Uranium-bearing coal in the central part of the Great Divide Basin, Sweetwater County, Wyoming

By G. N. Pipiringos

Trace Elements Investigations Report 477

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URANIUM-BEARING COAL IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, SWEETWATER COUNTY, WYOMING

By

George N. Pipiringos

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This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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	50

CONTENTS

ILLUSTRATIONS

Page

TABLES

URANIUM-BEARING COAL IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, SWEETWATER COUNTY, WYOMING

By George N. Pipiringos

ABSTRACT

Field work leading to this report was done by the U. S. Geological Survey for the Division of Raw Materials of the U. S. Atomic Energy Commission. Nearly 24 townships were mapped in the central part of the Great Divide Basin, Sweetwater County, Wyoming. Fourteen of these townships contain outcrops of uranium-bearing coal. Thirty coal beds were mapped, but only seven of them have uranium-bearing coal reserves as defined in this report. Coal beds 2.5 or more feet thick are considered in calculating coal reserves, and of these, only beds containing 0.003 or more percent uranium are considered in calculating reserves of uranium in coal. Reserves of uranium in coal ash include those beds 2.5 or more feet thick that contain 0.015 or more percent uranium in coal ash.

Measured and indicated coal reserves total about 700,000,000 short tons which contain about 2,600 short tons of uranium in the coal, or about 2,400 short tons of uranium in the coal ash. Strippable reserves, defined as reserves in beds beneath 60 or less feet of overburden, are about 250,000,000 short tons of coal containing about 1,100 short tons of uranium in coal, or about 600 tons of uranium in coal ash.

The thickest coal beds underlie a relatively narrow belt that trends northwest and coincides approximately with the axis of the Red Desert syncline. The coal beds contain the most uranium on the east flank of the syncline near the southwesternmost edge of the Battle Spring formation (new). This formation is of early and middle Eocene age and consists predominantly of very coarse-grained arkosic sandstone which is highly permeable. It intertongues southwestward with the less permeable Green River and Wasatch formations. The Green River formation consists from youngest to oldest of the Morrow Creek and Laney shale members and the Tipton and Luman (new) tongues. The Wasatch formation

interfingers with the Green River formation and consists from youngest to oldest of the Cathedral Bluffs, Niland, and Red Desert tongues. The latter two are here recognized for the first time and contain all the coal beds in the Wasatch formation. The Morrow Creek member of the Green River formation is of middle Eocene age. The Laney member and Cathedral Bluffs tongue of the Green River and Wasatch formation, respectively intertongue and are in part equivalent, and are of early or middle Eocene age. The other units are of early Eocene age.

A broad gentle arch which is either the eastern extension of the Wamsutter arch, or a separate arch en echelon to it, separates the Washakie Basin in the southeastern part of the map area from the Red Desert syncline in the northeastern part. The Red Desert syncline plunges gently northwest into the nearly circular structural Niland basin. The south flank of the Wamsutter (?) arch dips southeastward at an average rate of about 230 feet per mile. The northern flank of the arch dips northeastward at an average rate of about 140 feet per mile.

North of the Niland basin, the structure is more complex and is dominated by a northwestward-trending graben which parallels and includes the Cyclone Rim in the northern part of the map area. Schroeckingerite deposits in the northeastern part of the map area lie within this graben in a sequence of arkosic sandstone and clay shale stratigraphically equivalent to the lower part of the Cathedral Bluffs tongue of the Wasatch formation and to the uppermost part of the Tipton tongue of the Green River formation. Weakly radioactive tuffaceous sandstone beds of the Browns Park formation that probably once blanketed the entire Great Divide Basin are preserved a short distance north and northwest of the schroeckingerite deposits. The geologic settings of the schroeckingerite and uranium-bearing coal are similar and their source of uranium is probably the same. The uranium probably was leached from tuffaceous beds in the Browns Park formation and carried to its present site of deposition by groundwater whose circulation was guided by structure and changes in facies.

INTRODUCTION

Purpose of the work

Field work, primarily intended to determine reserves of uranium-bearing coal in the central part of the Great Divide Basin, Wyoming, was done during the summers of 1951-1953 by the Geological Survey for the Division of Raw Materials of the U. S. Atomic Energy Commission.

In addition, the stratigraphy and structure of the coal-bearing rocks, which are of early Eocene age, were studied in detail, and the geology of adjacent or related areas was examined in reconnaissance in order to determine how the uranium was deposited and where it came from.

Location of the area

The Great Divide Basin is an oval-shaped, undrained topographic depression on the Continental Divide embracing about 4,000 square miles in Sweetwater, Carbon and Fremont Counties, south central Wyoming (fig. 1).

This report is concerned primarily with the central part of the Great Divide Basin, but geologic features of adjacent or related areas are also discussed insofar as they affect the geologic interpretations of the report area.

Earlier investigations

Nearly all of the Great Divide Basin was mapped in reconnaissance and the main coal-bearing areas delimited by Smith (1909), Ball (1909), and Schultz (1909). Schultz (1920) later completed a more comprehensive report in which he defined and described several members of the Green River formation. Sears and Bradley (1924) described intertonguing of the Green River and Wasatch formations in northwestern Colorado and southwestern Wyoming, and later mapping and stratigraphic studies near or related to the central part of the Great Divide Basin by Bradley (1926, 1945), Nightingale (1930), and Nace (1939) have yielded much information concerning the complex stratigraphic relations of the early Tertiary rocks of this region.

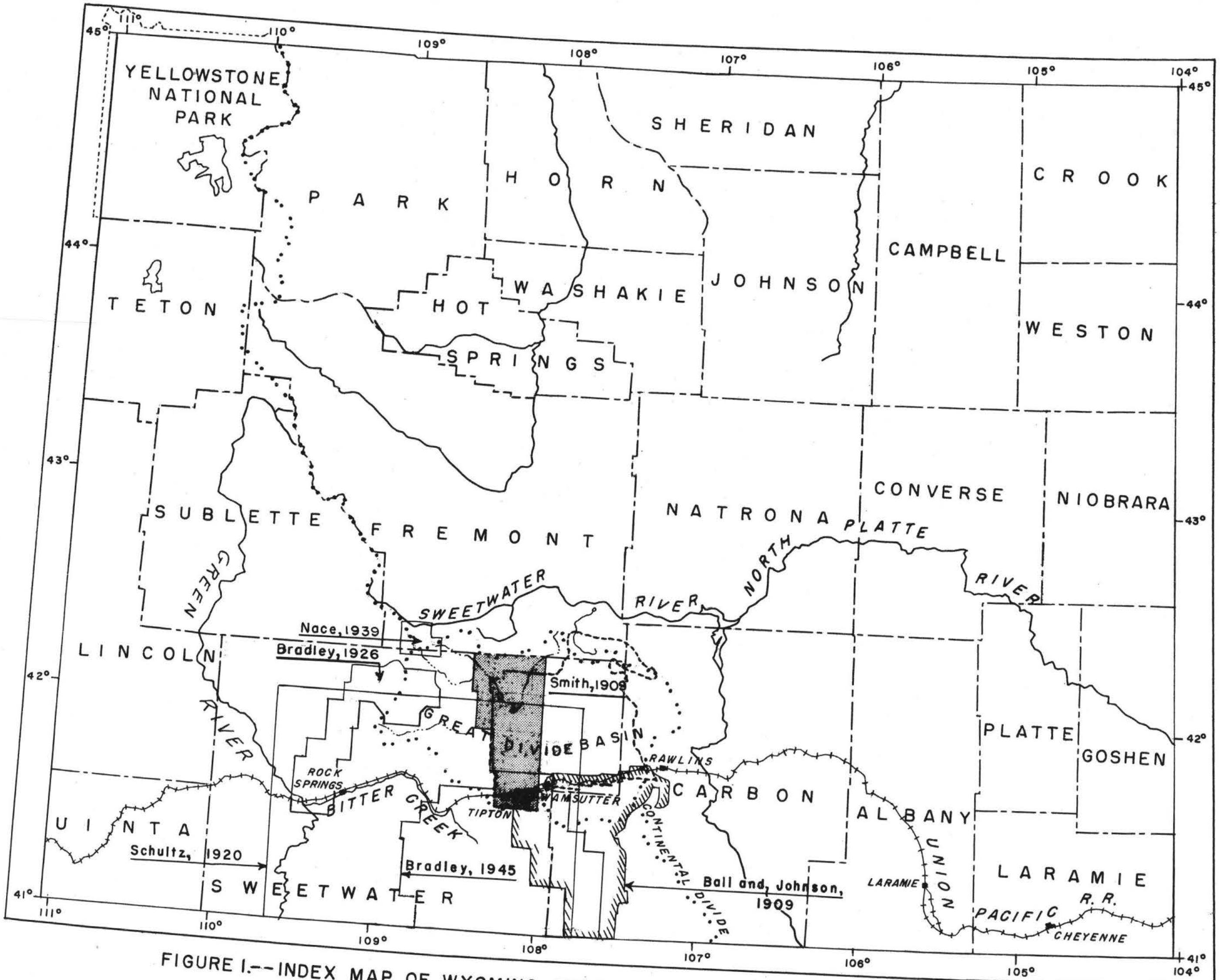


FIGURE I.--INDEX MAP OF WYOMING SHOWING LOCATION OF MAP AREA (SHADED) IN RELATION TO NEARBY AREAS DESCRIBED BY PUBLISHED REPORTS.

50 0 50 Miles

Uranium was first discovered in the north-central part of the Great Divide Basin by the late Mrs. Minnie McCormick, resident of Wamsutter, Wyoming, who in 1936 (?) found a yellow-green mineral, later identified as schroeckingerite, in the east bank of Lost Creek in the NW 1/4 sec. 31, T. 26 N., R. 94 W. (fig. 2). Radioactive carbonaceous shale and coal were discovered in 1945 by Slaughter and Nelson (written communication, 1946) at Sourdough Butte, a few miles east of the map area. Reconnaissance mapping during parts of 1949 and 1950 by Wyant, Sharp, and Sheridan (in preparation) indicated that very large tonnages of uranium-bearing coal underlie parts of the Great Divide Basin. Results of detailed investigations (1951-53) of the schroeckingerite locality are given in a report by Sheridan, Maxwell, and Collier (in preparation).

Field work

This report gives the results of the geologic mapping, sampling, and auger and core drilling in the western half of a larger area that was studied during the summers of 1951 to 1953. An area of about 850 square miles (approximately 24 townships or one 30-minute quadrangle) was mapped on aerial photographs at a scale of about 1:36,000 (fig. 2). Information, gathered on the distribution and uranium content of the coal beds by mapping and sampling outcrops was augmented by drilling about 120 auger holes and 10 core holes. A large number of stratigraphic sections were measured and 20 fossil collections were made during the investigation. Some preliminary results of the 1951 and 1952 field seasons have been given in an earlier report (Masursky and Pipiringos, in preparation).

Acknowledgments

Harold Masursky was in general charge of the work during the summers of 1951 and 1952, but the writer is responsible for the mapping and geologic interpretation of the areas here described. A. E. Burford, Howard Gower, and George W. Moore assisted in the mapping during 1952, and J. C. MacLachlan assisted in the mapping during 1953. Gower helped compile the drilling data during the winter of 1952, and MacLachlan, J. C. Benson, Harold Hyden, R. L. Koogle and P. E. Soister helped compile the geologic map or the coal reserve data at various times during 1953 and 1954. Fossils collected by members of the U. S. Geological Survey were identified by R. W. Brown and T. C. Yen of the U. S. Geological Survey, C. L. Gazin of the U. S. National Museum, and R. E. Peck of the Geology Department of the University of Missouri.

Special thanks are extended to N. M. Denson and R. W. Brown of the U. S. Geological Survey whose many helpful suggestions and stimulating discussions in the field were directly responsible for leading the author to two of the more important contributions of this report: 1) that the distribution of uranium in coal of this area primarily is related to sedimentary facies changes and 2) that the early Tertiary sequence on the east flank of the Rock Springs uplift, formerly mapped as the Wasatch formation of Eocene age, actually consists of both Paleocene and earliest Eocene rocks which are faunally and lithologically distinct and are separated by an angular unconformity.

W. J. Mapel made many valuable criticisms and suggestions that greatly improved this report.

J. M. Schopf of the Geological Survey Coal Geology Laboratory described the coal cores and sampled them for analysis.

Proximate and ultimate analyses of coal cores were made by the U. S. Bureau of Mines, Central Experiment Station, Pittsburgh, Pennsylvania, Roy F. Abernethy, Chemist in charge.

Analyses of coal and carbonaceous rocks were made at the U. S. Geological Survey laboratory, Washington, D. C. The radiometric analyses were made by B. A. McCall and E. G. Williams, the chemical analyses by Maryse Delevaux, Carmen Johnson, Shirley Lundine, Ivan Barlow, Harry Levine, W. P. Tucker, Jr., Joseph Budinsky, A. B. Caemmerer, Thomas Farley, J. J. Rowe, and Audrey Smith.

Analyses of samples of arkosic and tuffaceous sandstone were made at the U. S. Geological Survey laboratory, Denver, Colorado. The radiometric analyses were made by Sylvia Furman and the chemical analyses by Wayne Mountjoy and George Boyes.

GEOGRAPHY

Topography

Most of the central part of the Great Divide Basin is very nearly flat and featureless. Low hills and ridges rise to altitudes of 7,300 to 7,500 feet west and north of the Cyclone Rim in the extreme northern part of the map area, and at Laney Rim in the extreme southern part. These areas of high ground mark the two branches of the Continental Divide. The intermittent lakes and dry flats range from about 6,500 to 6,700 feet in altitude.

Several small buttes in some parts of the area stand 50 to 300 feet above the general level of the terrain. These include Flattop Buttes in the extreme northern part of the map area, Bastard Butte and Luman Butte in the northwestern part, Lost Creek Butte in the east-central part and the Tipton Buttes in the southwestern part. Much of the area is dissected by shallow valleys whose gentle slopes rise to and merge with extensive gravel terraces.

Endlich (1879) applied the name Red Desert to the reddish western part of what is now the Great Divide Basin. To the non-red area east of the Red Desert he gave the name Shoshone Basin. The name Shoshone Basin has been abandoned, and the name Red Desert has been extended to include outcrops of of the Cathedral Bluffs tongue southeastward as far as Baggs, Wyoming (Ball, 1909, pl. 13) and is now loosely applied to include much of the area east of Red Desert Flat.

Drainage and water supply

All the rain that falls in the Great Divide Basin either evaporates, sinks into the ground or forms intermittent streams that drain into intermittent lakes, dry lake flats, sumps and reservoirs. The intermittent lakes dry up within a few days following a rain. There is no drainage out of the area, except in the extreme northern and southern parts of the map area, which belong to the Atlantic and Pacific drainages respectively.

There are no permanent lakes or streams in the area except Grass Lake and Daly Lake, and the upper part of Lost Creek, which is spring-fed in the vicinity of the schroeckingerite locality.

Aside from the natural sources mentioned above, water is obtained from a large number of water wells drilled by local ranchers, from wells drilled by the Union Pacific Railroad at Tipton, Red Desert, and Frewen stations, and from the so-called "dry" hole drilled at the southwest edge of Lost Creek Flat by the Red Desert Oil Company. The "dry" hole yields an artesian flow of warm water at the rate of about 38 gallons a minute, but other wells in the area require the use of a motor pump to raise the water to the surface except for a few which are equipped with hand pumps. Auger drilling revealed that the ground water table in the central part of the area is from a few to about 25 feet below the surface of the flats.

Climate and vegetation

The Great Divide Basin is semiarid and semiboreal. The average annual precipitation is equivalent to less than 10 inches of rain. The winters are cold and the summers are warm. Maximum temperatures rarely exceed 90 degrees in the summer, but below-zero temperatures are common in the winter. Low humidity and continual breezes result in little discomfort from the heat in the warmest part of the summer, and little interruption of field work in the early winter months, inasmuch as snow in October, November and December disappears rapidly by being blown away, or melting and evaporating, or by sublimation.

The principal types of vegetation are few: grass, sagebrush, greasewood, salt sage, rabbitbrush and tumbleweed. No trees grow in the Great Divide Basin except at some of the railroad stations and locally along the periphery.

Settlement and roads

The only communities in the map area are those at Tipton, Red Desert and Frewen, which are stations on the Union Pacific Railroad, inhabited only by employees of the railroad. But Wamsutter station, about four miles east of Frewen, is a community of 103 inhabitants where food and other supplies can be be purchased as well as room and board. Wamsutter includes a fair-size settlement along U. S. Highway

30 and just north of the highway where the Utah Oil Company maintains a pumping station. Wamsutter is also the point where a number of truck-freight companies operating between Salt Lake City, Utah, and Denver, Colorado, maintain a stop-over station for refueling, vehicle repair and change of drivers. Rawlins (7,500 pop.) and Rock Springs (11,000 pop.) are situated on the railroad 47 miles east and 53 miles west of the map area respectively.

Most of the Great Divide Basin provides winter grazing for sheep owned by several ranchers and livestock companies. The sheep owners maintain several watering places, hay barns and sheep shearing pens in the area. From May to October the area does not provide enough water or feed to sustain large numbers of sheep; consequently, they are moved to nearby mountains for grazing during that time. A complex network of graded dirt roads, car trails and wagon trails, which join U. S. Highway 30 at many places, provides easy access by vehicle to nearly all parts of the map area except for short periods following heavy rains or snow falls.

Land survey

Horizontal control

All of the central part of the Great Divide Basin was surveyed in the late 1870's and early 1880's. A few of the old notched stone corners still stand, especially along the township and range lines, but most of them can no longer be found. The external boundaries of the townships south of T. 25 N. were resurveyed in 1936 by the General Land Office and are now well marked by brass-capped steel pipes, many of which are set alongside the old stone corners. Generally the distances between corners shown on the old plats differ by several chains per mile from those shown on the recent plats. Township tiers 25 and 26 N. were not resurveyed, and only a few of the old stone corners are left to mark the sections. Many of the corners that were found in these northerly tiers of townships were made of friable arkosic sandstone, so the chances are that the stones marking the external corners, which were generally smaller than those marking the internal corners, have for the most part completely disintegrated. Only the two townships, Tps. 23 and 24 N., R. 97 W., which contain parts of the Luman Ranch homestead, have been resurveyed internally.

The grid for the geologic map (fig. 2) was constructed by plotting the external corners of the townships according to the 1936 plats, and by connecting opposite corners by straight lines except where some of the old internal corners were recovered. The geologic mapping was transferred from the photographs (see section on Field work) onto the grid by means of a vertical projector.

Vertical control

Vertical control within the map area is limited to U. S. Coast and Geodetic Survey triangulation stations Delaney (alt. 7,445 feet), in sec. 29, T. 19 N., R. 95 W., Divide (alt. 6,986 feet), in sec. 16, T. 22 N., R. 94 W. and Red Desert (alt. 6,829 feet), in sec. 8, T. 22 N., R. 95 W. _/ and to several Wyoming State Highway Department benchmarks along the north side of U. S. Highway 30 (fig. 2). Transit surveys made by private companies (oral communications) indicated that the altitudes stamped on the Highway Department benchmarks are about 52 feet too high, and that the altitude of triangulation station Red Desert is about 15 feet too high. Numerous, repeated, altimeter traverses made by the author between the benchmarks and the triangulation stations, and between the triangulation stations, and between the triangulation stations Red Desert and Divide, likewise showed similar discrepancies.

The author believes that altitudes established by altimeter, shown on figure 2, and those on which the structure contour map (fig. 3) is based, are accurate within 5 feet inasmuch as all altimeter loop traverses closed within a few feet, and one linear traverse, more than 30 miles long, between triangulation station Divide and U. S. Geological Survey benchmark Girrard alt. 7, 212 feet, located a few miles north of Flattop Buttes) closed within 10 feet.

_/ Altitude above sea level established for Divide, "6,989 ft." and Red Desert, "6,832 ft." should be, "6,986 ft." and "6,829 ft." respectively, according to corrections published by the U. S. C. & G. S. in 1950.

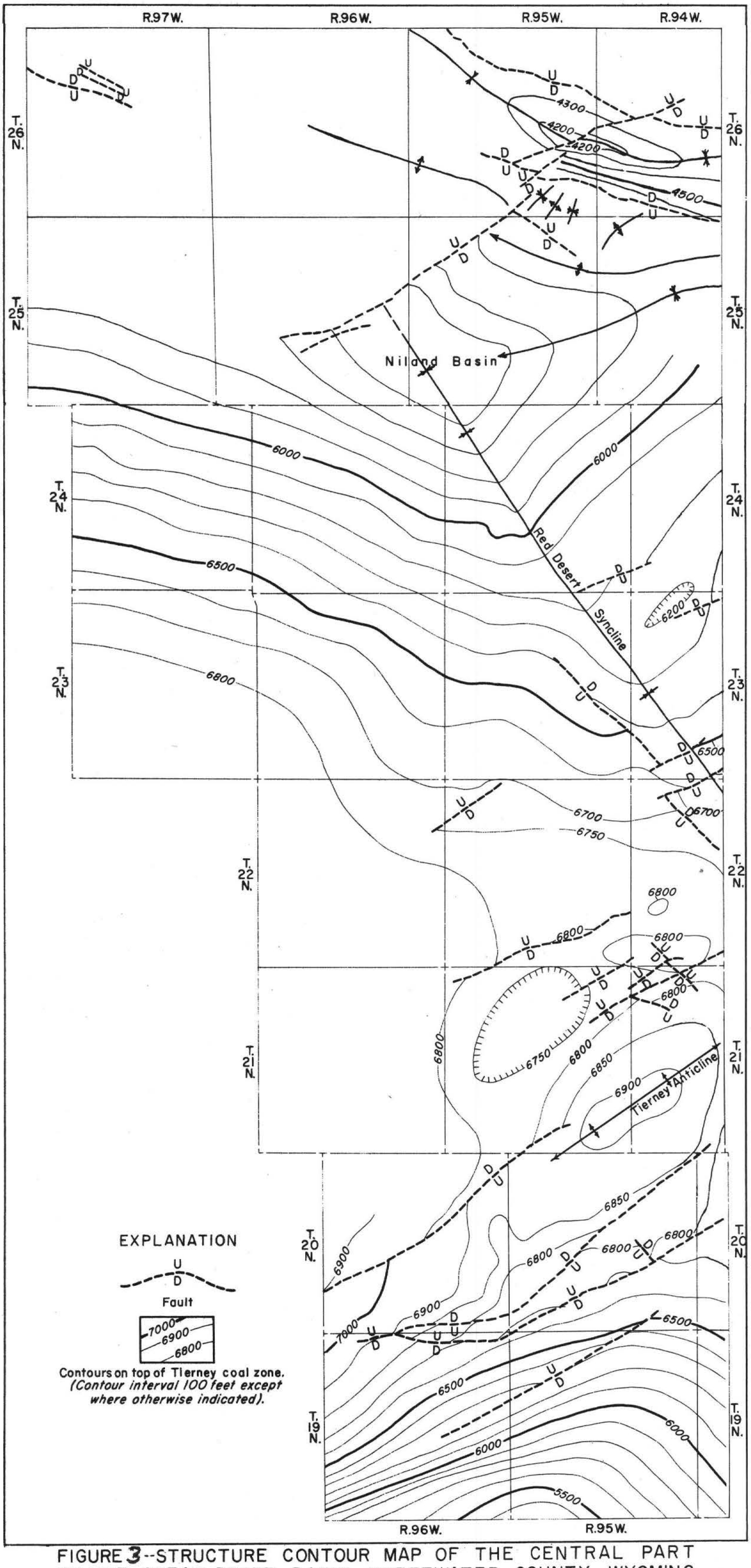


FIGURE 3--STRUCTURE CONTOUR MAP OF THE CENTRAL PART OF THE GREAT DIVIDE BASIN, SWEETWATER COUNTY, WYOMING.

No trace was found of the U. S. Geological Survey triangulation station Tipton established in the late 1880's on the highest part of the butte shown on plate 13. The U. S. Geological Survey benchmark (Z-2) at Red Desert station on the Union Pacific Railroad could not be located. The Wyoming State Highway Department benchmark, which was formerly located at the west edge of the east entrance road of the gasoline filling station on the north side of U. S. 30 at Red Desert, Wyoming, was destroyed by a snow plow in the winter of 1952.

STRATIGRAPHY

Summary statement

The sedimentary rocks exposed in the central part of the Great Divide Basin consist mostly of lake, swamp, and stream deposits of early Tertiary age and have an aggregate thickness of about 5,000 feet. The distribution and general lithology of the various rock units are shown on the geologic map and the composite stratigraphic sections (fig. 2).

The Fort Union formation of Paleocene age is the oldest formation exposed in the area. It consists of sandstone, siltstone, clay shale, and coal beds, and a few miles north of the map area it is about 1,000 feet thick and rests unconformably on Cretaceous rocks (Bell, 1954). The upper 50 feet of the formation crops out in a small area north of Cyclone Rim; elsewhere, the Fort Union formation is covered by younger sedimentary rocks.

Unconformably overlying the Fort Union formation is a sequence of beds of early and middle Eocene age about 3,400 feet thick consisting of sandstone, siltstone, oil shale, clay shale, limestone, conglomerate, and coal beds. Seven stratigraphic units can be recognized in this sequence. Three of these are made up predominantly of variegated claystone, or sandstone and siltstone, with subordinate limestone, conglomerate, shale and coal. They are, from youngest to oldest, the Cathedral Bluffs, Niland, and Red Desert tongues of the Wasatch formation. Alternating and intertonguing with these units are four stratigraphic units consisting predominantly of oil shale with subordinate sandstone, siltstone, and limestone. They are, from youngest to oldest, the Morrow Creek and Laney shale members and the Tipton and Luman tongues of the Green River formation.

In the northern part of the area, the various tongues and members of the Wasatch and Green River formations, with the exception of the Laney Shale member, grade laterally into and intertongue with coarse-grained to conglomeratic arkosic sandstone beds of the Battle Spring formation.

Rocks of Tertiary age younger than the Morrow Creek member of the Green River formation are exposed at Cyclone Rim. They include the Bridger formation of middle Eocene age, which is as much as 100 feet thick and consists of claystone and shale with several thin beds of limestone, and the Browns Park formation of Miocene age, which is at least 400 feet thick and consists of tuffaceous fine-grained to conglomeratic sandstone. An angular unconformity at the base of the Browns Park formation truncates the Bridger formation.

Surficial deposits of Quaternary age locally cover large areas in the west central part of the Great Divide Basin. The deposits include alluvium on the bottoms of large dry lakes and in the valleys of some of the large streams, delta and fan deposits along the margins of some of the dry lakes, sand dunes, and gravel deposits on some of the buttes and mesas.

The general stratigraphic relations of the various formations and members are shown by a restored cross section, figure 2, and the stratigraphic nomenclature used in this and other published reports on the Great Divide Basin and adjacent areas is shown by table 1. Fossils found in the Tertiary rocks during the investigations are listed in table 2, and, except for no. 16, fossil localities are shown on plate 1.

Tertiary rocks

Fort Union formation

The name Fort Union formation is tentatively applied to a sequence of sandstone, siltstone, clay shale and coal beds near Flattop Buttes at the northern edge of the area (fig. 2 and pl. 1). Only the upper 50 feet of the formation crops out in the map area, but its thickness directly north of Flattop Buttes in the south flank of Bison Basin is about 1,000 feet (Bell, 1954). Vertebrate fossils of late Paleocene (Tiffanian) age (table 2, loc. 20) were collected from within 300 feet of the top of the formation in the

Schultz, 1920	Bradley, 1926	Nightingale, 1930	Bradley, 1945	Pipiringos, 1956		Age
Rock Springs uplift, Sweetwater County, Wyoming	Northern Sweetwater County, Wyoming	Vermillion Creek gas area, N. W. Colo. & S. W. Wyo.	Washakie Basin, Sweetwater and Carbon Counties, Wyo.	Central part of the Great Divide Basin, Sweetwater County, Wyoming		Age
				Southern part	Northern part	
Bridger formation	Bridger formation	Bridger formation	Bridger formation	Bridger formation	Bridger formation	middle Eocene
Green River fm.: Plant beds and Tower sandstone of Powell	Morrow Creek member of Green River fm.	Green River formation	Morrow Creek member of Green River fm.	Morrow Creek member of Green River fm.	Morrow Creek member of Green River fm.	
Green River fm.: Laney shale member	Laney shale member of Green River fm.		Laney shale member of Green River fm.	Laney shale member of Green River fm.	*Battle Spring formation	
Green River fm.: Cathedral Bluffs red beds member	Cathedral Bluffs tongue of Wasatch fm.	Cathedral Bluffs tongue of Wasatch fm.	Cathedral Bluffs tongue of Wasatch fm.	Cathedral Bluffs tongue of Wasatch fm.		?
Green River fm.: Tipton shale member	Tipton tongue of Green River fm.	Tipton tongue of Green River fm.	Tipton tongue of Green River fm.	Tipton tongue of Green River fm.		early Eocene
Wasatch formation	Main body of Wasatch fm. (base not exposed in map area)	Hiawatha member of Wasatch fm. (lower 3,500 feet known only from drill cuttings)	Main body of Wasatch fm. (base not exposed in map area)	*Niland tongue of Wasatch fm.		
				*Luman tongue of Green River fm.		
				*Red Desert tongue of Wasatch fm.		
				unconformity	unconformity	
				Fort Union fm. (not exposed)	Fort Union formation	Paleoc.
unconformity	- - - - - - -	fault contact	- - - - - - -	unconformity (?)	unconformity	
Cretaceous		Cretaceous		Cretaceous (not exposed	Cretaceous (not exposed)	

Table 1.--Correlation of Paleocene and Eocene rocks of the central part of the Great Divide Basin with similar rocks in adjacent areas.

*New names proposed in this report.

Table 2.--Fossils collected in the central and western parts of the Great Divide Basin, Sweetwater County, Wyoming.

Localities are shown on plate 1 (except for loc. No. 16).

LOCALITY	STRATIGRAPHIC POSITION	IDENTIFICATION	AGE
	Browns Park formation		
1. NW 1/4, sec. 13 T. 26 N., R. 96 W.	More than 200 feet above the base	Blastometrix sp.	Miocene 1/
	Morrow Creek member of the Green River formation		
2. SE 1/4, NE 1/4, sec. 18, T. 26 N., R. 95 W.	About 40 feet above the base	Unio cf. U. Haydeni Meek Goniobasis cf. G. tenera (Hall)	Middle Eocene 2/
	Cathedral Bluffs tongue of the Wasatch formation		
3. SE 1/4, SE 1/4 sec. 33, T. 19 N., R. 95 W.	About 500 feet above the base	Hyopsodus (?) sp.	Indeterminate 3/
	Niland tongue of the Wasatch formation		
4. SE 1/4, NW 1/4, SW 1/4, sec. 24, T. 24 N., R. 96 W.	30 feet below top (2 feet below Bush No. 2 coal bed)	Salvinia preauriculta Berry Lygodium Kaulfussi Heer Lemna scutata Dawson Equisetum sp.	Earlier half of the Eocene 4/
5. NW 1/4, SW 1/4, sec. 21, T. 24 N., R. 95 W.	90 feet below top (30 feet above Hay No. 2 coal bed)	Aralia sp. Mimosites sp.	Eocene 4/
6. SE 1/4, NW 1/4, sec. 28, T. 24 N., R. 95 W.	185 feet below the top (3 feet below Luman No. 2 coal bed)	Typha sp.	Eocene 4/

1/ Collected and identified by W. G. Bell, Geology Dept., University of Wyoming.
2/ Identified by T. C. Yen, U. S. Geol. Survey.
3/ Identified by C. L. Gazin, Curator Vertebrate Paleontology, U. S. National Museum.
4/ Identified by R. W. Brown, U. S. Geol. Survey.

Table 2.--Fossils collected in the central and western parts of the Great Divide Basin, Sweetwater County, Wyoming. --Continued

Localities are shown on plate 1 (except for loc. No. 16)

LOCALITY	STRATIGRAPHIC POSITION	IDENTIFICATIONS	AGE
	Niland tongue of the Wasatch formation.--Continued		
7. SW 1/4, NE 1/4, NE 1/4, sec. 22, T. 24 N., R. 97 W.	50 feet below top (25 feet above Hay No. 2 coal bed)	Goniobasis carterii Valvata sp.	Probably Lower Eocene age 2/
8. SE 1/4, NW 1/4, sec. 28, T. 24 N., R. 95 W. (core hole no. 4)	85 and 50 feet above base (at depths 140-143, 1720176 feet)	Cypridea arvardensis (Swain) Candona pageii Swain Candona sp.	Paleocene or early Eocene 5/
	Luman tongue of the Green River formation		
9. SW 1/4, SW 1/4, sec. 15, T. 22 N., R. 94 W.	41 feet above base	Unio sp. Valvata sp. Viviparus cf. V. Paludinaeformis (Hall) Goniobasis cf. G. tenera (Hall) Gyraulus cf. G. militaris (White)	Lower Eocene 2/
10. SE 1/4, SE 1/4 sec. 21, T. 22 N., R. 94 W.	38 feet above base	Valvata sp. Viviparus sp. Goniobasis cf. G. tenera (Hall)	Probably Lower Eocene 2/
11. SE 1/4, NW 1/4, sec. 28, T. 24 N., R. 95 W. (core hole no. 4)	23 feet above base (at depths 458-463 feet)	Cypridea arvardensis (Swain) Candona pageii Swain Candona sp.	Paleocene or early Eocene 5/
12. NE 1/4, SW 1/4, SE 1/4, sec. 36, T. 23 N., R. 95 W.	5 feet above base	Unio sp. Sphaerium sp. Viviparus sp. Valvata sp. Gyraulus sp. Goniobasis nodulifera (Meek) Goniobasis cf. G. tenera (Hall)	Lower Eocene 2/
13. NE 1/4, NE 1/4, sec. 27, T. 20 N., R. 96 W.	At base (wormy ss.)	Unio sp. Goniobasis sp.	Indeterminate 2/

5/ Identified by R. E. Peck, Geology Department, University of Missouri.

Table 2. --Fossils collected in the central and western parts of the Great Divide Basin, Sweetwater County, Wyoming. --Continued.

LOCALITY	STRATIGRAPHIC POSITION	IDENTIFICATIONS	AGE
		Red Desert tongue of the Wasatch formation	
14. NE 1/4, NW 1/4, SW 1/4, sec. 4, T. 19 N., R. 96 W.	50 feet below top	Hyopsodus (?) sp.	Indeterminate 3/
15. SE 1/4, NW 1/4, SW 1/4, sec. 23, T. 20 N., R. 96 W.	280 feet below the top	Paramys sp. Esthonyx sp. Hyopsodus sp. Hyracotherium sp. Meniscotherium sp. Pelycodus or Notharctus sp. Creodont Tapiroid	Early Eocene 3/(Lysite or Lost Cabin
16. Sec. 12, T. 23 N., R. 100 W. 6/	Estimated 200 feet above base	Pelycodus (?) sp. Diacodexis sp. Hyracotherium sp. Esthonyx cf. bisulcatus Haplomylus cf. speirianus Meniscotherium, possibly M. priscum	Early Eocene 3/(Gray Bull, Sand Coulee)
17. NE 1/4, NE 1/4, sec. 27, T. 20 N., R. 96 W.	40 feet below top	Unio sp. Valvata sp. Gyraulus sp. Sphaerium sp. Goniobasis sp.	Probably Lower Eocene 2/
18. NE 1/4, NE 1/4, sec. 27, T. 20 N., R. 96 W.	205 feet below top ("holey" limestone)	Valvata sp. Viviparus sp. Physa cf. P. Bullatula White Physa cf. P. pleromatis White Gyraulus cf. G. militaris (White) Hydrobia cf. H. utahensis White "Planorbis" cf. P. convolutus Meek and Hyden	Lower Eocene 2/
19. SW 1/4, SW 1/4, sec. 4, T. 21 N., R. 96 W. (Map locality 78)	About 190 feet below top (directly over Tierney No. 4 coal bed)	Salvinia preauriculata Berry Sparganium antiquum (Newberry) Platanus raynoldsi Newberry Insect wings	Eocene 4/

6/ The exact location is uncertain. From the fossil locality, the compass bearing to the south end of Steamboat Mt. is S. 85 W., and to Black Rock Butte it is S. 40 W.

Table 2.--Fossils collected in the central and western parts of the Great Divide Basin, Sweetwater County, Wyoming.--Continued.

LOCALITY	STRATIGRAPHIC POSITION	IDENTIFICATION	AGE
		Fort Union formation	
20. NE 1/4, SE 1/4, sec. 28, T. 27 N., R. 95 W. 7/	Estimated 300 feet below top	Pleisiadapis cf. anceps Plesiadapis sp. Claenodon (at least 2 spp.) Chriacus (2 species) Tricentes sp. Promioclaenus (?) sp. Gidleyina (?) sp. Phenacodus sp. Condylarth near Protoselena	Paleocene (Tiffanian) 3/

7/ Collected in July, 1952, by R. W. Brown, H. R. Christner and Harold Masursky, U. S. Geol. Survey. A recent report describes this fauna in full (Gazin, 1956).

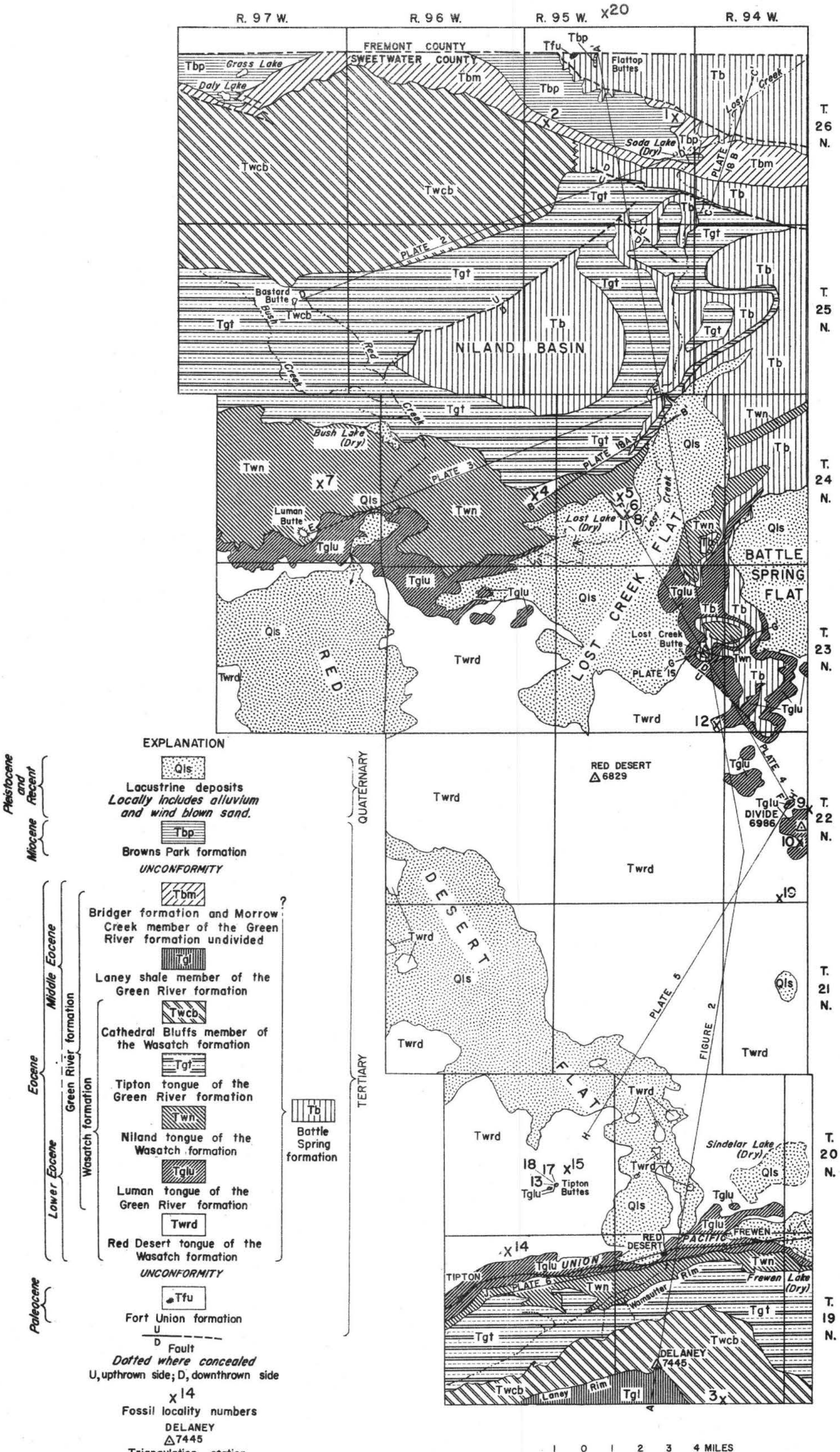


PLATE I.--GENERALIZED GEOLOGIC MAP OF THE CENTRAL PART OF THE GREAT DIVIDE BASIN SHOWING LINES OF SECTION AND FOSSIL LOCALITIES (EXCEPT NO. 16).

SE 1/4 sec. 28, T. 27 N., R. 95 W. about 1.5 miles north of Flattop Buttes. Because of similar lithology and stratigraphic position, this sequence is correlated with the Fort Union formation west of the Rawlins uplift (Brown, 1949; see also pl. 7) and with the Fort Union formation of the Wind River Basin of central Wyoming (Yenne and Pipiringos, 1954).

The Fort Union formation, in Bison Basin north of Flattop Buttes, rests unconformably on rocks of Late Cretaceous age, and is unconformably overlain by arkosic sandstone beds of Eocene age. Coal beds, iron oxide concretions, and a banded purple yellow and white appearance are characteristic of the Paleocene rocks of this and adjacent areas.

The lower part of the Wasatch formation as used by Schultz (1920) is here correlated with the Fort Union formation (table 1). It is discussed, together with the upper part of Schultz' Wasatch, near the end of the description of the Niland tongue of the Wasatch formation.

Wasatch and Green River formations

The restored sections (pls. 2-6 and on fig. 2) whose orientation is shown on plate 1, and the photographs (pls. 7-13) depict details of the stratigraphic units below. The restored sections were constructed by plotting well over 100 partial measured sections and drawing correlation lines between them. In these restored sections either the algal "ball" zone at the base of the upper Tipton or the "pastel" limestone marker bed at the base of the Luman tongue is the datum above and below which the partial sections are plotted in their true relative stratigraphic positions. The restored sections are intended to take the place of graphically plotted or written measured sections which ordinarily are part of a stratigraphic report, and at the same time present the author's concept of the stratigraphic relations of pre-existing portions of the Tertiary sequence which are now missing by erosion throughout much of the area, or are concealed by younger rocks.

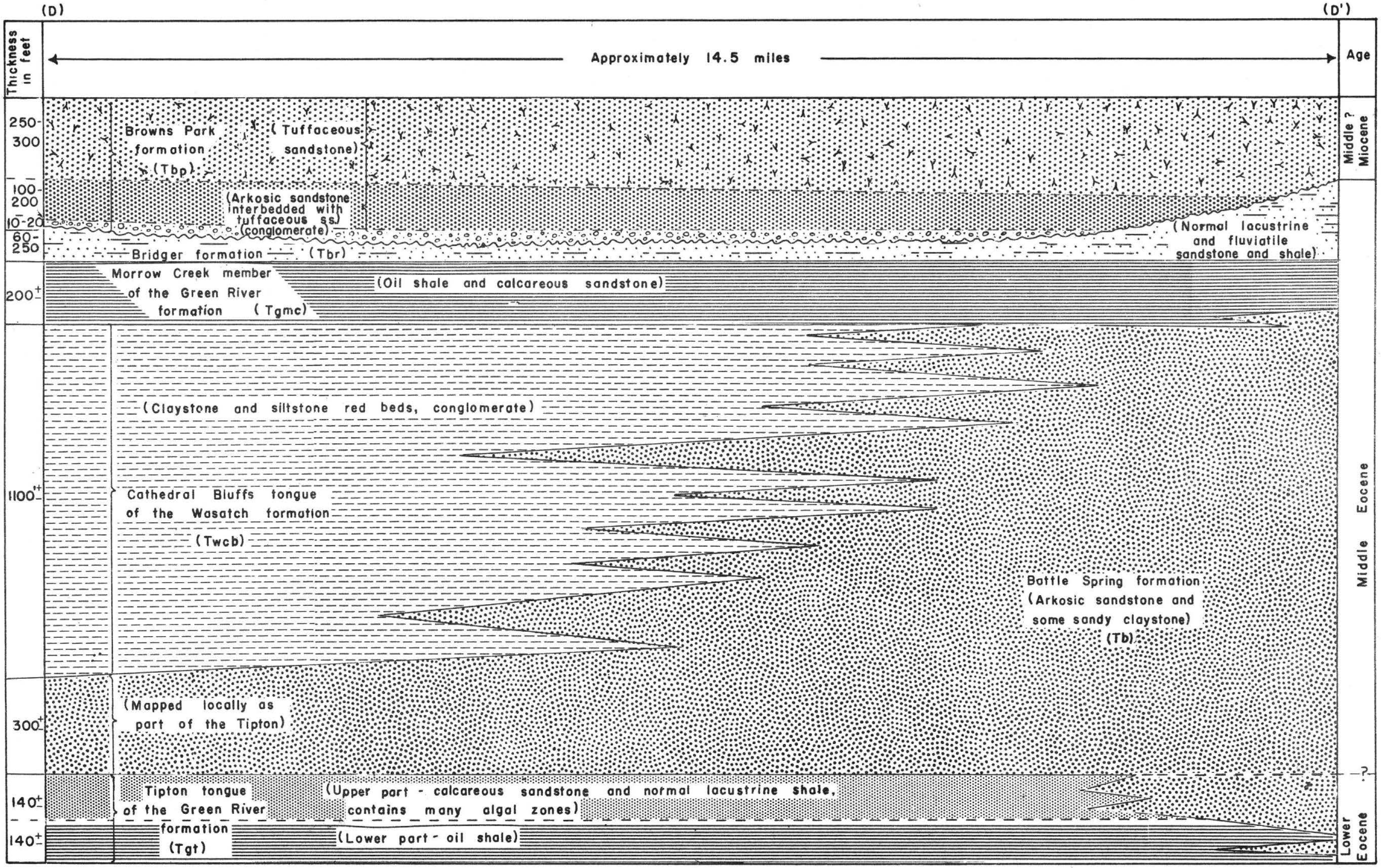


PLATE 2.-- DIAGRAM OF THE STRATIGRAPHIC RELATIONS OF TERTIARY ROCKS FROM BASTARD BUTTE NORTHEASTWARD TO SODA LAKE IN THE NORTH-CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING.
(NOT TO SCALE)

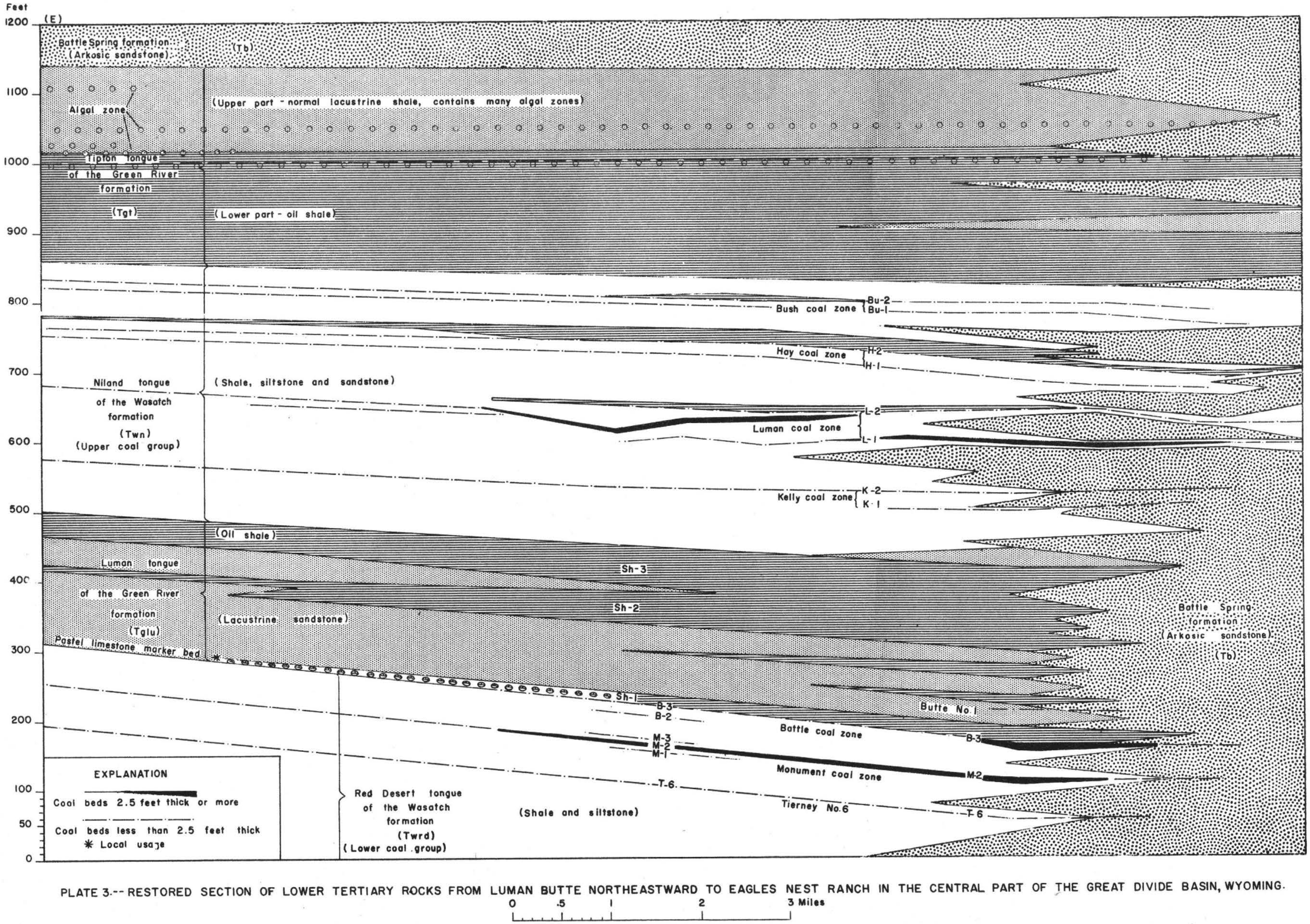


PLATE 3.-- RESTORED SECTION OF LOWER TERTIARY ROCKS FROM LUMAN BUTTE NORTHEASTWARD TO EAGLES NEST RANCH IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING.

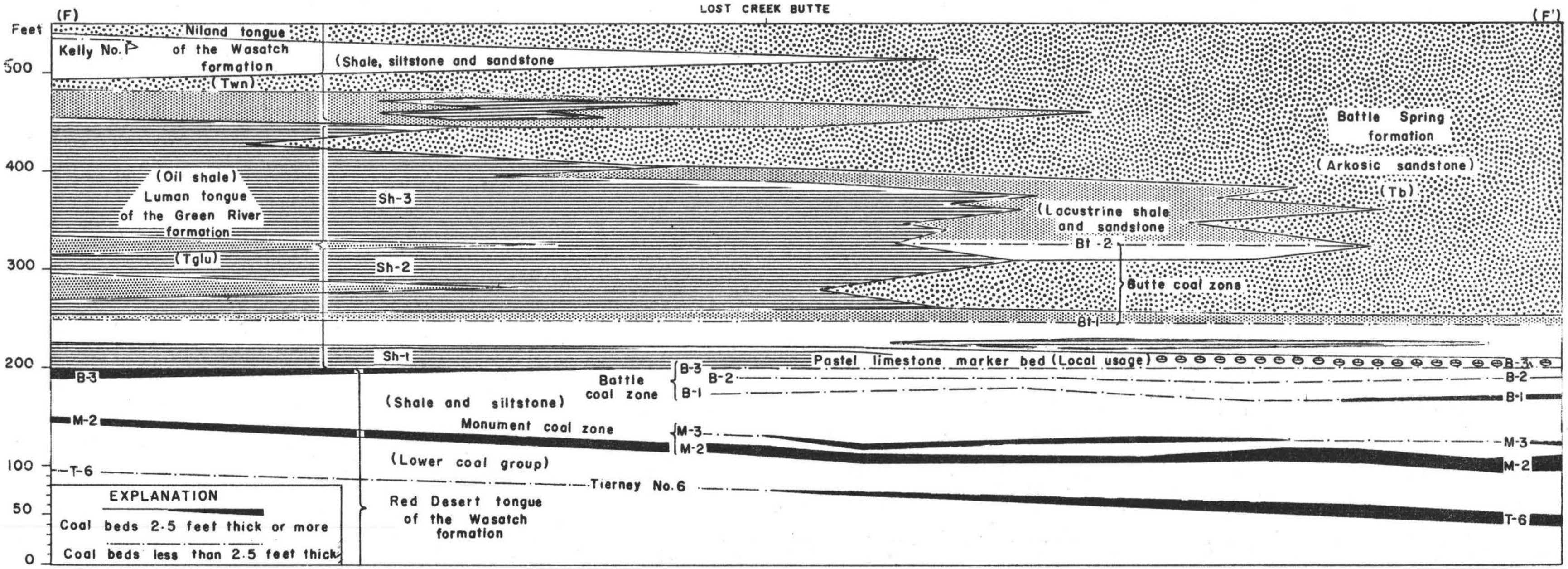


PLATE 4.-- RESTORED SECTION OF LOWER EOCENE ROCKS FROM THE VICINITY OF TRIANGULATION STATION DIVIDE SOUTHEASTWARD TO THE NORTH SHORE OF LOST CREEK FLAT IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING.

0 .5 1 2 3 Miles

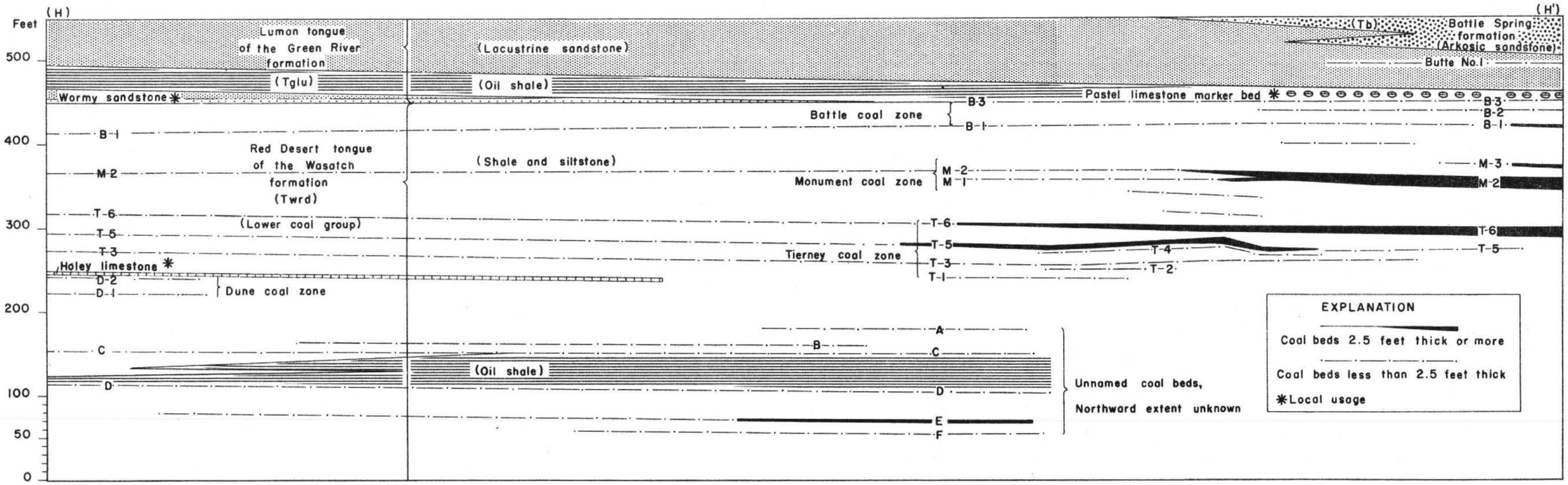


PLATE 5.-- RESTORED SECTION OF LOWER EOCENE ROCKS FROM THE TIPTON BUTTES AREA NORTHEASTWARD TO THE VICINITY OF TRIANGULATION STATION DIVIDE IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING.

0 .5 1 2 3 Miles

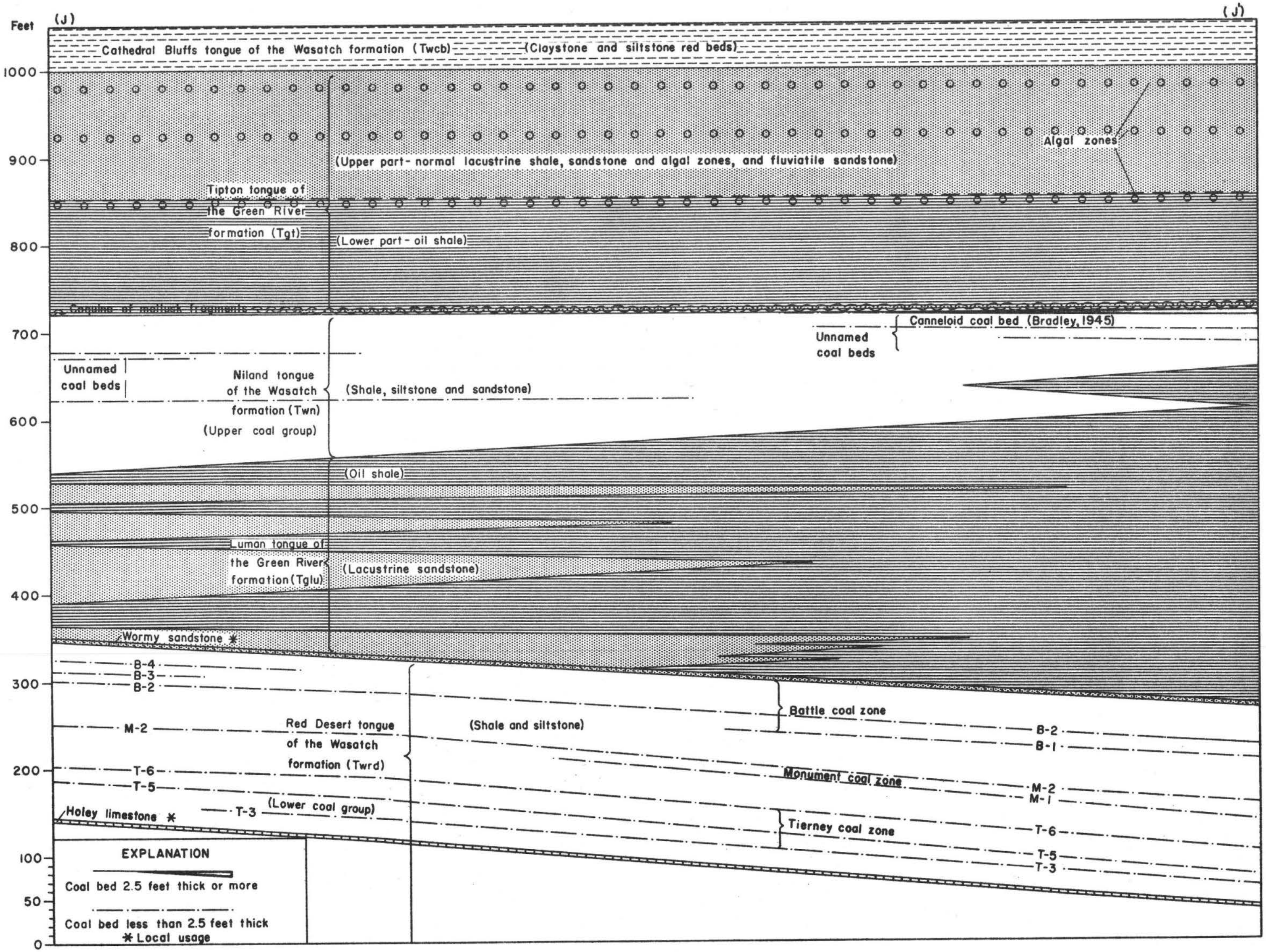
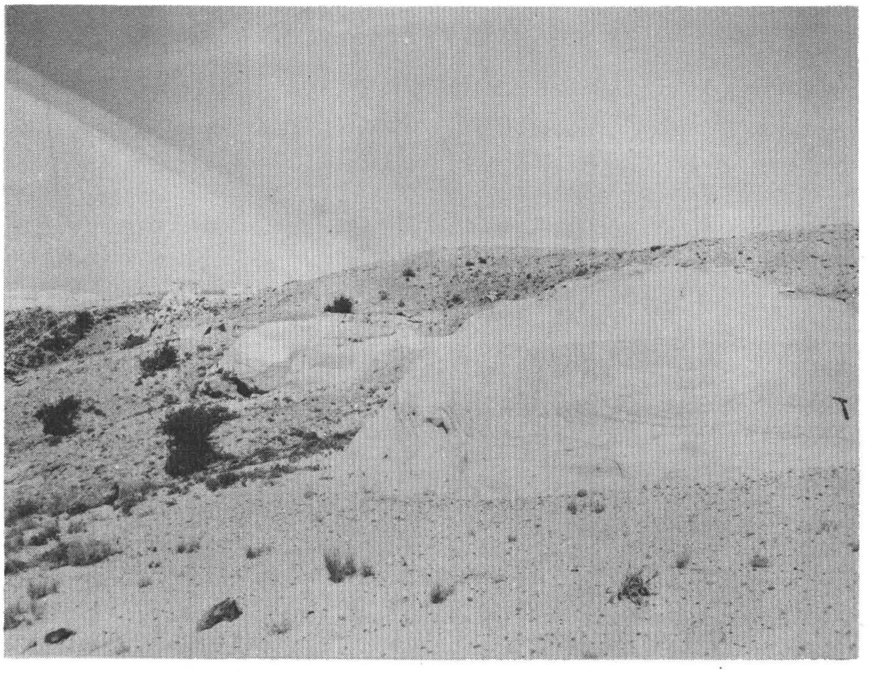


PLATE 6.--RESTORED SECTION OF LOWER EOCENE ROCKS FROM TIPTON STATION NORTHEASTWARD TO FREWEN LAKE IN THE SOUTH-CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING.

0 .5 1 2 3 Miles



A.--Crossbedded arkosic sandstone beds in the Battle Spring formation about 10 miles west of Rawlins, Wyoming.

B.--Coal-bearing claystone and siltstone beds in the Fort Union formation near the locality shown in plate 7A. Rawlins uplift in background.

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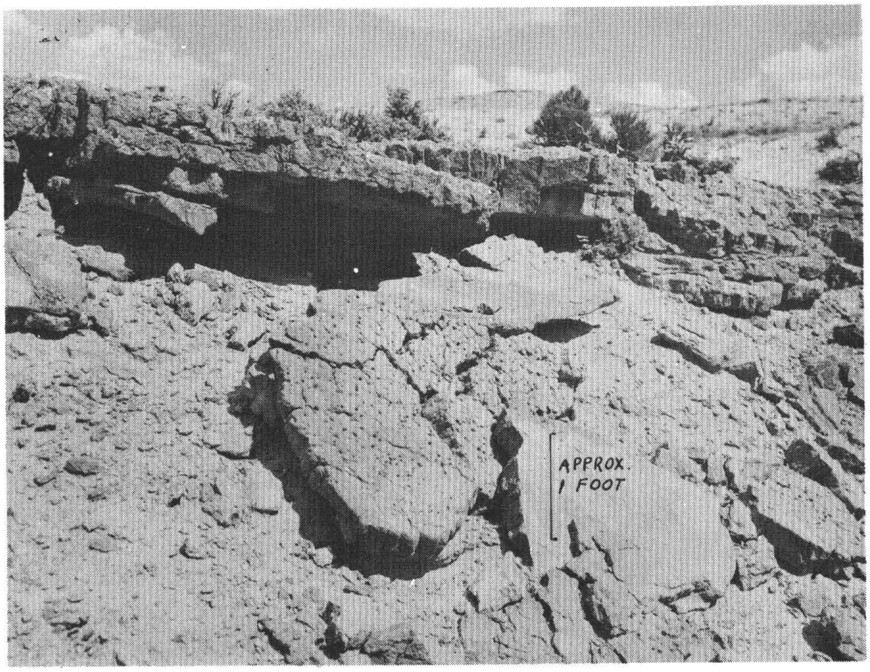
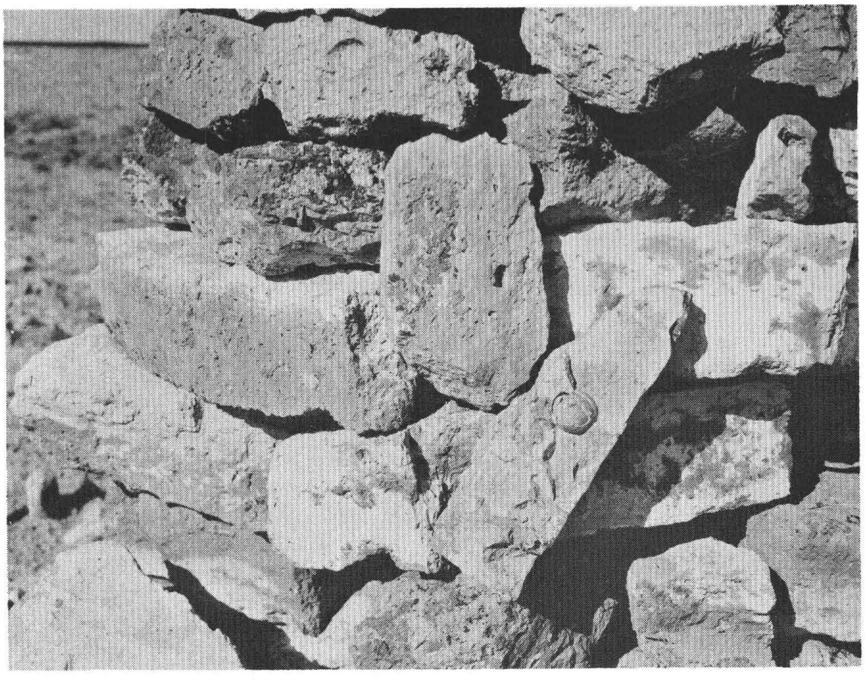
Plate 8



A.--The "wormy" sandstone bed at the base of the Luman tongue of the Green River formation in the NE 1/4 NE 1/4 sec. 8, T. 19 N., R. 96 W.



B.--Monument made from blocks of the "holey" limestone about 200 feet below the top of the Red Desert tongue of the Wasatch formation in the NE 1/4 SE 1/4 sec. 22, T. 20 N., R. 95 W. The gastropod at the lower right is about 2 inches in diameter.

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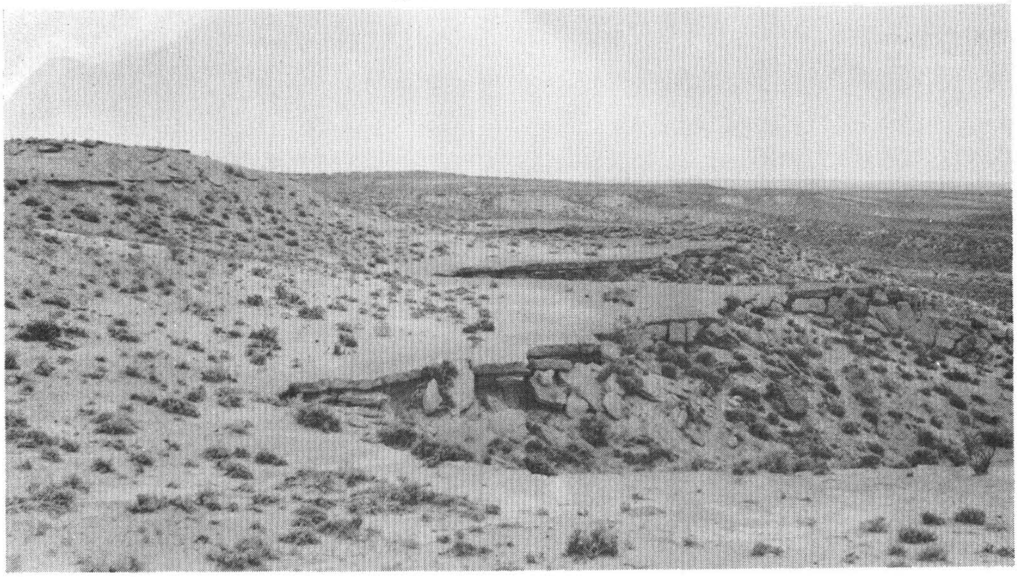
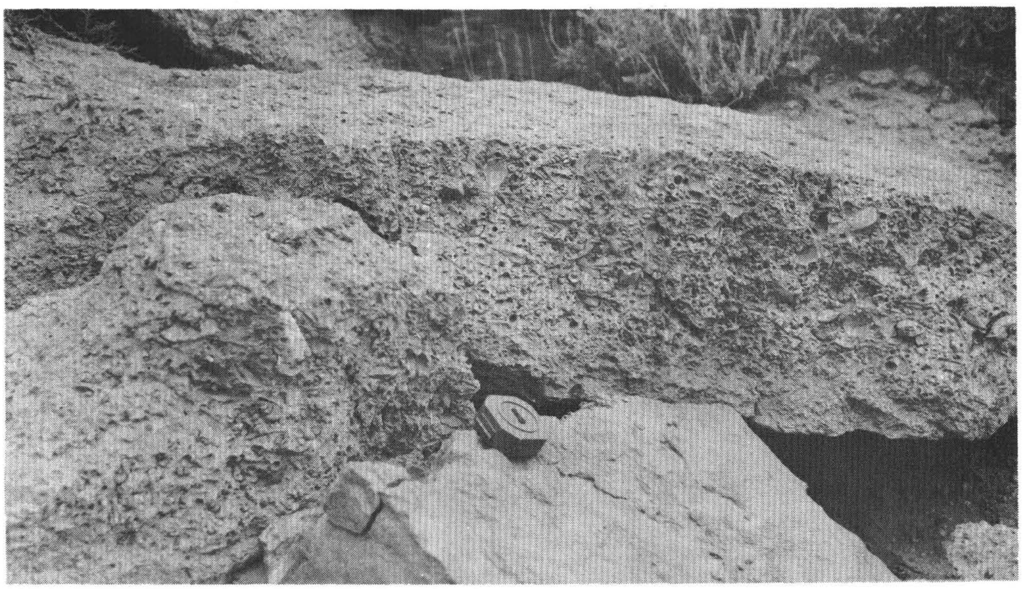


A.--One of the persistent sandstone beds in the lower part of the Luman tongue of the Green River formation in the NW 1/4 SE 1/4 sec. 8, T. 23 N., R. 96 W.



B.--Fossil mollusk molds in the sandstone bed shown in plate 9 A.

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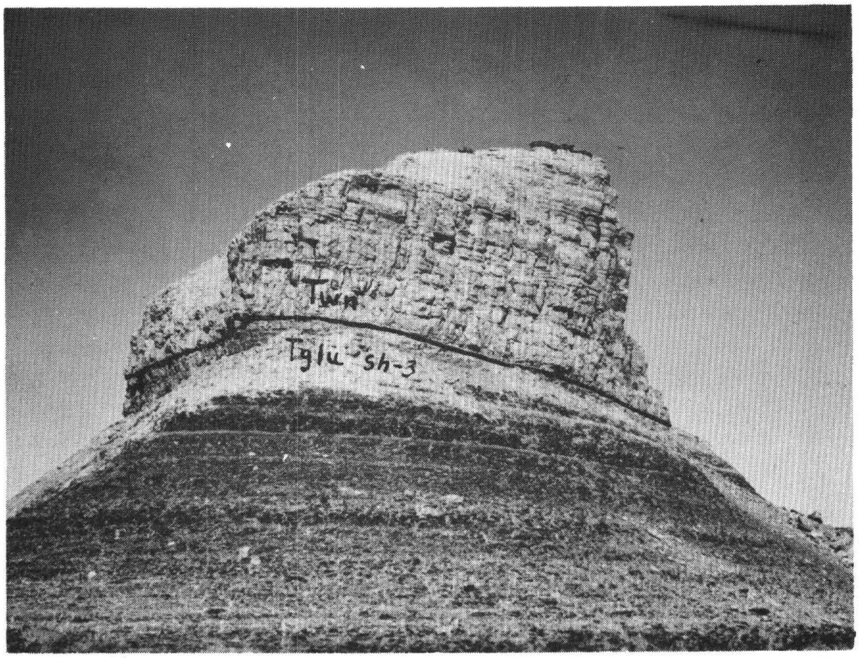
Plate 10



A.--Contact of the Luman tongue of the Green River formation (Tglu sh-3) with the Niland tongue of the Wasatch formation (Twn) in the NW 1/4 SW 1/4 sec. 35, T. 24 N., R. 96 W.

B.--Fragments of a limestone concretion in the "pastel limestone marker bed," a key zone in shale-1 at the base of the Luman tongue in SE 1/4 NW 1/4 sec. 28, T. 22 N., R. 94 W.

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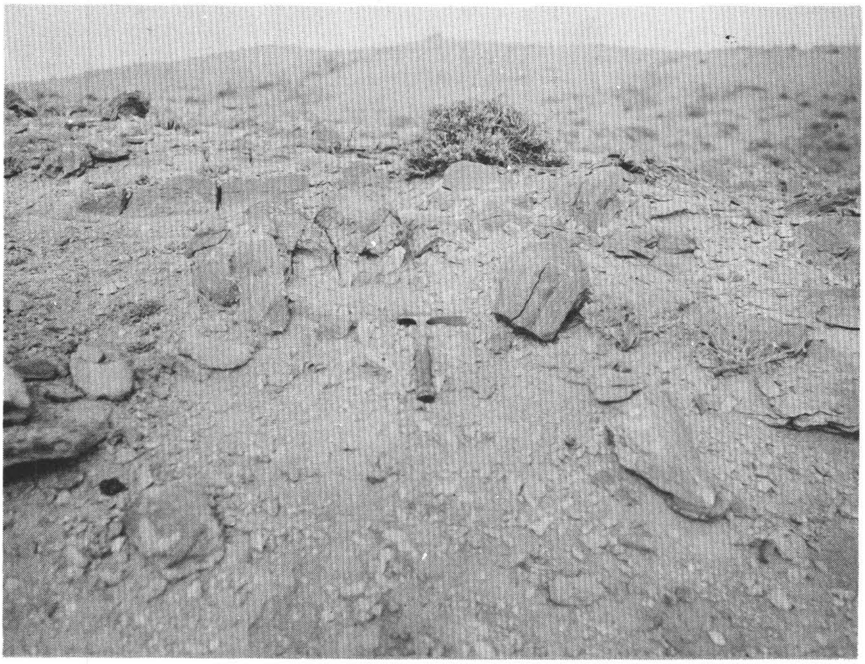
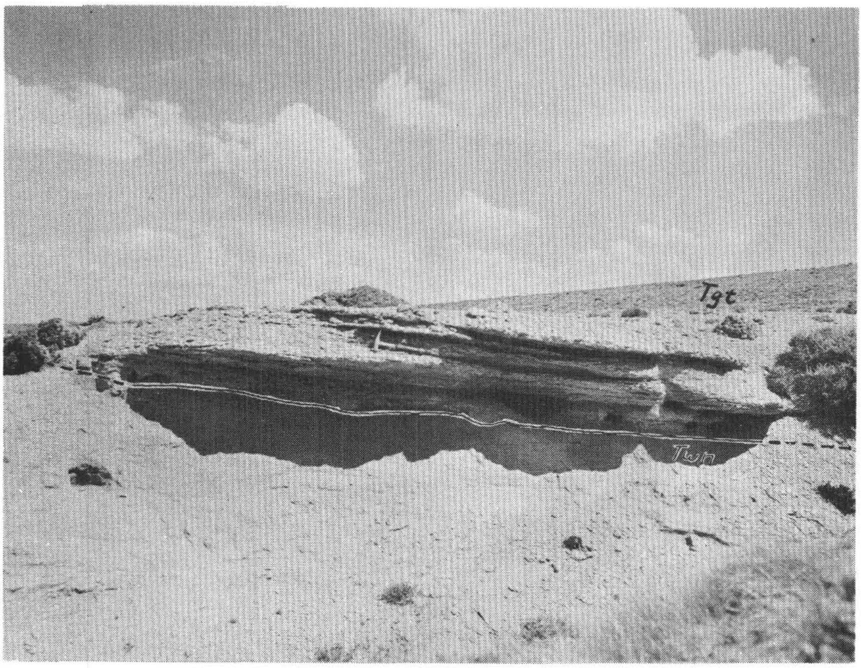
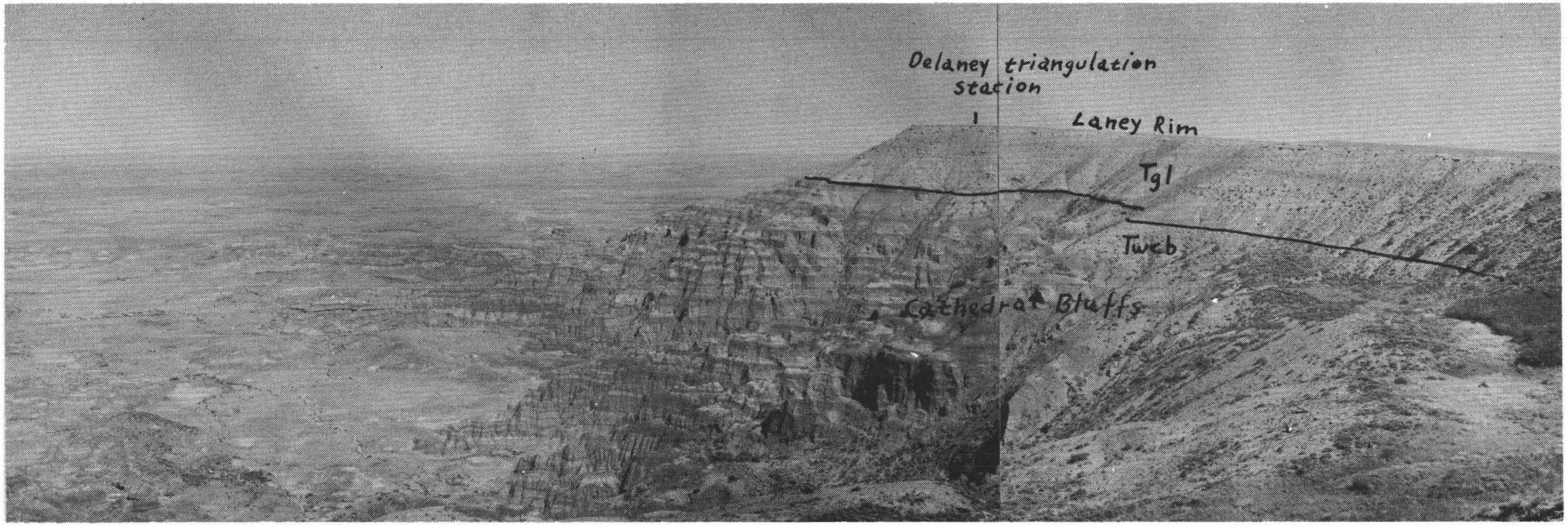


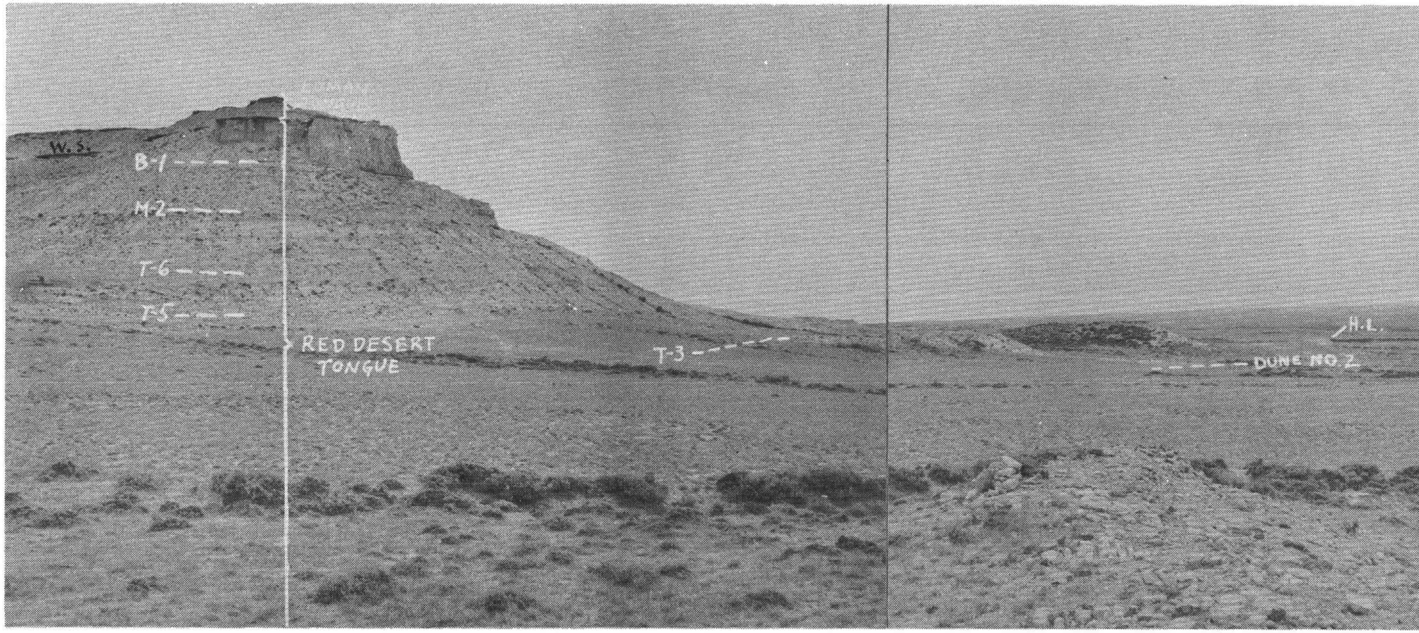
A.--Algal "ball" zone about 265 feet above the base of the Tipton tongue of the Green River formation in the SE 1/4 SE 1/4 sec. 18, T. 19 N., R. 94 W.



B.--Coquina at the base of the Tipton tongue in the NE 1/4 NE 1/4 sec. 17, T. 19 N., R. 96 W. Along the Wamsutter Rim, this bed marks the contact between the Tipton and the Niland tongues.



Contact of the Laney shale member of the Green River formation (Tgl) with the Cathedral Bluffs tongue of the Wasatch formation (Twcb) in sec. 29, T. 19N., R. 95 W.



North face of the largest of the Tipton Buttes in the NE 1/4 sec. 27, T. 20 N., R. 96 W. showing the contact of the Luman tongue of the Green River formation with the Red Desert tongue of the Wasatch formation, the positions of the "wormy" sandstone bed (W.S.), the "holey" limestone bed (H.L.), and coal beds Battle No. 1 (B-1), Monument No. 2 (M-2), Tierney No. 6 (T-6), Tierney No. 5 (T-5), Tierney No. 3 (T-3) and Dune No. 2 (D-2).

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Red Desert tongue of the Wasatch formation. -- The name Red Desert tongue of the Wasatch formation is here applied to the sequence of clay shale, siltstone, low grade oil shale, biotitic sandstone, and coal beds that overlies the Fort Union formation and underlies the Luman tongue of the Green River formation. Most of the coal in the map area is contained in the Red Desert tongue. This tongue is named from typical exposures of coal-bearing gray-white shale, siltstone and sandstone that crop out southwest of Red Desert Flat at Tipton Buttes and northeast of Red Desert Flat (pls. 1, 5, and 13) in the northeast corner of T. 21 N., R. 94 W. and adjoining parts of T. 21 N., R. 95 W.; T. 22 N., R. 94 W.; and T. 22 N., R. 95 W. Most of the southern part of the map area is directly underlain by the Red Desert tongue, and, although only the upper 400 feet of this tongue is exposed in the map area, similar rocks on the east flank of the Rock Springs uplift are about 1,000 feet thick, rest unconformably on the Fort Union formation, and conformably underlie beds equivalent to the Luman tongue of the Green River formation.

A peculiarly perforate sandstone and a gray-black limestone (pl. 8) were useful in correlating the rocks in the southeastern part of the area with those in the Tipton Buttes area west of Red Desert Flat. These key beds are described in the paragraphs preceding the discussion of uranium in coal.

Beds near the top of the Red Desert tongue yielded vertebrate fossils of early Eocene (Lysite or Lost Cabin) age near Tipton Buttes in the SW 1/4 sec. 23, T. 20 N., R. 96 W., and beds near the base of the tongue yielded vertebrate fossils of earliest Eocene (Graybull and Sand Coulee) age about 14 miles east of Steamboat Mountain in sec. 12, T. 23 N., R. 100 W. (table 2, localities 16 and 17).

Luman tongue of the Green River formation. -- The name Luman tongue of the Green River formation is here applied to a sequence of oil shale, fossiliferous muscovitic calcareous sandstone, varved siltstone, clay shale, and a few thin coal beds, that is excellently exposed on the south slope of Luman Butte (sec. 34, T. 24 N., R. 97 W.) in the northwest part of the area. The Luman tongue overlies the Red Desert tongue of the Wasatch formation and underlies the Niland tongue of the Wasatch formation (pls. 3, 10 and 16_/). The Luman tongue crops out in two belts; one extends from the vicinity of Luman Butte southeastward to the center of T. 22 N., R. 94 W., and the other extends across the

_/ Plate 16 on page 70

southern part of the area, parallel to U. S. Highway 30. The Luman tongue has been removed from the central part of the map area by erosion. It is 180 feet thick at Luman Butte but thickens eastward to to 270 feet in the vicinity of Lost Creek Butte (pls. 3-4). It also thickens from west to east in the southern part of the map area, from about 200 feet at Tipton Station to about 390 feet at Frewen Station (pl. 6).

The Luman tongue contains several constituent tongues of low grade oil shale separated by sandstone and siltstone beds. The three most conspicuous and persistent tongues were mapped separately, and are designated from bottom to top, shale tongues 1, 2 and 3. Shale 1, in the northern part of the area is characterized by gray-black silty limestone concretions averaging 1 foot in diameter (the "pastel" limestone marker bed) which have a splintery fracture and weather purple, pink, yellow, buff and brown, and, except in the vicinity of Luman Butte, rests directly on the highest coal bed of the Red Desert tongue of the Wasatch formation (pls. 3-4, 10 and 16). The stratigraphic association of coal overlain by low-grade oil shale containing the "pastel" limestone marker bed is unmistakable and constitutes one of the most useful horizons for correlating and structure contouring in the map area. Shale tongues 2 and 3 thicken eastward from Luman Butte at the expense of the intervening siltstone and sandstone, and in the vicinity of Lost Creek Butte, they coalesce into one body of oil shale 120 feet thick (core hole 4, figs. 2, 7; pls. 3-4). In the southern part of the map area, shale tongues 1, 2, and 3 thicken eastward from Tipton. In the vicinity of Frewen they coalesce and form one body of oil shale about 390 feet thick (pl. 6).

The Luman tongue contains several prominent beds of fossiliferous, calcareous, muscovite-bearing, fine-grained sandstone southeast of the Luman Ranch in the low bluffs crossing the sand dune belt in the northwest part of T. 23 N., R. 96 W. One of these sandstone beds (pl. 9), about 40 feet above the base of the tongue, is about 2 feet thick and persists from Luman Butte southeastward for a distance of about 20 miles to fossil locality 9 (pl. 1 and table 2) in sec. 16, T. 22 N., R. 94 W. Another of these beds called the "wormy" sandstone, which was chosen as the base of the Luman tongue in the southern part of the area is characterized by molluscan impressions and vertical borings probably made by worms (pls. 6 and 8). Mollusk and ostracode remains found at several stratigraphic horizons in the Luman tongue are of early Eocene age (table 2).

Niland tongue of the Wasatch formation. -- The name Niland tongue of the Wasatch formation is here applied to a sequence of coal beds, clay shale, siltstone, sandstone, and low grade oil shale, which crops out at the southern margin of the Niland Basin along the north side of Lost Creek Flat. The name is taken from Niland's spring in sec. 23, T. 25 N., R. 96 W. about 7 miles northwest of the best exposures of the Niland tongue and the type locality is SW 1/4 T. 24 N., R. 95 W. and SE 1/4 T. 24 N., R. 96 W. At this locality the Niland is about 400 feet thick, underlies the Tipton tongue, and rests on the Luman tongue of the Green River formation (pl. 10). The upper and lower contacts are conformable. The Niland tongue thins westward to about 325 feet in the Luman Butte area (pl. 3). It has been removed by erosion over the central part of the area but crops out again in the southern part of the area in a belt parallel to and south of U. S. Highway 30. In the southern part of the area the coal beds of the Niland are for the most part fewer, thinner, and less conspicuous (pl. 6) than in the northern part. An exception is the 5-foot coal bed at the top of the Niland tongue southeast of Frewen that is the continuation of a canneloid coal bed in the Wasatch formation mapped by Bradley (1945) along the northeast flank of the Washakie Basin.

In its type area, the Niland tongue contains four coal zones that constitute the upper coal group in this report, each of which is overlain by or interbedded with a low grade oil shale tongue (pl. 3, fig. 7). Fossil plants and mollusks collected from the middle of the formation are of early Eocene age (table 2).

As shown in table 1, the Red Desert, Luman, and Niland tongues are of early Eocene age and correlate with the upper part of the Wasatch formation as used by Schultz (1920), and with the upper parts of the Hiawatha member of the Wasatch formation as used by Nightingale (1930). At Bitter Creek Station on the Union Pacific Railroad, about 15 miles west of Tipton Station, the upper part of Schultz' "Wasatch" is about 1,400 feet thick and is separated from the lower part by an unconformity. The beds below the unconformity (the lower part of Schultz' "Wasatch") are about 1,100 feet thick, contain plants of Paleocene age, and rest unconformably on the Lance formation of Late Cretaceous age. The Bitter Creek exposures were examined briefly for fossils and overall thickness, not critically enough to determine the individual thicknesses of the Niland, Luman, and Red Desert tongues which can be distinguished in the upper part of Schultz' "Wasatch formation".

In light of the relationships of the Eocene and Paleocene rocks at Bitter Creek Station, it seems likely that Nightingale included rocks of both Eocene and Paleocene age in his Hiawatha member.

The Luman tongue of the Green River formation presumably pinches out northwestward inasmuch as the Niland and Red Desert tongues of the Wasatch formation cannot be differentiated in the vicinity of Steamboat Mountain near the north end of the Rock Springs uplift. The Luman and Niland tongues can be traced at least 6 miles southeast of the map area.

Tipton tongue of the Green River formation. -- The sequence of oil shale, clay shale and sandstone exposed in the low bluffs south of Tipton was named the Tipton shale member of the Green River formation by Schultz (1920). It was later redesignated the Tipton tongue of the Green River formation by Sears and Bradley (1924). In its type area, the Tipton separates the Niland and the Cathedral Bluffs tongues of the Wasatch formation. The areal distribution of this tongue is about the same as that of the Luman and Niland in the southern part of the area. The tongue is absent from the central part of the area because of erosion; it crops out in the northern part of the area in a wide belt extending from the northwest part of T. 24 N., R. 97 W. and the southwest part of T. 25 N., R. 97 W. eastward to and around the margins of Niland basin. The thickness of the Tipton tongue at Tipton station is difficult to measure because much of it underlies a long slope dipping southward from the Wamsutter Rim. Southwest of Red Desert station in sec. 18, T. 19 N., R. 95 W., the Tipton tongue is well exposed along the east side of a valley that trends from northwest to southeast across section 18. At this locality the tongue is about 280 feet thick. The lower part consists of low grade oil shale containing yellow dolomitic (?) limestone concretions and is about 160 feet thick. The upper part consists of loosely cemented sandstone and lesser amounts of clay shale, fine-grained calcareous sandstone and algal reefs (pls. 6 and 11) and is about 120 feet thick.

The upper part of the Tipton tongue differs strikingly in color and lithology from the lower part and from the overlying Cathedral Bluffs tongue of the Wasatch formation (pls. 3, 6, and 11), and can be mapped as a separate unit. The contact of the two parts of the Tipton tongue, shown as a dashed line on the map, is placed at the top of lowest zone of algal "balls", which consists of spheroidal onion-layered algal deposits of limestone. The occurrence of algal "ball" zones is diagnostic of the upper Tipton throughout the map area and adjacent areas.

The contact of the Tipton with the underlying Niland tongue of the Wasatch is conformable and is marked by a 5-foot coquina of loosely cemented mollusk fragments, which in the southeastern part of the area rests directly on the 5-foot canneloid coal bed at the top of the Niland, and in the southwestern part of the area on sandstone beds at the top of the Niland where the 5-foot canneloid coal bed is absent (pl. 11).

The Tipton-Cathedral Bluffs contact is concealed throughout the map area, but at the southeast corner of sec. 18, T. 19 N., R. 95 W. on the east side of a small reservoir, the uppermost bed of the Tipton tongue is a calcareous, ripple-marked sandstone that makes a resistant ledge which is separated from good exposures of redbeds in the Cathedral Bluffs tongue by alluvium that seems to conceal not more than 30 feet of section.

At the southeast margin of Niland basin, in secs. 9 and 16, T. 24 N., R. 95 W. the total exposed thickness of the Tipton tongue is 280 feet. The lower Tipton is 180 feet thick and consists of brown low-grade oil shale and lesser amounts of calcareous fine-grained sandstone and yellow dolomitic (?) limestone concretions. The contact of the Tipton with the underlying Niland tongue of the Wasatch is conformable and is marked by a 2-foot bed of highly fossiliferous sandstone resting on unfossiliferous massive sandstone beds at the top of the Niland. This contact is generally concealed throughout most of the northern part of the area but is well exposed south of the road junction shown in sec. 23, T. 24 N., R. 96 W. (fig. 2) and in the extreme western part of the area.

The 10-foot algal ball zone which marks the top of the lower Tipton (pl. 6) can be traced westward into an algal reef zone reported by Bradley (1926, p. 129, locality 1) to be about 100 feet above the base of the Tipton. The algal ball zone makes a prominent rim around the eastern side of Niland basin where it is overlain by a yellow limestone bed a few inches to 1 foot thick containing ostracodes of Eocene age.

An arkosic sandstone bed near the top of the lower Tipton, only a few feet thick at the south edge of the Niland basin, thickens northeastward to more than 25 feet and splits the lower Tipton into two tongues (fig. 2 and pl. 3). This relationship can be seen best in the exposures along Lost Creek at Eagle's Nest Ranch (abandoned) near the southwest corner of sec. 35, T. 25 N., R. 95 W.

Only the lower few feet of the upper Tipton is exposed in most of the northern part of the map area, but in the north-central part of sec. 16, T. 24 N., R. 95 W. steep dips of 35^{o} that die out with depth have caused about 100 feet of the upper Tipton to be preserved on the south flank of a very small tight syncline. There the upper Tipton consists of fine-grained slabby resistant ripple-marked sandstone with minor amounts of greenish paper shale and considerable thicknesses of arkosic sandstone. It contains a zone of algal "balls" about 50 feet above the lower algal "ball" zone that marks the top of the lower Tipton (pl. 3). The lacustrine components of the upper Tipton (calcareous sandstone, siltstone, paper shale, etc.) thicken westward at the expense of the fluviatile components (arkosic sandstone and sandy claystone.).

The stratigraphically highest fossil collection of probable early Eocene age was collected from the lower part of the Tipton tongue (D. M. Sheridan, written communication, 1954) about 1 mile west of the schroeckingerite deposits in the northeastern part of the map area.

No diagnostic fossils were collected from the upper part of the Tipton tongue, but, inasmuch as the contact with the lower part of the Tipton is gradational, the upper part of the Tipton is probably also of early Eocene age.

Cathedral Bluffs tongue of the Wasatch formation. -- The sequence of red and green claystone exposed in the steep slopes, called the Cathedral Bluffs, below the Laney Rim (pl. 12) along the southern edge of the map area, was named the Cathedral Bluffs red beds member of the Green River formation by Schultz (1920). Sears and Bradley (1924) redesignated it the Cathedral Bluffs tongue of the Wasatch formation. Near the U. S. Coast and Geodetic Survey triangulation station Delaney, situated on the Laney Rim, the Cathedral Bluffs tongue is about 900 feet thick and consists almost entirely of red and green banded claystone with a few beds of very coarse-grained gray channel sandstone and at least one thin bed of silty limestone near the base. The limestone contains ostracodes similar to those of the overlying Laney shale. The contact with the Laney is conformable, but the Laney thickens westward at the expense of the Cathedral Bluffs tongue at the rate of about 4 feet per mile. The Cathedral Bluffs tongue has been removed by erosion from the central part of the area and is not exposed north of the type area except in the vicinity of Bastard Butte. This butte is capped by red beds typical of the Cathedral Bluffs tongue and is an outlier of a thick sequence of red beds that is well exposed northwest of Bastard Butte. This sequence extends northwestward into and is a part of the red beds that weather into the badlands southeast of Oregon Buttes known locally as the "honeycombs" (Nace, 1939). Where the Cathedral Bluffs tongue crops out over a wide area northeast of Bastard Butte (fig. 2), several beds of cobble conglomerate are intercalated with the red and green claystone beds, and where the outcrop pattern narrows eastward, numerous beds of arkosic sandstone make their appearance (fig. 2 and pl. 2). The arkosic sandstone beds thicken eastward at the expense of the red beds and conglomerate. In the vicinity of Lost Creek, arkosic sandstone makes up all but a very small proportion of the formation.

In the Cyclone Rim area west of Lost Creek, the Cathedral Bluffs tongue is estimated to be from 1,400 to 1,600 feet thick. It conformably overlies a thick body of arkosic sandstone (locally assigned to the upper Tipton, as shown on pl. 2, because it contains some beds of brown, low-grade oil shale) and underlies the Morrow Creek member of the Green River formation. The contact with the Morrow Creek is not exposed in the map area, but it is probably conformable and intertonguing. The absence of the Laney shale and the increased thickness of the Cathedral Bluffs tongue suggest that the upper several hundred feet of the Cathedral Bluffs tongue in the Cyclone Rim area are equivalent to the Laney shale and to the lower part of the Morrow Creek. (See restored section, fig. 2.) The physical relationships of the Cathedral Bluffs to the Laney and Morrow Creek described above, suggest that the upper several hundred feet of the Cathedral Bluffs in the northern part of the map area is of the same age as the Laney and Morrow Creek members of the Green River formation, generally considered to be of middle Eocene age.

Fossils are extremely scarce in the Cathedral Bluffs tongue. No diagnostic fossils were found by the writer in the map area (table 2, loc. 3), but the Cathedral Bluffs in the area mapped by Nace yielded a single tooth, thought by G. G. Simpson to be of lower Bridger (middle Eocene) age (Nace, 1939, p. 11, 14, 17) and by Gazin to be of Lost Cabin (early Eocene) age (Gazin, 1952, p. 14). Morris (1954) made several small collections of vertebrate remains, which he considers to be of middle Eocene age, from the tongue at Cathedral Bluffs and at other localities along the eastern margin of the Washakie Basin. Morris does not show the stratigraphic position of his collections; but, if the homogeneity of the rocks making up the tongue means that all of the Cathedral Bluffs is of the same age, and if Morris' conclusions as to the age of his collections are correct, and if the age of the upper Tipton is indeed early Eocene, then the transition from rocks of early Eocene age (Wasatchian) to those of middle Eocene age (Bridgerian) should lie near the Tipton-Cathedral Bluffs contact.

Laney shale member of the Green River formation. -- Schultz (1920) named the Laney shale member from exposures a few miles southwest of the map area. In the southern part of the map area, the sequence of green and brown oil shale, oolitic sandstone, marl, and cherty algal deposits overlying the Cathedral Bluffs tongue, comprises the lower part of the Laney shale member of the Green River formation. These beds are 100 to 130 feet thick and are capped by the cherty botryoidal algal bed which makes the Laney Rim (pl. 12).

The remainder of the Laney shale of Schultz (1920) overlying the cherty botryoidal algal bed is not exposed in the map area. The Laney shale was not studied in detail, but a superficial examination of the sequence exposed in the map area suggests that the thickness of the stratigraphic interval from the cherty botryoidal algal bed up to the base of the Bridger formation, exposed about 10 miles south of the map area, is about 600 feet thick. The beds extending upward from a stratigraphic horizon 50 or 75 feet above the cherty botryoidal algal bed to the base of the Bridger resemble, and presumably are equivalent to, those of the Morrow Creek in the vicinity of Steamboat Mountain at the north end of the Rock Springs uplift. If this interpretation is correct, the Laney shale (restricted) is about 200 feet thick, and the Morrow Creek is about 500 feet thick in the southern part of the map area, and in the area adjacent to the south. No fossils were collected from the Laney, but mollusks of middle Eocene age were collected from the stratigraphically higher Morrow Creek in the Cyclone Rim area (pl. 1 and table 2, locality 2).

Morrow Creek member of the Green River formation.--In the Cyclone Rim area, a sequence of rocks consisting of oil shale, sandy limestone, calcareous sandstone and arkosic sandstone is here assigned to the Morrow Creek member of the Green River formation because of its stratigraphic similarity to the Morrow Creek of the Steamboat Mountain area (Bradley, 1926). The Morrow Creek contains mollusks of middle Eocene age (table 2). The contact with the underlying Cathedral Bluffs tongue is concealed, but probably conformable, and the contact with the overlying Bridger formation also appears to be conformable.

Battle Spring formation

A thick sequence of arkosic sandstone underlies most of the eastern part of the Great Divide Basin. The name Battle Spring formation is here applied to this sequence from typical exposures southwest of Battle Spring Flat and southeast of Lost Creek Butte. The Battle Spring formation intertongues with all of the subdivisions of the Green River and Wasatch formations described in preceding parts of this report, except the Laney shale. (See restored section, fig. 2, and pls. 2-3.)

The low structural and topographic relief of the rocks of the Great Divide Basin makes it impossible to determine the thickness of the Battle Spring directly or to designate a compact type locality. Its probable minimum thickness may be inferred from the thickness of the units with thich it intertongues. The inferred thickness is about 3,300 feet but probably is greater because tongues of arkosic sandstone in the lower part of the Morrow Creek appear to thicken eastward at the expense of the Morrow Creek. In the Cyclone Rim area the lithology of the Bridger formation is unlike that of the underlying rocks, so it may be inferred that the deposition of the Battle Spring formation ceased within or at the end of Morrow Creek time.

The base of the Battle Spring formation is exposed on the north slope of Flattop Buttes and at a point about 10 miles west of Rawlins, Wyoming (pl. 7) in the northwest part of T. 21 N., R. 98 W.; at both localities the Battle Spring formation overlies the Fort Union formation unconformbaly.

The Battle Spring formation consists of very coarse-grained to pebbly arkosic sandstone with less amounts of bright green claystone that contains abundant large grains of clear angular quartz. Locally the beds form low rounded bluffs in which the cross-bedded nature of the sandstone is clearly visible (pl. 7), elsewhere the sandstone weathers into soft slopes littered with spheroidal sandstone concretions that are moderately calcareous and often contain limonitic centers. The sediments that make up this formation appear to have been deposited in delatic sheets, the source of which appears to have been the Granite Mountains north and northeast of the map area.

Where the rivers that carried the sediments spilled out into one of the ancient Green River lakes, extensive areas of foreset beds were formed which today exhibit dips up to 15 degrees. Remnants of these foreset beds are preserved and well exposed in the Lost Creek Butte area especially along the west rim of a small plateau-like highland 3.5 miles northwest of Lost Creek Butte in the southwest part of sec. 38, T. 24 N., R. 95 W.

No fossils were found in the Battle Spring formation, but the formations with which it intertongues range in age from earliest Eocene through early middle Eocene. The Battle Spring formation seemingly represents a period of continuous deposition during this time.

In summary, the pre-Bridger Eocene rocks of this area may be thought of as products of three environments. The Green River formation is of lacustrine origin. It interfingers with the Wasatch formation of fluviatile and paludal origin. The Battle Spring formation of deltaic-fluviatile origin interfingers with both. In general, the Laney shale and Morrow Creek members of the Green River formation thin from southwest to northeast, whereas the Tipton and Luman tongues of the Green River formation, the Niland and Red Desert tongues of the Wasatch, and the Battle Spring formation thin from northeast to southwest.

Bridger formation

Overlying the Morrow Creek member of the Green River formation is a sequence of gray-green claystone and shale, containing several thin beds of limestone, fossil tree stumps, and cherty limestone algal deposits. The upper part of the formation was eroded prior to the deposition of the overlying beds; the formation ranges in thickness from 60 to 100 feet in the map area, but locally it is absent. The limestone beds of this sequence contain ostracodes of middle Eocene age (D. M. Sheridan, written communication, 1954); and, because these rocks occupy the stratigraphic position of the Bridger formation of adjacent areas and are of similar age, they are here correlated with that formation.

Browns Park formation

Unconformably overlying the Bridger formation is a conglomerate the constituents of which locally attain boulder size. The conglomerate is interbedded with and overlain by a sequence of very coarse-grained sandstone. Both of these units are lenticular, but locally, together, they are as much as 200 feet thick. They can be traced from the extreme northwest corner of the area to a point near the Cyclone Rim in sec. 23, T. 26 N., R. 95 W. East of this point these beds are absent and the overlying sequence of tuffaceous rocks rests directly on the Bridger formation.

The coarse-grained sandstone is in turn interbedded with and overlain by pinkish-white fine-grained tuffaceous sandstone. (See composite columnar section, fig. 2.) The tuffaceous sandstone overlying the coarse sandstone and conglomerate is at least 300 feet thick and crops out throughout most of the northern part of the area. These rocks are lithologically indistinguishable from similar rocks exposed northeast of the map area in the vicinity of Split Rock. The latter contain vertebrate fossils of undoubted middle Miocene age (McGrew, 1951). McGrew believes that these rocks near Split Rock are outliers of the Browns Park formation of northern Colorado and southwestern Wyoming. The Miocene rocks in the map area likewise probably are remants of the Browns Park formation which at one time probably blanketed the entire Great Divide Basin. Since the above was written, I have received a letter from Wallace Bell, Department of Geology, University of Wyoming, dated February 22, 1955, stating that vertebrate fossils of Miocene age were found in the NW 1/4 sec. 13, T. 26 N., R. 95 W. a few miles northwest of the schroeckingerite deposits. (See table 2, loc. no. 1.)

Quaternary deposits

The largest, most conspicuous quaternary features in the map area are the dry lake flats. Several are scattered throughout the area, the largest of which are Red Desert Flat in the southwestern part of the map area, and Lost Creek and Battle Spring Flats in the central and eastern parts of the area.

The intermittent streams leading into Red Desert Flat drain areas underlain in part by the red beds of the Cathedral Bluffs tongue, and in part by the light colored beds of the Red Desert tongue of the Wasatch. Consequently the deposits in the flat consist of red silt, locally overlain by thin smooth white sheets of clayey silt.

The Lost Creek and Battle Creek Flats are underlain by brownish silty clay whose color is derived from outcrops of brown oil shale of the Luman and Tipton tongues of the Green River exposed locally around their shores. In several places white silt is deposited in deltas along the margins of these flats; and where deltas have coalesced, as in the southern parts of these two flats, they consist of smooth areas that are white and dotted with clumps of greasewood.

Auger holes in the south end of Red Desert Flat, the northern part of Lost Creek Flat, and at the southern end of Battle Spring Flat indicate the lake deposits are about 25 feet thick.

Plate 14 shows a dry lake flat that is typical of those whose sediments are derived primarily from light colored fine-grained rocks of the Red Desert tongue of the Wasatch formation.

The oldest quaternary features are the isolated sand and gravel terrace deposits ranging from several square feet to several square miles in area which occur at altitudes ranging from 6,750 to 6,900 feet. These deposits are scattered throughout an area extending from the north line of T. 19 N. to the north edge of Niland basin and seem to be remnants of one pre-existing continuous layer.

The deposits south of the middle of T. 21 N. are separated from the underlying bedrock by several feet of red or brown silty clay very similar to that in the floors of the dry lake flats. Aside from the fact that the lithology of the gravel terrace deposits is locally quite unlike that of the Browns Park formation, the general level of the terraces is at least 400 feet lower than can be reasonably assumed for the surface on which the Browns Park was deposited. Likewise the difference in elevation between the terrace level and the level of the lower-lying dry lake flats ranges from about 60 feet in the southern part of the area to more than 300 feet in the northern. For these reasons it seems probable that the sand and gravel deposits are of Pleistocene rather than Recent or Miocene age.

Among the youngest quaternary features are the sand dunes that have been moved eastward by the wind across the western part of the Great Divide Basin from the vicinity of Steamboat Mountain at the north end of the Rock Springs Uplift along a sharply defined belt that terminates in Lost Creek Flat. Some of the active dunes are true barchans and are concave eastward, but most of the active dunes are produced by blowouts and are concave westward. Where the sand dunes have moved across the northern part of the Red Desert Flat, they have repeatedly interrupted and displaced the courses of the intermittent streams draining southward into the Red Desert Flat from the Hay Reservoir.

The lowest parts of the flats south of and parallel to the sand dune belt decrease in altitude eastward. Apparently in the recent past when the level of the lakes was high, drainage out of the map area took place from west to east out through Battle Spring Flat.

STRUCTURE

The structure of most of the central part of the Great Divide Basin is shown on figure 3 by contours drawn at intervals of 100 feet on the top of a coal zone in the Red Desert tongue of the Wasatch formation.

The main structural feature is a broad easterly plunging arch with a poorly defined axis that trends about N. 70° E. across the central part of the map area. This arch may be the eastward extension of the Wamsutter arch as mapped by Schultz (1920, pl. 1) or it may be a separate fold en echelon to the Wamsutter arch. Tertiary rocks older than the Browns Park formation dip away from the crest of this fold at angles that average about 2° on the southern limb and slightly less on the northern limb.

Several subsidiary folds are superimposed on the crest of the main arch. The largest of these, here called the Tierney anticline, trends about N. 45° E. at a slight angle to the axis of the larger fold and has about 50 feet of closure in T. 21 N., Rs. 94 and 95 W. Two smaller anticlines in T. 22 N., R. 94 W. with less than 50 feet of closure are separated from the Tierney anticline to the south by an area containing several minor faults one of which is shown on plate 14. Surface rocks involved in this folding belong to the Red Desert tongue of the Wasatch formation.

The Red Desert tongue of the Wasatch formation and younger Tertiary rocks exposed on the north limb of the Wamsutter (?) arch are folded in several shallow anticlines and synclines with diverse axial trends. One of these folds is the Red Desert syncline, a broad northwesterly-plunging fold that trends about N. 30° W. across the east-central part of the map area (figs. 2 and 3). The thickest parts of all the coal beds in the area with the exception of Luman No. 2, are near the axis of the Red Desert syncline, whereas the coal beds apparently thin and pinch out in the areas adjacent to the syncline. These relationships suggest that the folding of the syncline, which had probably started in Late Cretaceous time, continued to a slight extent during deposition of lower Eocene rocks.

The Red Desert syncline is of primary interest in this area because of its association with the thickest coal beds, the transition from coal beds of relatively high uranium content in the northeast to coal beds of relatively low uranium content in the southwest, and the transition from coarse-grained rocks of good permeability in the northeast to fine-grained rocks of moderate to slight permeability on the southwest. A section (G-G') across the axis of the syncline in the Lost Creek Butte area is shown in plate 15. The Red Desert syncline dies out northward in a shallow structural depression, here called Niland basin (figs. 2, 3 and pl. 1).

North of Niland basin, at Cyclone Rim, the Bridger formation and Morrow Creek member of the Green River formation dip about 22° N. on the flanks of an anticline and parallel syncline that trend about N. 60° W.

The exposed formations are cut by many normal faults, some of which can be traced for several miles. Most of the faults trend northeastward about parallel to the axial trend of the Wamsutter (?) arch; a few, however, trend northwestward at about right angles to the first set of faults and about parallel to the axial trend of the Red Desert syncline.

A normal fault with a displacement of about 3,000 feet, down-dropped on the south, may be traced across the northeastern corner of the area in T. 26 N., Rs 94 and 95 W. This fault, which forms the north side of the graben in the schroeckingerite area, at places brings the basal part of the Battle Spring formation on the north against the Morrow Creek member of the Green River formation on the south (see structure sections A-A', fig. 2 and C-C', pl. 18_/). The Browns Park formation, which unconformably overlies older rocks on either side of the fault, is down-dropped about 100 feet on the south side, thus indicating that most of the fault movement occurred before deposition of the Browns Park formation, but that some movement has occurred since. A second normal fault which forms the south side of the graben and has a maximum inferred displacement of about 200 to 300 feet, down-dropped on the north, parallels the first about 3 miles to the southwest (fig. 2 and pl. 18B). This fault dies out northwestward near the center of T. 25 N., R. 95 W. Other faults in the area have displacements of less than 100 feet (pl. 14).

_/ Plate 18 on page 82.

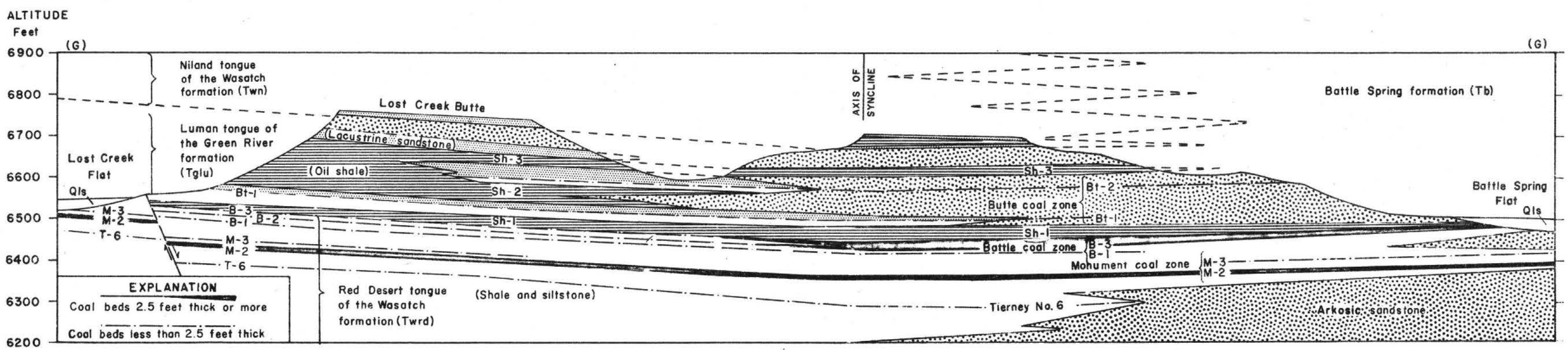


PLATE 15.-- DIAGRAMMATIC STRUCTURE SECTION ACROSS THE LOST CREEK BUTTE AREA IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING.

0 1000 2000 3000 4000 5000 FEET

VERTICAL EXAGGERATION APPROXIMATELY X5

The angular unconformities which separate the Fort Union formation of Paleocene age from both the older and the younger rocks indicate that some folding took place in the Great Divide Basin before as well as after deposition of the Fort Union, and that the main structural trends of the area were established in Late Cretaceous time or earlier. Therefore, it seems likely that the amplitude of the folding discernable in rocks of Eocene age at the surface increases with depth. Certainly it is not logical to assume the opposite; that the folds die out with depth.

The northwest trending structures appear to be older than the ones trending northeast.

COAL

Summary statement

Coal occurs in beds a few inches to as much as 21 feet thick in the Red Desert and Niland tongues of the Wasatch formation and in the intervening Luman tongue of the Green River formation. Nearly all of these coal beds are uraniferous. The occurrence, distribution and origin of the uranium will be discussed in a following section. In general, the coal beds are thickest in a belt about 10 miles wide that extends from the north side of Lost Creek Flat southeastward for about 30 miles to the vicinity of Latham station (Smith, 1909) on the Union Pacific Railroad about 13 miles east of Frewen (fig. 2). The coal beds thin both westward and eastward from this belt and little or no coal is present in the western and northeastern parts of the area.

There are about thirty coal and carbonaceous shale beds in the mapped area. These beds have been grouped into 10 coal zones which from oldest to youngest are: unnamed coal zone, the Dune, Tierney, Monument, and Battle coal zones in the Red Desert tongue of the Wasatch formation; the Butte coal zone in the Luman tongue of the Green River formation; and the Kelly, Luman, Hay, and Bush coal zones in the Niland tongue of the Wasatch formation (fig. 4). The coal zones in the Niland tongue of the Wasatch formation are collectively referred to as the upper coal group, and those in the underlying and Red Desert tongue of the Wasatch formation are collectively referred to as the lower coal group.

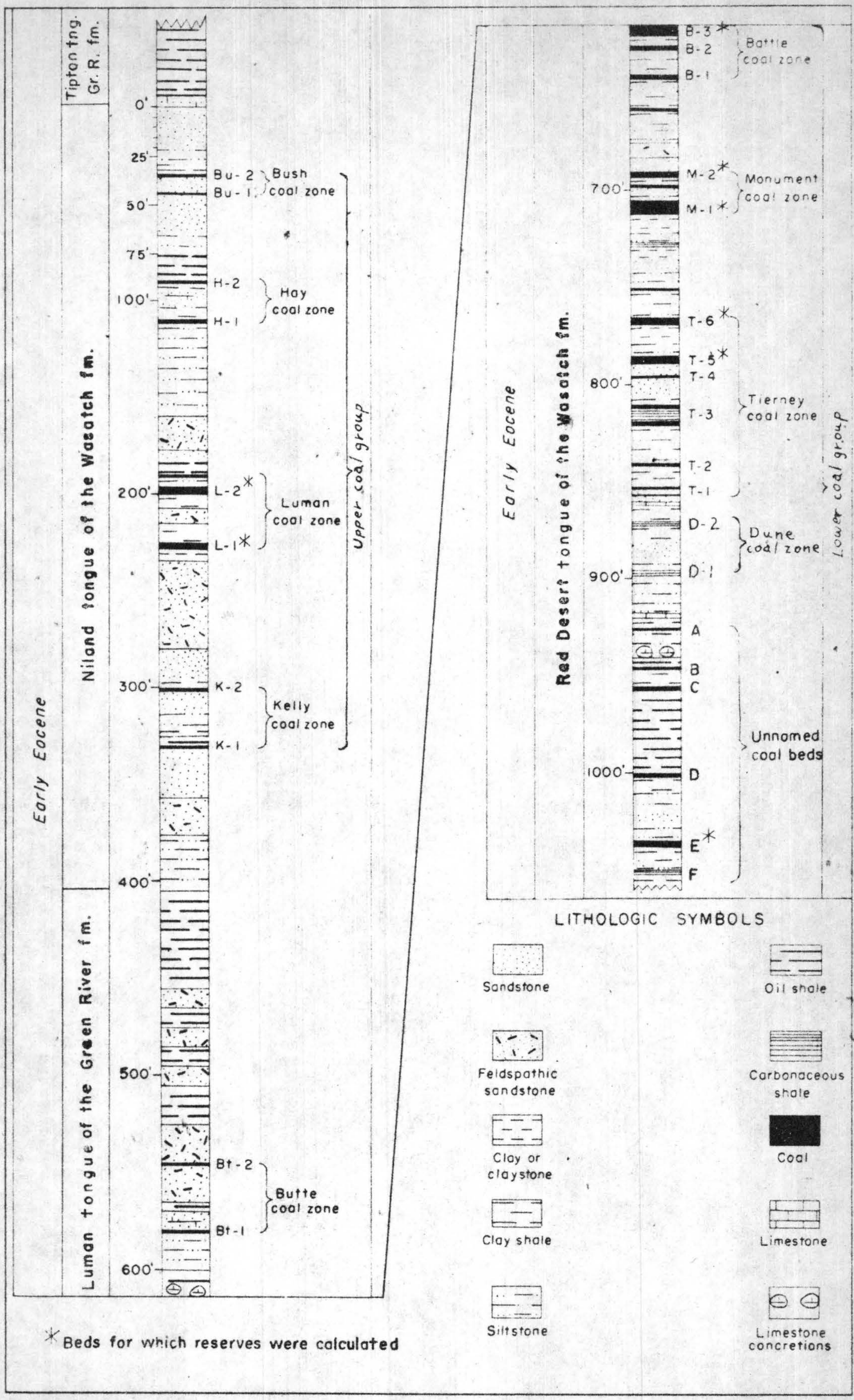


FIGURE 4.-COMPOSITE COLUMNAR SECTION SHOWING STRATIGRAPHIC POSITION OF THE COAL ZONES IN THE CENTRAL PART OF THE GREAT DIVIDE BASIN, SWEETWATER COUNTY, WYOMING.

For the most part, the individual coal beds within each zone are numbered consecutively beginning with number 1 for the oldest bed in each zone. The coal beds in the unnamed coal zone in the Red Desert tongue of the Wasatch formation are lettered from A to F beginning with the youngest bed in the zone.

The principal coal beds in the area, from youngest to oldest are the Luman No. 2 and No. 1 beds in the upper coal group; and the Battle No. 3 bed, the Monument coal zone, the Tierney No. 6 and No. 5 beds, and coal bed E in the lower coal group. Other coal beds in the area are too thin to be considered in calculating the coal reserves and are not shown on the geologic map (fig. 2).

Calcareous sandstone beds that make resistant ledges, and zones of limestone concretions are common in the sequences between coal zones, especially in the Red Desert tongue of the Wasatch formation.

The relative stratigraphic positions of the coal beds is shown by figure 4, and plates 3-6 and the thickness and correlation of the principal beds are shown graphically by figures 5 to 8.

The location and other data on core holes drilled in the map area during the 1952 field season are shown on figures 2, 7-8 and table 3.

The coal found in the central part of the Great Divide Basin area ranges in rank from subbituminous B to subbituminous C according to the classification of the American Society for Testing Materials (1938). Proximate and ultimate analyses of 17 coal samples recovered in drill cores are shown in table 4, and the rank classification of the various samples is listed in table 5.

Lithologic descriptions of coal cores made by J. M. Schopf of the Geological Survey Coal Geology Laboratory, Columbus, Ohio, were used to construct figure 8.

Table 3.--Data on core holes, Central Great Divide Basin, Sweetwater County, Wyoming

Core Hole No.	Location Sec., T., R.	Elevation (feet)	Total depth (feet)	Total thickness of coal beds penetrated (feet) 1/
1	SWSW 24-24N-96W	6,645	142	6.9
2	SENW 16-24N-95W	6,630	266	9.5
3	NWSW 16-24N-95W	6,610	173	8.2
4	SENW 28-24N-95W	6,610	600	26.4
5	SENW 15-24N-95W	6,580	202	3.7
6	SWNE 10-24N-95W	6,605	263	6.2
7	NWSW 20-24N-95W	6,560	55	5.1
8	NESW 22-24N-96W	6,715	119	4.7
9	NESW 2-24N-95W	6,620	206	4.7
10	NESW 17-23N-94W	6,510	245	26.8
		Totals	2,271	128.3

1/ General data on all individual coal beds which were penetrated in each hole are shown on figures 7 and 8. Specific information on only those beds of which proximate and ultimate analyses were made is shown on table 5.

Upper coal group

The coal beds that crop out north and northwest of Lost Creek Flat occur in the Niland tongue of the Wasatch formation. These beds occur in the Kelly, Luman, Hay and Bush coal zones, each of which contains two coal beds (fig. 4). The Niland tongue overlies the Luman tongue of the Green River formation. Thus, the lowest coal zone (Kelly) of the upper coal group is separated from the highest coal zone (Battle) of the lower coal group by about 300 feet of essentially non-coal bearing rocks (figs. 4, 7 and pls. 3 and 4). Calculations based on several analyses of samples of the Luman coal zone taken from core holes indicate that the coals of the upper group are subbituminous B and C in rank (table 5).

Table 4.--Analyses of coal cores, central part of the Great Divide Basin, Sweetwater County, Wyoming 1/

Hole number	Lab. number	Thickness of coal	Condition 2/	PROXIMATE: Moisture	Volatile matter 3/	Fixed carbon	Ash	ULTIMATE: Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	Forms of sulphur: Sulfate	Pyritic	Organic	British thermal units
1	D-97526	1.1'	1	22.8	33.5	31.5	12.2									
			2	-	43.5	40.6	15.9									
			3	-	51.6	48.4	-									
	D-97527	4.5'	1	22.9	32.4	31.0	13.7	6.3	46.5	1.4	29.9	2.2	.07	1.39	.78	8430
	4/ S. G. 1.51		2	-	42.0	40.3	17.7	4.9	60.3	1.8	12.4	2.9	.09	1.80	1.01	10930
	S. T. 2260		3	-	51.1	48.9	-	5.9	73.3	2.2	15.1	3.5	.10	2.19	1.23	13280
	D-96784															
	S. G. 1.55	1.2'	1	23.8	29.7	34.2	12.3					1.7				8200
			2	-	39.0	44.9	16.1					2.3				10770
			3	-	46.5	53.5	-					2.7				12840
	D-96785	0.6'	1	22.7	30.7	28.2	18.4					1.9				7770
	S. G. 1.57		2	-	39.7	36.5	23.8					2.5				10060
			3	-	52.1	47.9	-					3.2				13200
	D-96786	1.7'	1	24.3	31.5	32.2	12.0					2.6	.05	1.74	.80	8480
	S. G. 1.52		2	-	41.6	42.5	15.9					3.4	.07	2.30	1.06	11210
			3	-	49.5	50.5	-					4.1	.09	2.73	1.26	13320

1/ Analyses supplied by U. S. Bureau of Mines, Central Experiment Station, Pittsburgh, Pa., Roy F. Abernethy, Chemist in Charge.

2/ Condition: 1. As received
2. Moisture free
3. Moisture and ash free

3/ Determined by modified method.

4/ S. G., real specific gravity; S. T., softening temperature.

Table 4.--Analyses of coal cores, central part of the Great Divide Basin, Sweetwater County, Wyoming 1/--Continued

Hole number	Lab. number	Thickness of coal	Condition	PROXIMATE Moisture	Volatile matter	Fixed carbon	Ash	ULTIMATE Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Forms of sulphur: Sulfate	Pyritic	Organic	British thermal units
2	D-96787	0.7'	1	23.1	32.3	34.1	10.6					.8				8860
			2	-	41.9	44.3	13.8					1.0				11520
			3	-	48.7	51.3	-					1.2				13360
	D-96788	2.7'	1	22.3	30.3	30.6	16.8	6.1	42.4	1.2	32.4	1.1	.03	.39	.71	7990
	S.G. 1.54		2	-	39.0	39.3	21.7	4.6	54.6	1.5	16.2	1.4	.04	.50	.91	10280
	S.T. 2630		3	-	49.8	50.2	-	5.9	69.7	1.9	20.7	1.8	.05	.64	1.17	13120
3	D-96781	1.7'	1	23.0	31.1	31.7	14.2					2.4				8190
	S.G. 1.54		2	-	40.3	41.3	18.4					3.2				10640
			3	-	49.4	50.6	-					3.9				13040
	D-96782	0.7'	1	21.2	30.6	30.0	18.2					1.2				7890
	S.G. 1.56		2	-	38.8	38.1	23.1					1.6				10010
			3	-	50.4	49.6	-					2.0				13010
	D-96783	3.9'	1	20.3	32.4	30.5	16.8	6.1	46.3	1.2	28.2	1.4	.02	.62	.72	8330
	S.G. 1.53		2	-	40.7	38.2	21.1	4.8	58.1	1.6	12.7	1.7	.03	.78	.91	10450
	S.T. 2580		3	-	51.5	48.5	-	6.0	73.6	2.0	16.2	2.2	.04	.98	1.15	13240
4	D-96789	4.1	1	19.7	31.7	28.1	20.5	5.8	46.4	1.2	24.7	1.4	.04	.66	.67	7840
	S.G. 1.56		2	-	39.5	35.0	25.5	4.5	47.8	1.2	9.0	1.7	.05	.82	.84	9750
			3	-	53.0	47.0	-	6.0	77.6	2.0	12.1	2.3	.06	1.10	1.12	13100
	D-97235	9.2'	1	21.7	33.6	36.0	8.7	6.2	52.1	1.4	29.8	1.8	.06	1.10	.61	9240
	S.G. 1.47		2	-	42.8	46.1	11.1	4.8	66.6	1.7	13.5	2.3	.08	1.40	.77	11800
	S.T. 2140		3	-	48.2	51.8	-	5.4	74.9	1.9	15.3	2.5	.09	1.58	.87	13270

Table 4.--Analyses of coal cores, central part of the Great Divide Basin, Sweetwater County, Wyoming 1/--Continued.

Hole number	Lab. number	Thickness of coal	Condition	PROXIMATE: Moisture	Volatile matter	Fixed carbon	Ash	ULTIMATE: Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Forms of sulphur: Sulfate	Pyritic	Organic	British thermal units
4	D-97236	1.4'	1	23.4	30.3	30.7	15.6									
			2	-	39.5	40.1	20.4									
			3	-	49.6	50.4	-									
	D-97237	5.7'	1	24.2	29.1	37.8	8.9	6.3	50.1	1.3	31.8	1.6	.04	1.02	.59	8860
	S.G. 1.48		2	-	38.3	49.9	11.8	4.7	66.0	1.8	13.5	2.2	.05	1.34	.78	11690
	S.T. 2150		3	-	43.5	56.5	-	5.4	74.9	2.0	15.2	2.5	.06	1.52	.89	13250
5	D-96790	2.6'	1	18.9	26.8	24.7	29.6	5.3	36.7	.9	26.8	.7	.01	.18	.54	6560
	S.G. 1.69		2	-	33.0	30.5	36.5	3.9	45.3	1.2	12.2	.9	.02	.22	.67	8090
			3	-	52.0	48.0	-	6.1	71.4	1.8	19.3	1.4	.02	.34	1.05	12740
6	D-96791	4.0'	1	14.1	23.1	16.0	46.8	4.2	25.8	.6	21.9	.7	.02	.30	.38	4600
	S.G. 1.91		2	-	26.9	18.6	54.5	3.1	30.0	.7	10.9	.8	.02	.35	.45	5350
	S.T. 2800		3	-	59.1	40.9	-	6.8	65.9	1.6	23.9	1.8	.05	.78	.98	11750
7	D-97233	4.8'	1	22.1	33.3	40.4	4.2	6.3	48.5	1.5	38.4	1.1	.02	.37	.70	8710
	S.G. 1.48		2	-	42.8	51.9	5.3	5.0	62.3	1.9	24.1	1.4	.03	.48	.90	11190
	S.T. 2440		3	-	45.2	54.8	-	5.2	65.8	2.0	25.5	1.5	.03	.50	.95	11820
8	D-97528	4.0'	1	25.9	31.0	30.8	12.3					4.0				8100
			2	-	41.9	41.6	16.5					5.4				10930
			3	-	50.2	49.8	-					6.4				13100
9	D-97530	1.1'	1	15.9	26.3	27.1	31.5					3.9				6590
			2	-	30.9	32.0	37.1					4.5				7750
			3	-	49.1	50.9	-					7.2				12320

Table 4.--Analyses of coal cores, central part of the Great Divide Basin, Sweetwater County, Wyoming 1/ --Continued.

					PROXIMATE			ULTIMATE					Forms of sulphur			
Hole number	Lab. number	Thickness of coal	Condition	Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Sulfate	Pyritic	Organic	British thermal units
10	D-98226	6.9'	1	20.7	32.8	37.0	9.5									
	S.G. 1.49		2	-	41.3	46.7	12.0									
			3	-	47.0	53.0	-									
	D-98227	2.5'	1	18.3	30.9	35.8	15.0	5.6	49.0	.9	26.6	2.9	.10	2.10	.70	8660
	S.G. 1.56		2	-	37.8	43.9	18.3	4.4	60.0	1.1	12.7	3.5	.13	2.57	.85	10590
			3	-	46.3	53.7	-	5.3	73.4	1.3	15.7	4.3	.15	3.14	1.04	12970
	D-98228	2.2'	1	18.4	31.1	34.3	16.2					1.6				8500
	S.G. 1.55		2	-	38.2	42.0	19.8					1.9				10420
			3	-	47.6	52.4	-					2.4				13000
	D-98230	2.5'	1	20.8	31.1	38.8	9.3					1.6				9190
	S.G. 1.52		2	-	39.2	49.0	11.8					2.0				11600
			3	-	44.5	55.5	-					2.2				13150
	D-98231	5.4'	1	20.2	32.4	37.6	9.8	6.1	52.5	1.1	29.1	1.4	.03	.65	.71	9290
	S.G. 1.48		2	-	40.6	47.1	12.3	4.8	65.9	1.4	13.9	1.7	.04	.82	.89	11650
			3	-	46.3	53.7	-	5.4	75.1	1.6	15.9	2.0	.04	.93	1.01	13280
11	D-98232	3.4'	1	23.2	30.6	33.4	12.8					2.9				8100
			2	-	39.9	43.5	16.6					3.6				10550
			3	-	47.9	52.1	-					4.4				12660

Table 4.--Analyses of coal cores, central part of the Great Divide Basin, Sweetwater County, Wyoming 1/--Continued.

11	D-98233	2.1'	1	22.1	30.9	33.9	13.1					1.5				8450
	4/S.G. 1.53		2	-	39.7	43.4	16.9					1.9				10860
			3	-	47.7	52.3	-					2.2				13060
	D-98234	5.8'	1	12.2	27.6	28.8	31.4					1.8	.06	1.25	.53	6970
			2	-	31.4	32.8	35.8					2.1	.07	1.43	.60	10860
			3	-	49.0	51.0	-					3.3	.10	2.23	.93	12370
	D-98235	1.8'	1	22.5	31.6	37.4	8.5					1.8				9040
	S.G. 1.49		2	-	40.7	48.4	10.9					2.4				11660
			3	-	45.7	54.3	-					2.7				13100
	D-98236	4.5'	1	10.1	41.6	36.4	11.9	5.8	50.4	1.0	27.9	3.0	.05	2.25	.73	8970
	S.G. 1.53		2	-	46.2	40.5	13.3	5.2	56.0	1.1	21.0	3.4	.06	2.21	.82	9980
			3	-	53.3	46.7	-	6.0	64.6	1.3	24.2	3.9	.07	2.89	.94	11510

Table 5.--Rank of three principal coal beds in the central part of the Great Divide Basin, Sweetwater County, Wyoming

Core hole 1/	A.S.T.M. symbol 2/	Coal bed		Subbituminous group 2/	Overburden (in feet)	Lab. number 3/
8	(52-93)	Luman	No. 2	C	90	D-97528
1	(50-99)	do.	2	B	69	D-97527
7	(57-91)	do.	1	C	41	D-97233
2	(51-91)	do.	1	C	256	D-96788
3	(50-102)	do.	1	B	134	D-96783
4	(48-100)	do.	1	B	44	D-96789
5	(50-93)	do.	1	C	102	D-96790
6	(51-93)	do.	1	C	195	D-96791
9	(55-100)	do.	1	B	194	D-97530
4	(53-102)	Battle	No. 3	B	481	D-97235
10	(54-102)	do.	3	B	55	D-98226
10	(55-104)	do.	3	B	65	D-98227
10	(54-103)	do.	3	B	69	D-98228
10	(57-99)	do.	3	B	73	D-98229
4	(59-98)	Monument	No. 2	B	530	D-97237
10	(56-102)	do.	2	B	144	D-98230
10	(55-104)	do.	2	B	148	D-98231

1/ Location of core holes shown on fig. 2; depths to coal beds shown on fig. 8.

2/ This classification of coals is described in the standard specifications adopted in 1937 by the American Society for Testing Materials, as revised in 1938 (p. 652-657). Coals having less than 69 percent fixed carbon on the dry, mineral-matter-free basis are classified according to Btu. on the moist, mineral-matter -free basis (p. 652). Subbutuminous B coal is defined as coal containing 9,500 or more and less than 11,000 Btu. on the moist, mineral-matter-free basis, and Subbituminous C coal is defined as coal containing 8,300 or more and less than 9,500 Btu. on the moist, mineral-matter-free basis. The symbols in column 2 express the classification "in condensed form as in the following example: (62-146) in which the parenthesis signifies that the contained numbers are on the mineral-matter-free basis. The first number represents fixed carbon on the dry basis, reported to the nearest whole percent. The second number represents Btu. on the moist basis, expressed as hundreds of Btu. (to the nearest hundred); for example, 14,580 Btu. would be represented as 146." (p. 653).

3/ Proximate and ultimate coal analyses made by the U. S. Bureau of Mines are listed in Appendix A. The sample interval is shown on fig. 8.

The coal zones of the upper coal group were mapped and sampled throughout the map area; but, because the beds in the Kelly, Hay and Bush zones are less than 2.5 feet thick, except in a few isolated localities, no reserves were computed for these beds, and they are not shown on figure 2. They are, however, shown on a previous map of the area (Masursky and Pipiringos, in preparation) and some idea may be obtained of their character by referring to figures 4, 7-8 and plate 3 of this report.

Luman coal zone.-- The two coal beds of the Luman zone that contain reserves in the northern part of the area have approximately the same outcrop pattern; and, because the interval between them is small, only the outcrop pattern of Luman No. 2 is shown on the map except near locality 19 where the outcrop pattern is that of Luman No. 1 (fig. 2).

Luman No. 2.--The Luman No. 2 coal bed is well exposed and is typically overlain by a bed of brown, papery-fissile, low-grade oil shale 10 feet or less in thickness, throughout most of the area in which this coal bed outcrops. It attains a maximum thickness of 4.5 feet in core hole no. 1 and thins eastward and westward from this locality. It is typically developed and best exposed near the base of a low bluff which trends westward for several miles in the southeast corner of T. 24 N., R. 96 W. (Localities 2-7, fig. 2). In these localities it consists of an upper bed, too thin to be considered in computing reserves, and a lower bed which contains all the coal estimated in the Luman No. 2 reserves. The upper bed continues eastward from locality 7 for three miles to locality 17, where it consists of about 2 feet of coal and black shale. Beyond this point, the Luman No. 2 shales out (figs. 2, 5, 7). The area underlain by the lower bed where it is 2.5 feet or more thick is shown in figure 9.[/] There it averages 3.6 feet in thickness. It is of Subbituminous C rank at core hole 8 and of Subbituminous B rank at core hole 1 (table 5).

The interval from the top of the Luman No. 2 coal bed to the top of the underlying Luman No. 1 coal bed ranges from 30 feet to 50 feet and averages 33 feet (figs. 4, 5, 7-8 and pl. 3).

/ Figures 9 to 27 on pages 99-117.

Luman No. 1. -- The Luman No. 1 coal bed is exposed only at locality 15 (figs. 2, 5) at the tip of the "peninsula" which juts south into Lost Creek Flat. At this locality, the coal bed is 4.7 feet thick. The area underlain by the Luman No. 1 where it is 2.5 or more feet thick was determined by auger holes and core holes (figs. 5, 7, 8) and is shown in figure 10. Within that area, the Luman No. 1 attains a maximum thickness of 5 feet, at locality 17, and averages about 3.8 feet.

At core hole localities 7, 2, 5 and 6, the Luman No. 1 is of subbituminous C rank and at localities 3, 4 and 9 it is of subbituminous B rank.

The Luman No. 1 is thickest along the axis of the Red Desert syncline and in the area adjacent on the west. It thins abruptly westward from core hole 7, but thins only gradually eastward from the axis of the syncline (figs. 2, 7, and 8).

Locally, the Luman No. 1 has two or more thin shale or siltstone partings near the top (figs. 5, 7, 8).

The 5-foot bed of carbonaceous shale that crops out at locality 19 sec. 4, T. 24 N., R. 94 W. (figs. 2 and 5) is very probably equivalent to the Luman No. 1 bed. The approximate line of outcrop of the Luman No. 1 bed shown on the geologic map of a preliminary report (Masursky and Pipiringos, in preparation) was predicted on the basis of structure contours and coincides within 500 feet of the actual line of outcrop as mapped by the author in the summer of 1953 (fig. 2). Furthermore, inasmuch as the Luman No. 1 bed is much thicker than the nearest overlying or underlying coal beds, and should extend the farthest, it is logical to assume that the 5-foot bed of carbonaceous shale at locality 19 is an extension of the Luman No. 1 coal bed.

Butte coal zone. -- The Luman tongue of the Green River formation, which separates the upper from the lower coal group, contains a few thin coal beds assigned to the Butte coal zone. This zone was named from good exposures in the vicinity of Lost Creek Butte where it contains two coal beds, named from bottom to top Butte No. 1 and Butte No. 2. A few lenticular coal stringers a few inches thick in the Luman tongue in the vicinity of Luman Butte may be part of this zone but cannot be correlated with the named beds in the Lost Creek Butte area. The coal beds in the Butte zone are too thin to contain coal reserves but can be used locally for stratigraphic and structural interpretations.

Butte No. 2. -- The Butte No. 2 bed consists of a few feet of carbonaceous shale containing a few inches of coal at the base and is known only from outcrops east of Lost Creek Butte and southwest of Battle Spring Flat. It is perfectly exposed in the SE 1/4 sec. 7, NW1/4 sec. 17, SE 1/4 sec. 18, N1/2 sec. 29 and the SE 1/4 sec. 30, T. 23 N., R. 94 W. It was mapped and sampled because its relatively high uranium content (0.016 percent) appears related to its proximity to permeable beds of the Battle Spring formation (pls. 4 and 15). Near core hole 10 the interval from Butte No. 2 and the overlying shale tongue 3 is about 40 feet.

Butte No. 1.--The Butte No. 1 bed is about 75 feet stratigraphically below Butte No. 2 and about 50 feet above the top of Battle No. 3. It generally is less than 1 foot thick and is well exposed at the base of the southwest slope of Lost Creek Butte in the NE 1/4 sec. 23, T. 23 N., and near the top of the north slope of a butte in the NE 1/4 sec. 36, T. 23 N., R. 95 W. At the latter locality it is of interest because its high uranium content (0.013 percent in the upper part) appears related to the overlying sand and gravel deposit which caps the butte. (See discussion in last few paragraphs of uranium in coal.) The Butte No. 1 bed occurs northward as far as core hole 4 (fig. 8) where it is a few inches thick and about 49 feet above the top of Battle No. 3, and southward as far as the SE 1/4 sec. 23, T. 22 N., R. 94 W. about one-half mile south of triangulation station Divide.

Lower coal group

The coal beds that crop out in the area south of a line extending from Lost Creek Butte to Luman Butte and north of U. S. Highway 30 are in the Red Desert tongue of the Wasatch formation (figs. 2, 4, pls. 4-5). For convenience of discussion these coal beds are referred to in this report as the "lower coal group."

The coal beds of the lower coal group are more numerous, thicker, and contain more coal reserves than those of the upper coal group. The coal beds range from a few inches to 21 feet in thickness (core hole 10, figs. 7-8) and commonly are 5 feet thick or more (figs. 5-8).

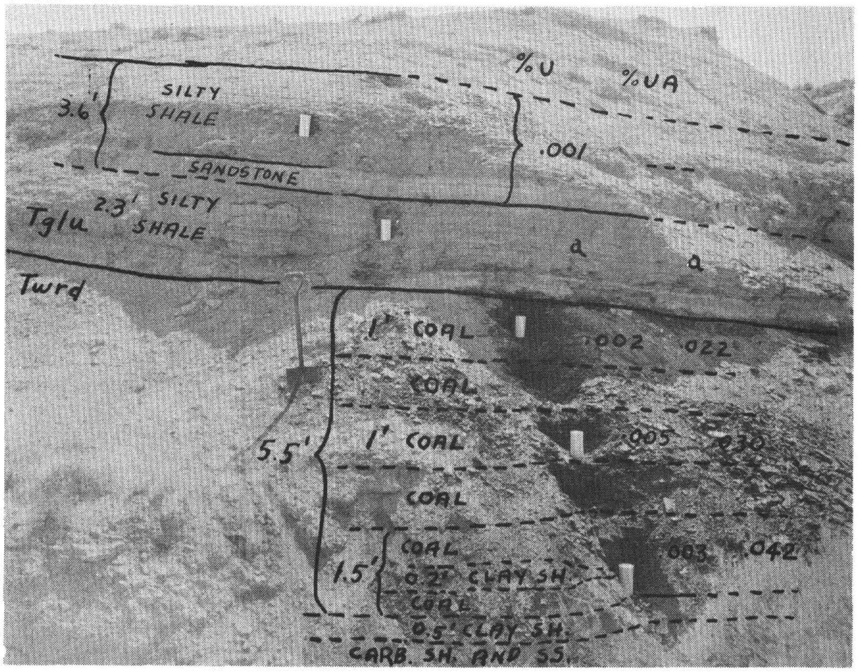
Analyses of 8 samples from coal beds in the Battle and Monument zones indicate that coal in the lower group is subbituminous B in rank (table 5).

Battle coal zone. -- The Battle coal zone was named from exposures at the south end of Battle Spring Flat near locality 31. Inasmuch as only Battle No. 3 is exposed there, and only Battle No. 1 and No. 3 are present at the nearest locality to the south (32), a more typical locality is in the small valley south of the nearest approach of the dirt road to the base of shale tongue 1 in sec. 36, T. 23 N., R. 95 W. There Battle No. 3 is about 0.5 feet thick and lies about 10 feet stratigraphically above the top of Battle No. 2. The latter is about 2 feet thick and the interval from the top of Battle No. 2 to the top of the underlying Battle No. 1 is about 15.5 feet. Battle No. 1 is about 1.6 feet thick. The thickest beds of the Battle coal zone occur in a belt which extends from core hole 4 southeastward to the east boundary of the map area near auger hole 35 (figs. 2, 6, 8, 11, 15). The trend of the belt is nearly parallel to that of the Red Desert syncline, and to that of the normal faults mapped in Tps. 22, 23 N., Rs. 94, 95 W. (fig. 2).

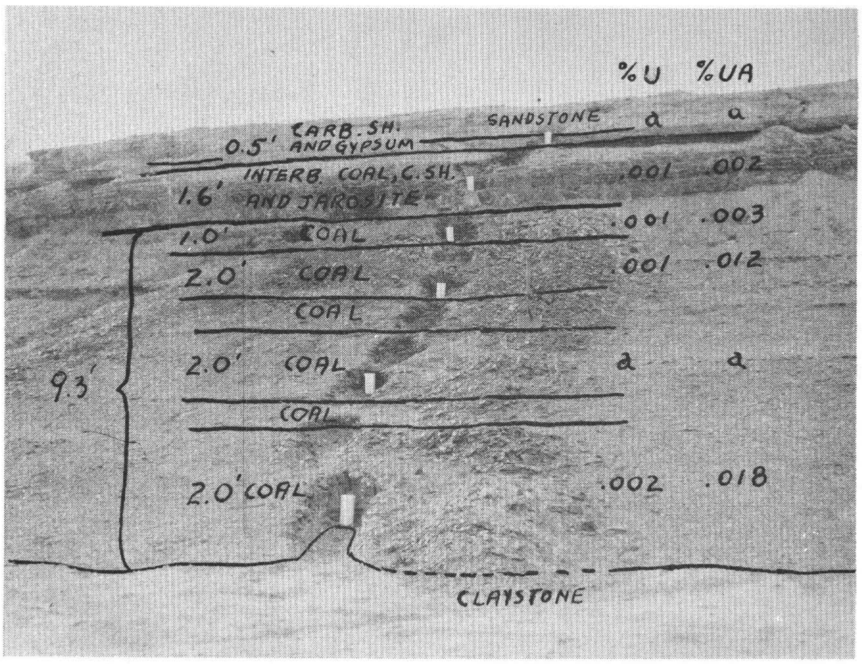
The only coal bed in this zone that is thick enough to contain coal reserves in the map area is Battle No. 3. Inasmuch as the contact between the Red Desert tongue and the Luman tongue is identical with the outcrop pattern of Battle No. 3, the coal bed symbol has been omitted from the geologic map (fig. 2).

Battle No. 3. -- The Battle No. 3 coal bed averages 7.5 feet in thickness (table 5) beneath huge areas and locally is as much as 21 feet thick (core hole 10). Battle No. 3 locally, as in auger hole 29, is split into two distinct beds. The lowermost bed of the Battle zone is designated Battle No. 1. Westward Battle No. 3 splits into two distinct beds, as happens a few hundred feet west of the southeast corner of T. 23 N., R. 95 W. There the beds are designated from top to bottom Battle No. 3, No. 2 and No. 1. The base of shale tongue 1 of the Luman tongue of the Green River formation rests directly on Battle No. 3 throughout the northern half of the map area (pl. 16) as far west as section 8, T. 23 N., R. 96 W. Westward beyond this point, no trace remains of the Battle coal beds, and shale tongue 1 thins to less than two feet thick and cannot be shown separately on the map scale used in figure 2.

Plate 16



A.--Battle No. 3 coal bed at map locality 31, fig. 2, south of Battle Spring Flat, showing percent uranium (U) and percent uranium in ash (UA) of sampled intervals. Tglu: Luman tongue of the Green River formation; Twrd: Red Desert tongue of the Wasatch formation.



B.--Monument No. 2 coal bed, Red Desert tongue, about 1.5 miles southwest of triangulation station Divide, at map locality 67, fig. 2, showing percent uranium (U) and percent uranium in ash (UA) of sampled intervals.

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The interval between the top of Battle No. 3 (base of the shale tongue) and the top of the Monument coal zone ranges from 87 feet (core hole 10) at the southwest edge of Battle Spring Flat to 57 feet (locality 22) near the southwest margin of Lost Creek Flat. The interval is about 87 feet at the map localities 62 and 68 and about 60 feet at locality 32. This difference of interval from place to place is caused partly by the fact that the Monument No. 3 bed is lenticular and does not mark the top of the Monument zone everywhere. Aside from the effect the lenticularity of Monument No. 3 has on it, the interval from the base of shale tongue 1 to the top of the Monument zone is constant when measured in a direction parallel to the trend of the Red Desert syncline, but decreases when measured westward at an angle to the syncline. Most of the decrease in interval is due to thinning of the non-coaly rocks between the coal beds.

Wherever the Battle coal zone was observed in outcrops west of the northwesterly trending normal faults south of the Lost Creek Butte, it consists of coal beds 2.5 or less feet thick. East of the faults, coal beds in the Battle zone are much thicker, which suggests that minor movements along these faults occurred during early Eocene time.

The rank of the coal beds in the Battle coal zone, as determined from the few analyses available (table 4) is subbituminous B (table 5).

Monument coal zone.--The Monument coal zone at some places consists of about 20 feet of coal and carbonaceous shale (localities 33 and 34, fig. 5) and at other places it consists of two or three coal beds separated by clay shale, siltstone and fine-grained sandstone, all in an interval ranging in thickness from 11 fo 29 feet (localities 46 and 60). Monument No. 2, which splits into Monument No. 1 and No. 2 in the northwest part of the coal-bearing area, is considerably thicker and more persistent than the overlying Monument No. 3. Because of the small vertical interval and the small horizontal distance between the outcrop patterns of these beds, the Monument zone is shown by one line on the geologic map (fig. 2), drawn at the top of Monument No. 2 except in Tps. 23 and 24 N., R. 94 W. where it is drawn at the top of Monument No. 3.

The Monument coal zone contains coal beds 2.5 feet thick or more that underlie much of T. 22 N., Rs. 94 , 95 W.; T. 23 N., R. 94, 95 W.; and T. 24 N., R. 95 W.; and coal beds in the zone may underlie most of Lost Creek Flat as indicated by surface sections south and southwest of the Flat (localities 20, 21, 22, 41 and 28) and in core holes 10 and 4.

Monument No. 2 was named from good exposures of this bed about a mile west of Monument Lake (dry) just outside the east edge of the map area in the SE 1/4 of sec. 27, T. 22 N., R. 94 W. Monument No. 2 is magnificanently exposed at locality 67 (fig. 2 and pl. 16) where the bed is about 9 feet thick and crops out on the sides of a small low oval butte. The wind has swept away the coal which once was continuous from the butte to the exposures about 50 feet south of the butte, and scattered it over the sparse grass, sage brush, and greasewood directly east of the butte. The butte is capped by gleaming white beds of micaceous siltstone and fine-grained sandstone. It is too low to be seen from the trail which passes it closely, but the effect is startling and spectacular as one leaves the trail and suddenly catches sight of the outcrop. The brilliant white cap of the butte contrasts with the black sides and with bright orange and yellow pieces of jarosite and sparkling pieces of selenite crystals, which are scattered in profusion on the hollowed out floor of the depression south of the butte.

This bed is also well exposed at locality 59 where all but the bottom 2 feet of coal crops out. The bed can be traced from locality 59 northeastward across a fault of small displacement to locality 60 where it underlies Monument No. 3. Monument No. 3 at locality 60 is about 3.5 feet thick. An auger hole at locality 60 (fig. 6) starting at the base of Monument No. 3 reached the top of Monument No. 2 at a depth of about 11 feet and showed Monument No. 2 to be about 14 feet thick. The thickest bed of coal (15 feet) in the Monument zone was penetrated in an auger hole at locality 34 (fig. 5). The average thickness of coal in the reserve area of the Monument zone (figs. 12, 13, 16, 18, 21) is about 7.5 feet (table 6).

The Monument coal zone in the northern part of the reserve area is of subbituminous B rank (table 5). The coal of this zone in the southern part of the reserve area is probably of equal rank.

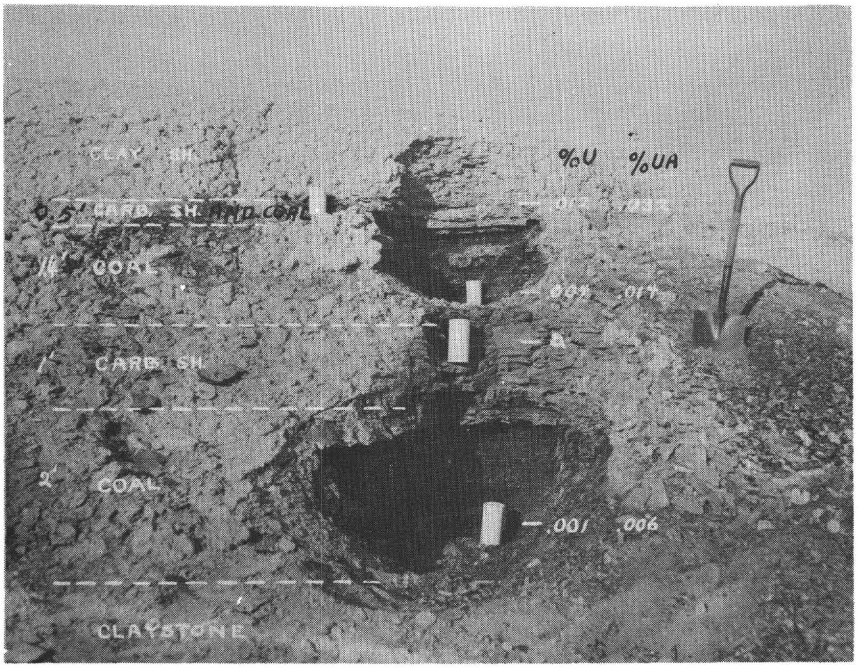
The interval between the top of Monument No. 2 and the underlying Tierney coal zone ranges from about 57 to 76 feet in core holes 4 and 10, and the interval is about 65 feet at four surface localities (47-48 and 66-67) where surface and augered sections were combined. The increase of interval between these two zones in core hole 10 coincides with the presence of a coarse-grained sandstone tongue of the Battle Spring formation intercalated between the fine-grained rocks that separate the two coal zones.

Tierney coal zone. -- The Tierney coal zone was named from excellent exposures about 2.5 miles northeast of Tierney's ranch at map localities 78, 79 and 80 in the NW1/4 of T. 21 N., R. 94 W. (figs. 2, 6 and pl. 17). At least six distinct beds of coal and/or carbonaceous shale occupy a stratigraphic interval of about 90 feet in the Tierney zone. These have been numbered 1 to 6 from bottom to top (fig. 4), but only Tierney Nos. 5 and 6 are thick enough (2.5 feet or more) to be considered in estimating the coal reserves.

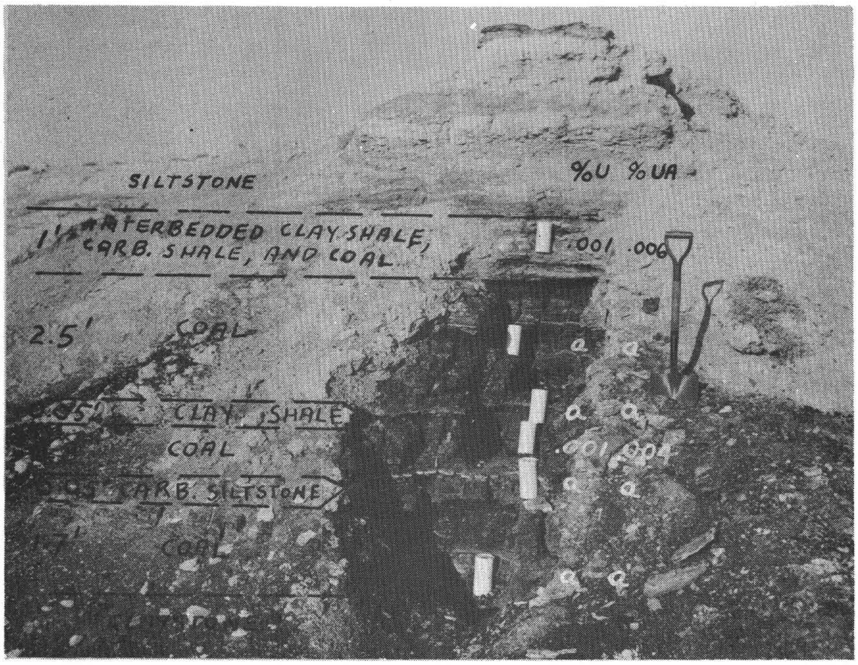
The rank of the Tierney and underlying coal zones of the lower coal group is not known in this area but presumably is comparable to that of the overlying Monument and Battle zones.

Tierney No. 6. -- The Tierney No. 6 bed underlies parts of T. 23 N., R. 94 W., T. 22 N., Rs. 94, 95 W., and T. 21 N., R. 94 W. Within this area Tierney No. 6 is as much as 13 feet thick (locality 56, fig. 6) and averages about 6 feet (table 6).

The Tierney No. 6 bed is well exposed and typical at locality 79 (pl. 17A) where it contains a silty carbonaceous shale parting (locally diagnostic of this bed) which is about 1 foot thick and remarkably persistent. Exposures of this bed lying within a northwesterly trending belt bounded on the east by a line drawn from locality 70 to 66, and on the west by a line connecting localities 79 and 48, all contain the diagnostic silty carbonaceous shale parting (fig. 6, localities 47, 48, 64, 66, 70, 71, 75, and 79). East of this belt Tierney No. 6 is generally much thicker and relatively free of partings as at localities 55, 56, 69. West of the belt the carbonaceous shale parting has entirely replaced the coal in the upper part of the bed (localities 37, 38, 43, 44 shown on figure 6, and localities 24, 26, 27 shown on figure 5). Thus sections of Tierney No. 6 measured in a northwesterly direction are of similar



A.--Tierney No. 6 coal bed, Red Desert tongue, about 1.5 miles southwest of Twelve-mile hole at map locality 79, fig. 2, showing percent uranium (U) and percent uranium in ash (UA) of sampled intervals.



B.--Tierney No. 5 coal bed, Red Desert tongue, about 1.75 miles southwest of Twelve-mile hole at map locality 80, fig. 2, showing percent uranium (U) and percent uranium in ash (UA) of sampled intervals.

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thickness and appearance, whereas, sections measured in a southwesterly direction change in thickness and appearance from east to west, from thick "solid" coal to coal containing a thick carbonaceous shale parting, to thin coal overlain by an equal or greater thickness of carbonaceous shale. It retains the latter character as far west as the southern part of Lost Creek Flat. From there westward Tierney No. 6 is covered by surficial Quaternary deposits. A thin carbonaceous shale that crops out in section 5, T. 23 N., R. 97 W. at approximately the stratigraphic position of the Tierney No. 6 may possibly be the wedge edge of this bed.

Tierney No. 5.--The Tierney No. 5 bed underlies parts of Tps. 21, 22, 23 N., R. 95 W., and Tps. 21, 22 N., R. 94 W. (figs. 2, 14, 20, 23, 24, 26). Tierney No. 5 attains a maximum thickness of 5.5 feet in the extreme southeast corner of the reserve area at locality 76 (fig. 2, 6). The average thickness for the combined reserve areas is about 3.3 feet (table 6).

Tierney No. 5 is well exposed and typical at locality 80 (pl. 17B) where it is about 4.5 feet thick and contains a brownish-white carbonaceous siltstone parting 1/2-inch thick about two feet above the base. This parting is locally persistent and diagnostic of Tierney No. 5. The parting occurs also at localities 48, 72, 74, 76, 77, and 78 (fig. 6).

The interval between the top of Tierney No. 6 and the top of Tierney No. 5 ranges from 12 feet at locality 75 to 26.5 feet at locality 79, and averages 21 feet. Invariably where the interval between these two beds contains a bed of soft slope-forming sandstone capped by a calcareous sandstone ledge-maker, the interval ranges from 23.5 to 26.5 feet; where the sandstone beds are missing, the interval ranges from 12 to 19 feet in thickness.

Locally, as at localities 48 and 76, the Tierney No. 5 bed contains minute clear crystals of tschermigite; ammonia alum- $(NH_4)\,Al(SO_4)_2$.

Lower beds in Tierney coal zone. -- The remaining beds in the Tierney coal zone are of no economic interest but are useful for correlating locally and in one instance in determining the displacement on the fault in the southern half of sec. 6, T. 21 N., R. 94 W. (pl. 14). There Tierney No. 5 is faulted down against Tierney No. 3 which indicates a 25-foot downward displacement on the south side. The average intervals between the lower Tierney beds are shown on figure 4 and plate 5. Locally, Tierney No. 4 consists of coal overlying carbonaceous shale, as at locality 80 where it lies 10.5 feet below the top of Tierney No. 5; elsewhere, as at map locality 78, it consists of coal overlain by clay shale which contains impressions of the floating fern Salvinia preauriculata Berry, an Eocene species (locality 19, table 2). The interval from the top of Tierney No. 4 to the top of Tierney No. 3 ranges from 13 to 17.5 feet. Tierney No. 3 consists of about 10 feet of carbonaceous shale, which locally contains thin layers of coal. Along the hills south of the closed depression in sec. 4, T. 21 N., R. 94 W. (known locally as 12-mile hole) it consists of a thin bed of coal overlain by soft dark green shale containing large quantities of selenite crystals. In the vicinity of locality 80 it contains ostracodes and resembles low grade oil shale. Tierney No. 2 crops out only in the northeast quarter of sec. 7, T. 21 N., R. 95 W. and was penetrated in an auger hole at locality 78 which started at the base of Tierney No. 3 and reached the top of Tierney No. 2 at a depth of about 13 feet. In sec. 7 it is 2 feet thick and lies about 13 feet above Tierney No. 1, as determined by auger drilling.

Dune coal zone. -- The Dune coal zone contains two beds consisting for the most part of carbonaceous shale, which were mapped locally for the purposes of stratigraphic and structural control. These beds are designated from bottom to top: Dune no. 1 and Dune no. 2. The zone was named from exposures (pl. 13) south of the sand dune belt that occupies a strip of land a few miles north of Tipton Buttes.

The zone is best exposed on the north side of a small isolated hill in the SE 1/4 NE 1/4 sec. 8, T. 21 N., R. 94 W. where each of the Dune beds consist of a few inches of coal and are about 26 feet apart. The interval down to the next coal zone (fig. 4) was determined by a series of auger holes drilled in the area between localities 78 and 81, supplemented by mapping of locally persistent calcareous sandstone beds and zones of limestone concretions.

Unnamed coal zone. -- There are six mappable coal beds in this unnamed zone which underlie large areas of very few coal outcrops. These beds are tentatively called, from top to bottom, beds A, B, C, D, E, and F. Correlation with thicker beds having similar stratigraphic positions, which were penetrated in core holes drilled in the area adjacent to the east is uncertain. The stratigraphic position of these coal beds is shown on figure 4 and in plate 5.

Between the latitude passing through locality 80, and south to about the latitude of the middle of T. 20 N. there are less than a half-dozen localities where outcrops of coal beds A-E can be examined (F does not crop out). Fortunately most of these coal beds as well as some of the intervening rocks are distinctive and can be identified by careful examination of the rock fragments adjacent to animal burrows, which generally are more helpful than auger cuttings because the spill piles are dry and give an accurate picture of how the concealed coal and the associated rocks would weather in outcrop.

Bed B is characterized by brown fossil wood and by white fossil wood. It underlies a bed of low grade oil shale, which contains at or near the top a thin zone of limestone concretions which weather bright yellow buff. The interval between Beds B and C is made up of greenish shale and siltstone.

Bed C does not contain fossil wood and rests directly on brown, papery low grade oil shale. The oil shale is about 50 feet thick and rests on coal Bed D.

This bed contains a moderate amount of fossil wood that weathers brown. It rests on a gray green shale and siltstone sequence about 40 feet thick, which in turn rests on coal bed E. The latter contains a layer of brown-weathering fossil wood generally 2 or more inches thick and in a few places contains a moderate amount of white-weathering fossil wood also.

Thus, the position of a coal bed can be inferred from spill piles and the identity of the bed can be determined by the presence or absence of the brown low grade oil shale and by the types, thickness and amount of fossil wood in the spill piles. With the exception of coal bed E, auger holes indicate that these unnamed coal beds generally are less than 2.5 feet thick.

Although coal bed E is thin at locality 82, it is slightly more than 2.5 feet thick at locality 81. The area for which coal reserves in this bed were calculated is shown in figure 27. Coal bed F is about 15 feet below E and is known only from animal burrow tailings.

The discussion of the coal beds to this point has been limited to outcrops in the area between the axis of the Red Desert syncline and the Tierney anticline. The rest of this discussion concerns coal in the area south and southeast of the Tierney anticline.

South of the circular outcrop pattern that coal bed E makes along the crest of the Tierney anticline (figs. 2, 3) the section is repeated; with younger and younger rocks exposed as the southern part of the area is approached. In the southern part of the area, the Tierney, Monument and Battle zones of the lower coal group have a slightly different stratigraphic interval from that in the northern part of the area. None of the coal beds in the southern part of the area are thick enough to constitute coal reserves.

Two key beds help to correlate the beds in the lower coal group in the southeastern part of the area with those in the Tipton Buttes area west of Red Desert Flat. These key beds are not present in the northern part of the area. One of the key beds underlies the shale tongue at the base of the Luman formation. It consists of a thin (2 or less feet) fossiliferous sandstone bed, and throughout most of its extent contains numerous fossil worm burrows whose long axes are normal to the bedding. The sandstone filling the burrows is softer than the surrounding rock and in plan view the weathered surface of this bed is covered with circular pits averaging about 1/4-inch in diameter (pl. 8). This peculiarity led to nicknaming it the "wormy" sandstone. The "wormy" sandstone is generally 35 to 40 feet above Battle No. 1 in the southern part of the map area.

The second key bed is a gray-black limestone, which occurs about 200 feet below the top of the Red Desert tongue, a few feet below Tierney No. 1 (fig. 4, pls. 5, 6 and 8) and contains abundant mollusk fragments. Locally the fossils have been leached out giving the limestone bed a perforate appearance, which gave rise to the nickname, "holey" limestone. The limestone is about one foot thick in the east-central part of sec. 22, T. 20 N., R. 95 W. This limestone is thin but prominent and well exposed around the base of the largest of the Tipton Buttes (pl. 13) in sec. 27, T. 20 N., R. 96 W. The Tierney, Monument and Battle coal zones above the "holey" limestone and below the "wormy" sandstone crop out in an east west belt throughout the southern part of the map area.

The upper coal group crops out south of U. S. Highway 30 where it is represented by thin coal and carbonaceous beds with one exception. Near the southeast corner of the area in the NE 1/4 sec. 7, T. 19 N., R. 94 W. a five-foot coal bed crops out directly beneath the molluscan coquina at the base of the Tipton. The westward continuation of the coquina is shown in plate 11. The coal bed thins abruptly westward but maintains a five-foot thickness for several miles eastward and southeastward before thinning to less than 2.5 feet. Thus, this bed makes a lenticular outcrop around the northeast corner of the Washakie Basin. In some places it is mined by the local ranchers (Bradley, 1945).

URANIUM IN COAL

Nearly all of the coal beds that crop out in the central part of the Great Divide Basin contain from 0.001 to 0.003 percent uranium. In some places, parts of these beds apparently contain no uranium and in other places parts of these beds contain as much as 0.026 percent uranium (fig. 5, localities 15 and 27).

In general, the least uraniferous coal beds are those in the western and southern parts of the area and the most uraniferous are those in the central and northeastern parts. The higher concentrations of uranium (defined as 0.003 percent uranium or more) are found in the coal beds that underlie an area a few miles wide that extends southeastward from the "peninsula" on the northwest side of Lost Creek Flat to and for an undetermined distance beyond the south edge of Battle Spring Flat.

This area of higher concentrations of uranium in coal coincides approximately with 1) the east side of the trough of the Red Desert syncline and 2) with the zone of intertonguing of the permeable arkosic sandstone beds of the Battle Spring formation with the less permeable and impermeable sandstone, siltstone, clay shale and paper-shale beds of the Wasatch and Green River formations.

The areal distribution of uranium in coal beds may be described in various ways. The uranium content decreases westward with distance from 1) the Battle Spring formation, 2) the trough of the Red Desert syncline, 3) the zone of intertonguing (facies changes). And inasmuch as the thickest coal beds, which lie on the west side of the trough of the Red Desert syncline, contain far less uranium than the thinner beds on the east side, it may be stated that the uranium content decreases as the thickness of the coal beds increases. Thick coal beds and high uranium content are in effect mutually exclusive.

Plate 18 of A (sections B-B') shows the apparent relationship of uranium content in the Luman coal zone to southwest-northeast facies changes across the Red Desert syncline. The geologic setting of the Luman coal zone is very similar to that of all the coal zones in this area. The average uranium and ash content shown in the graphs for each locality is the weighted average of the coal bed exclusive of clay shale and carbonaceous shale partings.

As shown in plate 18 A the uranium content of the Luman No. 2 coal bed ranges from about 0.002 percent at the left or west side of the diagram to about 0.012 percent in the middle, near the axis of the syncline. From locality 1 to locality 4, about 1.8 miles apart, the uranium content ranges from 0.0023 to 0.0055, an increase in percent uranium of 0.0032. From locality 4 to locality 5, about 0.7 mile apart the uranium content rises to 0.009, an increase of 0.0035 in less than half the distance between localities 1 and 4. From locality 5 the uranium content increases eastward to a maximum of 0.012 percent at locality 7 and then decreases again at locality 8. Eastward beyond this point the Luman No. 2 coal bed grades completely into a carbonaceous shale and then pinches out. At locality 15, the Luman No. 2 bed consists of a few inches of carbonaceous shale and contains 0.002 percent uranium.

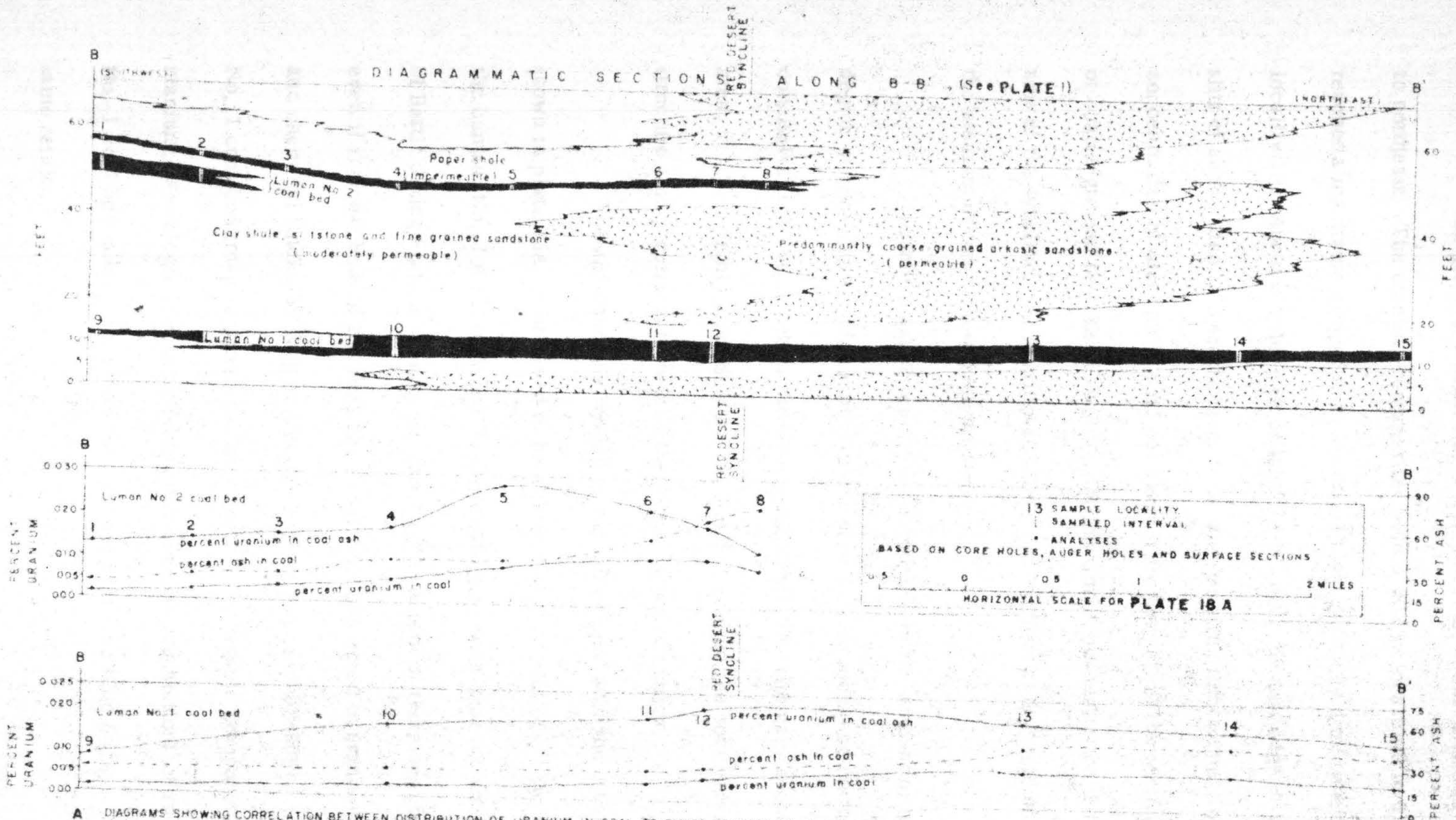
The relatively sharp rise in uranium content of Luman No. 2 between localities 4 and 5 coincides with the first appearance in the section of coarse-grained permeable rocks, and all the localities (5-8) with the relatively higher concentrations of uranium are in or near the lowest part of the syncline.

Data used to construct plate 18 are taken from surface and auger samples _/ (fig. 5) and core samples (figs. 7 and 8). The sample localities shown by an arbitrary series of numbers on plate 18 correspond to the map localities (fig. 2) as follows:

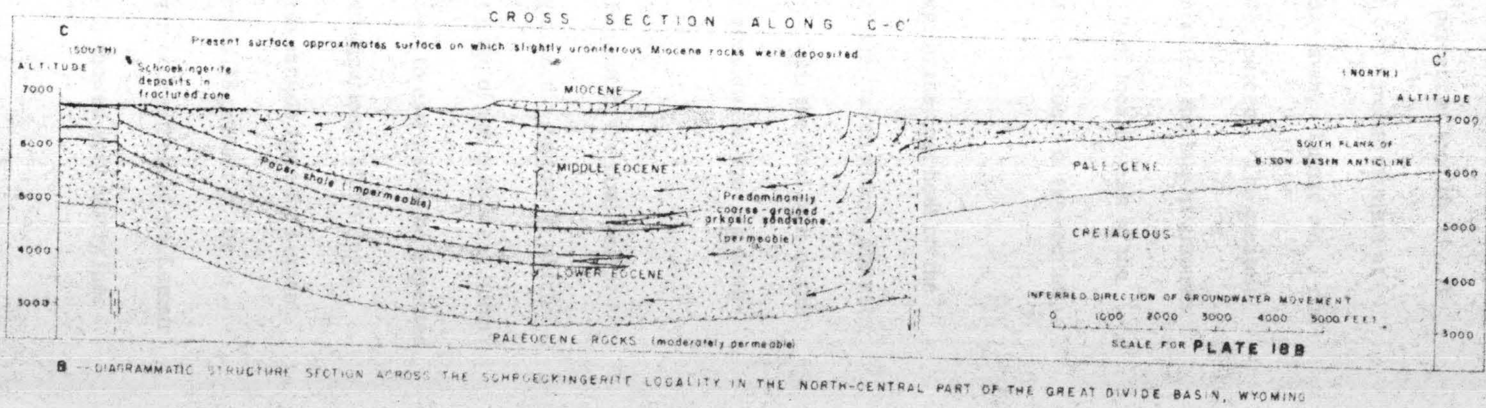
Locality number plate 18	Locality number figure 2
1	1 (core hole)
2	7 (surface section)
3	8 (" ")
4	9 (" ")
5	11 and 12 (auger holes, average)
6	14 (surface section)
7	16 (" ")
8	18 (" ")
9	1 (core hole)
10	7 (" ")
11	4 (" ")
12	17 (auger hole)
13	5 (core hole)
14	6 (" ")
15	9 (" ")

_/ Ash content of auger samples estimated. Comparison of weighted ash contents of five auger samples and nearby core samples from the same coal bed indicates that the ash content of an auger sample ranges from 43 to 69 percent and averages 55 percent too high.

PLATE 18



A DIAGRAMS SHOWING CORRELATION BETWEEN DISTRIBUTION OF URANIUM IN COAL TO FACIES CHANGES NEAR AXIS OF RED DESERT SYNCLINE.



B --DIAGRAMMATIC STRUCTURE SECTION ACROSS THE SCHROECKINGERITE LOCALITY IN THE NORTH-CENTRAL PART OF THE GREAT DIVIDE BASIN, WYOMING

The graph of Luman No. 1 (pl. 18A) also shows a rise in uranium content from southwest to northeast. The uranium content rises from 0.002 at locality 9 to 0.004 percent at locality 11. It reaches a maximum of 0.0082 at locality 13 and gradually diminishes to 0.006 percent uranium at locality 15. About 3 miles east of locality 15, near the east edge of the map area, Luman No. 1 consists of about 5 feet of carbonaceous shale and has a uranium content of 0.002 percent. The greatest concentration of uranium in coal coincides with that part of the section containing the largest amounts of coarse-grained permeable rocks. The maximum concentration is in the first locality east of the axis of the syncline. At locality 15 where there is a local decrease of permeable rocks in the section, the uranium content likewise decreases.

These two examples of the dependence of the amount of uranium in the coal beds on the degree of permeability of the overlying and underlying rocks and on the syncline, taken alone, are not conclusive; but, inasmuch as the same general relationships can be observed in all the coal beds of this area, it seems highly probable that the uranium entered the coal beds from groundwater moving downstructure along permeable beds of the Battle Spring formation.

The apparent relationship of the ash content with the uranium content in the coal beds, shown in plate 18A, is believed to be almost entirely fortuitous. The margins of the swamps in which the Luman No. 1 and No. 2 coal beds were formed were near the northeast edge of the map area, north of Battle Spring Flat, so that an increase in ash content of these beds from west to east was to be expected even if the coal beds of this area had never been subjected to uranium mineralization. Mineralogic and chemical studies by Breger, Deul and Meyerowitz (1955) showed that in a sample from the Luman No. 1 coal bed (map locality 15, figs. 2 and 5) the organic components carried 98 percent of the uranium. Petrologic studies by Schopf and Gray (in preparation) of an 8-inch core sample of the Luman No. 1 coal bed taken from a core hole drilled near core hole 5 (figs. 2 and 8) showed very nearly the same results.

In light of the foregoining, the only effect the author can think of that impurities in coal might have on the distribution of uranium in coal is to make the impure coalslightly more permeable and thus slightly more accessible to uranium-bearing groundwater. The observations of Schopf and Gray (in preparation) that ". . . highly uraniferous layers usually have a considerable amount of amorphous waxy and clayey mineral matter and commonly lie adjacent to a layer of greater mineral content." might be explained in that way.

Locally, relatively high uranium concentrations in coal beds seem related to sand and gravel deposits of probable Pleistocene age. At a locality about two miles southeast of Lost Creek Butte, in NE 1/4 sec. 31, T. 23 N., R. 94 W. a layer of sand and gravel about 20 feet thick rests on a 10-foot sequence of coarse-grained sandstone which directly overlies a 10-inch coal bed (Butte No. 1). The average uranium content of the coal bed is 0.009 percent. Another thin coal bed (Battle No. 3) about 45 feet lower in the section is overlain directly by a 20-foot bed of low grade oil shale (shale 1 of the Luman tongue) and contains only 0.0015 percent uranium. Two other samples of Butte No. 1 coal bed collected from outcrops 500 and 1,000 feet east of the first locality contain 0.005 and less than 0.001 percent uranium respectively. The eastward decrease in uranium content of the Butte No. 1 coal bed is local and is associated with an increase in interval between Butte No. 1 and the sand and gravel layer, and also is associated with a gradation from coarse-grained sandstone to clay shale in the beds directly above Butte No. 1.

In the SE 1/4 sec. 25, T. 22 N., R. 95 W., about 8 miles south of Lost Creek Butte, the uranium content of 5 coal beds distributed through 80 feet of section ranges from 0.014 percent in the highest (Monument No. 1) to absent in the lowest (Tierney No. 5; locality 48, fig. 6). The highest coal bed is directly overlain by a 20-foot sequence of medium-grained sandstone beds which is capped by a layer of sand and gravel about 10 feet thick. The four lower coal beds are interbedded with clay shale, siltstone and fine-grained sandstone. Chemical analyses of sand and gravel samples from both localities showed 0.003 or less percent equivalent uranium and less than 0.001 percent uranium. Presumably the water in which the sand and gravel were deposited was uranium-bearing, and most of the uranium that may have been deposited with the sand and gravel has since been leached and redeposited in the first coal bed beneath it.

SCHROECKINGERITE DEPOSITS

Schroeckingerite ($NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$) is a yellow-green secondary mineral containing 26.8 percent uranium (Frondel and Fleischer, 1955) which was discovered in the Red Desert area by the late Mrs. Minnie McCormick of Wamsutter, Wyoming, prior to February 1937. The mineral was thought to be new and was named dakeite by Larsen (1937). Later Novacek (1939) showed that dakeite was a synonym for schroeckingerite which had been named many years previously. Consequently the name dakeite has been abandoned.

The schroeckingerite locality is in the northeast corner of the map area in sections 30 and 31, T. 26 N., R. 94 W. The Geological Survey conducted brief intermittent reconnaissance investigations of the locality from 1944 to 1950 and detailed investigations from 1951 to 1953. The results of these investigations are described in detail in reports by Wyant, Sharp and Sheridan (in preparation) and Sheridan, Maxwell and Collier (in preparation).

The deposits are caliche-like and are confined to the alluvium and the upper several feet of the underlying bedrock. The schroeckingerite was formed so recently that the uranium and its disintegration products have not attained radioactive equilibrium (Wyant, Sharp and Sheridan, in preparation). Reconnaissance mapping and stratigraphic studies by the author indicate that at least part of the bedrock of the schroeckingerite locality is in the Tipton tongue of the Green River formation. The presence of low-grade oil shale suggests, furthermore, that some of these beds are in the upper part of the lower Tipton. (See stratigraphic discussion of the Tipton tongue, and the restored section and geologic map on figure 2.)

ORIGIN OF THE URANIUM DEPOSITS

Wyant, Sharp and Sheridan (in preparation) consider two ways in which the uranium may have accumulated in the coal beds of the Red Desert area. 1) Syngenetic--the uranium was introduced by ground and surface water into swamps where coal was forming and was fixed before coalification by biogenetic processes or by carbon fixation; and 2) epigenetic--the uranium was leached from overlying source rocks, such as volcanic ash, by ground and surface water and carried down to precipitate in, or be adsorbed by lignite.

They expressed a preference for explanation 1) a syngenetic or at least pre-coalification origin for the uraniferous lignite beds in the Red Desert area.

Because of the much greater amount of information now available for this area the suggested explanations outlined above can be refined and amplified as follows:

1) Syngenetic--the uranium accumulated while the coal was forming (early Eocene time). It was introduced into the swamps by ground and surface water or by direct uranium-bearing ash falls.

Possible sources of uranium: a) the Granite Mountains, b) the Battle Spring formation, c) a deep-seated hydrothermal source emplaced during or shortly before early Eocene time, d) volcanic eruptions during early Eocene time.

2) Diagenetic--the uranium accumulated during or shortly after the formation of the coal, but before hardening of the coal and the surrounding sediments.

The Eocene rocks were folded prior to the deposition of younger rocks (Browns Park of this report) inasmuch as none of the Eocene rocks show signs of having been folded while still in an unconsolidated state. Lithification of the coal-bearing rocks must have occurred no later than the closing stages of Eocene time. Thus the time of mineralization under the diagenetic explanation was confined to the Eocene. The uranium was introduced primarily by groundwater, and to some extent, by surface water and direct volcanic ash falls.

Possible sources of uranium: a) the younger parts of the Wasatch and Green River formations, b) the Bridger formation and c) the sources listed under the syngenetic explanation above. Hydrothermal sources could have come into existence any time during the Eocene.

3) Epigenetic--the uranium accumulated after the coal beds and surrounding rocks were formed, hardened, folded and eroded. Mineralization occurred after the close of the Eocene. Uranium was introduced into the coal by circulating groundwater.

Possible sources of uranium: a) the Battle Spring formation, b) the Granite Mountains _/, c) post-Eocene sedimentary rocks d) post-Eocene deep-seated hydrothermal sources and e) post Eocene volcanic ash falls.

It is doubtful that upper Eocene and Oligocene rocks ever covered the map area. The only identifiable post-Eocene Tertiary rocks in the map area are confined to the northern edge and belong to the Browns Park formation of Miocene age. Pliocene rocks overlie Miocene rocks in the Granite Mountains (J. D. Love, 1952, written communication) and quite possibly at one time overlay the Browns Park of the map area.

The basal conglomerate and the interbedded arkosic and tuffaceous sandstone beds in the lower part of the Browns Park formation of this report are believed by some geologists to be either of late Eocene or Oligocene age or both (Nace, 1939, p. 25; J. D. Love, oral communication, 1951; Wyant, Sharp and Sheridan, in preparation; W. G. Bell, oral communication, 1953).

4) In addition to the above, it may be that a combination of all three methods could have accounted for the present day distribution of uranium in coal.

The author believes that the following epigenetic explanation, one of the possibilities listed under 3), is more likely to be closer to the true explanation than any of the others.

The uranium accumulated after the coal-bearing Eocene rocks were formed, hardened, folded and eroded, and after the Eocene rocks were buried by uranium-bearing post-Eocene rocks. The uranium was introduced almost entirely by groundwater moving downward and then laterally for considerable distances guided by structural conditions and stratigraphic facies changes.

The source of the uranium was the Browns Park formation. The uranium in this formation, undoubtedly contained in volcanic constitutents such as glass shards, presumably would not be released until the shards were devitrified (Waters and Granger, 1953, p. 21). The process of transferring uranium from the Browns Park formation to underlying rocks began as soon as that formation came into existence, but probably the transfer of the bulk of the uranium took place after deposition and lithification of the Browns Park formation and overlying Pliocene rocks, if any, and after post-Pliocene uplift giving surface and groundwater a chance to percolate through these rocks and leach the uranium. The process of devitrification likewise would not be rapid until after lithification and uplift of the post-Eocene Tertiary rocks.

Objections to a syngenetic or diagenetic origin for uranium occurrences in coal are: 1) the distribution of uranium apparently is influenced by regional structure and 2) the vertical and lateral distribution of uranium in coal is considerably less uniform than would reasonably be expected if the uranium accumulated at the time the coal was formed or shortly thereafter. 3) Some of the more uraniferous coal beds are definitely associated with Pleistocene gravel deposits.

Larsen (1937, p. 7) believes that the final steps in the formation of the schroeckingerite deposits are 1) rising of water solutions to the surface by capillarity, 2) evaporation of the water, 3) deposition of dissolved minerals. Wyant, Sharp and Sheridan (in preparation) agree and further note that the deposits are confined to the Cyclone Rim fault zone and are apparently related to iron-stained solution zones. The southern limit of this fault zone is shown south of the schroeckingerite locality on figure 2 of the present report. They concluded that the zone of faulting is a major control for the localization of the schroeckingerite deposits.

To the above information on factors controlling groundwater movement, the author would add the following. (See also discussion of the schroeckingerite area in section on structure.)

Plate 18, section C-C', is a diagrammatic south-north structure section across the graben along whose southern border the schroeckingerite deposits are located. The section shows only major stratigraphic units and structural features. The Miocene rocks have been projected into the plane of section. Numerous small east-west trending south-dipping normal faults that occur in the schroeckingerite locality (Wyant, Sharp and Sheridan, in preparation; Sheridan, Maxwell and Collier, in preparation) are not shown. A structure section drawn from west to east nearly normal to section C-C' and along the axis of the syncline in the graben, would show that the syncline plunges eastward, flattens out in the area northwest of the schoreckingerite deposits, and rises again east of the deposits (fig. 3). The structural setting is such that groundwater north of the schroeckingerite deposits presumably is under hydrostatic pressure from the west, north and east. Lost Creek flows south across the structurally lowest part of the graben.

The asymmetric distribution of the deposits with respect to Lost Creek (nearly all of the deposits lie east of Lost Creek) may be due to the fact that the graben is structurally higher in the west causing the area of hydrostatic equilibrium to be displaced slightly eastward, up-structure from the lowest part of the syncline in the graben.

The stratigraphic and structural circumstances and the caliche-like nature of the schroeckingerite make it highly probable that the deposits are made by evaporation of uranium-charged ground water brought to the surface by a combination of artesian conditions and capillary action.

SOURCE OF THE URANIUM

The probable origins of the uranium in the coal and in the schroeckingerite deposits have been described above together with the evidence favoring an epigenetic origin over diagenetic or syngenetic origins. Determination of the source of the uranium in these two types of deposits is considerably more difficult inasmuch as it has proved impossible to tell from an examination of the deposits themselves anything about the source of the uranium. Conclusions as to the source must depend on indirect or negative evidence, regional considerations and purely theoretical considerations.

In connection with the schroeckingerite deposits, Wyant, Sharp and Sheridan (in preparation) favored the possibility that the uranium was leached by groundwater from uranium-bearing coal beds which were inferred to underlie the schroeckingerite deposits and carried to the surface along the Cyclone Rim fault zone.

Subsequent work has rendered this possibility highly improbable because 1) it is questionable whether the coal beds these authors had reference to (upper coal group of the present report) extend north as far as the schroeckingerite locality and 2) it is practically impossible for groundwater to leach uranium from coal.

In discussing the results of laboratory experiments demonstrating the facility with which low rank coals can extract uranium from aqueous solution, Moore (1954) states, "The uranium is apparently retained in the coal by an irreversible process."

Wyant, Sharp and Sheridan assumed that uranium could be leached from coal by groundwater because most of the nine surface samples of coal and carbonaceous shale which they collected apparently contained an insufficient amount of uranium (U, determined by chemical analyses) to account for the radioactivity (eU, determined radiometrically).

Chemical and radiometric analyses of 485 samples of coal, carbonaceous shale, carbonaceous siltstone, black shale and coaly shale taken from the cores shown on figures 7 and 8 show that only six samples (none of which were coal) contain an excess of eU over U of more than 0.003 percent (maximum analytical error), indicating that the uranium in the coal beds of this area is not subject to leaching by the present groundwater.

Breger, Deul and Meyrowitz (1955, p. 620-621) point out that the presence of schroeckingerite in this area suggests that the groundwater contains uranium in the form of soluble alkaline or alkaline-earth uranyl carbonate. Alkaline uranium-bearing groundwater not only is incapable of leaching uranium from coal but would most probably surrender its uranium to the coal upon contact.

The above practically rules out the possibility that the uranium in the schroeckingerite deposits came from underlying uranium-bearing coal beds.

The groundwater and/or surface water which carried the uranium now in the coal beds and in the schroeckingerite deposits could have acquired the uranium from 1) a deep-seated hydrothermal source, 2) from granite-derived uranium minerals in the arkose of the Battle Spring formation, or 3) from the weakly uraniferous tuffaceous Browns Park formation. Other possible sources appear to be too improbable to consider.

The author knows of no conclusive evidence to support the first possibility in this area. Iron-staining, carbonate veins (Lincoln R. Page, oral communication) and iron oxide cement in the rocks associated with the schroeckingerite deposits cannot be considered as unequivocal evidence of the presence of a hydrothermal source beneath the schroeckingerite locality or surrounding areas inasmuch as these features can also be formed by action of groundwater that has not come in contact with hydrothermal solutions.

The lava flows capping the Leucite Hills, some 50 miles southwest of the schroeckingerite locality, are too far away to be cited as evidence of a deep-seated hydrothermal source that might have contributed uranium directly to the schroeckingerite deposits. The suggestion that such a hydrothermal body might have contributed uranium to groundwater which then carried the uranium westward to the schroeckingerite deposits and to the coal beds in contradicted by the distribution of the uranium deposits. Contrary to what might be expected under such a hypothesis the uranium content of the coal beds increases eastward with distance from the Leucite Hills, and the deposits, both in the coal and in the schroeckingerite deposits, are situated adversely with respect to structural and stratigraphic controls of hypothetical groundwater movement from the Leucite Hills eastward.

The possibility that the Battle Spring formation was the source of the uranium, is in the author's opinion, improbable. The arkosic sandstone beds were clearly derived from the Granite Mountains north and northeast of the map area. Inasmuch as the uranium in minerals that withstand transportation well, such as monazite, is not leachable under normal groundwater conditions, consideration must be given to interstitial uranium that may be present in the granite of the Granite Mountains. Such interstitial uranium from granites elsewhere is said to be readily leachable (Larsen, Jr., and Phair, 1954, p. 80). But whether the interstitial uranium is readily leachable under field conditions is uncertain.

The Granite Mountains are overlapped by a minimum of 900 feet of weakly uraniferous tuffaceous rocks (Love, 1952, written communication) that almost certainly at one time completely covered them and it may be difficult to determine how much of the interstitial uranium that may be present in the granite was derived from magma and how much of it from overlying uranium-bearing tuffaceous rocks.

The suggestion that the overlying tuffaceous rocks may have supplied the interstitial uranium that may be present in the granite of the Granite Mountains is essentially the same as that made by Hurley (1950, p. 5) to explain discrepancies in helium age determinations of igneous rocks: "If it is true that supergene alterations have effected these changes in igneous rocks, the cause of low helium-ages in igneous rocks may be due to modification of the radioactivity late in the rocks' history rather than the losses of helium."

From previous discussions it seems certain that structure played an important role in determining the distribution of the uranium in this area. It then seems difficult to explain the widespread occurrences of uranium in coal far removed from the Battle Spring formation and in structurally unfavorable positions, if that formation were the source of the uranium.

The coal beds in the Tipton Buttes area locally contain as much as 0.005 percent uranium (Tierney No. 5 at the locality shown in pl. 13), yet they are many miles from the Battle Spring formation and are separated from it by the Wamsutter (?) arch.

A sample from a coal bed in the Fort Union formation many miles west of the map area on the east flank of the Rock Springs uplift contained 0.025 percent uranium. Obviously, because of the structural and stratigraphic conditions, groundwater could not have carried uranium up-structure from the Battle Spring formation to these localities. Such widespread sporadic distribution of uranium occurrences in an area that locally contains smaller well defined areas of relatively higher concentrations, as along the Red Desert syncline, seems to require a widespread source of uranium.

In contrast to the real or apparent lack of evidence in favor of the two possibilities discussed thus far, remnants of the weakly radioactive tuffaceous sandstone beds of the Browns Park formation of Miocene age crop out less than a mile from the schroeckingerite deposits. Remnants of this formation are also preserved at the Rawlins Uplift and south at least as far as Baggs, Wyoming; and at Aspen Mountain and other areas in the southern part of the Rock Springs Uplift southwest of the Great Divide Basin. Similar rocks cap the Oregon Buttes in the northwest corner of the Great Divide Basin. Thus at one time these tuffaceous rocks quite likely covered the entire Great Divide Basin.

These tuffaceous rocks are weakly radioactive and the following analyses of tuffaceous sandstone made by analysts of the Geological Survey, Denver Laboratory are typical of the Browns Park formation in the northern part of the map area:

Locality	eU (percent)	U (percent)	Serial No.
SE1/4 sec. 24 T. 26 N., R. 95 W.	0.003	---	58387
SE1/4 sec. 14 T. 26 N., R. 95 W.	.001	0.001	56751
	.001	.001	56752
	.002	---	56864
SE1/4 sec. 31 T. 27 N., R. 95 W.	.002	---	56865
	.001	---	56866

These few analyses are admittedly inadequate to support the contention that the Browns Park formation was the source of the uranium in this area. A suite of 20 samples of this formation, which were collected by the author for detailed analyses and study, unfortunately were lost in shipment.

Nevertheless, the analyses available suggest that at one time this formation locally contained at least 0.003 percent uranium, which has since been leached. The upper part of the Bridger formation directly below the Browns Park contains numerous beds of silicified claystone and limestone, white and brown chalcedony layers, and black, completely silica-replaced, fossil tree stumps and trunk segments. The silica in the upper part of the Bridger is interpreted to have been derived from the devitrification of volcanic glass shards in the overlying Browns Park. Such a process would facilitate the oxidation, removal, and transport of the uranium in the shards. This possibility was suggested by Waters and Granger (1953, p. 20-21).

Miocene and Pliocene (?) rocks northeast, southeast and south of the central part of the Great Divide Basin are known to contain uranium. Pliocene (?) rocks of the Split Rock area (part of the Granite Mountains) contain as much as 0.005 percent uranium and 0.016 percent equivalent uranium (J. D. Love, written communication, 1952). Miocene (?) and Miocene rocks of the Miller Hill and Baggs areas locally contain more than 0.1 percent uranium (Love, 1953, p. 7; Vine and Prichard, 1954, p. 4).

The foregoing indirect evidence is in keeping with the suggestion that the source of the uranium in the central part of the Great Divide Basin probably was the Browns Park formation.

Though the uranium content of the Browns Park is low, such a source can adequately account for the large tonnages of uranium in the coal beds of this area as well as its widespread areal distribution.

The process of leaching of the uranium from tuffaceous beds stratigraphically high in the section by percolating ground water and the redeposition of uranium in coal beds lower in the section was advanced in 1950 as an explanation of the uranium occurrences in the coal beds of northwestern South Dakota by Denson, Bachman and Zeller (in preparation). There, the proximity of highly uraniferous coals to the tuffaceous beds of the Oligocene White River and the Miocene Arikaree formations capping the buttes served to focus attention primarily on the role played by the downward movement of ground water; the necessity to postulate lateral movements of any appreciable magnitude is absent.

Because of the presence of numerous thick tongues of impermeable low grade oil shale throughout most of the coal-bearing area of the central part of the Great Divide Basin, the distribution of uranium cannot be explained primarily by downward movement of uranium-bearing ground water and necessitates the supposition that lateral movements of water played the dominant role in the emplacement of the uranium in the coal beds.

The author believes that the most probable source of uranium in the coal beds and schroeckingerite deposits of this area was and is the weakly uraniferous tuffaceous sandstone beds of the Browns Park formation. Transfer of the uranium from the source rocks directly downward was prevented throughout most of the coal-bearing area by intervening thick sequences of nearly impermeable beds of the Green River formation. Where these impermeable beds were absent and the source rocks rested on permeable Battle Spring formation, uranium-bearing water percolated downward and laterally for several miles in response to structural and permeability controls such as the Red Desert syncline and the zone of facies changes described previously.

Absorption of uranium by coal from groundwater is a process that generally seems irreversible in nature. The coal beds nearest the permeable tongues of the Battle Spring formation accumulated higher concentrations of uranium than did the coal beds farther away.

The process of leaching and transport of uranium from the Browns Park formation to its present sites of deposition presumably commenced as soon as that formation came into existence, probably reached a climax in the wet periods of the Pleistocene and continues at a greatly diminished rate today. The vast areas once underlain by the Browns Park formation are now represented by relatively small remnants and only in their vicinity, as at the schroeckingerite locality, is the process of leaching, transport, and deposition of uranium noticeable operative.

SUGGESTIONS FOR PROSPECTING

Uranium in coal

The east flank and the trough of the Red Desert syncline offer the best possibilities for developing uranium-bearing coal if such an operation becomes economically feasible. No uranium minerals have been found as yet in the coarse-grained rocks that crop out in the coal-bearing part of the area, but it seems reasonable to suppose that prospecting might disclose occurrences of uranium minerals in the coarse sandstone associated with coal beds within the map area and in the sandstone beds in the area adjacent to the northeast.

Schroeckingerite

In prospecting for other schoreckingerite deposits all areas should be examined that are underlain by coarse-grained rocks whose structure would favor channeling and restricting the flow of ground water which in turn would enhance the possibility of caliche-type uranium deposits. The most favorable (because of nearness to tuffaceous rocks, the hypothetical source of the uranium) such locality in the map area lies in the vicinity of Grass and Daly Lakes in the extreme northwest corner of the map area. There the Browns Park, the Bridger and the Morrow Creek all contain coarse-grained beds, and in the last named two, impermeable shale beds occur which guarantee the presence of some stratigraphic traps which could be mineralized. The second and less favorable area lies along the fault zone in the vicinity of Niland's Spring in T. 25 N., R. 96 W.

Other uranium minerals

While the manuscript of this report was being written, the writer was informed by J. D. Love (written communication, 1955) of the discovery of meta-autunite by prospectors in conglomeratic beds in sec. 15, T. 26 N., R. 96 W. Love indicates his belief that the conglomerates in which the mineral occurs are in place. If so, the mineral occurs in the Cathedral Bluffs tongue of the Wasatch. This occurrence is near one of the topographically highest parts of the map area and could not have been separated by any appreciable thickness of sediments from the Miocene tuffaceous rocks, remnants of which are still preserved in this part of the area. Inasmuch as conglomeratic beds are numerous in the Cathedral Bluffs tongue from about the middle of R. 97 W. and eastward, and considerable parts of this area lie at relatively high altitudes, it seems probable that other finds will be made there, if the supposition that the tuffaceous beds of the Browns Park formation are the source of the uranium in this area is correct.

Oil and gas

Since the days of Hayden (1868, p. 252) the area now known as the Great Divide Basin has been considered to be a structural, as well as a topographic basin, and has received scant attention from oil geologists. The Great Divide Basin probably is synclinal in eastwest cross section, but it is anticlinal in north-south cross section (fig. 2 structure section and fig. 3). The resultant structure is saddle-shaped: the Rock Springs uplift forms the west side and the Rawlins uplift forms the east side of the structurally high broad open parts of the "saddle"; the Washakie Basin forms the structurally low relatively narrow south side of the saddle; and the structurally complex area of en echelon folds and faults, extending from the Green Mountains westward to Oregon Buttes, forms the north side.

The broad gentle Wamsutter (?) arch contains a number of structural highs on its crest, the largest of which is the Tierney anticline (fig. 3). It seems probable that these folds increase in amplitude with depth. The arch, which may be a continuation of the Wamsutter arch of Schultz (1920) or may be independent of it and en echelon to it, presumably was folded penecontemporaneously with the Rock Springs uplfit and the Rawlins uplift. In both these uplifts angular unconformities exist between Cretaceous and Paleocene rocks and between Paleocene and Eocene rocks. Even though the Wamsutter (?) arch might not have been as severely affected as these uplifts, it doubtless was affected to some extent; and, therefore, the effects of deformation resulting in folds such as those shown in figure 3 should be more pronounced at depth as is the case along the flanks of the afore-mentioned uplifts. Certainly it seems unreasonable to assume that they die out with depth. There are a number of producing oil and/or gas fields peripheral to the Great Divide Basin so that it seems possible that within the Basin itself other oil or gas accumulations may be present.

In addition to the structures shown on figure 3, the township tiers 25 and 26 North, which were mapped in reconnaissance and without sufficient vertical control to draw a complete structure contour map, apparently contain some geologic features of interest for oil prospecting. Several inferred anticlinal axes are shown on figures 2 and 3 and in addition, the southwest part of T. 26 N., R. 96 W. and the southeastern part of T. 26 N., R. 97 W. may be underlain by a broad fold or by a structural terrace. This possibility is suggested by the broadening of the outcrop pattern of the Cathedral Bluffs tongue in these areas, and by the distinct change in the strike of the beds from northwest to northeast as shown by the outcrop pattern of the overlying Morrow Creek member and the Bridger formation in the northern parts of these two townships.

RESERVES

Computation of reserves

The following table shows the category cut-off limits used in calculating coal and uranium reserves shown on figures 9-27.

MEASURED AND INDICATED COAL RESERVES

Category cut-off limits

Thickness of coal (feet)
10 or more
5 to 10
2.5 to 5

INFERRED URANIUM RESERVES

Category cut-off limits

Uranium in coal (percent)	Uranium in coal ash (percent)
0.010 or more	0.050 or more
.005 to .010	.020 to .050
.003 to .005	.015 to .020

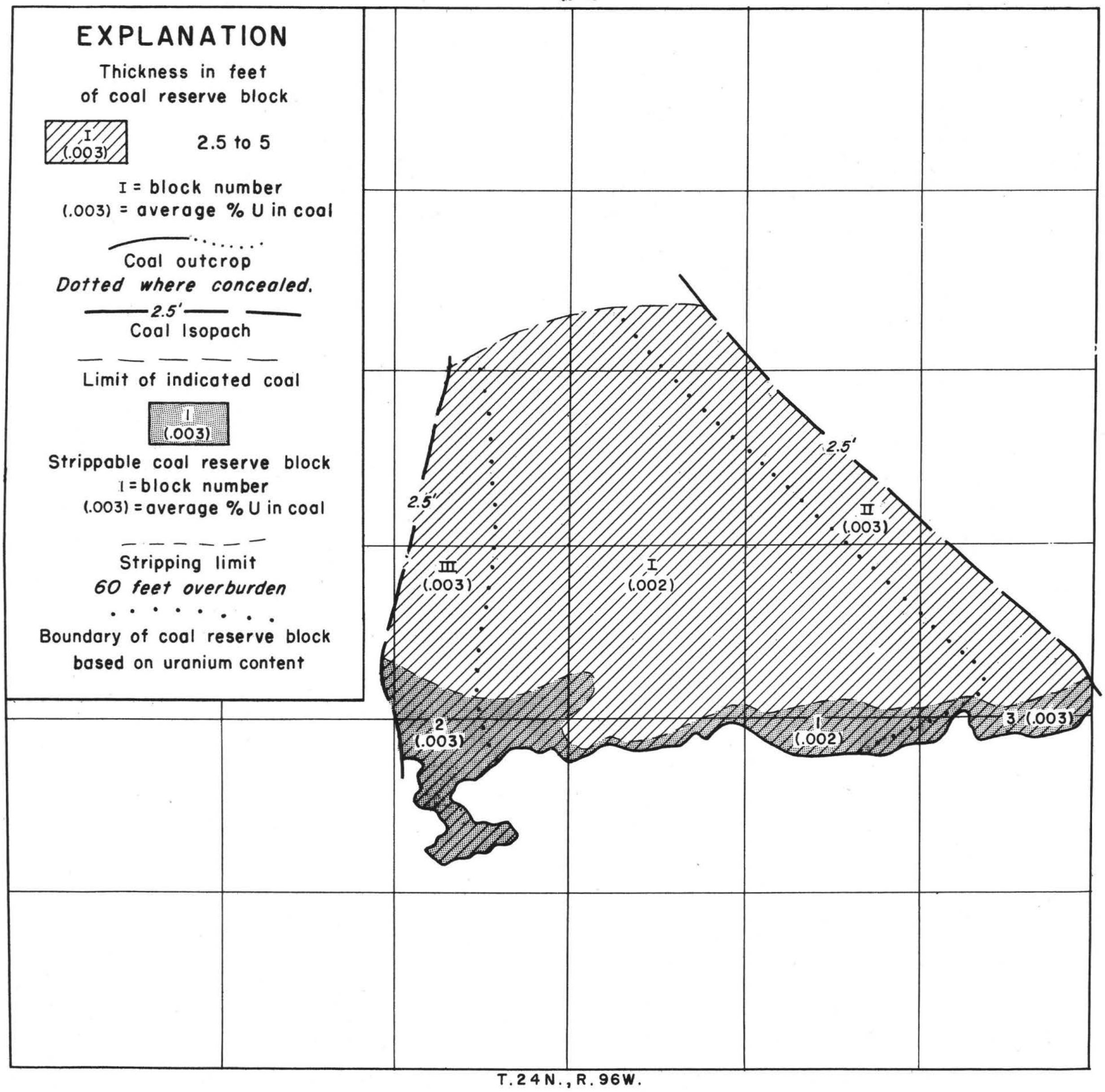
Coal beds less than 2.5 feet thick or which might be present more than 2 miles from the nearest surface section, auger hole or core hole are not included in computation of reserves. Also excluded from consideration are those coal beds whose ash content exceeds 33 percent, or contain partings whose combined thickness is more than half the total thickness of the bed.

Coal beds containing less than 0.003 percent uranium are excluded from uranium-in-coal reserve computation, but their uranium content is shown in the tables if the coal beds are 2.5 or more feet thick. Similarly, coal beds whose ash contains less than 0.015 percent uranium are excluded from computation of uranium-in-coal-ash reserves, but their uranium content is shown if the coal bed is 2.5 or more feet thick. (See Block I, fig. 9.)

Measured coal reserves are those within a half-mile radius of the nearest control point (surface section, auger hole, core hole). Indicated coal reserves are those within a 2-mile radius of the nearest control point. Measured and indicated reserves are combined into one category for the purposes of this report. About one-fourth to one-third of the total coal reserves (table 5) is measured coal.

The tons of coal contained in each bed in the reserve areas was computed as follows:

An isopachous map of each coal bed was prepared for each township. It was impractical to consider the three main beds of the Monument zone separately and the coal reserves shown for this zone are based on the combined thickness of Monument No. 1, No. 2 and No. 3, except where otherwise indicated.

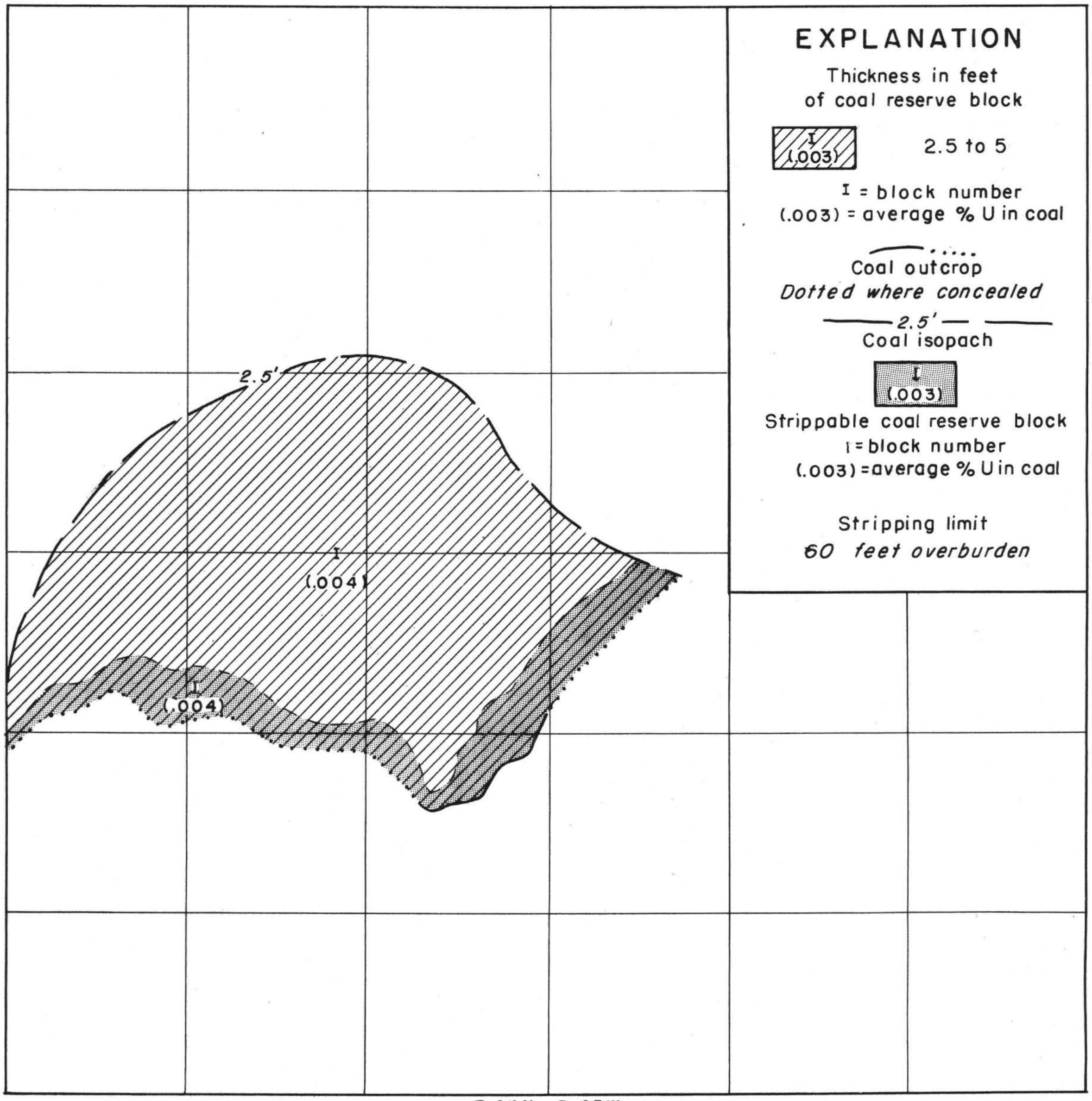


MEASURED AND INDICATED COAL RESERVES — INFERRED URANIUM RESERVES

Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	URANIUM IN ASH: Average uranium content (percent) 2/	URANIUM IN ASH: Uranium 1/ (short tons)	URANIUM IN COAL: Average uranium content (percent) 3/	URANIUM IN COAL: Uranium 1/ (short tons)
I	2,980	3.8	20,000,000	17.0	0.013	---	0.002	---
II	956	3.8	6,400,000	17.0	.016	170	.003	170
III	750	2.8	3,700,000	17.2	.016	100	.003	100
Total 1/			30,000,000			270		270
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	331	4.0	2,400,000	20.0	0.013	---	0.002	---
2	261	2.7	1,300,000	17.2	.016	30	.003	30
3	125	3.5	780,000	17.0	.016	20	.003	20
Total 1/			4,500,000			50		50

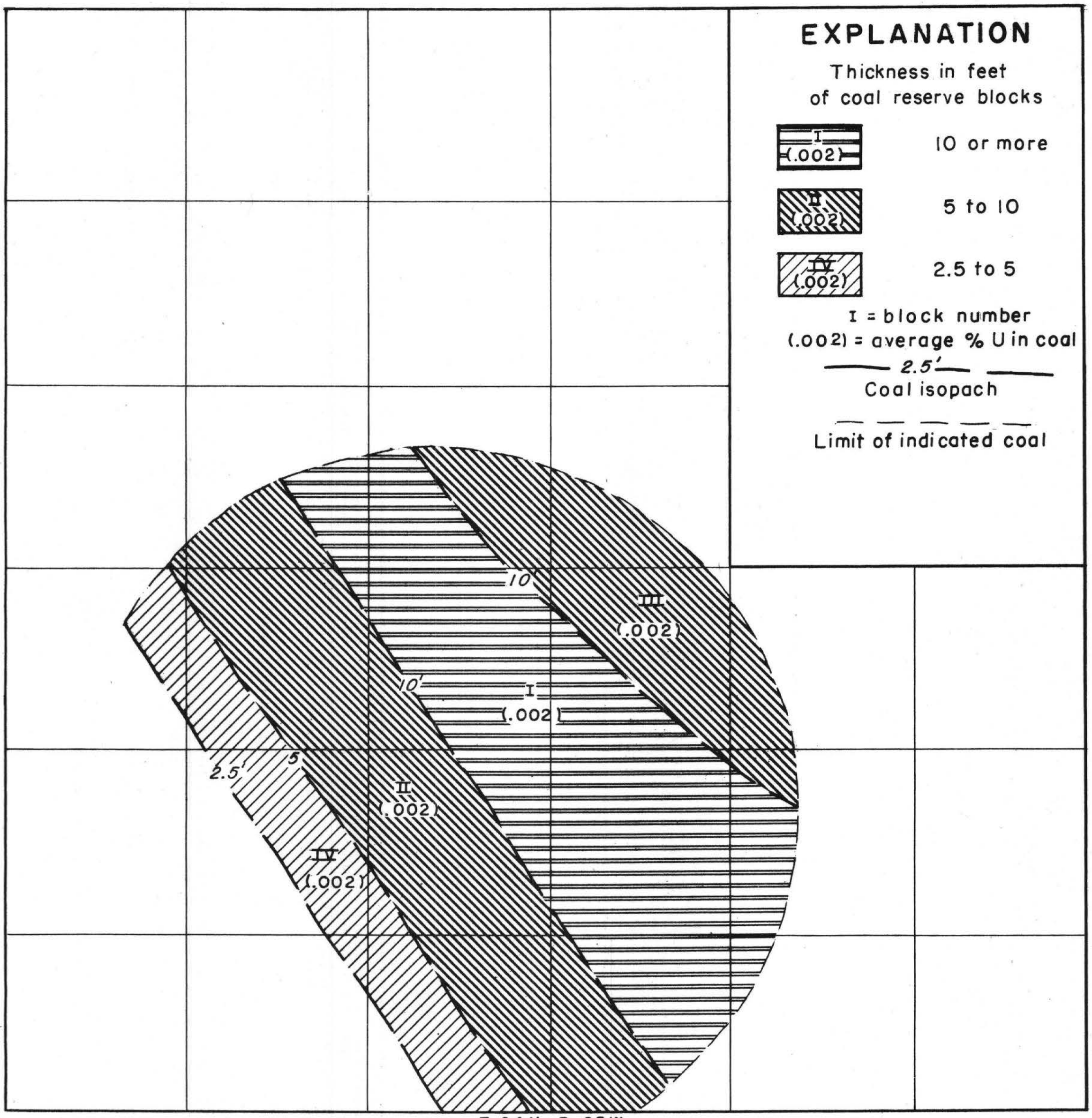
1/ All tonnage estimates rounded to two significant figures. Dashes mean not calculated. See section, "Computation of reserves" for formulas used to obtain these estimates, and for cutoff limits.
2/ Analyses by the U. S. Geological Survey laboratory, Washington, D. C.
3/ Calculated from percent ash and percent uranium in ash.

Figure 9.--Reserves of uranium-bearing coal for Luman No. 2 bed in T. 24 N., R. 96 W. in central part of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	3,542	3.8	24,000,000	20.0	0.019	910	0.004	910
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	607	3.8	4,100,000	26.0	0.017	180	0.004	180

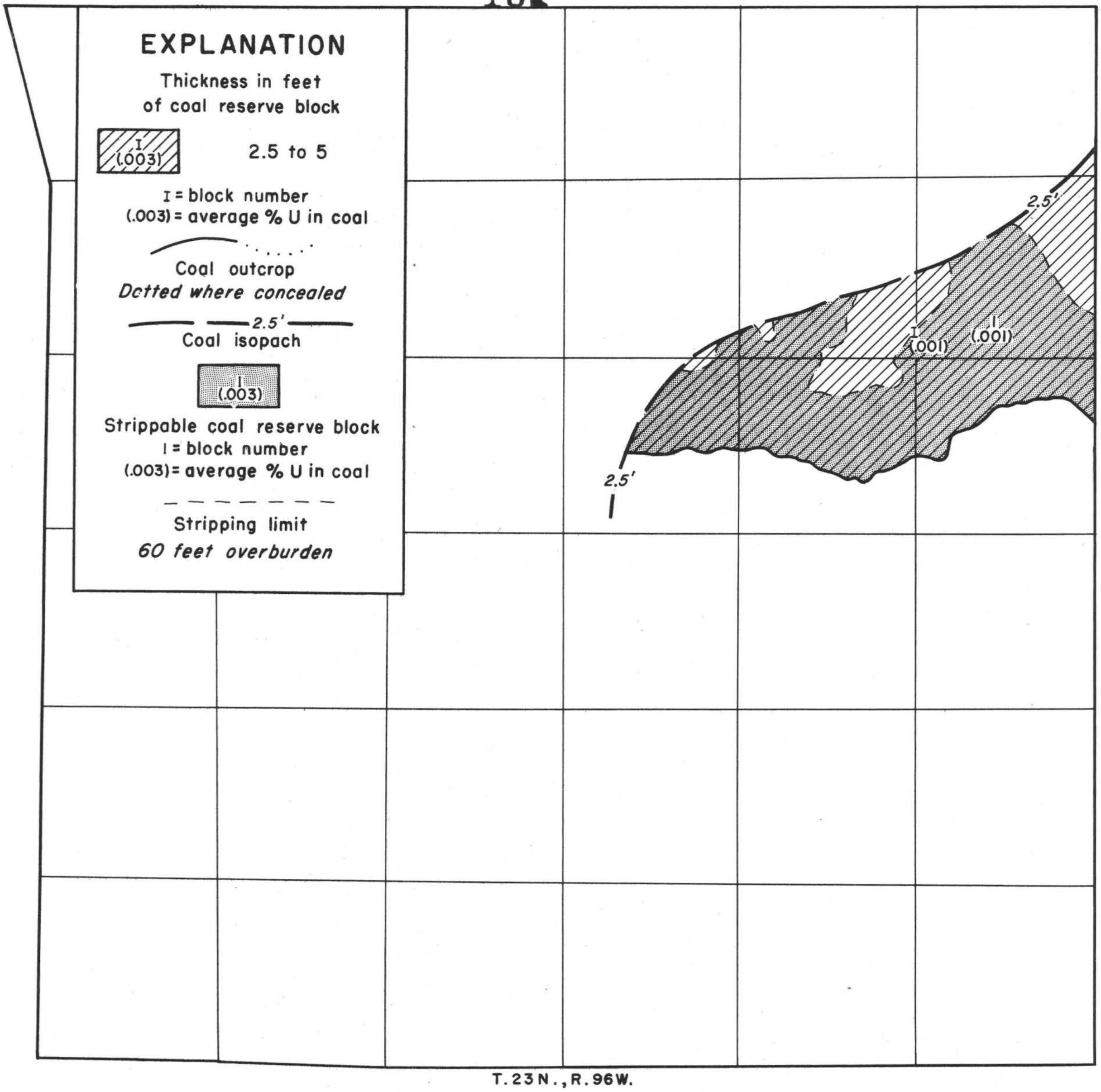
Figure 10.--Reserves of uranium-bearing coal for Luman No. 1 bed in T. 24 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



T. 24 N., R. 95 W.

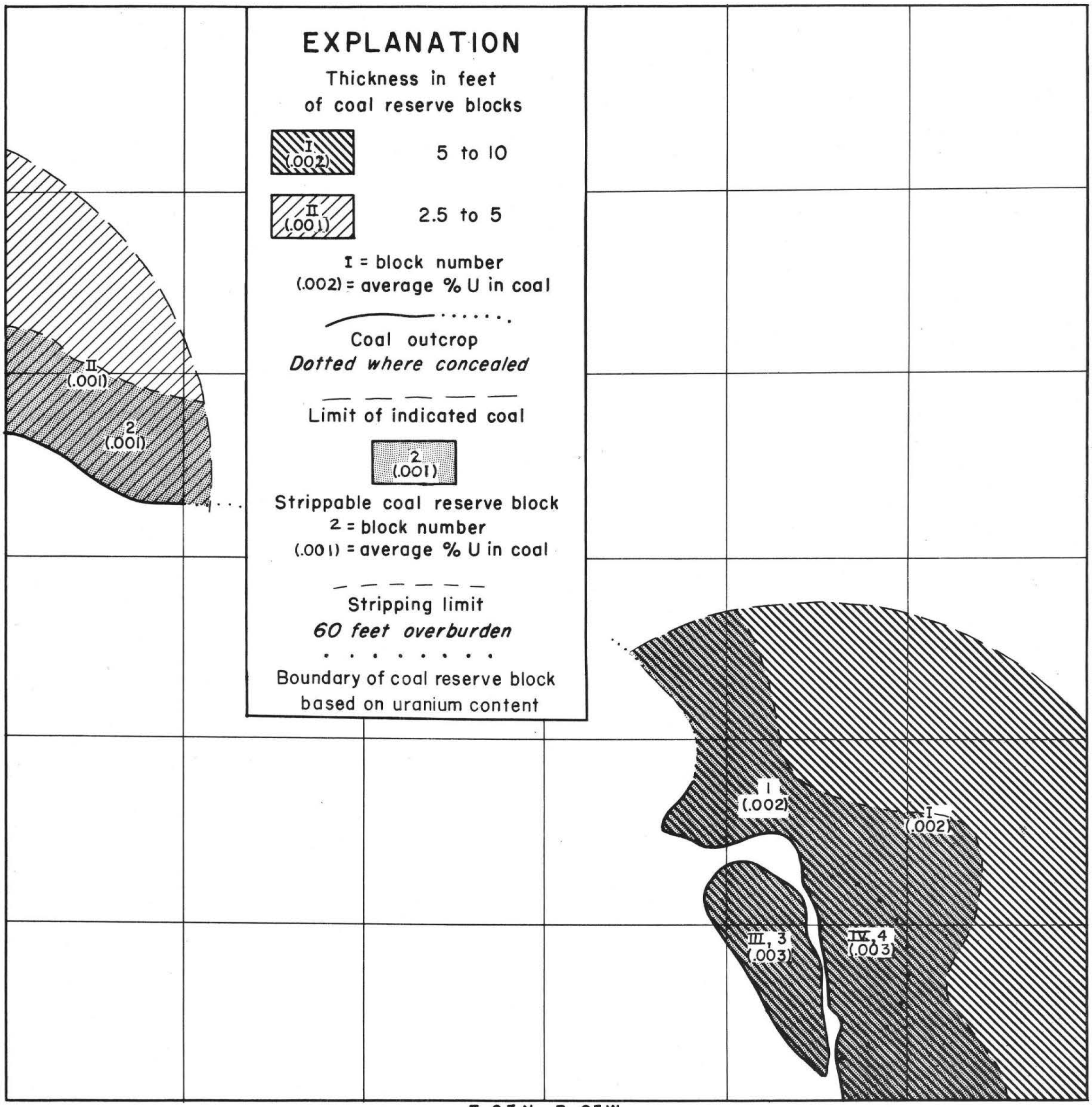
MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	2,353	11.0	46,000,000	11.5	0.013	---	0.002	---
II	1,765	7.5	24,000,000	11.5	.013	---	.002	---
III	950	8.0	14,000,000	11.5	.013	---	.002	---
IV	790	3.8	5,300,000	11.5	.013	---	.002	---
Total 1/			88,000,000					

Figure 11.--Reserves of uranium-bearing coal for Battle No. 3 bed in T. 24 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



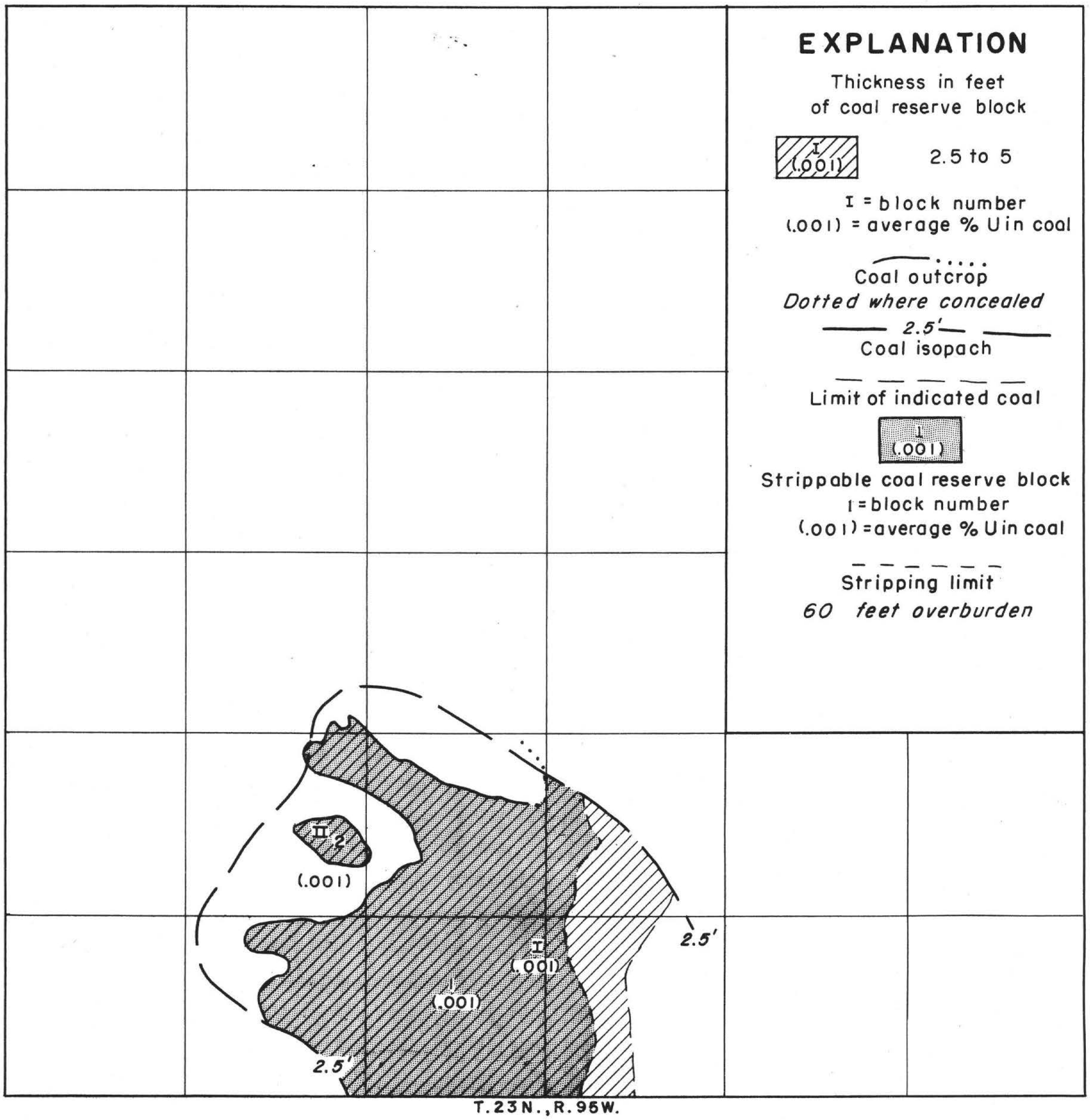
MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	1,459	3.0	7,700,000	22.0	0.003	---	0.001	---
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	1,117	3.3	6,800,000	15.0	0.003	---	0.001	---

Figure 12.--Reserves of uranium-bearing coal for Monument No. 2 bed in T. 23 N., R. 96 W. in central part of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	2,833	7.0	35,000,000	17.7	0.012	---	0.002	---
II	950	3.4	5,700,000	21.0	.007	---	.001	---
III	271	5.5	2,600,000	12.0	.022	70	.003	70
IV	226	6.4	2,600,000	12.0	.022	70	.003	70
Total 1/			46,000,000			140		140
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	1,168	6.0	12,000,000	17.7	0.012	---	0.002	---
2	442	3.1	2,400,000	21.0	.007	---	.001	---
3	271	5.5	2,600,000	12.0	.022	70	.003	70
4	226	6.4	2,600,000	12.0	.022	70	.003	70
Total 1/			20,000,000			140		140

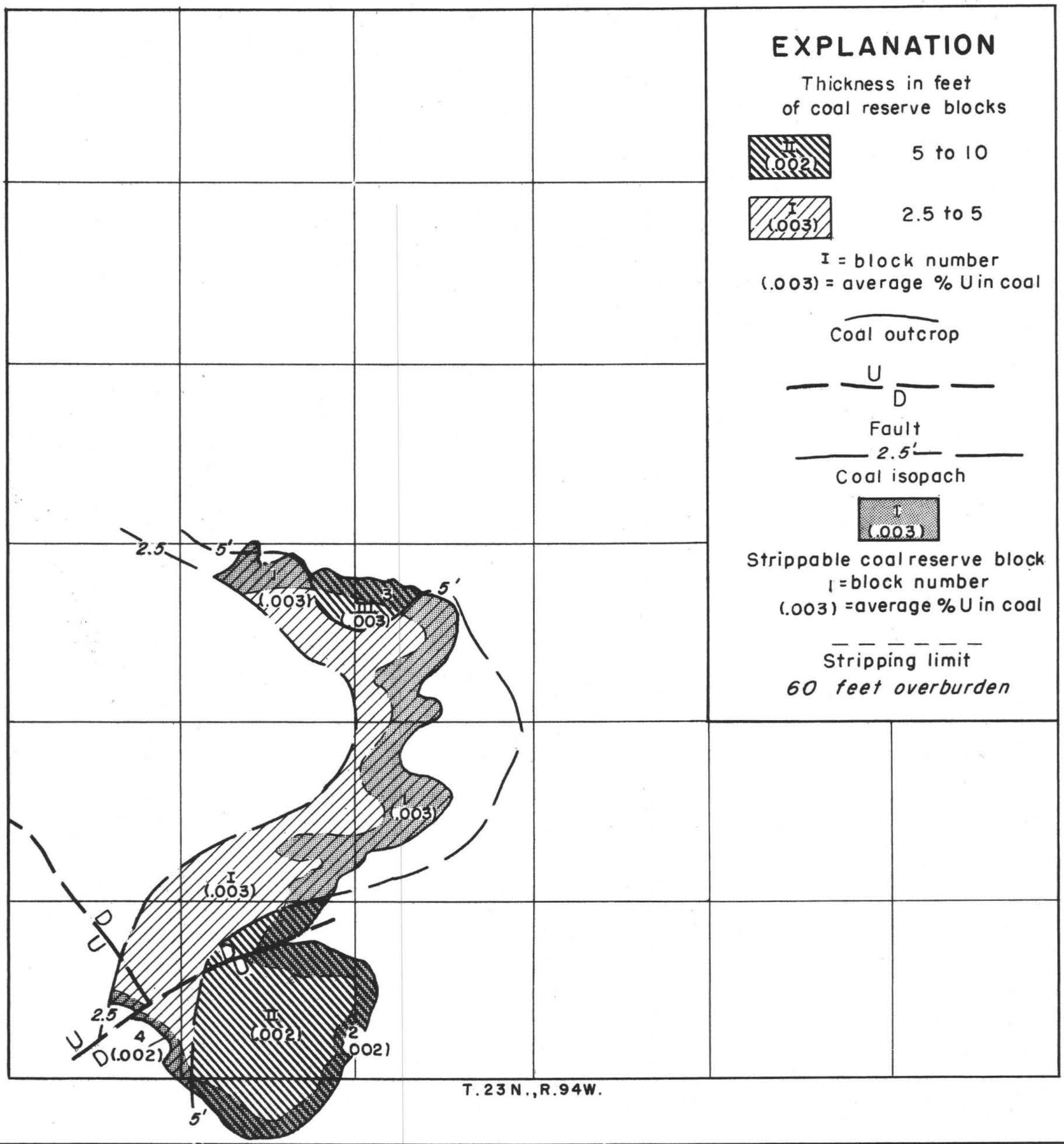
Figure 13.--Reserves of uranium-bearing coal for Monument No. 2 bed in T. 23 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES — INFERRED URANIUM RESERVES

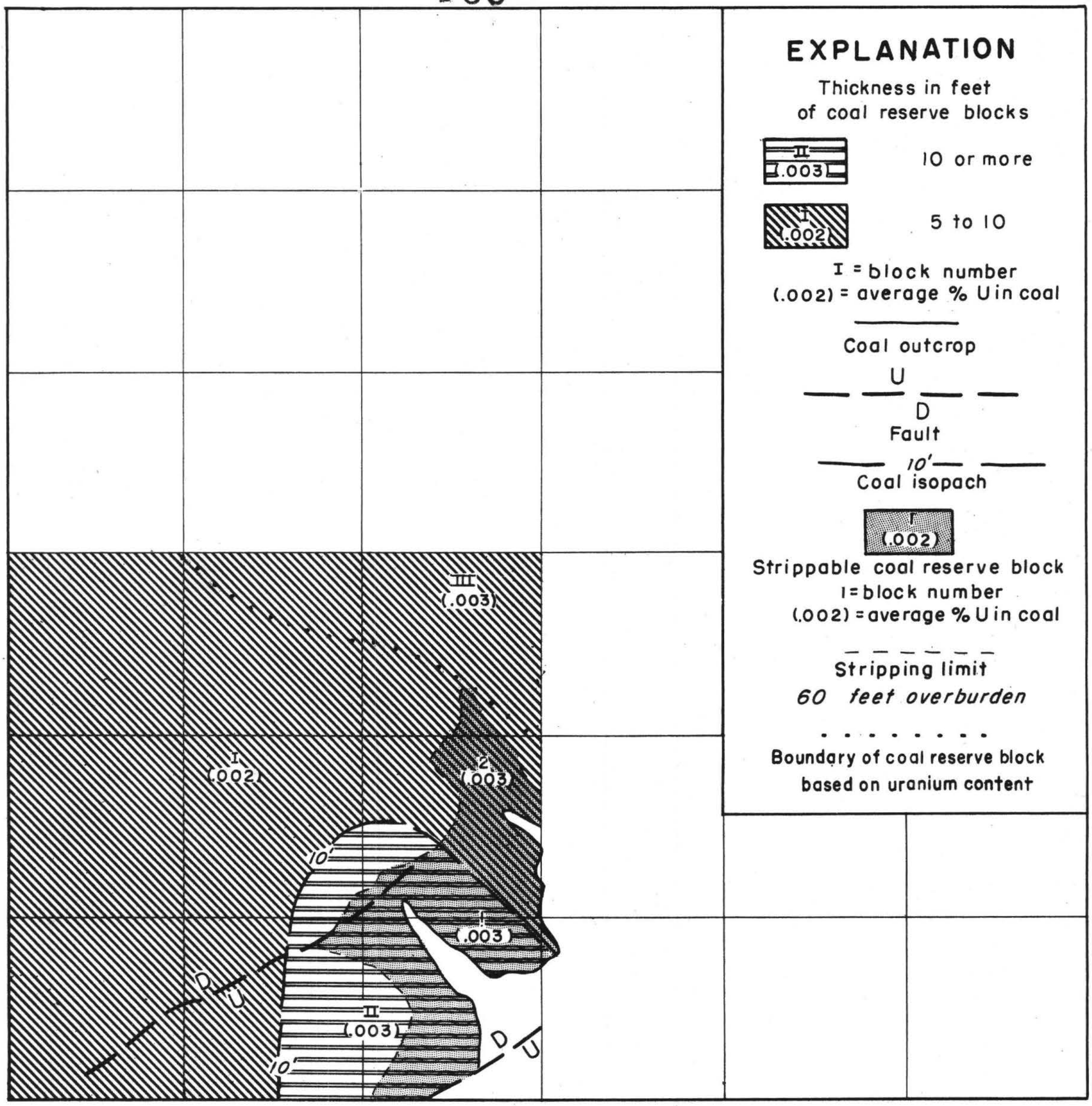
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	URANIUM IN ASH: Average uranium content (percent) 2/	URANIUM IN ASH: Uranium 1/ (short tons)	URANIUM IN COAL: Average uranium content (percent) 3/	URANIUM IN COAL: Uranium 1/ (short tons)
I	1,905	3.5	12,000,000	15.0	0.007	---	0.001	---
II	41	2.8	200,000	15.0	.007	---	.001	---
Total 1/			12,000,000					
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	1,575	3.6	10,000,000	15.0	0.007	---	0.001	---
2	41	2.8	200,000	15.0	.007	---	.001	---
Total 1/			10,000,000					

Figure 14.--Reserves of uranium-bearing coal for Tierney No. 5 bed in T. 23 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



	MEASURED AND INDICATED COAL RESERVES				INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	1,070	3.2	6,100,000	18.9	0.018	210	0.003	210
II	552	6.8	6,600,000	33.0	.005	---	.002	---
III	92	6.9	1,200,000	33.0	.008	---	.003	30
Total 1/			14,000,000			210		240
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	591	3.6	3,800,000	15.0	0.018	100	0.003	100
2	184	6.9	2,200,000	33.0	.005	---	.002	---
3	40	8.5	580,000	33.0	.010	---	.003	20
4	37	4.0	260,000	33.0	.005	---	.002	---
Total 1/			6,800,000			100		120

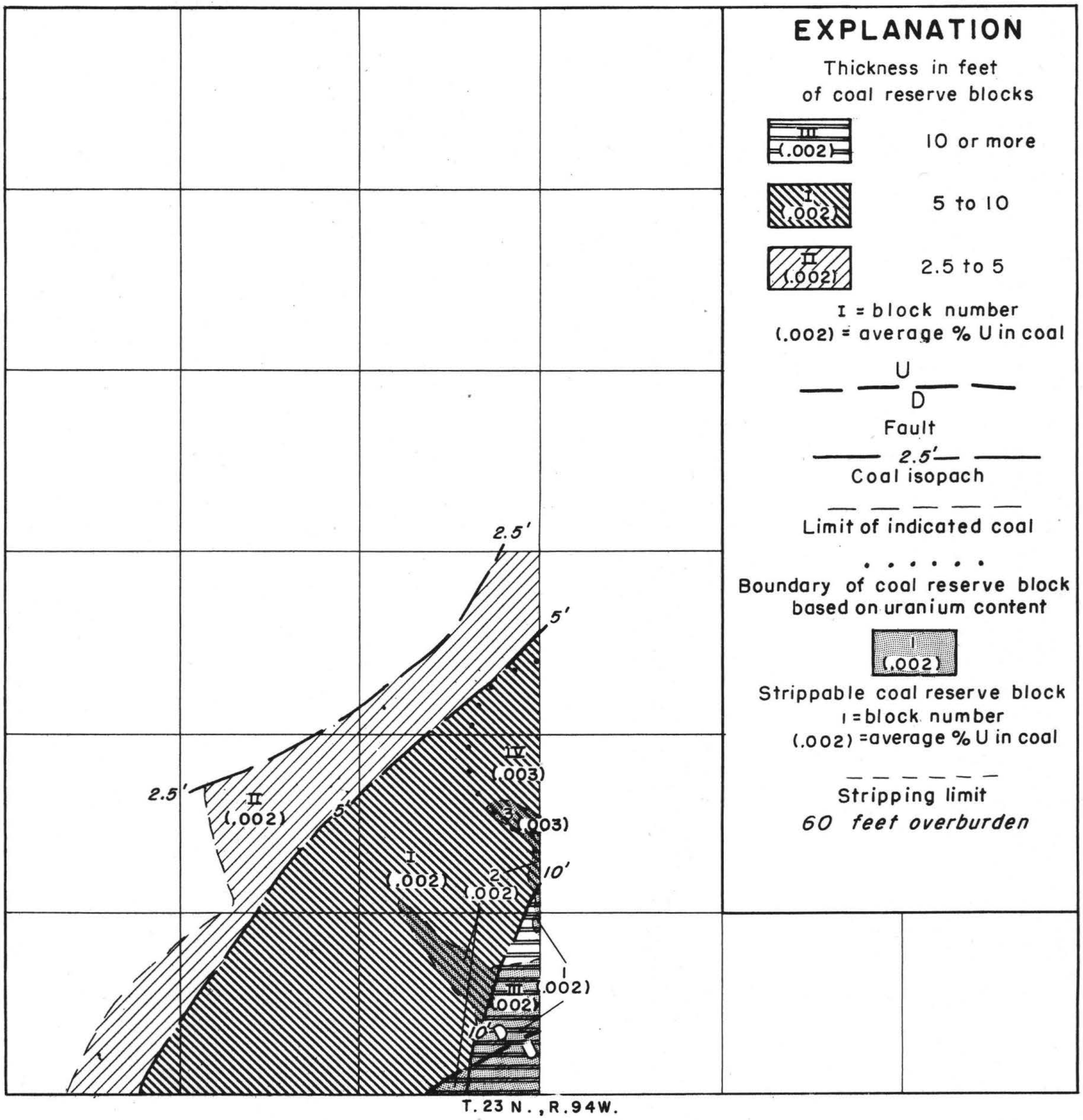
Figure 15.--Reserves of uranium-bearing coal for Battle No. 3 bed in southwest quarter of T. 23 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



T.23 N., R. 94 W.

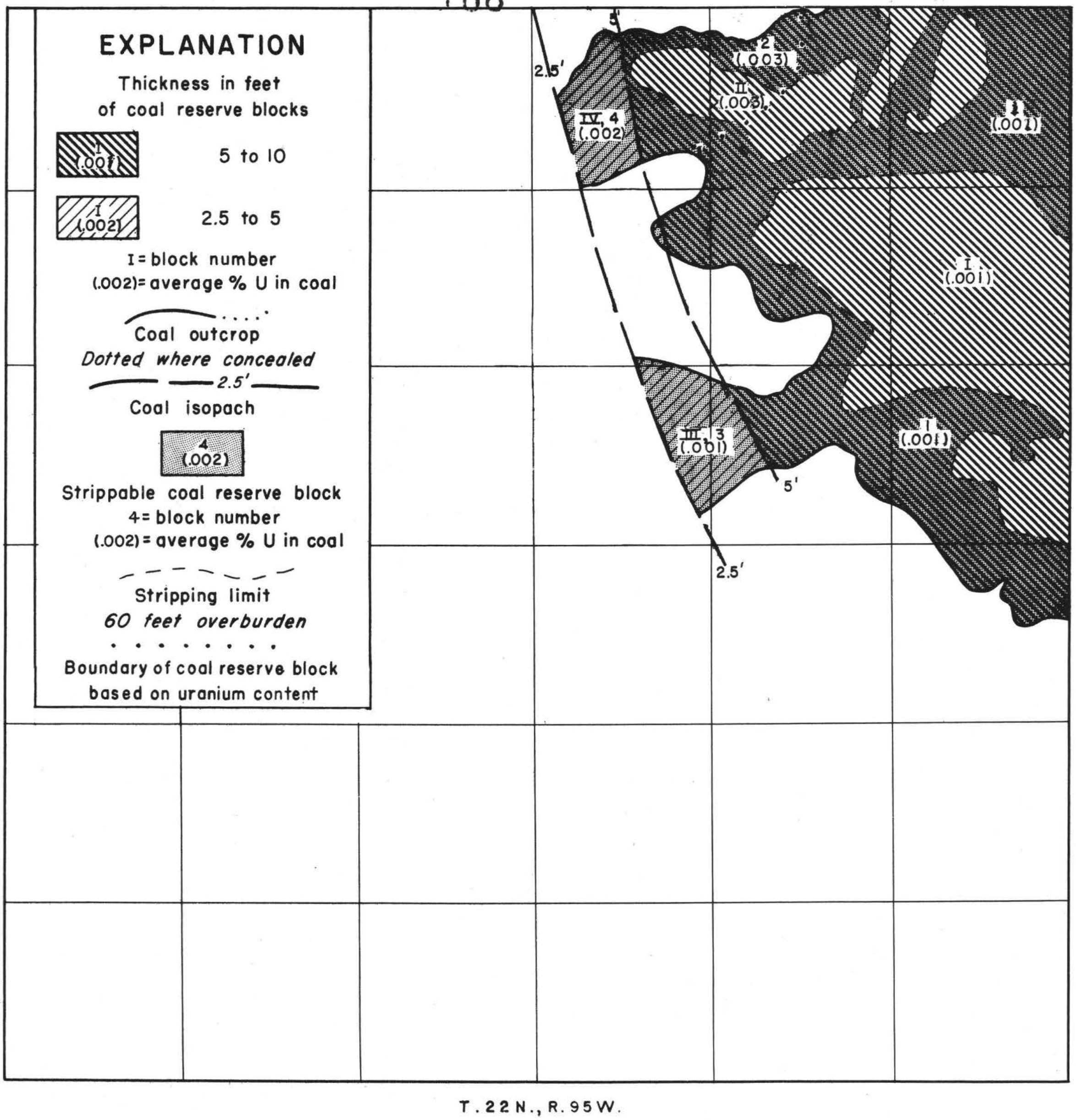
	MEASURED AND INDICATED COAL RESERVES				INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	3,850	8.5	58,000,000	30.0	0.007	---	0.002	---
II	951	12.5	21,000,000	31.0	.009	---	.003	590
III	630	7.9	8,800,000	20.0	.017	300	.003	300
Total 1/			88,000,000			300		890
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	582	13.0	11,000,000	30.0	0.010	---	0.003	330
2	269	8.9	4,200,000	31.2	.011	---	.003	150
Total 1/			15,000,000					480

Figure 16.--Reserves of uranium-bearing coal for Monument zone in southwest quarter of T. 23 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



					INFERRED URANIUM RESERVES			
MEASURED AND INDICATED COAL RESERVES					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	1,695	7.4	22,000,000	25.0	0.008	---	0.002	---
II	871	3.8	5,900,000	21.0	.009	---	.002	---
III	189	10.1	1,900,000	17.1	.010	---	.002	---
IV	171	7.0	1,200,000	14.4	.021	40	.003	40
Total 1/			31,000,000			40		40
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	157	10.2	2,800,000	19.0	0.013	---	0.002	---
2	88	9.7	1,600,000	19.0	.013	---	.002	---
3	23	8.0	310,000	15.2	.018	10	.003	10
Total 1/			4,700,000			10		10

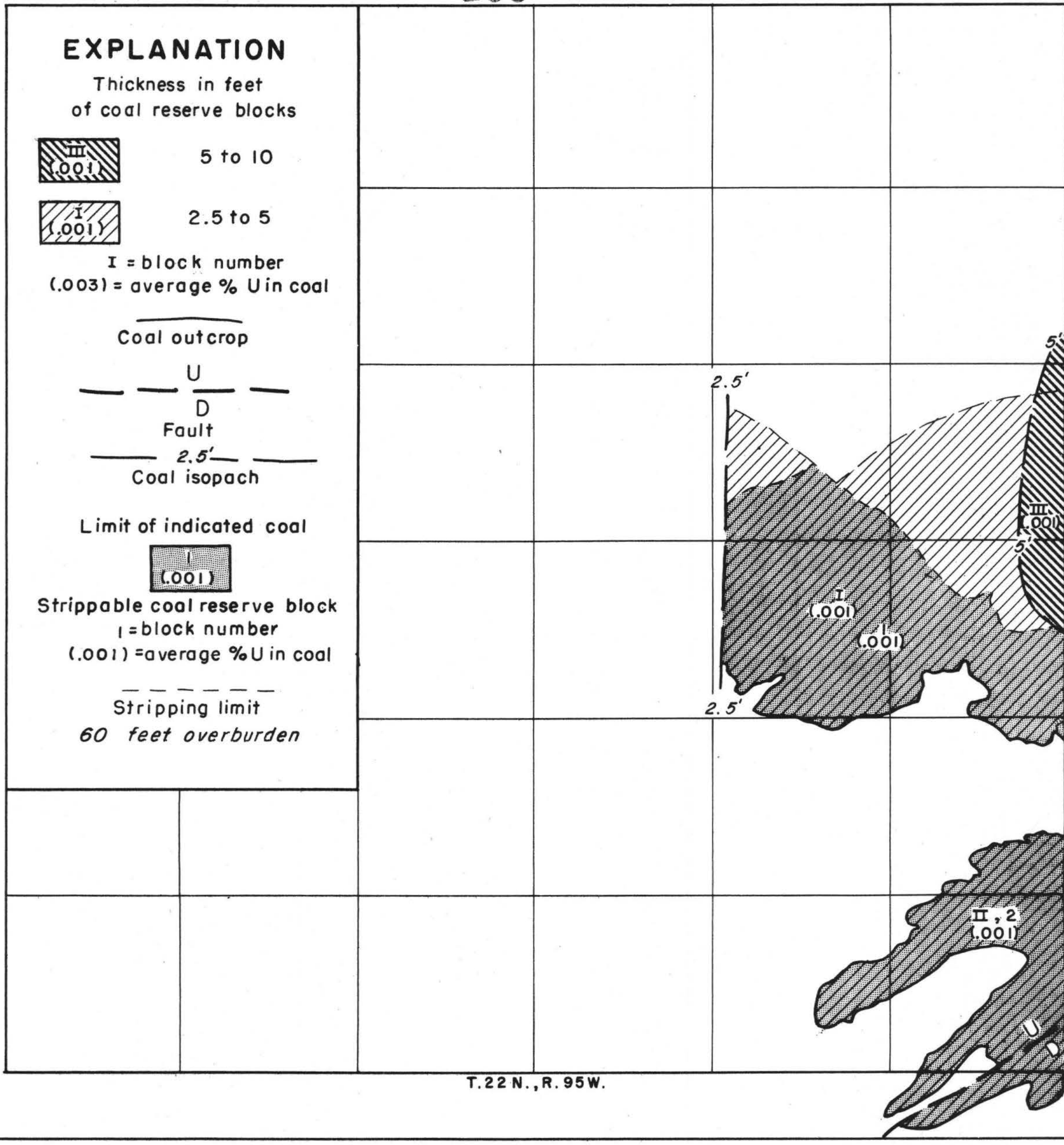
Figure 17.--Reserves of uranium-bearing coal for Tierney No. 6 bed in southwest quarter of T. 23 N., R. 94 W. of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	3,750	7.7	51,000,000	21.0	0.007	---	0.001	---
II*	357	4.2	2,700,000	13.0	.023	80	.003	80
III	215	3.7	1,400,000	21.0	.007	---	.001	---
IV	170	3.8	---------	45.0	.004	---	.002	---
Total 1/			55,000,000			80		80
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	2,020	7.1	26,000,000	21.0	0.007	---	0.001	---
2*	225	4.2	1,700,000	13.0	.023	50	.003	50
3	215	3.7	1,400,000	21.0	.007	---	.001	---
4	170	3.8	---------	45.0	.004	---	.003	---
Total 1/			29,000,000			50		50

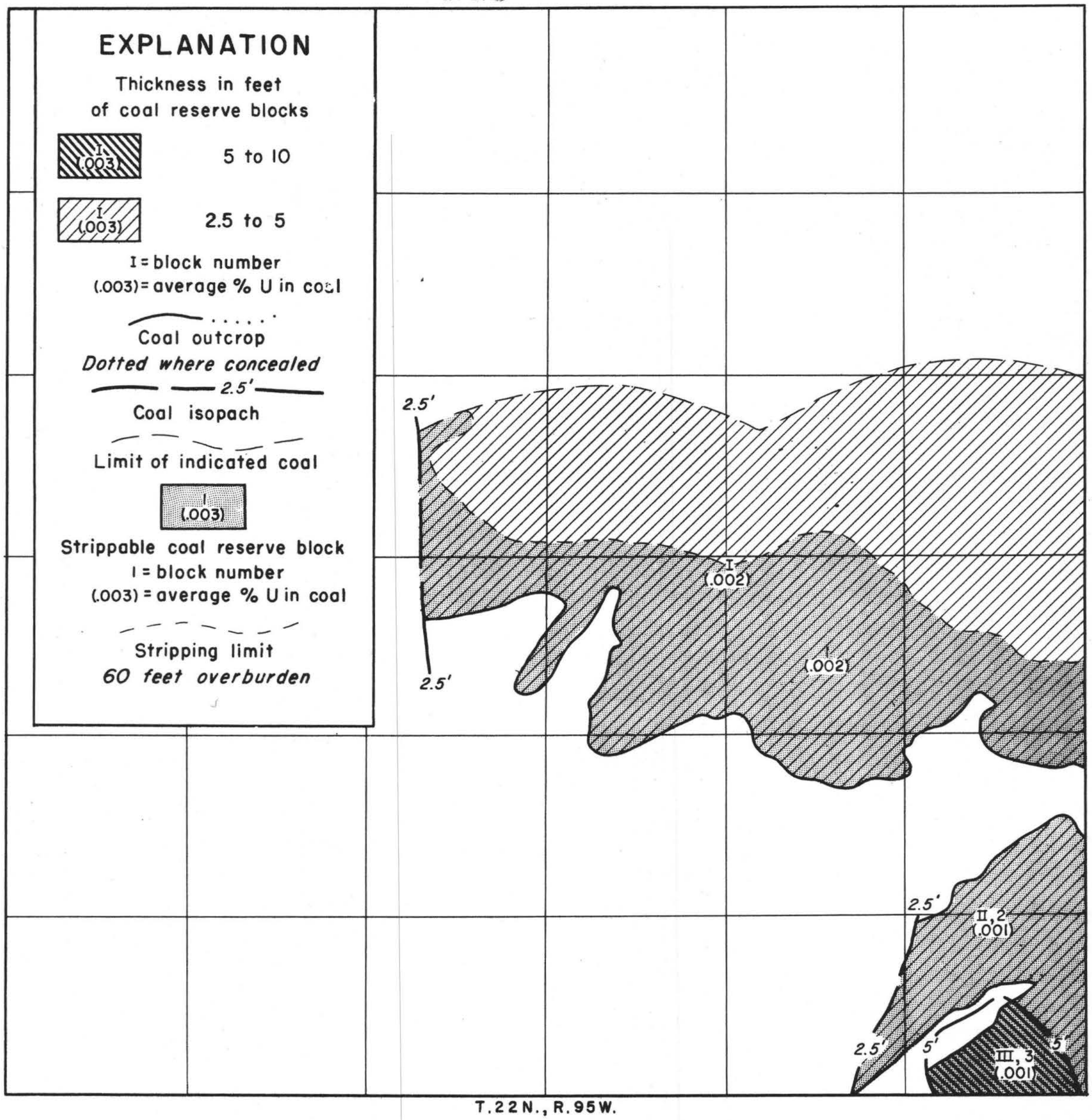
* Monument No. 2 only

Figure 18.--Reserves of uranium-bearing coal for Monument zone in T. 22 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



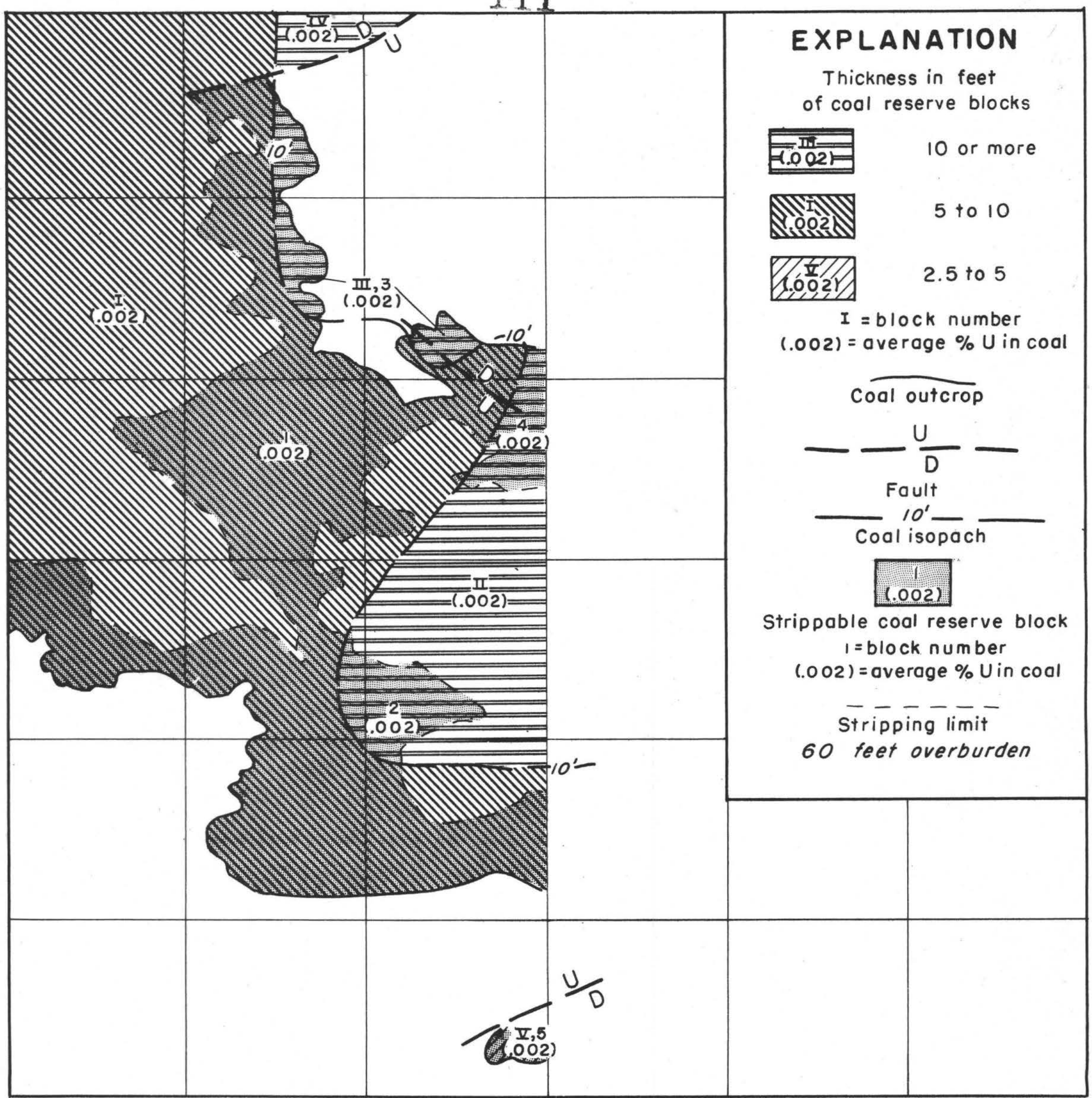
					INFERRED URANIUM RESERVES			
MEASURED AND INDICATED COAL RESERVES					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	1,774	3.7	12,000,000	12.0	0.008	---	0.001	---
II	697	2.9	3,600,000	19.0	.007	---	.001	---
III	198	5.1	1,800,000	10.0	.008	---	.001	---
Total 1/			17,000,000					
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	1,181	3.5	11,000,000	12.0	0.010	---	0.001	---
2	697	2.9	3,600,000	19.0	.007	---	.001	---
Total 1/			15,000,000					

Figure 19.--Reserves of uranium-bearing coal for Tierney No. 6 bed in T. 22 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	4,261	3.3	24,900,000	19.7	0.009	---	0.002	---
II	614	3.2	3,500,000	23.5	.007	---	.002	---
III	162	5.1	1,500,000	26.0	.008	---	.002	---
Total 1/			30,000,000					
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	1,985	3.9	14,000,000	20.5	0.009	---	0.002	---
2	614	3.2	3,500,000	23.5	.007	---	.002	---
3	162	5.1	1,500,000	26.0	.008	---	.002	---
Total 1/			19,000,000					

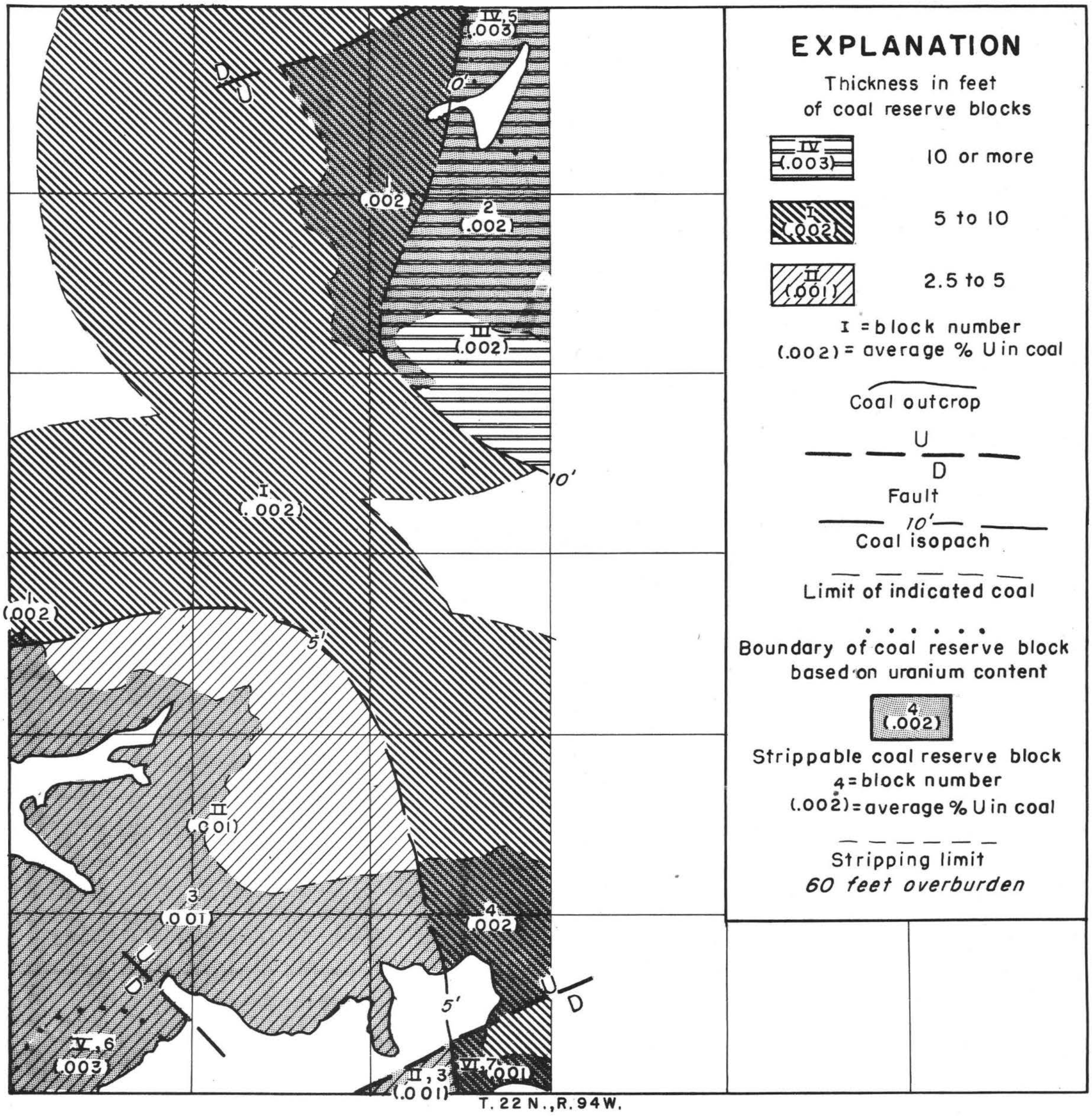
Figure 20.--Reserves of uranium-bearing coal for Tierney No. 5 bed in T. 22 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



T.22 N., R.94W.

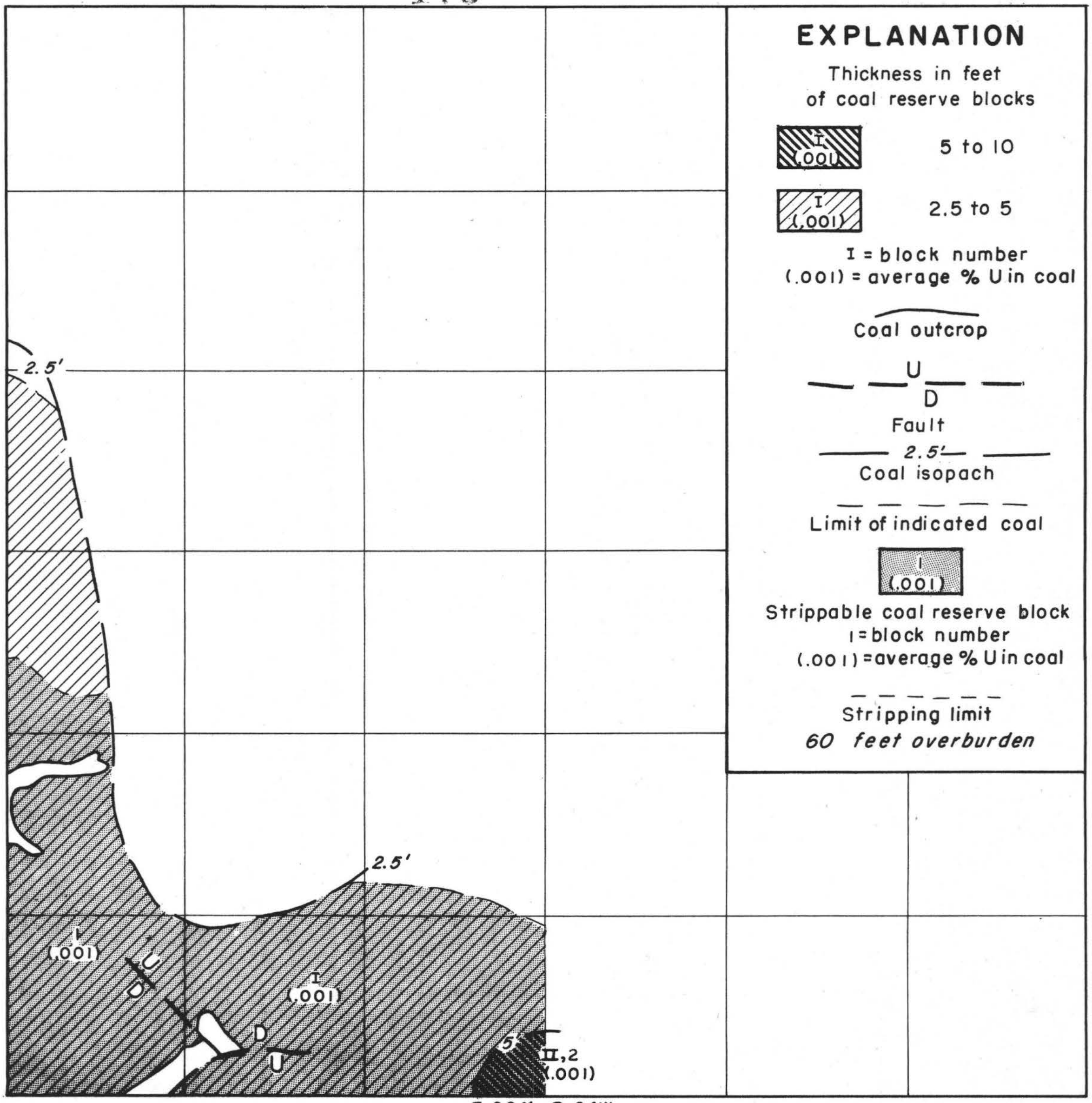
MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	5,524	9.2	90,000,000	22.7	0.007	---	0.002	---
II	1,226	10.4	23,000,000	13.0	.016	470	.002	---
III	159	10.3	2,900,000	16.0	.009	---	.002	---
IV	104	10.8	2,000,000	18.0	.012	---	.002	---
V	52	4.0	370,000	32.0	.007	---	.002	---
Total 1/			118,000,000			470		
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	2,472	9.6	42,000,000	24.0	0.007	---	0.002	---
2	188	10.7	3,600,000	14.0	.016	80	.002	---
3	159	10.3	2,900,000	16.0	.009	---	.002	---
4	103	10.3	1,900,000	15.1	.011	---	.002	---
5	52	4.0	360,000	32.0	.007	---	.002	---
Total 1/			51,000,000			80		

Figure 21.--Reserves of uranium-bearing coal for Monument zone in the west half of T. 22 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	5,702	7.5	76,000,000	29.0	0.007	---	0.002	---
II	2,886	3.7	19,000,000	17.0	.009	---	.001	---
III	795	11.0	15,000,000	27.0	.008	---	.002	---
IV	125	12.0	2,700,000	22.0	.012	---	.003	70
V	180	2.6	830,000	19.0	.016	3	.003	3
VI	70	6.0	740,000	16.0	.008	---	.001	---
Total 1/			114,000,000			3		73
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	662	9.2	11,000,000	32.0	0.007	---	0.002	---
2	515	11.0	10,000,000	27.5	.008	---	.002	---
3	1,880	2.7	9,000,000	15.3	.010	---	.002	---
4	300	5.7	3,000,000	32.0	.007	---	.002	---
5	125	12.0	2,700,000	22.0	.012	---	.003	70
6	180	2.6	830,000	19.0	.016	3	.003	3
7	70	6.0	740,000	16.0	.008	---	.001	---
Total 1/			37,000,000			3		73

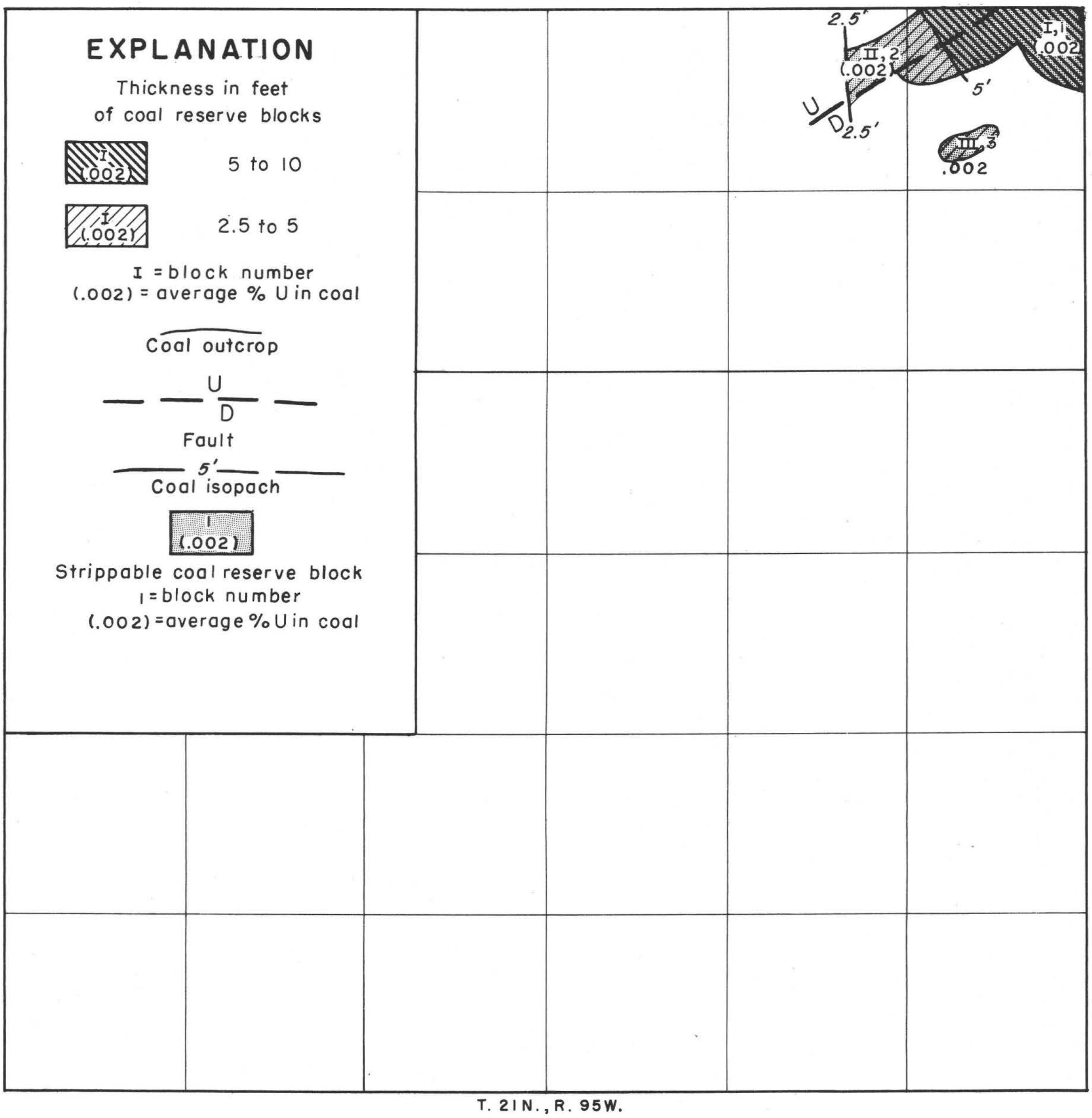
Figure 22.--Reserves of uranium-bearing coal for Tierney No. 6 bed in west half of T. 22 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



T. 22 N., R. 94 W.

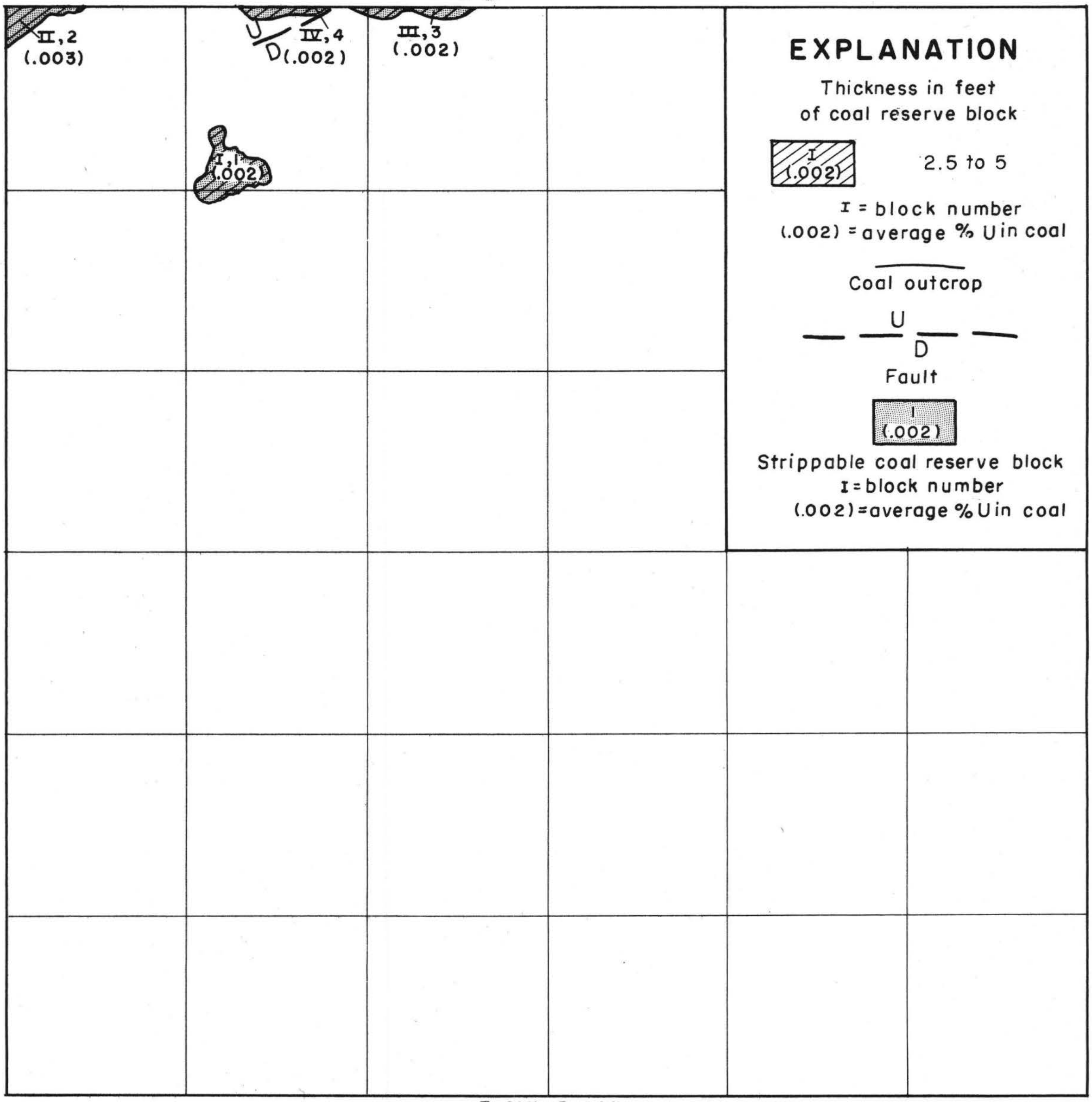
MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	2,760	3.0	15,000,000	15.0	0.006	---	0.001	---
II	74	5.1	660,000	16.0	.005	---	.001	---
Total 1/			16,000,000					
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	2,340	3.1	12,000,000	15.5	0.006	---	0.001	---
2	74	5.1	660,000	16.0	.005	---	.001	---
Total 1/			13,000,000					

Figure 23.--Reserves of uranium-bearing coal for Tierney No. 5 bed in west half of T. 22 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	177	5.2	1,600,000	25.2	0.006	---	0.002	---
II	107	3.7	700,000	32.0	.006	---	.002	---
III	22	4.0	160,000	27.0	.007	---	.002	---
Total 1/			2,500,000					
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	177	5.2	1,600,000	25.2	0.006	---	0.002	---
2	107	3.7	700,000	32.0	.006	---	.002	---
3	22	4.6	160,000	27.0	.007	---	.002	---
Total 1/			2,500,000					

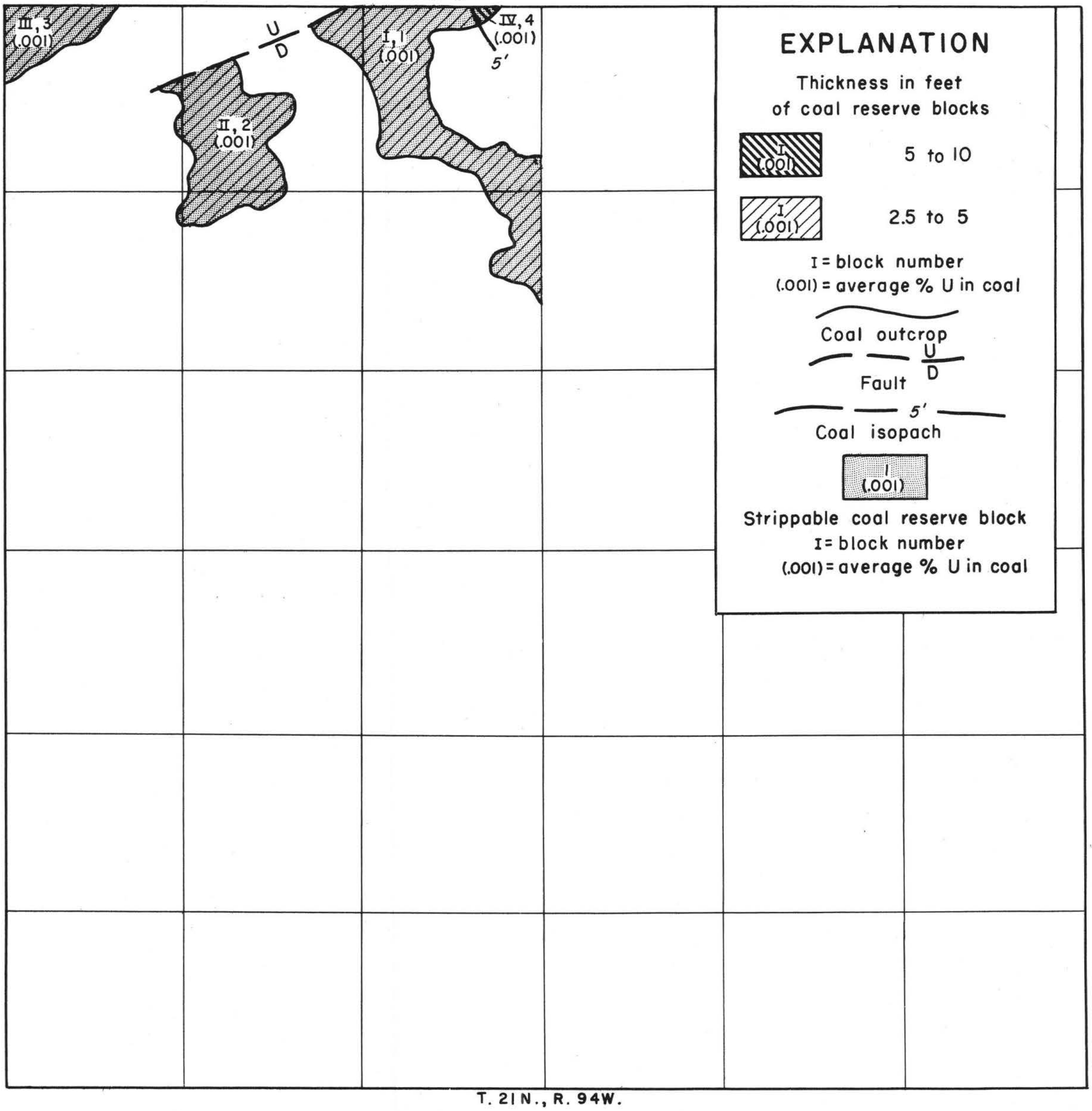
Figure 24.--Reserves of uranium-bearing coal for Tierney No. 5 bed in T. 21 N., R. 95 W. in central part of Great Divide Basin, Wyoming.



T. 21 N., R. 94 W.

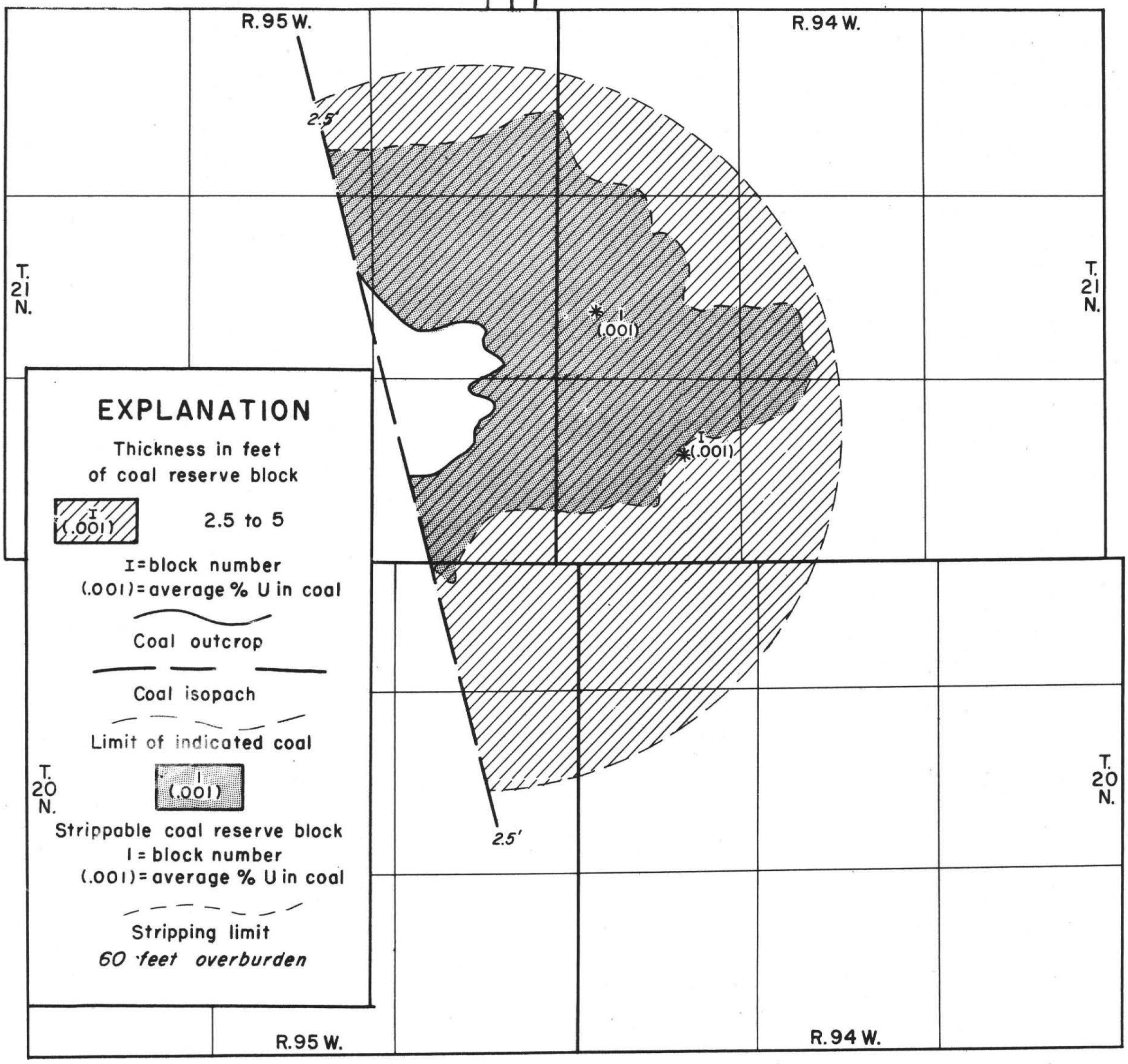
MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	53	3.3	310,000	24.0	0.010	---	0.002	---
II	39	2.6	180,000	16.0	.016	5	.003	5
III	13	4.6	110,000	15.0	.008	---	.001	---
IV	18	3.1	100,000	16.0	.008	---	.001	---
Total 1/			700,000			5		5
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	53	3.3	310,000	24.0	0.010	---	0.002	---
2	39	2.6	180,000	16.0	.016	5	.003	5
3	13	4.6	110,000	15.0	.008	---	.001	---
4	18	3.3	100,000	16.0	.008	---	.001	---
Total 1/			700,000			5		5

Figure 25.--Reserves of uranium-bearing coal for Tierney No. 6 bed in west half of T. 21 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



					INFERRED URANIUM RESERVES			
MEASURED AND INDICATED COAL RESERVES					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	404	4.0	2,900,000	15.0	0.007	---	0.001	---
II	261	3.9	1,800,000	15.0	.004	---	.001	---
III	110	4.5	880,000	21.8	.004	---	.001	---
IV	11	5.2	100,000	16.0	.005	---	.001	---
Total 1/			5,700,000					
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	404	4.0	2,900,000	15.0	0.007	---	0.001	---
2	261	3.9	1,800,000	15.0	.004	---	.001	---
3	110	4.5	880,000	21.8	.004	---	.001	---
4	11	5.2	100,000	16.0	.005	---	.001	---
Total 1/			5,700,000					

Figure 26.--Reserves of uranium-bearing coal for Tierney No. 5 bed in west half of T. 21 N., R. 94 W. in central part of Great Divide Basin, Wyoming.



	MEASURED AND INDICATED COAL RESERVES				INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Block no.	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
I	4,800	2.6	22,000,000	---	---	---	*0.001	---
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
1	2,152	2.6	10,000,000	---	---	---	*0.001	---

* Estimated equivalent uranium

Figure 27.--Reserves of uranium-bearing coal for bed E in Tps. 20-21 N., Rs. 94-95 W. in central part of Great Divide Basin, Wyoming.

97755

The isopach interval used on the work sheets was as small as 1 foot or one-half if necessary, but only the 2.5- and 10-foot isopachs are shown on figures 9-27. The areas bounded by the isopach lines, by the outcrop line and by the 2-mile limit line are designated by a roman numeral and shown in figures 9-27 as "Block no. I," "Block no. II," etc. A good example of such blocks is shown in figure 11. For areas containing strippable reserves, the dashed line (representing the 60-foot overburden limit used in this report) forms one boundary of the strippable block which is designated by an arabic numeral as in the example on figure 27. The strippable reserves are included in the measured and indicated reserves.

The area in acres of each coal reserve block was determined by planimeter. The estimate of 1,770 short tons of subbituminous coal per acre-foot used in this report may be conservative for the area as a whole.

The coal beds were sampled at the localities shown on figures 2, 5-8, in vertical intervals ranging from 2 feet to less than 0.1 feet. The samples were ashed and analyzed chemically and radiometrically and the percent of coal ash, uranium in coal ash and equivalent uranium was determined. Most of these analyses are shown graphically in figures 5-8. The percent of uranium in coal is the product of the percent ash and percent uranium in ash, rounded off to the nearest thousandth. For example, Block I in figure 10 is shown to contain 910 tons of uranium in coal. This figure is the product of tons of coal per acre-foot, acres, thickness, percent ash and percent uranium in ash (1,770 x 3,542 x 3.8 x 20 x 0.00019) and not the product of tons of coal and percent uranium in coal, which would yield a figure of 960 tons of uranium in coal (24,000,000 x 0.00004). Inasmuch as thickness measurements of the coal beds are significant only to two figures and inasmuch as these measurements enter in all reserve calculations, all estimates are rounded to two significant figures.

The uranium content of the coal at each locality was determined by adding the products of the percent uranium and the thickness sampled and dividing by the total thickness. Lines connecting points of equal uranium content were drawn at intervals of 0.0005 percent, and the average percent uranium for each block was determined by adding the products of the areas and their uranium content and dividing by the total area. "Iso-percentage" lines are not shown except where parts of a coal reserve block contain 0.003 or more percent uranium if considered separately rather than as part of the whole block. An example is shown in figure 9 where the eastern and western parts of the coal reserve area contain a high enough percentage of uranium to constitute reserves if considered separate from the middle.

An analogous procedure is used to determine the average ash and the average percent uranium in ash for each block. Inasmuch as no appreciable amount of uranium is lost when the coal is ashed, the number of tons of uranium in the coal ash is equal to the number of tons of uranium in coal. Sometimes the ash content of a given reserve block will exceed the cut-off limit (33 percent) and no estimate of reserves of uranium in ash is shown despite the fact that the same reserve block will be shown to contain reserves of uranium in coal. (See reserve Block III, fig. 15 and reserve Block II, fig. 16.)

In summary the basic calculations used in this report for tons of coal and uranium contained in a given reserve block are:

1/ Tons of coal = 1,770 x A x T

Where 1,770 = tons subbituminous coal per acre-foot

A = area in acres

T = average thickness of coal in feet

2/ Percent U in coal = PA x PUA

Where PA = percent ash

PUA = percent uranium in ash

3/ Tons U in coal or in coal ash = 1,770 x A x T x PA x PUA

The values of T and PA contain only two significant figures. Inasmuch as either T or PA enters into all computations of reserves all of the estimates are rounded off to two significant figures.

Summary of reserves

Coal

The Luman, Battle, Monument and Tierney coal zones and coal bed E are estimated to contain a coal reserve of about 700,000,000 short tons of measured and indicated coal (table 6) 250,000,000 tons of which is covered by 60 feet or less overburden. From one-fourth to one-third of this reserve is measured coal. The reserves in each bed for each township is shown on figures 9-27.

Uranium in coal

About 83,000,000 tons of the coal reserves contain 0.003 or more percent uranium and constitutes a reserve of about 2,600 tons of inferred uranium in coal. About 1,100 tons of the uranium is contained in about 27,000,000 tons of coal covered by 60 feet or less overburden.

Uranium in coal ash

About 81,000,000 tons of the coal reserve contain 0.015 or more percent uranium in the coal ash and constitutes a reserve of about 2,400 tons of inferred uranium in the coal ash. About 600 tons of this uranium is contained in coal beds covered by 60 feet or less overburden totaling about 22,000,000 tons.

The cut-off 0.003 or more percent uranium used in this report serves to emphasize the areas containing the most uranium per unit area. It is interesting to note, however, that if 0.002 or more percent uranium is used as the cut-off, the total reserves of uranium in coal in the areas shown in figures 9-27 would total about 15,000 tons.

Table 6.--Summary of uranium-bearing coal reserves in the central part of the Great Divide Basin, Sweetwater County, Wyoming

MEASURED AND INDICATED COAL RESERVES					INFERRED URANIUM RESERVES			
					URANIUM IN ASH		URANIUM IN COAL	
Coal bed or zone	Area (acres)	Average thickness (feet)	Coal 1/ (short tons)	Ash 2/ (percent)	Average uranium content (percent) 2/	Uranium 1/ (short tons)	Average uranium content (percent) 3/	Uranium 1/ (short tons)
Luman No. 2	4,686	3.6	30,000,000	17.0	0.013	270	0.002	270
Luman No. 1	3,542	3.8	24,000,000	20.0	.019	910	.004	910
Battle No. 3	7,572	7.5	102,000,000	14.5	.013	210	.002	240
Monument Zone	22,713	7.5	310,000,000	22.8	.008	990	.002	1,100
Tierney No. 6	15,476	5.9	160,000,000	22.1	.008	48	.002	120
Tierney No. 5	10,909	3.3	66,000,000	18.0	.007	---	.002	---
Coal bed E	4,800	2.6	22,000,000	---	---	---	.001*	---
Total 1/			710,000,000			2,400		2,600
RESERVES COVERED BY 60 FEET OR LESS OVERBURDEN (Included in the above)								
Luman No. 2	717	3.4	4,500,000	18.4	0.015	50	0.003	50
Luman No. 1	607	3.8	4,100,000	26.0	.017	180	.004	180
Battle No. 3	852	4.6	6,800,000	20.5	.014	100	.003	120
Monument Zone	9,747	6.9	120,000,000	20.9	.008	270	.002	670
Tierney No. 6	6,001	5.4	57,000,000	19.2	.010	18	.002	18
Tierney No. 5	7,883	3.6	50,000,000	18.9	.007	---	.001	---
Coal bed E	2,152	2.6	10,000,000	---	.001	---	.001*	---
Total 1/			250,000,000			620		1,100

1/ All tonnage estimates rounded to two significant figures. Dashes mean not calculated. See section, "Computation of reserves" for formulas used to obtain these estimates, and for cut-off limits.

2/ Analyses by the U. S. Geological Survey laboratory, Washington, D. C.

3/ Calculated from percent ash and percent uranium in ash.

*Estimated equivalent uranium

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