse-grained to gritty, arkosic sandstones, fine- to very fine-grained sandstones, siltstones, mudstones, claystones, brown-to-black carbonaceous shales, and coal beds. These sediments are noticably to imperceptibly coarser than the underlying Fort Union clastics.

The Arvada Quadrangle is located in an area where surface rocks are classified within the Wasatch Formation. Although the Wasatch Formation is reportedly up to 1,800 feet (549 m) thick (Denson and Horn, 1975), Olive (1957) mapped 700 to 800 feet (213 to 244 m). Only 800 to 900 feet (244 to 274 m) of Wasatch Formation are exposed in the quadrangle. Olive (1957) correlated coal beds in the Spotted Horse coal field with coal beds in the northward extension of the Sheridan coal field, Montana (Baker, 1929), and Gillette coal field, Wyoming (Dobbin and Barnett, 1927), and with coal beds in the Ashland coal field (Bass, 1932) in southeastern Montana. This report utilizes, where possible, the coal bed nomenclature used in previous reports. The Felix and Arvada coal beds were named by Stone and Lupton (1910). The Smith coal bed was named by Taff (1909), and the Cook coal bed was named by Bass (1932). The Swartz coal bed was named by McKay and Mapel (1973). Baker (1929) named the Anderson, Canyon, and Wall coal beds, and the Pawnee coal bed was named by Warren (1959). IntraSearch (1979, 1978) informally named the Moyer and Oedekoven coal beds.

Local. The Arvada Quadrangle lies on the eastern flank of the Powder River Basin, where the strata dip gently westward. The Wasatch Formation crops out over the entire quadrangle and is composed of friable, coarse-grained to gritty, arkosic sandstones, fine- to very fine-grained sandstones, siltstones, mudstones, claystones, brown-to-black carbonaceous shales, and coal beds.

The structure contours drawn on the coal bed tops generally depict a gentle, regional dip to the southwest. Minor flexures and broad, shallow folds occur on some of the structure maps.

III. Data Sources

Areal geology of the coal outcrops is derived from the Powder River coal field, Wyoming (Stone and Lupton, 1910). The coal outcrops are adjusted to fit the current topographic map of the area.

Geophysical logs from oil and gas test bores and producing wells compose the source of subsurface control. Some geophysical logs are not applicable to this study, for the logs relate only to the deep, potentially productive oil and gas zones. More than 80 percent of the logs include resistivity, conductivity, and self-potential curves. Occasionally, the suite of geophysical logs includes gamma, density, and sonic curves. These logs are available from several commercial sources.

All geophysical logs available in the quadrangle and its 3-mile perimeter area were scanned to select those with data applicable to Coal Resource Occurrence mapping. Paper copies of the logs were obtained and interpreted, and coal intervals were annotated. Maximum accuracy of coal bed identification was accomplished where gamma, density, and resistivity curves were available. Coal bed tops and bottoms were identified on the logs at the midpoint between the minimum and maximum curve deflections. The correlation of coal beds within and between quadrangles was achieved utilizing a fence diagram to associate local correlations with regional coal occurrences.

The reliability of correlations, set forth by IntraSearch in this report, varies depending on: the density and quality of lithologic and geophysical logs; the details, thoroughness, and accuracy of published and unpublished surface geological maps, and interpretative proficiency. There is no intent on the part of IntraSearch to refute nomenclature established in the literature or used locally by workers in the area. IntraSearch's nomenclature focuses upon the suggestion of regional coal bed names applicable throughout the eastern Powder River Basin. It is expected and entirely reasonable that some differences of opinion regarding correlations, as suggested by IntraSearch, exist. Additional drilling for coal, oil, gas, water, and uranium, coupled with expanded mapping of coal bed outcrops and associated clinkers, will broaden the data base for coal bed correlations and allow continued improvement in the understanding of coal bed occurrences in the eastern Powder River Basin.

The topographic map of the Arvada Quadrangle is published by the U. S. Geological Survey, compilation date 1971. Land network and mineral ownership data are compiled from land plats available from the U. S. Bureau of Land Management in Cheyenne, Wyoming. This information is current to October 13, 1977.

IV. Coal Bed Occurrence

Wasatch Formation and Fort Union Formation coal beds that are present in all or part of the Arvada Quadrangle include, in descending stratigraphic order: the Felix, Arvada, Upper Smith, Lower Smith, Swartz, Upper Anderson, Lower Anderson, Upper Canyon, Lower Canyon, Cook, local, Wall Pawnee, Moyer, and Oedekoven coal beds. The Wall coal beds and the Pawnee coal beds are mapped as coal zones. The Moyer coal bed and the Oedekoven coal bed are combined into a coal bed composite. A suite of maps composed of: coal isopach and mining-ratio, where appropriate; structure; overburden isopach; areal distribution of identified resources; identified resources and hypothetical resources, where applicable, is prepared for each of these coal beds or coal zones. Mining ratios are presented on the isopach maps of the Felix, Arvada, Upper Smith, Lower Smith, and Anderson-Upper Canyon coal beds. The Swartz coal bed is not mapped due to the coal thickness being less than 5 feet (1.5 m).

The Arvada and Upper Smith coal beds were cored in this quadrangle in U. S. Geological Survey drill-hole number 78-2. The unpublished proximate analyses were made available for this report.

No physical or chemical analyses are known to have been published regarding samples from this quadrangle of the other coal beds. For eastern Sheridan County coal beds, the "as received" proximate analysis; the Btu value computed on a moist, mineral-matter-free basis;* and the coal rank are as follows:

COAL BED NAME		DATA SOURCE IDENTIFICATION	AS RECEIVED BASIS						MOIST, M-M-F BTU/LB	COAL RANK
			ASH %	FIXED CARBON %	MOISTURE %	VOLATILES %	SULFUR %	BTU/LB		
Felix	(**)	Lab.No. 6432	5.6	35.7	25.8	32.9	0.39	8465	9010	Subbtm. C
Arvada	(1)	Hole 78-2	10.5	32.9	28.5	28.1	1.6	7575	8538	Subbtm. C
Upper Smith	(1)	Hole 78-2	6.4	36.3	28.9	28.4	0.8	8084	8682	Subbtm. C
Swartz	(U)	Hole 7338	5.7	34.1	31.2	28.9	0.70	7735	8239	Lignite A
Anderson-Upper Canyon	(1)	Hole 78-3	4.2	37.9	27.8	30.1	0.2	8709	9123	Subbtm. C
Cook	(2)	Hole SH-64	3.1	36.2	30.8	29.9	0.15	7948	8223	Lignite A
Wall	(U)	Hole 7426	9.5	29.3	32.2	29.0	0.50	7279	8108	Lignite A
Pawnee	(U)	Hole 7424	7.9	31.0	31.9	29.2	0.39	7344	7674	Lignite A

* The moist, mineral-matter-free Btu values are calculated in the manner stipulated in the publication by American Society for Testing and Materials (1971).

** Stone and Lupton (1910).

(1) Correia, G. A. (unpublished).

(2) Matson, R. E., and Blumer, J. W., (1973).

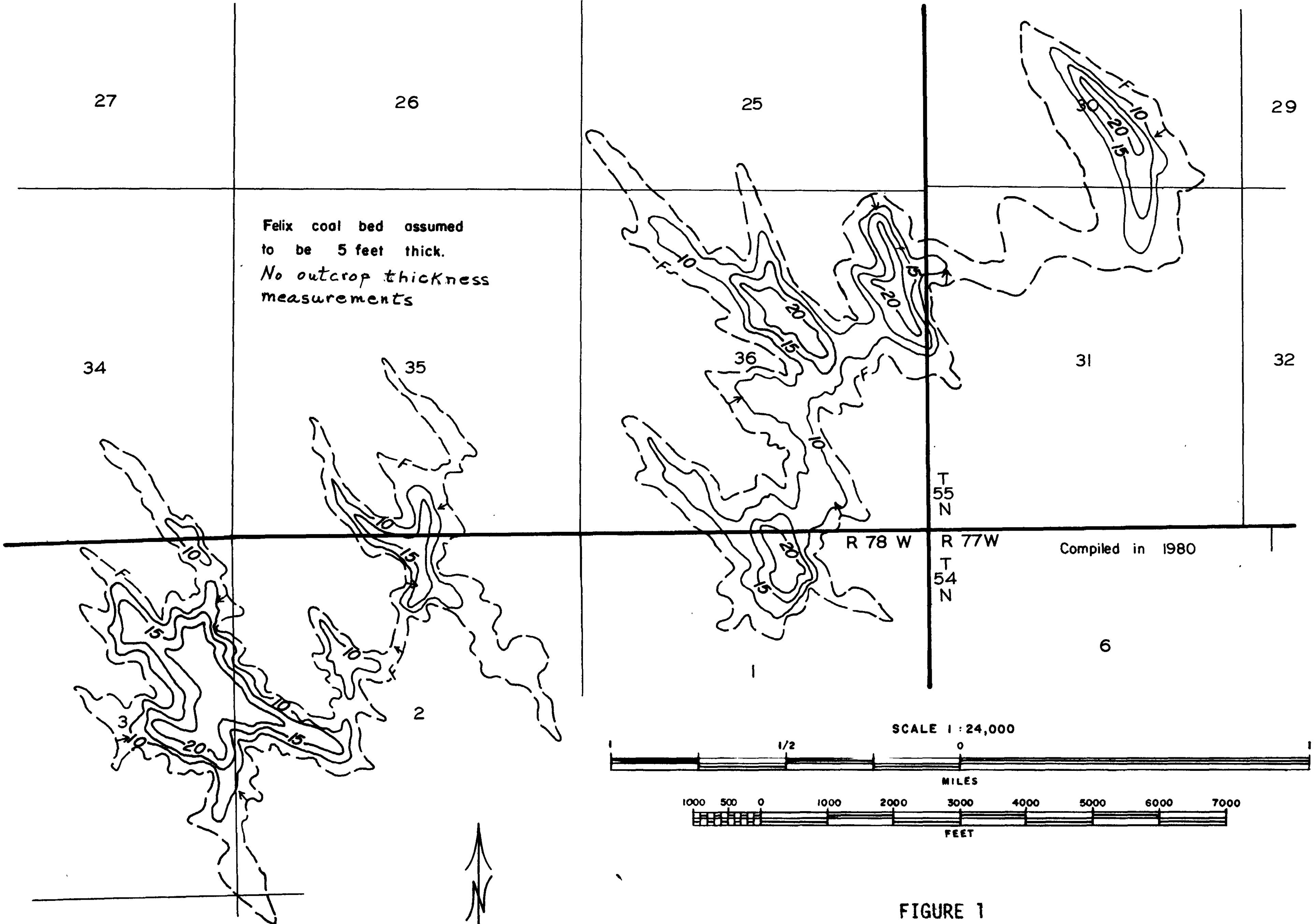
(U) U. S. Geological Survey and Montana Bureau of Mines and Geology (1974 and 1976).

Except for the Arvada, Upper Smith, and Anderson-Upper Canyon coal beds, the proximate analyses presented above are from core hole or outcrop locations in excess of 20 miles (32 km) from this quadrangle. For simplification of tonnage computations, all coal beds in the Arvada Quadrangle are tentatively classified as subbituminous C rank.

The Coal Data sheet, plate 3, shows the down-hole identification of coal beds within the quadrangle as interpreted from U. S. Geological Survey and Montana Bureau of Mines and Geology drill holes and geophysical logs from oil and gas test bores and from producing sites. This portrayal is schematic by design; hence, no structural or coal thickness implications are suggested by the dashed correlation lines projected through No Record (NR) intervals. Inasmuch as the Anderson-Upper Canyon coal beds underlie the entire quadrangle, they are designated as datum for the correlation diagram. The Wall coal zone shows the thickest coal occurrence throughout the quadrangle. The other coal beds are relatively thin throughout the Arvada Quadrangle.

The Felix coal bed, assumed to be 5 feet (1.5 m) thick, is eroded from all of the Arvada Quadrangle except for a small area of occurrence in the central portion of the quadrangle. Structure contours drawn on the top of the projected outcrop depict gentle northeast dip. The Felix coal bed attains a maximum depth of burial of 220 feet (67 m).

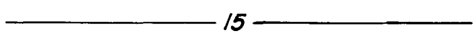
The Arvada coal bed lies 400 to 650 feet (122 to 198 m) beneath the Felix coal bed, where the Felix coal is present, and is eroded along the northern and eastern boundaries of the Arvada Quadrangle.



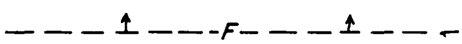
Base from U.S. Geological Survey, 1971

FIGURE 1
ISOPACH AND MINING-RATIO MAP
OF FELIX COAL BED IN
ARVADA QUADRANGLE
SHERIDAN COUNTY, WYOMING
(See following page for Explanation)

EXPLANATION FOR FIGURE 1

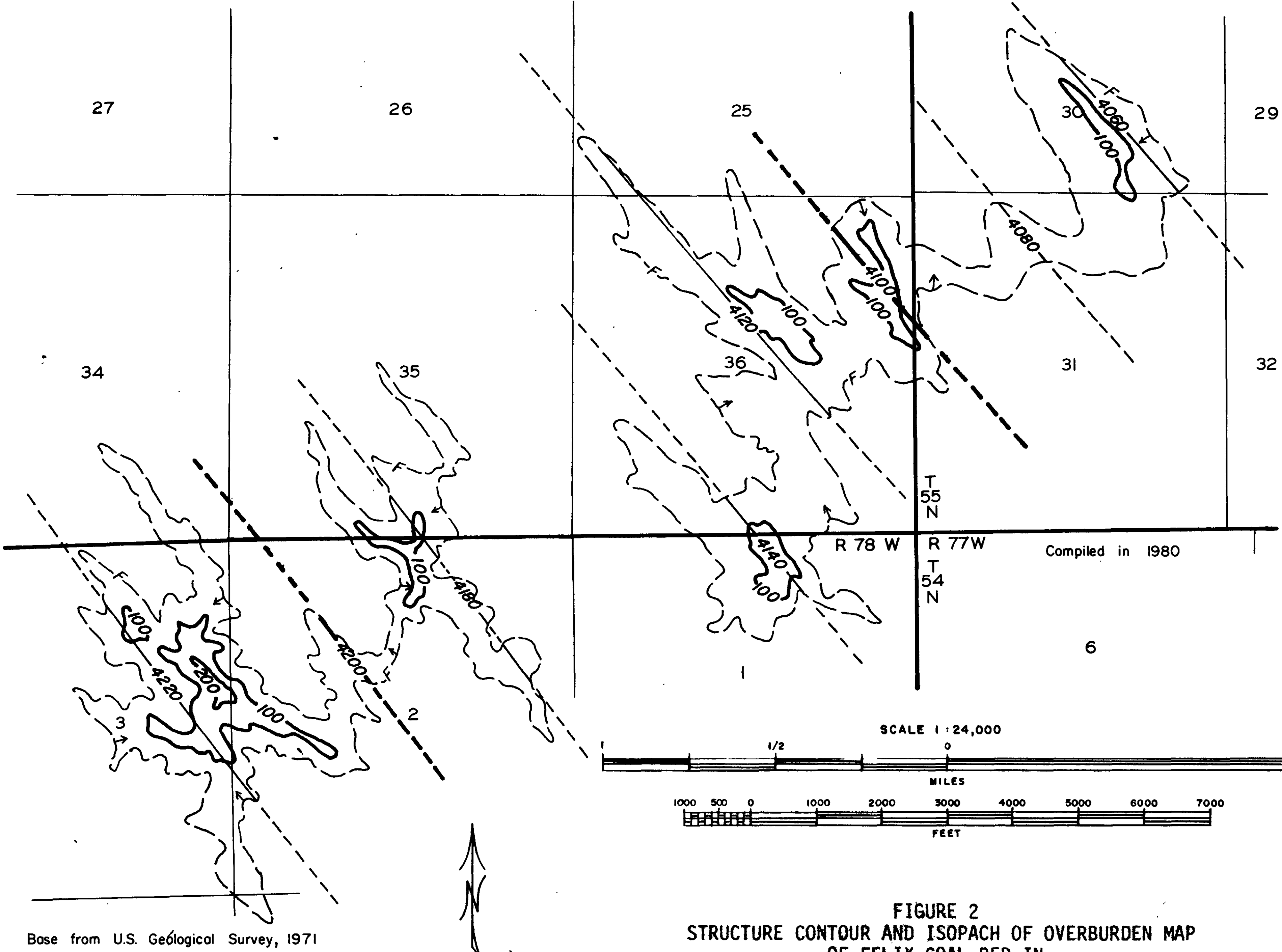


MINING-RATIO CONTOUR-Number indicates cubic yards of overburden per ton of recoverable coal by surface mining methods. Contours shown only in area suitable for surface mining within the stripping limit.



TRACE OF COAL BED OUTCROP-Showing coal thickness in feet, measured at triangle. Arrow points toward the coal-bearing area. Coal bed dashed where inferred or projected. No coal thicknesses were measured along the inferred outcrop.

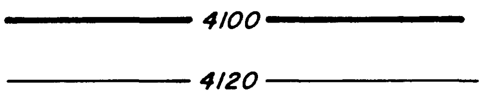
To convert feet to meters, multiply feet by 0.3048.



Base from U.S. Geological Survey, 1971

FIGURE 2
STRUCTURE CONTOUR AND ISOPACH OF OVERBURDEN MAP
OF FELIX COAL BED IN
ARVADA QUADRANGLE
SHERIDAN COUNTY, WYOMING
(See following page for Explanation)

EXPLANATION FOR FIGURE 2



STRUCTURE CONTOURS-Drawn on top of coal bed. Contour interval 20 feet. Datum is mean sea level. Dashed where coal is burned or eroded.

OVERBURDEN ISOPACH-Showing thickness of overburden, in feet, from the surface to the top of the coal bed. Isopach interval 100 feet.

TRACE OF COAL BED OUTCROP-Arrow points toward the coal-bearing area. Coal bed dashed where inferred or projected.

To convert feet to meters, multiply feet by 0.3048.

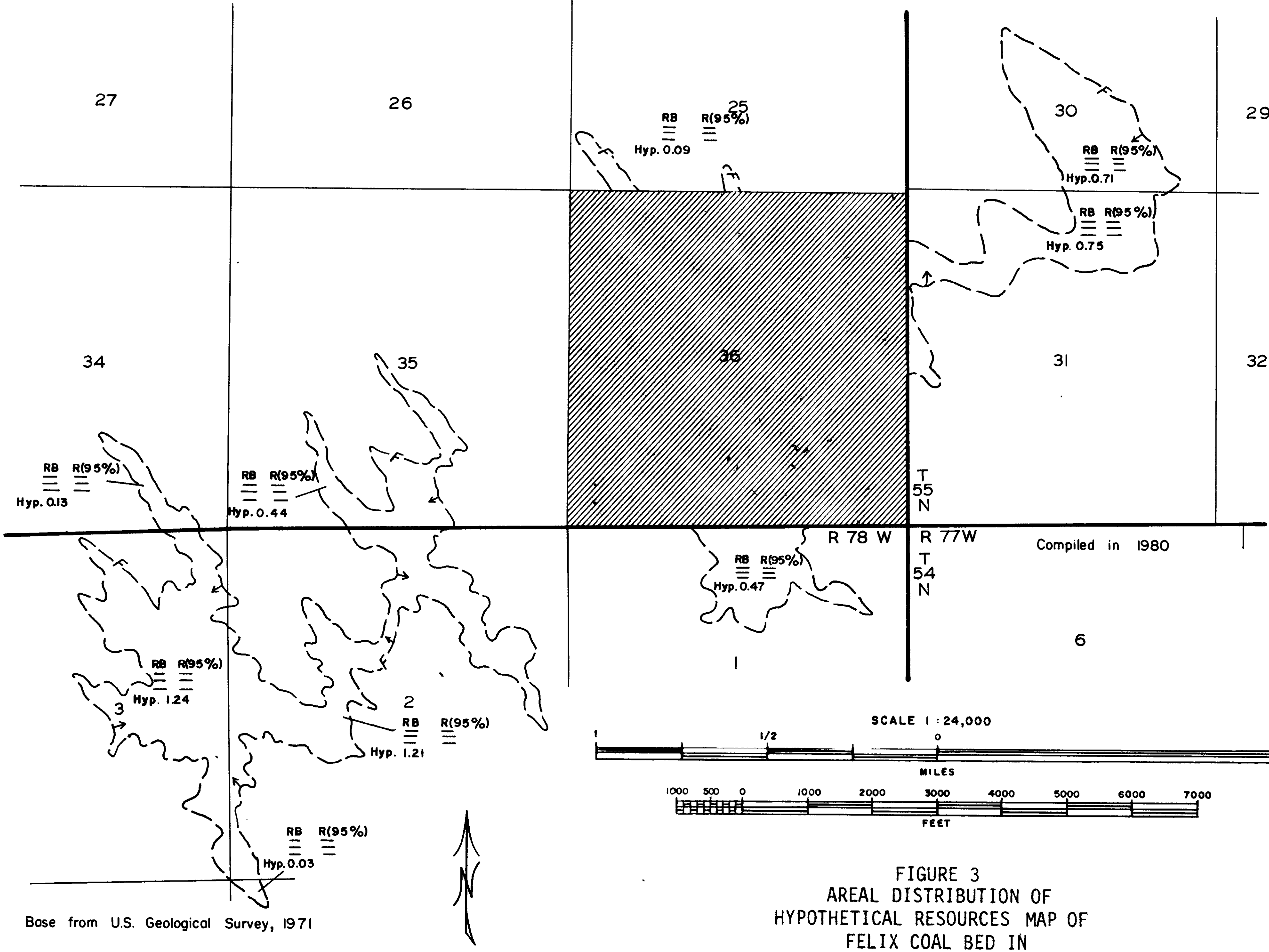
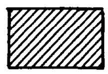
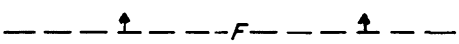


FIGURE 3
AREAL DISTRIBUTION OF
HYPOTHETICAL RESOURCES MAP OF
FELIX COAL BED IN
ARVADA QUADRANGLE
SHERIDAN COUNTY, WYOMING
(See following page for Explanation)

EXPLANATION FOR FIGURE 3



NON-FEDERAL COAL LAND-Coal tonnages not evaluated.



TRACE OF COAL BED OUTCROP-Arrow points toward the coal-bearing area. Coal bed dashed where inferred or projected.

RB	R(95%)	
—	—	(Measured)
—	—	(Indicated)
—	—	(Inferred)
Hyp. 0.75		(Hypothetical)

IDENTIFIED AND HYPOTHETICAL RESOURCES OF COAL BED--In millions of short tons. Dash indicates no resources in that category. Reserve Base (RB) x the recovery factory (95%) = Reserves (R).

Reserves are not calculated for coal beds greater than 500 feet in depth.

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

To convert miles to kilometers, multiply miles by 1.069.

The Arvada coal bed ranges from 14 feet (4 m) thick in the southwestern corner to 8 feet (2.4 m) thick in the northeastern and northwestern corners. A broad, shallow, westward-plunging syncline is present in the central area of the study area, with a southwestward-plunging anticline located in the southeast quarter. The overburden thickness ranges from 0 feet (0 m) at the outcrop to 1,100 feet (335 m).

The Upper Smith coal bed lies 160 to 300 feet (49 to 91 m) beneath the Arvada coal bed and ranges in thickness from 8 feet (2.4 m) in the east-central area to 14 feet (4 m) in the southeastern corner. The Upper Smith coal bed is folded into a south-plunging anticline that trends through the central area and a south-plunging syncline located in the northeastern quarter. The Upper Smith is buried under 60 to 1,240 feet (18 to 378 m) of clastic sediments.

The Lower Smith coal bed is separated by 30 to 360 feet (9 to 110 m) of clastic sediment from the overlying Upper Smith coal bed. The Lower Smith coal bed is absent from the northwestern quadrant and ranges up to 16 feet (5 m) thick in the southeastern corner. Structure contours drawn on top of the Lower Smith coal bed depict a southwest-plunging anticline in the southeastern quarter, and a southwest-plunging syncline in the northwestern quarter. The Lower Smith coal bed lies from 220 to 1,240 feet (67 to 378 m) beneath the surface.

The Anderson-Upper Canyon coal beds include two, thin Anderson coal beds and the Upper Canyon coal bed, and lie 120 to 260 feet (37 to 79 m) beneath the Lower Smith coal Bed. The total coal thickness ranges from 10 feet (3 m) in the northwestern corner to 40 feet (12 m) along the southern boundary of the study area. The Anderson coal beds are absent in the northwestern quadrant. Structure contours drawn on top of the Anderson-Upper Canyon coal beds depict a southwest-plunging syncline trending from the northeastern corner into the west-central area, and a southwest-plunging anticline in the southeastern quarter. The clastic interval between the coal beds ranges from 64 to 205 feet (20 to 62 m), increasing to the northwest. The coal beds are from 460 to 1,630 feet (140 to 497 m) beneath the surface. In the area where the Anderson coal beds are absent, the Upper Canyon coal bed is buried from 920 to 1,140 feet (280 to 347 m).

The Lower Canyon-Cook coal beds occur 207 to 269 feet (63 to 82 m) below the Anderson-Upper Canyon coal beds, and consist of one or two, thin, Lower Canyon coal beds and a single Cook coal bed. The total thickness of the coal beds ranges from 10 feet (3 m) in the northwestern corner to 30 feet (9 m) in the southwestern quarter. The Lower Canyon coal beds are absent in the extreme northwestern corner of the quadrangle. Minor flexures superimposed on regional southwestward dip characterize the structure map. The Lower Canyon-Cook coal beds lie from 820 to 2,200 feet (250 to 671 m) beneath the surface. The Cook coal bed is between 1,250 and 1,500 feet (381 and 457 m) beneath the surface in the area where the Lower Canyon coal beds are absent.

The Wall coal zone lies from 138 to 187 feet (42 to 57 m) beneath the Cook coal bed, and consists of one to three coal beds. The upper coal bed of the Wall coal zone is moderately thick, and the lower two coal beds are thin. The Wall coal zone is a single, thick coal bed in the southern one-third of the quadrangle, and splits into two or three coal beds to the north. The clastic section within the coal zone is approximately 109 feet (33 m) thick. Based on subsurface control located south of the Arvada Quadrangle, the Wall coal zone attains a maximum thickness of 65 feet (20 m) in the south-central area, and thins to 25 feet (8 m) in the northwestern corner. Structure contours drawn on top of the Wall coal zone depict gentle, southwestward dip with minor flexures in the west-central and southwestern areas. The Wall coal zone lies from 1,150 to 2,470 feet (351 to 753 m) beneath the surface.

The Pawnee coal zone is composed of one-to-three, thin coal beds, and lies from 111 to 256 feet (34 to 78 m) beneath the Wall coal zone. The total coal zone thickness ranges from 3 feet (0.9 m) in the west-central area to 14 feet (4 m) in the east-central part. The two upper coal beds of the Pawnee coal zone are absent from the west-central portion of the quadrangle. Structure contours drawn on top of the Pawnee coal beds depict a broad, shallow syncline in the northern two-thirds of the Arvada Quadrangle. Minor flexures are present in the southern one-third of the map. The non-coal interval within the Pawnee coal zone is approximately 92 feet (28 m) thick. The Pawnee coal zone lies from 1,500 to 2,720 feet (457 to 829 m) beneath the surface. The lowest coal bed of the Pawnee coal zone lies from 1,850 to 2,640 feet (564 to 805 m) beneath the surface in the area where the two upper coal beds are absent.

The Moyer-Oedekoven coal-bed composite lies from 304 to 353 feet (93 to 108 m) beneath the Pawnee coal zone and comprises one or two, thin, Moyer coal beds with up to 5 feet (1.5 m) of clastic interburden, and one or two, thin Oedekoven coal beds separated by a maximum of 13 feet (4 m) of clastic sediments. The interval between the Moyer coal beds and the Oedekoven coal beds ranges from 275 to 290 feet (84 to 88 m) in thickness. The coal bed composite thickness ranges from 20 feet (6 m) along the northern boundary and in the south-central area, to 35 feet (11 m) in the north-central portion of the Arvada Quadrangle. A southwest-plunging syncline is present in the central area, and a southwest-plunging anticline is located in the southwestern quarter of the study area. The Moyer-Oedekoven coal-bed composite lies from 1,940 to 2,980 feet (591 to 908 m) beneath the surface.

V. Geological and Engineering Mapping Parameters

The correct horizontal location and elevation of drill holes utilized in subsurface mapping are critical to map accuracy. IntraSearch plots the horizontal location of the drill hole as described on the geophysical log heading. Occasionally this location is superimposed on or near to a drillsite shown on the topographic map, and the topographic map horizontal location is utilized. If the ground elevation on the geophysical log does not agree with the topographic elevation of the drillsite, the geophysical log ground elevation is adjusted to conformance. If there is no indication of a drillsite on the topographic map, the "quarter, quarter, quarter" heading location is shifted within a small area until the ground elevation on the heading agrees with the topographic map elevation. If no elevation agreement can be reached, the well heading or data sheet is rechecked for footage measurements and ground elevation accuracy. Inquiries to the companies who provided the oil and gas geophysical logs frequently reveal that corrections have been made in the original survey. If all horizontal location data sources have been checked and the information accepted as the best available data, the drillsite elevation on the geophysical log is modified to agree with the topographic map elevation. IntraSearch considers this agreement mandatory for the proper construction of most subsurface maps, but in particular, the overburden isopach, the mining ratio, and Coal Development Potential maps.

Subsurface mapping is based on geologic data within, and adjacent to, the Arvada Quadrangle area. Data from geophysical logs are used to correlate coal beds and control contour lines for the coal thickness, structure, and overburden maps. Isopach lines are also drawn to honor selected surface measured sections in areas where there is sparse subsurface control. Where coal isopach contours do not honor surface measured sections, the surface thicknesses are thought to be attenuated by oxidation and/or erosion: hence, they are not reflective of total coal thickness. Isopach lines extend to the coal bed outcrops, the projections of coal bed outcrops, and the contact between porcellanite (clinker) and unoxidized coal in place. Attenuation of total coal bed thickness is known to take place near these lines of definition; however, the overestimation of coal bed tonnages that results from this projection of total coal thickness is insignificant to the Coal Development Potential maps. Structure contour maps are constructed on the tops of the main coal beds. Where subsurface data are scarce, supplemental structural control points are selected from the topographic map along coal outcrops.

In preparing overburden isopach maps, no attempt is made to identify coal beds that occur in the overburden above a particular coal bed under study. Mining-ratio maps for this quadrangle are constructed utilizing a 95 percent recovery factor. Contours of these maps identify the ratio of cubic yards of overburden to tons of recoverable coal. Where ratio control points are sparse, interpolated points are computed using coal structure, coal isopach, and topographic control. On the Areal Distribution of Identified Resources Map (ADIR), coal bed reserves are not calculated where the coal is less than 5 feet (1.5 m) thick, where the coal occurs at a depth greater than 500 feet (152 m), and where non-federal coal exists, or where federal coal leases, preference-right lease applications, and coal prospecting permits exist.

Coal tonnage calculations involve the planimetering of areas of measured, indicated, and inferred parts of identified resources, and hypothetical resources to determine their areal extent in acres. An Insufficient Data Line is drawn to delineate areas where surface and subsurface data are too sparse for CRO map construction. Various categories of resources are calculated in the unmapped areas by utilizing coal bed thicknesses mapped in the geologically controlled area adjacent to the insufficient data line. Acres are multiplied by the average coal bed thickness and 1,750, or 1,770--the number of tons of lignite A or subbituminous C coal per acre-foot, respectively (12,874 or 13,018 metric tons per hectare-meter, respectively)--to determine total tons in place. Recoverable tonnages (reserves) are calculated at 95 percent of the total tons in place. Where tonnages are computed for the CRO-CDP map series, resources and reserves are expressed in millions of tons. Frequently, the planimetering of coal resources on a sectionized basis involves complexly curvilinear lines (coal bed outcrop and 500-foot stripping limit designations) in relationship with linear section boundaries and circular resource category boundaries. Where these relationships occur, generalizations of complex curvilinear lines are discretely utilized, and resources and/or reserves are calculated within an estimated 2 to 3 percent, plus or minus, accuracy.

VI. Coal Development Potential

Strippable Coal Development Potential. Areas where coal beds are 5 feet (1.5 m) or more in thickness and are overlain by 500 feet (152 m) or less of overburden are considered to have potential for surface mining and are assigned a high, moderate, or low development potential based on the mining ratio (cubic yards of overburden per ton of recoverable coal). The formula used to calculate mining ratios for subbituminous coal is as follows:

$$MR = \frac{to\ (0.911)^*}{tc\ (rf)}$$

where MR = mining ratio
to = thickness of overburden
tc = thickness of coal
rf = recovery factor
0.911 = conversion factor (cu. yds./ton)

*A conversion factor of 0.922 is used for lignite.

A surface-mining development potential map (plate 44) was prepared utilizing the following mining-ratio criteria for coal beds 5 feet to 40 feet (1.5 to 12 m) thick:

1. Low development potential = 15:1 and greater ratio.
2. Moderate development potential = 10:1 to 15:1 ratio.
3. High development potential = 0 to 10:1 ratio.

The following mining-ratio criteria are utilized for coal beds greater than 40 feet (12 m) thick:

1. Low development potential = 7:1 and greater ratio.
2. Moderate development potential = 5:1 to 7:1 ratio.
3. High development potential = 0 to 5:1 ratio.

The surface-mining development potential is high for approximately 3 percent of the quadrangle. These high development potential areas result from the thin Felix, Arvada, and Upper Smith coal beds lying near the surface along the eastern quadrangle boundary and in the northwestern quarter. Scattered areas of moderate mining development potential occurring in the northern half and in the southeastern quarter involve approximately 3 percent of the quadrangle, and result from the increased overburden thickness over the Felix, Arvada, and Upper Smith coal beds. Approximately 40 percent of the quadrangle is rated as low development potential for surface-mining methods due to the thick overburden above the thin coal beds. These areas are primarily located in the central and southeastern portions of the quadrangle. In the southwestern quarter, the area of no potential for surface-mining development covers approximately 24 percent of the quadrangle. The remaining 30 percent of the Arvada Quadrangle involves either non-federal coal or leased federal coal, hence, no evaluation is included in this report. Table 1 sets forth the estimated strippable reserve base tonnages per coal bed for this quadrangle.

Underground Mining Coal Development Potential. Subsurface coal mining development potential throughout the Arvada Quadrangle is considered low. Inasmuch as recovery factors have not been established for the underground development of coal beds in this quadrangle, recoverable reserves are not calculated for coal beds that occur more than 500 feet (152 m) beneath the surface. Table 2 sets forth the estimated coal resources in tons per coal bed.

In-Situ Gasification Coal Development Potential. The evaluation of subsurface coal deposits for in-situ gasification development potential relates to the occurrence of coal beds more than 5 feet (1.5 m) thick and buried from 500 to 3,000 feet (152 to 914 m) beneath the surface. This categorization is as follows:

1. Low development potential relates to: 1) a total coal section less than 100 feet (30 m) thick that lies 1,000 feet (305 m) to 3,000 feet (914 m) beneath the surface, or 2) a coal bed or coal zone 5 feet (1.5 m) or more in thickness that lies 500 feet (152 m) to 1,000 feet (305 m) beneath the surface.

2. Moderate development potential is assigned to a total

coal section from 100 to 200 feet (30 to 61 m) thick and buried from 1,000 to 3,000 feet (305 to 914 m) beneath the surface.

3. High development potential involves 200 feet (61 m) or more of total coal thickness buried from 1,000 to 3,000 feet (305 to 914 m).

The coal development potential for in-situ gasification (plate 45) on the Arvada Quadrangle is moderate for 50 percent of the study area. The areas of moderate development potential are located in the southwestern half of the quadrangle, and result from the total coal section, deeper than 1,000 feet (305 m), attaining a thickness of 100 feet (30 m) or more. Areas of low development potential cover about 20 percent of the quadrangle, and are located in the northern and eastern quadrants. These low development potential areas result from coal beds thinning or the reduction in the depth of burial to less than 1,000 feet (305 m). No rating is set forth for approximately 30 percent of the quadrangle where either non-federal coal or leased federal coal exist.

Table 1.--Strippable Coal Reserve Base and Hypothetical Resource Data (in short tons) for Federal Coal Lands in the Arvada Quadrangle, Sheridan County, Wyoming.

Development potentials are based on mining ratios (cubic yards of overburden/ton of recoverable coal).

Coal Bed	High Development Potential (0-10:1 Mining Ratio)	Moderate Development Potential (10:1-15:1 Mining Ratio)	Low Development Potential (>15:1 Mining Ratio)	Total
Reserve Base Resources				
Arvada	27,370,000	33,600,000	227,990,000	288,960,000
Upper Smith	330,000	4,790,000	205,770,000	210,890,000
Lower Smith	-	-	82,300,000	82,300,000
Anderson-Upper Canyon	-	630,000	6,440,000	7,070,000
Total	27,700,000	39,020,000	522,500,000	589,220,000
Hypothetical Resources				
Felix	-	-	5,070,000	5,070,000
Upper Smith	-	-	4,160,000	4,160,000
Lower Smith	-	-	80,000	80,000
Total	-	-	9,310,000	9,310,000
GRAND TOTAL	27,700,000	39,020,000	531,810,000	598,530,000

Table 2.--Coal Reserve Base and Hypothetical Resource Data (in short tons) for Underground Mining Methods for Federal Coal Lands in the Arvada Quadrangle, Sheridan County, Wyoming.

Coal Bed Name	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Reserve Base Resources				
Arvada	-	-	168,880,000	168,880,000
Upper Smith	-	-	235,360,000	235,360,000
Lower Smith	-	-	248,420,000	248,420,000
Anderson-Upper Canyon	-	-	1,299,230,000	1,299,230,000
Lower Canyon-Cook	-	-	916,050,000	916,050,000
Wall	-	-	1,951,000,000	1,951,000,000
Pawnee	-	-	295,820,000	295,820,000
Moyer-Local-Oedekoven	-	-	1,072,520,000	1,072,520,000
Total	-	-	6,187,280,000	6,187,280,000
Hypothetical Resources				
Lower Smith	-	-	2,020,000	2,020,000
Anderson-Upper Canyon	-	-	330,000	330,000
Lower Canyon-Cook	-	-	45,650,000	45,650,000
Wall	-	-	93,000,000	93,000,000
Pawnee	-	-	16,790,000	16,790,000
Moyer-Local Oedekoven	-	-	39,010,000	39,010,000
Total	-	-	196,800,000	196,800,000
GRAND TOTAL	-	-	6,384,080,000	6,384,080,000

Table 3.--Coal Reserve Base and Hypothetical Resource Data for In-Situ Gasification for Federal Coal Lands in the Arvada Quadrangle, Sheridan, County, Wyoming.

Coal Bed Name	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Reserve Base Resources	-	4,359,390,000	1,827,890,000	6,187,280,000
Hypothetical Resources	-	-	196,880,000	196,800,000
TOTAL	-	4,359,390,000	2,024,770,000	6,384,080,000

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