

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

TEXT TO ACCOMPANY:

COAL RESOURCE OCCURRENCE

AND

COAL DEVELOPMENT POTENTIAL

MAPS

OF THE

LARIAT QUADRANGLE,

SHERIDAN, JOHNSON, AND CAMPBELL COUNTIES, WYOMING

BY

INTRASEARCH INC.

ENGLEWOOD, COLORADO

OPEN FILE REPORT 79-169
1980

This report was prepared under contract to the U.S. Geological Survey and has not been edited for conformity with Geological Survey standards and nomenclature. Opinions and conclusions expressed herein do not necessarily represent those of the Geological Survey.

TABLE OF CONTENTS

	<u>PAGE</u>
I. INTRODUCTION	1
II. GEOLOGY	4
III. DATA SOURCES	8
IV. COAL BED OCCURRENCE	10
V. GEOLOGICAL AND ENGINEERING MAPPING PARAMETERS	16
VI. COAL DEVELOPMENT POTENTIAL	18
Table 1.--Strippable Coal Reserve Base and Hypothetical Resource Data (in short tons) for Federal Coal Lands in the Lariat Quadrangle, Sheridan, Johnson and Campbell Counties, Wyoming.	22
Table 2.--Coal Reserve Base and Hypothetical Resource Data (in short tons) for Underground Mining Methods for Federal Coal Lands in the Lariat Quadrangle, Sheridan, Johnson and Campbell Counties, Wyoming.	23
Table 3.--Coal Reserve Base and Hypothetical Resource Data (in short tons) for In-Situ Gasification for Federal Coal Lands in the Lariat Quadrangle, Sheridan, Johnson and Campbell Counties, Wyoming.	24
SELECTED REFERENCES	25

TABLE OF CONTENTS (continued)

<u>MAPS</u>	<u>PLATES</u>
1. Coal Data Map	1
2. Boundary and Coal Data Map	2
3. Coal Data Sheet	3
4. Isopach and Mining Ratio Map of Felix Coal Bed	4
5. Structure Contour Map of Felix Coal Bed	5
6. Isopach Map of Overburden of Felix Coal Bed	6
7. Areal Distribution of Identified Resources of Felix Coal Bed	7
8. Identified and Hypothetical Resources of Felix Coal Bed	8
9. Isopach and Mining Ratio Map of Arvada Coal Bed	9
10. Structure Contour Map of Arvada Coal Bed	10
11. Isopach Map of Overburden of Arvada Coal Bed	11
12. Areal Distribution of Identified Resources of Arvada Coal Bed	12
13. Identified and Hypothetical Resources of Arvada Coal Bed	13
14. Isopach and Mining Ratio Map of Upper and Lower Smith Coal Beds	14
15. Structure Contour Map of Upper and Lower Smith Coal Beds	15
16. Isopach Map of Overburden of Upper and Lower Smith Coal Beds	16
17. Areal Distribution of Identified Resources of Upper and Lower Smith Coal Beds	17
18. Identified and Hypothetical Resources of Upper and Lower Smith Coal Beds	18
19. Isopach Map of Swartz Coal Bed	19
20. Structure Contour Map of Swartz Coal Bed	20

TABLE OF CONTENTS (continued)

<u>MAPS</u>	<u>PLATES</u>
21. Isopach Map of Overburden of Swartz Coal Bed	21
22. Areal Distribution of Identified Resources of Swartz Coal Bed	22
23. Identified and Hypothetical Resources of Swartz Coal Bed	23
24. Isopach Map of Anderson and Upper Canyon Coal Beds	24
25. Structure Contour Map of Anderson and Upper Canyon Coal Beds	25
26. Isopach Map of Overburden of Anderson and Upper Canyon Coal Beds	26
27. Areal Distribution of Identified Resources of Anderson and Upper Canyon Coal Beds	27
28. Identified and Hypothetical Resources of Anderson and Upper Canyon Coal Beds	28
29. Isopach Map of Lower Canyon and Cook Coal Beds	29
30. Structure Contour Map of Lower Canyon and Cook Coal Beds	30
31. Isopach Map of Overburden of Lower Canyon and Cook Coal Beds	31
32. Areal Distribution of Identified Resources of Lower Canyon and Cook Coal Beds	32
33. Identified and Hypothetical Resources of Lower Canyon and Cook Coal Beds	33
34. Isopach Map of Wall Coal Bed	34
35. Structure Contour Map of Wall Coal Bed	35
36. Isopach Map of Overburden of Wall Coal Bed	36
37. Areal Distribution of Identified Resources of Wall Coal Bed	37
38. Identified and Hypothetical Resources of Wall Coal Bed	38
39. Isopach Map of Pawnee Coal Beds	39
40. Structure Contour Map of Pawnee Coal Beds	40

TABLE OF CONTENTS (continued)

<u>MAPS</u>	<u>PLATES</u>
41. Isopach Map of Overburden of Pawnee Coal Beds	41
42. Areal Distribution of Identified Resources of Pawnee Coal Beds	42
43. Identified and Hypothetical Resources of Pawnee Coal Beds	43
44. Isopach Map of Cache Coal Bed	44
45. Structure Contour Map of Cache Coal Bed	45
46. Isopach Map of Overburden of Cache Coal Bed	46
47. Areal Distribution of Identified Resources of Cache Coal Bed	47
48. Identified and Hypothetical Resources of Cache Coal Bed	48
49. Isopach Map of Moyer-Oedekoven Coal Bed Composite	49
50. Structure Contour Map of Moyer-Oedekoven Coal Bed Composite	50
51. Isopach Map of Overburden of Moyer-Oedekoven Coal Bed Composite	51
52. Areal Distribution of Identified Resources of Moyer-Oedekoven Coal Bed Composite	52
53. Identified and Hypothetical Resources of Moyer-Oedekoven Coal Bed Composite	53
54. Coal Development Potential for Surface-Mining Methods	54
55. Coal Development Potential for In-Situ Gasification	55

CONVERSION TABLE

<u>TO CONVERT</u>	<u>MULTIPLY BY</u>	<u>TO OBTAIN</u>
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 Lariat Quadrangle, Sheridan, Johnson, and Campbell Counties, Wyoming. This CRO and CDP map series includes 55 plates (U. S. Geological Survey Open-File Report 79-169). 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 Lariat Quadrangle is located in Sheridan, Johnson, and Campbell Counties, in northeastern Wyoming. It encompasses all or parts of Townships 52, 53, and 54 North, Ranges 76 and 77 West, and covers the area: 44°30' to 44°37'30" north latitude; 106°00' to 106°07'30" west longitude.

Main access to the Lariat Quadrangle is provided by two maintained gravel roads. One road extends north-to-south along the Powder River valley in the western half of the study area. The other road extends northwest-to-southeast along Wild Horse Creek in the northeast quarter connecting Arvada and Croton, Wyoming. Minor roads and trails that branch from these gravel roads provide additional access to the more remote areas. Burlington Northern trackage extends northwest-to-southeast along Wild Horse Creek in the northeast quarter of the study area.

The Powder River, which meanders northward across the western half of the study area, provides drainage for the Lariat Quadrangle. The northwestward-flowing Wild Horse Creek provides drainage for the northeast quarter of the quadrangle. Deer Creek, Bull Creek, Mickelberry Creek, and other intermittent streams supplement the drainage throughout the remainder of the study area. The rugged terrain attains maximum heights of 4,583 feet (1,397 m) above sea level in the southeast quarter of the quadrangle, 800 to 900 feet (244 to 274 m) above the Powder River valley floor to the west.

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 $+5^{\circ}$ to $+15^{\circ}\text{F}$ (-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, Johnson, and Campbell County Courthouses in Sheridan, 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 10.7 billion tons (9.7 billion metric tons) of total, unleased federal coal-in-place resources in the Lariat 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-Tulloch 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 noticeably to imperceptibly coarser than the underlying Fort Union clastics.

The Lariat 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). 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. (1979, 1978) informally assigned the names to the Moyer and Oedekoven coal beds.

Local. The Lariat 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 coal outcrop is derived from the Powder River coal field report (Stone and Lupton, 1910). The coal bed outcrops are 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 ^{by} 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 Lariat 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 Lariat Quadrangle include, in descending stratigraphic order: the Felix, local, Arvada, Upper Smith, Lower Smith, Swartz, Anderson, Upper Canyon, Lower Canyon, Cook, Wall, Upper Pawnee, Lower Pawnee, Cache, Wildcat, Moyer, local, and Oedekoven coal beds. The Upper and Lower Smith, the Anderson and Upper Canyon, and the Lower Canyon and Cook coal beds are mapped as coal zones. 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, ^{was} prepared for each of these coal beds or coal zones. Mining ratios are presented on the isopach maps of the Felix, Arvada, and Smith coal beds. Insufficient thickness and limited areal extent preclude any detailed mapping of the Wildcat or local coal beds.

No physical or chemical analyses are known to have been published regarding coal bed ^{samples from} the Lariat Quadrangle. For Sheridan, 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						MOIST, M-M-F BTU/LB	COAL RANK
		ASH %	FIXED CARBON %	MOISTURE %	VOLATILES %	SULFUR %	BTU/LB		
	Lab.No.								
Felix (**)	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 But values are calculated in the manner stipulated in the publication by American Society for Testing and Materials (1971).

** Stone and Lupton (1910).

(1) Correia (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 the tonnage computations, all coal beds in the Lariat 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 Anderson coal bed underlies the entire quadrangle, it is designated as datum for the correlation diagram. The Anderson and Wall coal beds show the thickest coal bed occurrence throughout the study area. The Arvada, Upper and Lower Smith, Upper Canyon, and Moyer coal beds show a moderately thick coal bed occurrence. The remaining coal beds are relatively thin throughout the Lariat Quadrangle.

The Felix coal bed crops out in the higher elevations of the quadrangle and is eroded from approximately 70 percent of the study area. The coal bed thickness ranges from 2 to 13 feet (0.6 to 4 m) with maximum thickness in the southern and eastern parts of the quadrangle. Structure contours drawn on top of the Felix coal bed indicate a broad, westward-plunging anticline extending across the northern half, and gentle, westward dip in the southern half of the study area. The Felix coal bed occurs from 0 to 550 feet (0 to 168 m) beneath the surface.

The Arvada coal bed occurs approximately 400 to 450 feet (122 to 137 m) beneath the Felix coal bed. The coal bed thickness ranges from 5 to 18 (1.5 to 5 m) with maximum thicknesses occurring in the south-central part of the study area. Structure contours drawn on top of the Arvada coal

bed indicate westward regional dip to the west with minor flexures. The Arvada coal bed lies from 50 to 995 feet (15 to 303 m) below the surface.

The Upper and Lower Smith coal beds occur approximately 140 to 160 feet (43 to 49 m) below the Arvada coal bed. The combined coal bed thickness ranges from 30 to 45 feet (9 to 14 m) with maximum thickness occurring in the eastern half of the study area. The clastic interval separating the Upper and Lower Smith coal beds ranges from 74 to 91 feet (23 to 28 m). Structure contours drawn on top of the Upper Smith coal bed indicate a shallow, westward-plunging syncline extending across the southeast quarter of the quadrangle. The Upper and Lower Smith coal bed occurs from 185 to 1,170 feet (56 to 357 m) beneath the surface.

The Swartz coal bed lies approximately 125 to 160 feet (38 to 49 m) below the Lower Smith coal bed. The coal bed thickness ranges from 0 to 15 feet (0 to 5 m) with maximum thicknesses in the southeast corner of the study area. The Swartz coal bed is absent from approximately 15 percent of the quadrangle in the north-central and southwest parts of the study area. Structure contours drawn on top of the Swartz coal bed indicate minor flexures superimposed on a regional westward dip. The Swartz coal bed occurs from 390 to 1,300 feet (119 to 396 m) beneath the surface.

The Anderson and Upper Canyon coal beds occur approximately 146 to 221 feet (45 to 67 m) beneath the Swartz coal bed. The total coal bed thickness ranges from 40 to 70 feet (12 to 21 m) with maximum thicknesses occurring in the southeast quarter of the study area. The clastic interval separating the Anderson and Upper Canyon coal beds ranges from 22 to 69 feet (7 to 21 m). Structure contours drawn on top of the

Anderson coal bed indicate a broad, westward-plunging anticline extending across the central part of the study area. This anticline separates two, broad, shallow synclines in the northern and southern parts of the study area. The Anderson and Upper Canyon coal beds lie from 625 to 1,575 feet (191 to 480 m) beneath the surface.

The Lower Canyon and Cook coal beds occur approximately 70 to 230 feet (21 to 70 m) below the Upper Canyon coal bed. The total Lower Canyon and Cook coal bed thickness ranges from 15 to 30 feet (5 to 9 m) with maximum thicknesses occurring along the southern boundary of the study area. The clastic interval separating the Lower Canyon and Cook coal beds ranges from 28 to 167 feet (9 to 51 m). Structure contours drawn on top of the Lower Canyon coal bed indicate a regional dip to the west with minor flexures. The Lower Canyon and Cook coal beds lie from 920 to 1,650 feet (280 to 503 m) below the surface.

The Wall coal bed occurs approximately 150 to 250 feet (46 to 76 m) below the Cook coal bed. The coal bed thickness ranges from 30 to 60 feet (9 to 18 m) with maximum thickness occurring in the southwest corner of the study area. A minor, non-coal interval ranging from 0 to 54 feet (0 to 16 m) locally separates the Wall coal bed. Structure contours drawn on top of the Wall coal bed indicate a closed anticline in the east-central part of the study area. The western half of the quadrangle dips gently to the west. The Wall coal bed lies from 1,200 to 2,025 feet (366 to 617 m) beneath the surface.

The Upper and Lower Pawnee coal beds occur approximately 150 to 225 feet (46 to 69 m) below the Wall coal bed. The coal bed thickness

ranges from 0 to 20 feet (0 to 6 m) with maximum thicknesses in the northeast quarter of the quadrangle. The Upper Pawnee coal bed is absent from approximately 6 percent of the study area along the western boundary. Both Upper and Lower Pawnee coal beds are locally absent in approximately 3 percent of the study area in the southeast quarter. The clastic interval separating the Upper and Lower Pawnee coal beds ranges from approximately 30 to 60 feet (9 to 18 m). Structure contours drawn on top of the Upper Pawnee, where present, indicate a regional dip to the west superimposed with minor flexures. The Upper and Lower Pawnee coal beds occur from 1,400 to 2,400 feet (427 to 732 m) beneath the surface of the quadrangle.

The Cache coal bed occurs approximately 175 to 275 feet (53 to 84 m) below the Lower Pawnee coal bed. The coal bed thickness ranges from 0 to 5 feet (0 to 1.5 m) with maximum thicknesses occurring along the eastern and southern boundaries of the study area. The Cache coal bed is absent from approximately 50 percent of the quadrangle, primarily in the northwestern half. Structure contours drawn on top of the Cache coal bed indicate gentle dip to the west. The Cache coal bed occurs from 1,900 to 2,600 feet (579 to 792 m) beneath the surface.

The Moyer-Oedekoven coal bed composite lies approximately 200 to 250 feet (61 to 76 m) beneath the Cache coal bed. The total composite thickness ranges from 0 to 30 feet (0 to 9 m) with maximum thicknesses occurring in the northwest corner of the study area. The Moyer-Oedekoven coal bed composite is absent from approximately 1 percent of the quadrangle along the western boundary. The clastic interval separating the coal beds composing the composite ranges from 225 to 325 feet (69 to 99 m). Structure contours drawn on top of the Moyer coal bed indicate a gently rolling dip to

the west. The Moyer-Oedekoven coal bed composite ranges from 1,900 to 2,760 feet (579 to 841 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 Lariat 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 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 planimetry 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 planimetry 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 54) 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 40 percent of the quadrangle. These high development potential areas result primarily from low overburden-to-coal ratios for the Felix and Smith coal beds. The Arvada also supplements the high development potential rating in the northwest quarter of the study area. Moderate development potential

rating covers approximately 25 percent of the quadrangle, and is attributed to intermediate overburden-to-coal ratios for the Felix, Arvada, and Smith coal beds. These high and moderate development potential areas occur primarily in and along the sides of the Powder River and Wild Horse Creek alluvial valleys in the western half and northeast quarter of the study area, respectively. A low development potential rating covers approximately 25 percent of the quadrangle and is attributed to high overburden-to-coal ratios for the Felix, Arvada, and Smith coal beds. The low development potential areas occur throughout higher, more rugged terrain of the study area, primarily in the southeast quarter. The remaining 10 percent of the quadrangle is classified as non-federal coal land and is not evaluated in this study, or the coal beds occur greater than 500 feet (152 m) in depth beneath the surface. 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 Lariat 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 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 55) on the Lariat Quadrangle is moderate for approximately 45 percent of the study area. This moderate development potential rating occurs primarily in the southern half of the quadrangle, and is attributed to the combined moderate coal bed thicknesses of the Smith, Anderson, Upper and Lower Canyon, and Cook coal beds. A low development potential rating covers approximately 50 percent of the quadrangle, and is attributed to the combined coal bed thicknesses of the Anderson, Upper and Lower Canyon, Cook, Wall, Pawnee, Cache, Moyer, and Oedekoven coal beds. The low potential rating occurs primarily along the Powder River and Wild Horse Creek alluvial valleys. The remaining 5 percent of the quadrangle is classified as non-federal coal 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 Lariat Quadrangle, Sheridan, 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				
Felix	70,280,000	42,220,000	54,900,000	167,400,000
Arvada	11,880,000	10,360,000	216,440,000	238,680,000
Smith	872,590,000	60,220,000	-	932,810,000
Total	954,750,000	112,800,000	271,340,000	1,338,890,000
Hypothetical Resources				
Felix	-	-	10,290,000	10,290,000
Arvada	-	-	1,670,000	1,670,000
Smith	-	-	71,570,000	71,570,000
Total	-	-	83,530,000	83,530,000
GRAND TOTAL	954,750,000	112,800,000	354,870,000	1,422,420,000

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

Coal Bed Name	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Reserve Base Resources				
Felix	-	-	460,000	460,000
Arvada	-	-	106,050,000	106,050,000
Smith	-	-	891,100,000	891,100,000
Swartz	-	-	148,750,000	148,750,000
Anderson- Upper Canyon	-	-	3,010,040,000	3,010,040,000
Lower Canyon- Cook	-	-	1,008,640,000	1,008,640,000
Wall	-	-	2,321,000,000	2,321,000,000
Pawnee	-	-	449,590,000	449,590,000
Cache	-	-	50,370,000	50,370,000
Moyer- Oedekoven	-	-	784,830,000	784,830,000
Total	-	-	8,770,830,000	8,770,830,000
Hypothetical Resources				
Arvada	-	-	1,830,000	1,830,000
Smith	-	-	164,730,000	164,730,000
Swartz	-	-	5,690,000	5,690,000
Anderson- Upper Canyon	-	-	17,500,000	17,500,000
Lower Canyon- Cook	-	-	60,160,000	60,160,000
Wall	-	-	74,350,000	74,350,000
Pawnee	-	-	63,960,000	63,960,000
Cache	-	-	10,000	10,000
Moyer- Oedekoven	-	-	28,980,000	28,980,000
Total	-	-	416,940,000	416,940,000
GRAND TOTAL	-	-	9,187,770,000	9,187,770,000

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

Coal Bed Name	High Development Potential	Moderate Development Potential	Low Development Potential	Total
Reserve Base Resources	-	5,348,940,000	3,421,890,000	8,770,830,000
Hypothetical Resources	-	-	416,940,000	416,940,000
TOTAL	-	5,348,940,000	3,838,830,000	9,187,770,000

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 NE Quadrangle, Sheridan and Campbell Counties, Wyoming, and Powder River County, Montana: U. S. Geological Survey Open-File Report 78-064, 21 p.

- IntraSearch Inc., 1979, Coal resource occurrence and coal development potential maps of the Larey Draw Quadrangle, Campbell County, Wyoming: U. S. Geological Survey Open-File Report 79-023, 29 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, Campbell 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.

U. S. Geological Survey and Montana Bureau of Mines and Geology,
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.

Weimer, R. J., 1977, Stratigraphy and tectonics of western coals in
Geology of Rocky Mountain Coal, A Symposium, 1976: Colorado
Geological Survey Resources Series 1, p. 9-27.