UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TEXT TO ACCOMPANY:

COAL RESOURCE OCCURRENCE

AND

COAL DEVELOPMENT POTENTIAL

MAPS

OF THE

LIVINGSTON DRAW QUADRANGLE,

JOHNSON AND CAMPBELL COUNTIES, WYOMING

BY

INTRASEARCH INC.

ENGLEWOOD, COLORADO

OPEN FILE REPORT 79-171
1980

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

MAPS		PLATES

TABLE OF CONTENTS (continued)

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 Livingston Draw Quadrangle, Johnson and Campbell Counties, Wyoming. This CRO and CDP map series includes 50 plates (U. S. Geological Survey Open-File Report 79-171). 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 Livingston Draw Quadrangle is located in Johnson and Campbell Counties, in northeastern Wyoming. It encompasses all or parts of Townships 51 and 52 North, Ranges 76 and 77 West, and covers the area: 44°22'30" to 44°30' north latitude; 106°00' to 106°07'30" west longitude.

Main access to the Livingston Draw Quadrangle is provided by Montgomery Road which extends westward into the quadrangle from the southeast boundary of the quadrangle (section 9, T. 51 N., R. 76 W.). This maintained gravel road merges with Echeta Road approximately 22 miles (35 km) to the east of the study area. Another maintained gravel road is located in the extreme northwestern corner and extends to Arvada, Wyoming, 12 miles (19 km) to the north of the study area. Minor roads and trails provide additional access to the more remote areas. The closest railroad is the Burlington Northern trackage approximately 7 miles (11 km) to the east of the study area near Echeta, Wyoming.

The primary drainage within the quadrangle is the Powder River, which meanders northeastward across the extreme northwestern corner. Fortification Creek flows northwestward across the middle of the quadrangle. Bull Creek, Livingston Draw, and other minor streams supplement the drainage throughout the quadrangle. The entire drainage network within the quadrangle flows to the northwest into the Powder River. The rugged terrain attains maximum heights of 4,620 feet (1,408 m) above sea level in the southeast quarter of the quadrangle, 750 to 850 feet (229 to 259 m) above the Powder River valley floor to the northwest.

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) or 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 Johnson and Campbell County Courthouses, Buffalo and Gillette, Wyoming, respectively. 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 15.0 billion tons (13.6 billion metric tons) of total, unleased federal coal-in-place resources in the Livingston Draw 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 Livingston Draw 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 and Horn, 1975), Olive (1957) mapped 700 to 800 feet (213 to 244 m). Only 750 to 850 feet (229 to 259 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). Taff (1909) named the Smith coal bed. The Swartz coal bed was named by McKay and Mapel (1973). The Anderson, Canyon, and Wall coal beds were named by Baker (1929). The Cook coal bed was named by Bass (1932). Warren (1959) named the Pawnee and Cache coal beds. IntraSearch Inc. (1978) informally assigned the name to the Oedekoven coal bed.

Local. The Livingston Draw 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.

III. Data Sources

Areal geology of the Upper Felix coal outcrop is derived from the Barber coal field report (Wegemann, 1913) and from the Powder River coal field report (Stone and Lupton, 1910). The coal bed outcrop is adjusted to fit the current topographic maps 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 Livingston Draw Quadrangle is published by the U. S. Geological Survey, compilation date 1972. 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

The Wasatch Formation and Fort Union Formation coal beds that are present in all or part of the Livingston Draw Quadrangle include, in descending stratigraphic order: the Upper Felix, Lower Felix, Arvada, local, Upper Smith, Lower Smith, Upper Anderson, Lower Anderson, Canyon, local, Cook, Wall, Upper Pawnee, Lower Pawnee, local, Cache, Oedekoven, Local #1, Local #2, and local coal beds. 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 Upper Felix, Arvada, and Smith coal beds. Insufficient thickness and areal extent preclude any detailed mapping of the Lower Felix and local coal beds.

No physical or chemical analyses are known to have been published regarding samples of coal beds in the Livingston Draw Quadrangle. For Johnson and Campbell 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 ASH %	FIXED CARBON %	MOISTURE %	VOLATILES %	SULFUR %	BTU/LB	MOIST, M-M-F BTU/LB	COAL RANK
Felix	(**)	Lab.No. 6432	5.6	35.7	25.8	32.9	0.39	8465	9010	Subbtm. C
Arvada	(1)	Hole 78-3	8.2	32.4	29.8	29.6	1.40	7736	8483	Subbtm. C
Smith	(1)	Hole 78-2	6.4	36.3	28.9	28.4	0.80	8084	8682	Subbtm. C
Swartz	(U)	Hole 7338	5.7	34.1	31.2	28.9	0.66	7735	8239	Lignite A
Anderson	(1)	Hole 78-3	4.2	37.9	27.8	30.1	0.20	8709	9123	Subbtm. C
Canyon-Cook	(U)	Hole 7334	5.1	34.9	29.4	30.5	0.28	8329	8814	Subbtm. C
Wall	(U)	Hole 7426	9.5	29.3	32.2	29.0	0.50	7279	8112	Lignite A
Pawnee	(U)	Hole 7424	7.9	31.0	31.9	29.2	0.39	7344	8025	Lignite A
Cache	(U)	Hole 741	9.5	30.5	31.4	28.6	0.49	7271	8097	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) Corriea, U. S. Geological Survey unpublished data.

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

Except for the Felix, Arvada, Smith and Anderson coal beds, the proximate analyses presented above are from core hole or outcrop locations in excess of 20 miles (32 km) from this quadrangle. In order to simplify tonnage computations, all coal beds in the Livingston Draw Quadrangle are tentatively classified as subbituminous C in 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 Wall coal bed underlies the entire quadrangle, it is designated as datum for the correlation diagram. The Lower Anderson, Canyon, and Wall coal beds coal beds show the thickest coal bed occurrence throughout the study area. The Upper Anderson, Lower Smith, Cook, Pawnee, Local #1, and Local #2 coal beds show a moderate coal bed occurrence throughout the study area. The remaining coal beds are relatively thin throughout the Livingston Draw Quadrangle.

The Upper Felix coal bed crops out primarily along the alluvial valleys of the Powder River, Bull Creek, and Fortification Creek in the northwest quarter of the quadrangle. The coal bed thickness ranges from 4 to 10 feet (1.2 to 3.0 m) with maximum thicknesses occurring in the northwest quarter of the study area. Structure contours drawn on top of the Upper Felix coal bed indicate two, westward-plunging anticlines in the northwest and southwest quarter, respectively. The Upper Felix coal bed ranges from 0 to 640 feet (0 to 195 m) beneath the surface.

The Arvada coal bed occurs approximately 350 to 650 feet (107 to 198 m) beneath the Upper Felix coal bed. The coal bed thickness ranges from 0 to 10 feet (0 to 3 m) with maximum thicknesses occurring along the northern boundary of the study area. It is absent from approximately 40 percent of the quadrangle primarily in the southeast quarter and along the northwest boundary. Structure contours drawn on top of the Arvada coal bed indicate dip to the southwest. The Arvada coal bed ranges from 250 to 1,080 feet (76 to 329 m) beneath the surface.

The Upper-Lower Smith coal beds occur approximately 125 to 200 feet (38 to 61 m) beneath the overlying Arvada coal bed. The total coal thickness ranges from 10 to 40 feet (3 to 12 m) with maximum thicknesses occurring in the northwest quarter of the study area. A clastic interval ranging from 40 to 80 feet (12 to 24 m) separates the Upper Smith coal bed from the Lower Smith coal bed. The Upper-Lower Smith coal beds dip gently to the west and occur approximately 490 to 1,150 feet (149 to 351 m) beneath the surface.

The Swartz coal bed occurs approximately 200 to 225 feet (61 to 69 m) below the Smith coal beds. The thin coal bed is absent from 95 percent of the quadrangle, and attains a maximum thickness of 15 feet (5 m) in the northeast corner of the study area. Structure contours drawn on top of the Swartz coal bed indicate gentle dip to the west. The Swartz coal bed occurs from 800 to 1,300 feet (244 to 396 m) beneath the surface.

The Upper-Lower Anderson coal beds occur approximately 85 to 285 feet (26 to 87 m) beneath the Lower Smith coal bed. The total coal thickness ranges from 40 to 70 feet (12 to 21 m) with maximum thicknesses in the southwest quarter of the study area. A clastic interval ranging

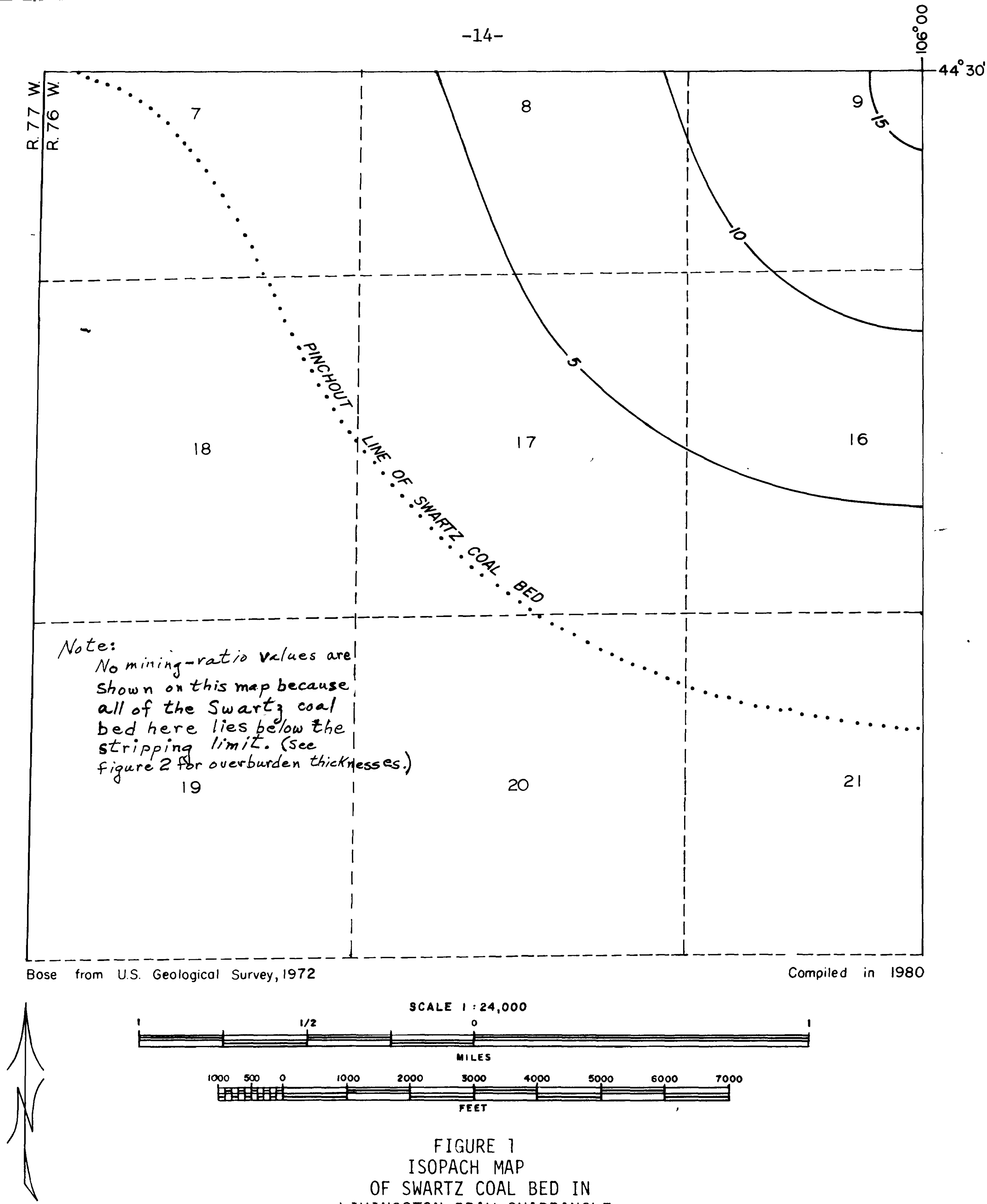


FIGURE 1
ISOPACH MAP
OF SWARTZ COAL BED IN
LIVINGSTON DRAW QUADRANGLE
JOHNSON AND CAMPBELL COUNTIES, WYOMING

(See following page for Explanation)

EXPLANATION FOR FIGURE 1

——— 10 ———
——— 5 ———

ISOPACHS OF COAL BED-Showing thickness in feet. Isopach interval 5 feet.

To convert feet to meters, multiply feet by 0.3048.

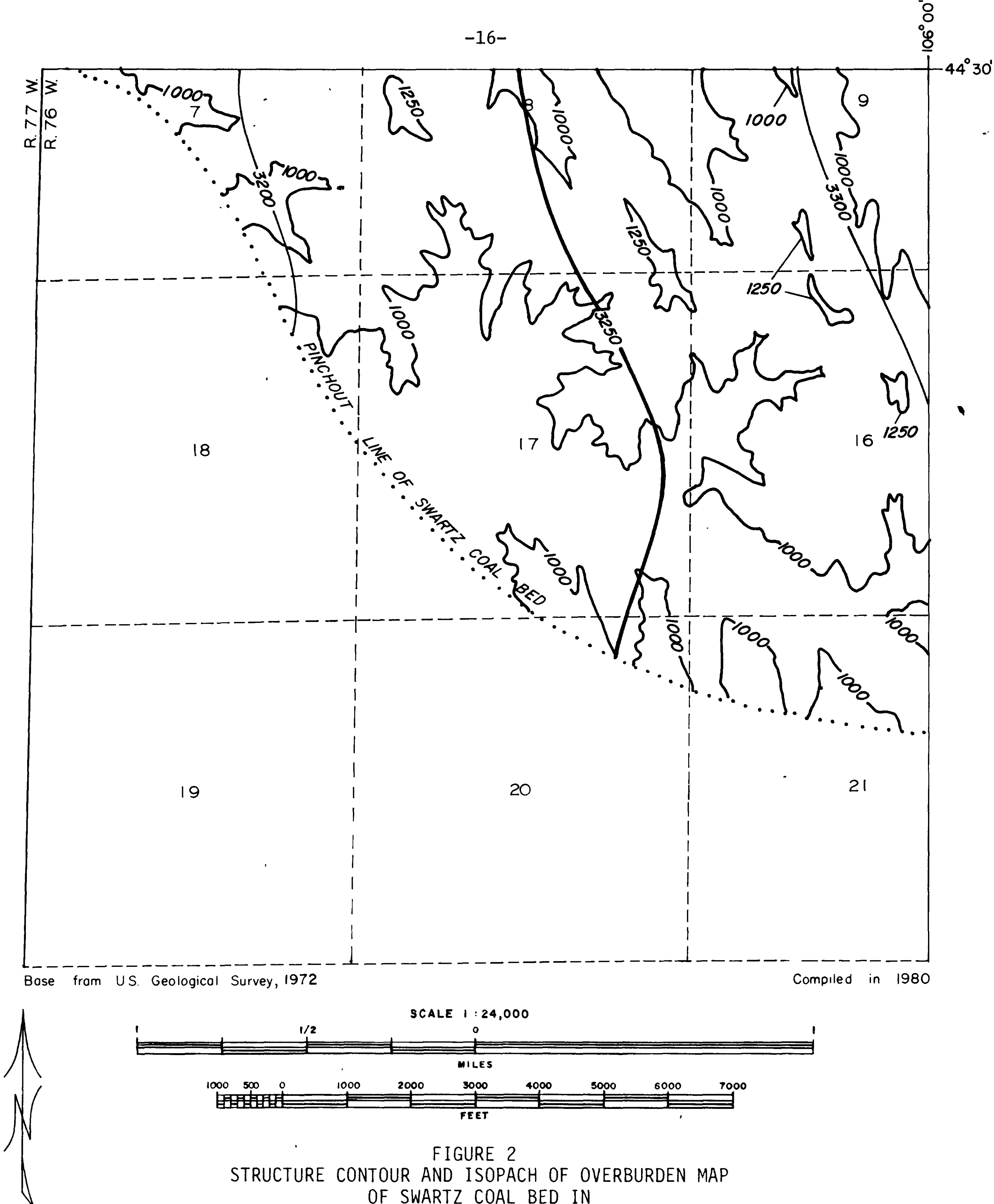


FIGURE 2
STRUCTURE CONTOUR AND ISOPACH OF OVERBURDEN MAP
OF SWARTZ COAL BED IN
LIVINGSTON DRAW QUADRANGLE
JOHNSON AND CAMPBELL COUNTIES, WYOMING
(See following page for Explanation)

EXPLANATION FOR FIGURE 2

3300 3250	STRUCTURE CONTOURS-Drawn on top of coal bed. Contour interval 50 feet. Datum is mean sea level.
1000	OVERBURDEN ISOPACH-Showing thickness of overburden, in feet, from the surface to the top of the coal bed. Isopach interval 250 feet.

To convert feet to meters, multiply feet 0.3048.

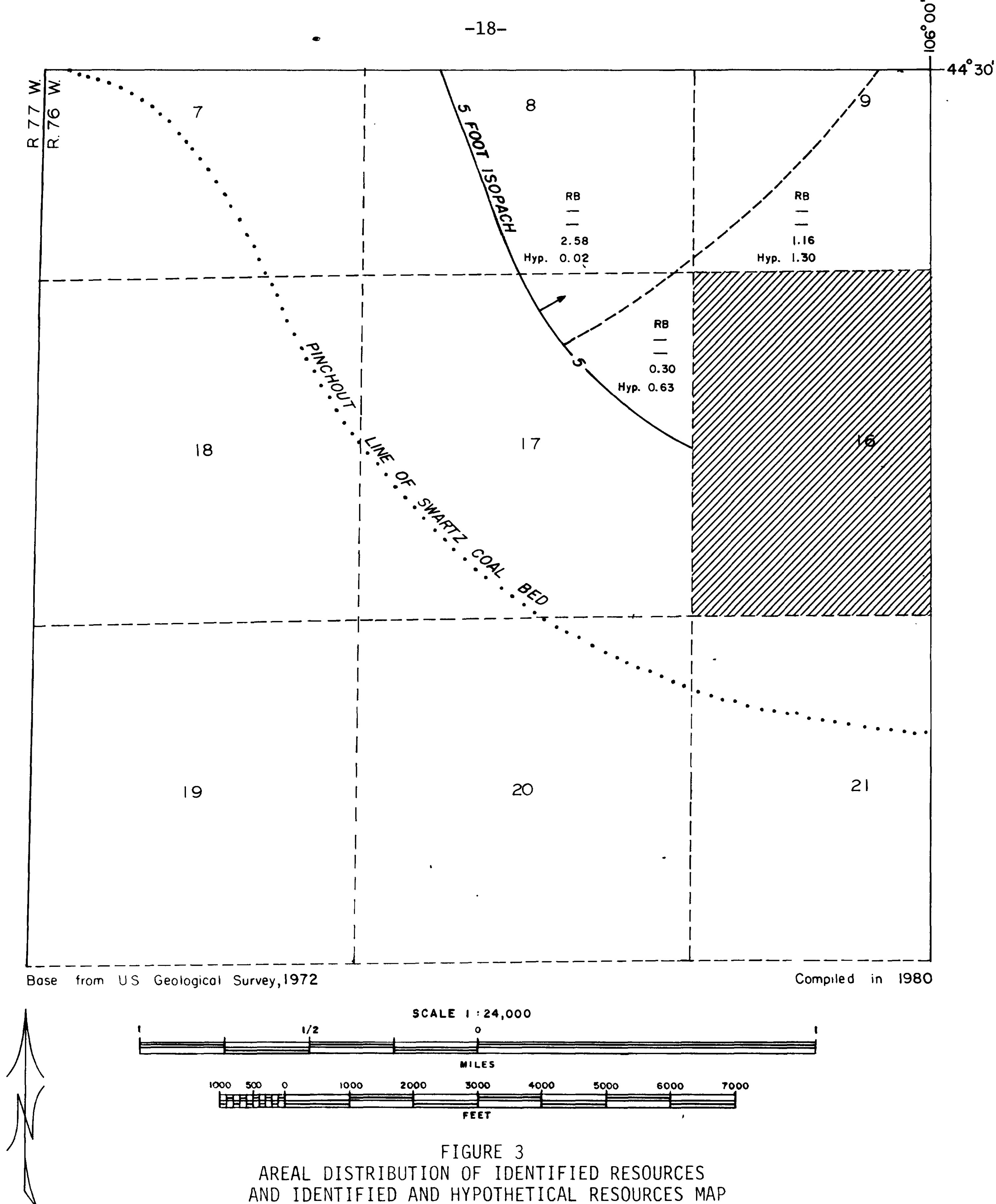
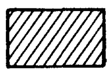
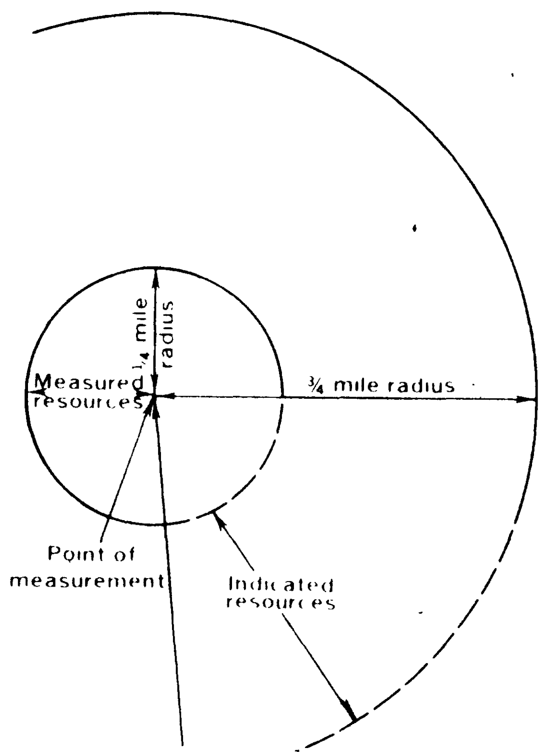


FIGURE 3
AREAL DISTRIBUTION OF IDENTIFIED RESOURCES
AND IDENTIFIED AND HYPOTHETICAL RESOURCES MAP
OF SWARTZ COAL BED IN
LIVINGSTON DRAW QUADRANGLE
JOHNSON AND CAMPBELL COUNTIES, WYOMING
(See following page for Explanation)

EXPLANATION FOR FIGURE 3



NON-FEDERAL COAL LAND-Coal tonnages not evaluated.



BOUNDARY LINES-Enclosing areas of measured, indicated and inferred coal resources of the coal bed. Dashed where projected from adjacent quadrangles.

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

RB	
—	(Measured)
—	(Indicated)
0.30	(Inferred)
Hyp. 0.63	(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 factor (95%) = Reserves (R).

To convert miles to kilometers, multiply miles by 1.609.

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

from 9 to 250 feet (2.7 to 76 m) separates the Upper and Lower Anderson coal beds. Structure contours drawn on top of the Upper Anderson coal bed indicate a shallow, northwest-plunging syncline extending across the southern half of the study area. The Upper-Lower Anderson coal beds lie between 900 and 1,600 feet (274 and 488 m) beneath the surface.

The Canyon-Cook coal zone occurs approximately 120 to 225 feet (37 to 69 m) beneath the overlying Lower Anderson coal bed. The total coal zone thickness ranges from 39 to 70 feet (12 to 21 m) with maximum thicknesses in the southwest quarter of the study area. The clastic interval separating the Canyon and Cook coal beds ranges from 36 to 65 feet (11 to 20 m). Structure contours drawn on top of the Canyon coal bed depict a gentle dip to the west. A narrow, westward-plunging anticline is present in the northwest quarter of the quadrangle. The Canyon-Cook coal zone occurs from 1,125 to 1,990 feet (343 to 607 m) beneath the surface.

The Wall coal bed lies approximately 85 to 275 feet (26 to 84 m) below the Cook coal bed and ranges in thickness from 25 to 67 feet (8 to 20 m). Maximum thicknesses extend from a thick, northwest-southeast trend which diagonally bisects the quadrangle. A non-coal interval ranging from 0 to 70 feet (0 to 21 m) occurs within the Wall coal bed with maximum clastic thicknesses located in the western half of the study area. Structure contours drawn on top of the Wall coal bed indicate a bifurcated syncline in the southwest quarter of the quadrangle. This syncline separates two, small anticlinal features in the northwest and southwest quarters of the study area. The Wall coal bed occurs from

1,450 to 2,275 feet (442 to 693 m) beneath the surface.

The Upper-Lower Pawnee coal beds occur approximately 55 to 190 feet (17 to 58 m) below the Wall coal bed. The total coal thickness ranges from 10 to 50 feet (3 to 15 m) with maximum thicknesses occurring in the southeast quarter of the study area. The clastic interval separating the Upper and Lower Pawnee coal beds ranges from 5 to 62 feet (1.5 to 19 m). Structure contours drawn on top of the Upper Pawnee coal bed depict a regional dip to the west. A small, westward-plunging anticline extends across the southern half of the study area. The Upper-Lower Pawnee coal beds lie from 1,700 to 2,475 feet (518 to 754 m) beneath the surface.

The Cache coal bed lies approximately 100 to 330 feet (30 to 101 m) beneath the Lower Pawnee coal bed. The coal bed thickness ranges from 4 to 10 feet (1.2 to 3 m) with maximum thicknesses occurring the east-central part of the study area. Structure contours drawn on top of the Cache coal bed indicate a regional dip to the west. The Cache coal bed occurs from 1,950 to 2,740 feet (594 to 835 m) beneath the surface.

The Oedekoven-Local 1-Local 2 coal bed composite occurs approximately 150 to 440 feet (46 to 134 m) beneath the Cache coal bed. The coal bed composite is composed of two, thin Oedekoven coal beds overlying two, thin-to-moderately-thick local coal beds. All of the coal beds show a continuous areal extent covering the entire quadrangle. The total coal composite thickness ranges from 10 to 50 feet (3 to 15 m) with maximum thicknesses occurring in the south-central part of the quadrangle. The clastic interval separating the various coal beds composing the coal bed composite ranges from 210 to 275 feet (64 to 84 m). Structure contours drawn on top of the Oedekoven coal bed indicate a minor flexures superimposed on the westward regional dip. The Oedekoven-Local 1-Local 2 coal bed composite lies from 2,200 to 2,990 feet (671 to 911 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 Livingston Draw 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 measured sections 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 49) 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 10 percent of the quadrangle. A moderate development potential covers approximately 7 percent of the study area. These high and moderate development potential areas occur primarily in the northwest quarter of the quadrangle and are due to the shallow burial of the Upper Felix coal bed. The Upper Felix and the underlying Arvada and Smith coal beds contribute to the low potential rating for surface mining which covers approximately 75 percent of the quadrangle. The remaining area is classified as non-federal land and not evaluated in this study, or the coal is deeper than 500 feet (152 m) and not subject to surface mining. 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 Livingston Draw Quadrangle is considered low. Inasmuch as recovery factors have not been established for the underground development of coal beds in this quadrangle, 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 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 50) on the Livingston Draw Quadrangle is high for approximately 75 percent of the study area. This high development potential rating is attributed primarily to the combined coal bed thicknesses of the Lower Anderson, Canyon, and Wall coal beds. A moderate development potential rating occurs primarily in the northeast quarter of the quadrangle, and covers approximately 15 percent of the quadrangle. It is attributed to the combined moderate coal bed thicknesses of all of the coal beds below the Canyon-Cook coal zone, and to the thinning of the coal beds to the north. The remaining area is classified as non-federal land and not evaluated in this study.

Table 1.--Strippable Coal Reserve Base and Hypothetical Resource Data (in short tons) for Federal Coal Lands in the Livingston Draw Quadrangle, Johnson and Campbell Counties, 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				
Upper Felix	37,900,000	33,950,000	112,970,000	184,820,000
Arvada	-	-	14,150,000	14,150,000
Smith	-	-	1,450,000	1,450,000
Total	37,900,000	33,950,000	128,570,000	200,420,000
Hypothetical Resources				
Upper Felix	-	-	139,000,000	139,000,000
Total	-	-	139,000,000	139,000,000
GRAND TOTAL	37,900,000	33,950,000	267,570,000	339,420,000

Table 2.--Coal Reserve Base and Hypothetical Resource Data (in short tons) for Underground Mining Methods for Federal Coal Lands in the Livingston Draw Quadrangle, Johnson and Campbell Counties, Wyoming.

Coal Bed Name	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Reserve Base Resources				
Upper Felix	-	-	5,340,000	5,340,000
Arvada	-	-	41,800,000	41,800,000
Smith	-	-	1,617,720,000	1,617,720,000
Swartz	-	-	4,040,000	4,040,000
Anderson	-	-	2,579,780,000	2,579,780,000
Canyon-Cook	-	-	2,999,140,000	2,999,140,000
Wall	-	-	2,968,900,000	2,968,900,000
Pawnee	-	-	1,718,370,000	1,718,370,000
Cache	-	-	356,310,000	356,310,000
Oedekoven	-	-	1,760 690,000	1,760,690,000
Total	-	-	14,052,090,000	14,052,090,000
Hypothetical Resources				
Upper Felix	-	-	1,610,000	1,610,000
Smith	-	-	212,270,000	212,270,000
Swartz	-	-	1,950,000	1,950,000
Anderson	-	-	332,040,000	332,040,000
Pawnee	-	-	530,000	530,000
Cache	-	-	2,420,000	2,420,000
Total	-	-	550,820,000	550,820,000
GRAND TOTAL	-	-	14,602,910,000	14,602,910,000

Table 3.--Coal Reserve Base and Hypothetical Resource Data (in short tons) for In-Situ Gasification for Federal Coal Lands in the Livingston Draw Quadrangle, Johnson and Campbell Counties, Wyoming.

Coal Bed Name	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Reserve Base Resources	10,746,270,000	3,305,820,000	-	14,052,090,000
Hypothetical Resources	-	-	550,820,000	550,820,000
Total	10,746,270,000	3,305,820,000	550,820,000	14,602,910,000

SELECTED REFERENCES

American Society of Testing and Materials, 1971, Standard specifications for classification of coals by rank (ASTM Designation D 388-66) in Gaseous fuels, coal, and coke: American Society for Testing and Materials, pt. 19, p. 57-61.

Baker, A. A., 1929, The northward extension of the Sheridan coal field, Big Horn and Rosebud Counties, Montana: U. S. Geological Survey Bull. 806-B, p. 15-67.

Bass, N. W., 1932, The Ashland coal field, Rosebud, Powder River, and Custer Counties, Montana: U. S. Geological Survey Bull. 831-B, p. 19-105.

Brown, R. W., 1958, Fort Union Formation in the Powder River Basin, Wyoming: Wyoming Geological Association Guidebook, Thirteenth Annual Field Conf., p. 111-113.

Correia, G. A., 1980, Preliminary results of 1978 coal assessment drilling in Northern and Western Recluse Geologic Analysis Area, northern Campbell County and eastern Sheridan County, Wyoming: U. S. Geological Survey Open-File Report 80-80, 70 p.

Denson, N. M., and Horn, G. H., 1975, Geologic and structure map of the southern part of the Powder River Basin, Converse, Niobrara, and Natrona Counties, Wyoming: U. S. Geological Survey Miscellaneous Investigations Series, Map I-877, scale 1:125,000.

Dobbin, C. E., and Barnett, V. H., 1927 (1928), The Gillette coal field, northeastern Wyoming: U. S. Geological Survey Bull. 796-A, 50 p.

IntraSearch Inc., 1978, Coal resource occurrence and coal development potential maps of the Cabin Creek Northeast Quadrangle, Sheridan and Campbell Counties, Wyoming, and Powder River County, Montana: U. S. Geological Survey Open-File Report 78-064, 21 p.

Jacob, A. F., 1973, Depositional environments of Paleocene Tongue River Formation: Am. Assoc. of Petroleum Geologists Bull., vol. 56, no. 6, p. 1038-1052.

McKay, E. J., 1974, Preliminary geologic map of the Bertha 2 NW (Rocky Butte) Quadrangle, Campell County, Wyoming: U. S. Geological Survey Open-File Report 74-173, scale 1:24,000.

McKay, E. J., and Mapel, W. J., 1973, Preliminary geologic map of the Calf Creek Quadrangle, Campbell County, Wyoming: U. S. Geological Survey Open-File Report, 1973.

Olive, W. W., 1957, The Spotted Horse coal field, Sheridan and Campbell Counties, Wyoming: U. S. Geological Survey Bull. 1050, 83 p.

Stone, R. W., and Lupton, C. T., 1910, The Powder River coal field, Wyoming, adjacent to the Burlington Railroad: U. S. Geological Survey Bull. 381-B, p. 115-136.

Taff, J. A., 1909, The Sheridan coal field, Wyoming: U. S. Geological Survey Bull. 341-B, p. 123-150.

U. S. Bureau of Mines and U. S. Geological Survey, 1976, Coal resource classification system of the U. S. Bureau of Mines and U. S. Geological Survey: U. S. Geological Survey Bull. 1450-B, 7 p.

U. S. Geological Survey and Montana Bureau of Mines and Geology, 1974, Preliminary report of coal drill-hole data and chemical analyses of coal beds in Campbell County, Wyoming: U. S. Geological Survey Open-File Report 74-97, 241 p.

_____1976 , Preliminary report of coal drill-hole data and chemical analyses of coal beds in Campbell and Sheridan Counties, Wyoming: Custer, Prairie, and Garfield Counties, Montana; and Mercer County, North Dakota: U. S. Geological Survey Open-File Report 76-319, 377 p.

Warren, W. C., 1959, Reconnaissance geology of the Birney-Broadus coal field, Rosebud and Powder River Counties, Montana: U. S. Geological Survey Bull. 1072-J, p. 561-585.

Wegemann, C. H., 1913, The Barber coal field, Johnson County, Wyoming: U. S. Geological Survey Bull. 531, p. 263-284.