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DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY OF THE THOMPSON CREEK COAL MINING AREA, PITKIN COUNTY, COLORADO, AS RELATED TO SUBSURFACE HYDRAULIC MINING POTENTIAL

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INTRODUCTION

Some of the coal fields of Washington and Colorado contain large underground deposits of bituminous coal in beds pitching from 15 to 50 degrees. It is difficult to recover such coal at competitive mining costs because gradients of that magnitude place increasingly sharp limitations on the use of conventional mining machines. However, some of those deposits of pitching coal may be recovered by subsurface hydraulic mining methods, in which the pitch of the coal bed can be used to advantage.

In 1977, the Bureau of Mines initiated a cooperative program of work with the Geological Survey, by selecting five geographic areas of pitching coal for which additional geologic information was needed for an adequate appraisal of their hydraulic mining potential. The Geological Survey was to prepare a geologic report on each of those areas, in support of Bureau research on the technology of subsurface hydraulic mining. In order of priority assigned by the Bureau, the five areas are identified as follows:

Area 1: Coal deposits, Wilkeson-Carbonado coal field, vicinity of Carbonado, Pierce County, Washington.

Area 2: Thompson Creek coal deposits, Carbondale coal field, 8 miles southwest of Carbondale, Pitkin County, Colorado.

Area 3: Coal deposits, Carbondale coal field, from vicinity of town of Marble, north along trend of coal-bearing rocks, to a point about 4 miles southwest of Glenwood Springs, Gunnison, Pitkin, and Garfield Counties, Colorado.

Area 4: Coal deposits, Grand Hogback coal field, from point about 4 miles southwest of Glenwood Springs, north along trend of coal-bearing rocks, to vicinity of town of Meeker, Garfield and Rio Blanco Counties, Colorado.

Area 5: Coal deposits, Crested Butte coal field, vicinity of town of Crested Butte, Gunnison County, Colorado.

This report, on the Thompson Creek coal deposits in Pitkin County, Colorado (Area 2), is the first of a series of four reports on the Colorado areas selected. The four Colorado areas are contiguous (see fig. 1) and Area 2 is a component part of Area 3. In order to define a report area for purposes of description and discussion, the Thompson Creek coal deposits are herein contained geographically as the "Thompson Creek coal mining area." (See figure 2).

THOMPSON CREEK COAL MINING AREA

Location

As defined here, the Thompson Creek coal mining area is a rectangular area of about 14 square miles located in the center part of the Stony Ridge 7½-minute topographic quadrangle map (see fig. 4). The "Thompson Creek Mine" by North Thompson Creek in sec. 34/35, T. 8 S., R. 89 W., is 8 miles southwest of Carbondale, Colorado, and 16 miles south of Glenwood Springs (see fig. 3).

Surface-minerals land ownership

Surface and minerals land ownership in the Thompson Creek mining area and vicinity is indicated by patterns on the surface-minerals management map (fig. 3). The map was assembled from parts of maps compiled and published by the Bureau of Land Management.

Although the Thompson Creek mining area is within the White River National Forest, sections and parts of sections that are not patterned on the map (fig. 3) are patented (i.e. privately owned), presumably by coal companies. Locations of coal mines are shown on figure 3. As of May 1977, however, only the "Thompson Creek mine(s)" were active.

Access

Vehicle access to the Thompson Creek mining area is via a light-duty road from Carbondale, Colorado. The route is shown on the surface-minerals management map (fig. 3). The bulk of the route is within incompetent shales of the Mancos Shale and the Iles Formation (see fig. 4). Road maintenance for high-volume coal transport by truck is expected to be difficult, particularily along the north wall of North Thompson Creek.

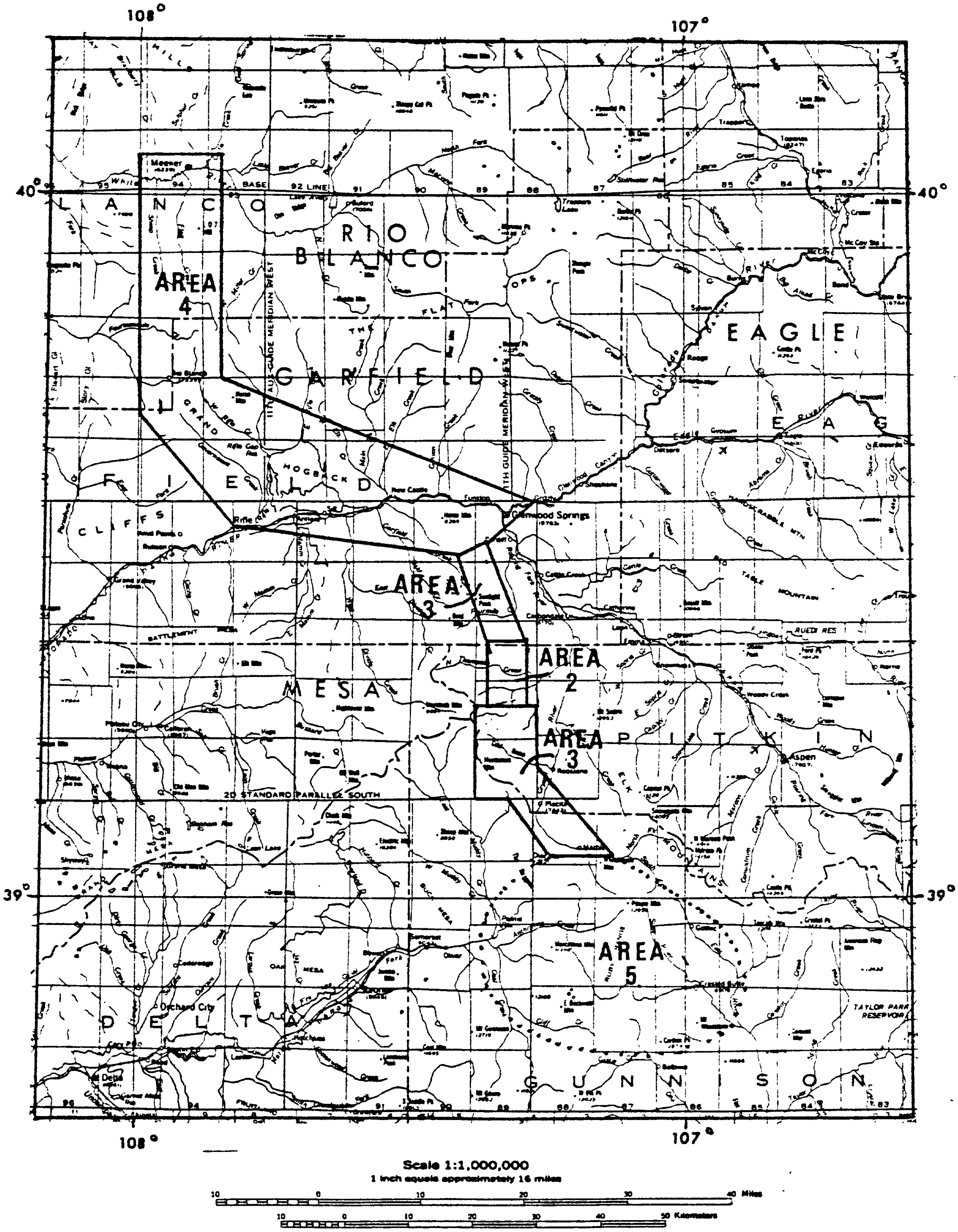

Figure 1.--Index map of part of western Colorado, showing locations of Areas 2, 3, 4, and 5.

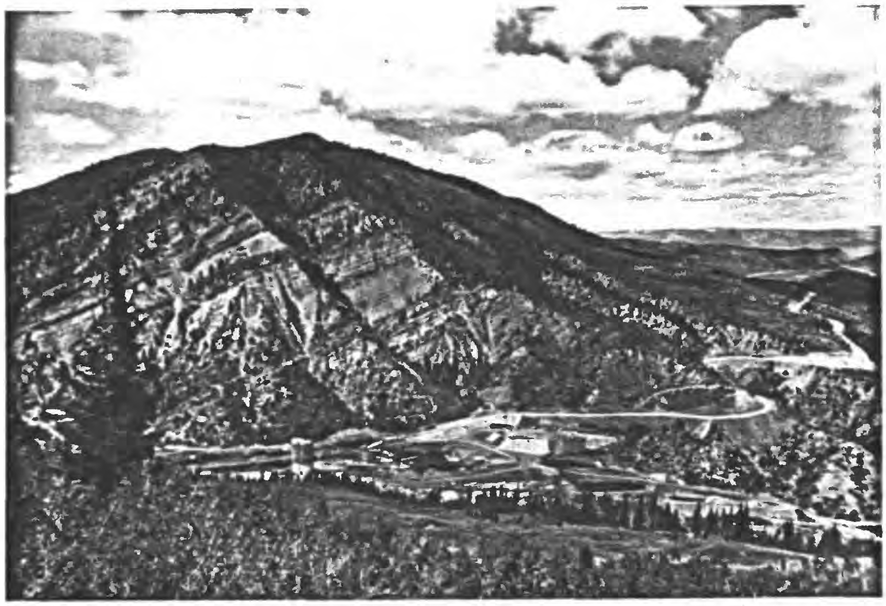

Figure 2.--View of a northern part of the Thompson Creek coal mining area, and of the mine site on North Thompson Creek, looking north from a high point on the ridge south of the mine. The light-toned band near the base of the stratigraphic section exposed represents the Rollins Sandstone Member of the Iles Formation. The lower zone of coal beds directly overlies the Rollins.

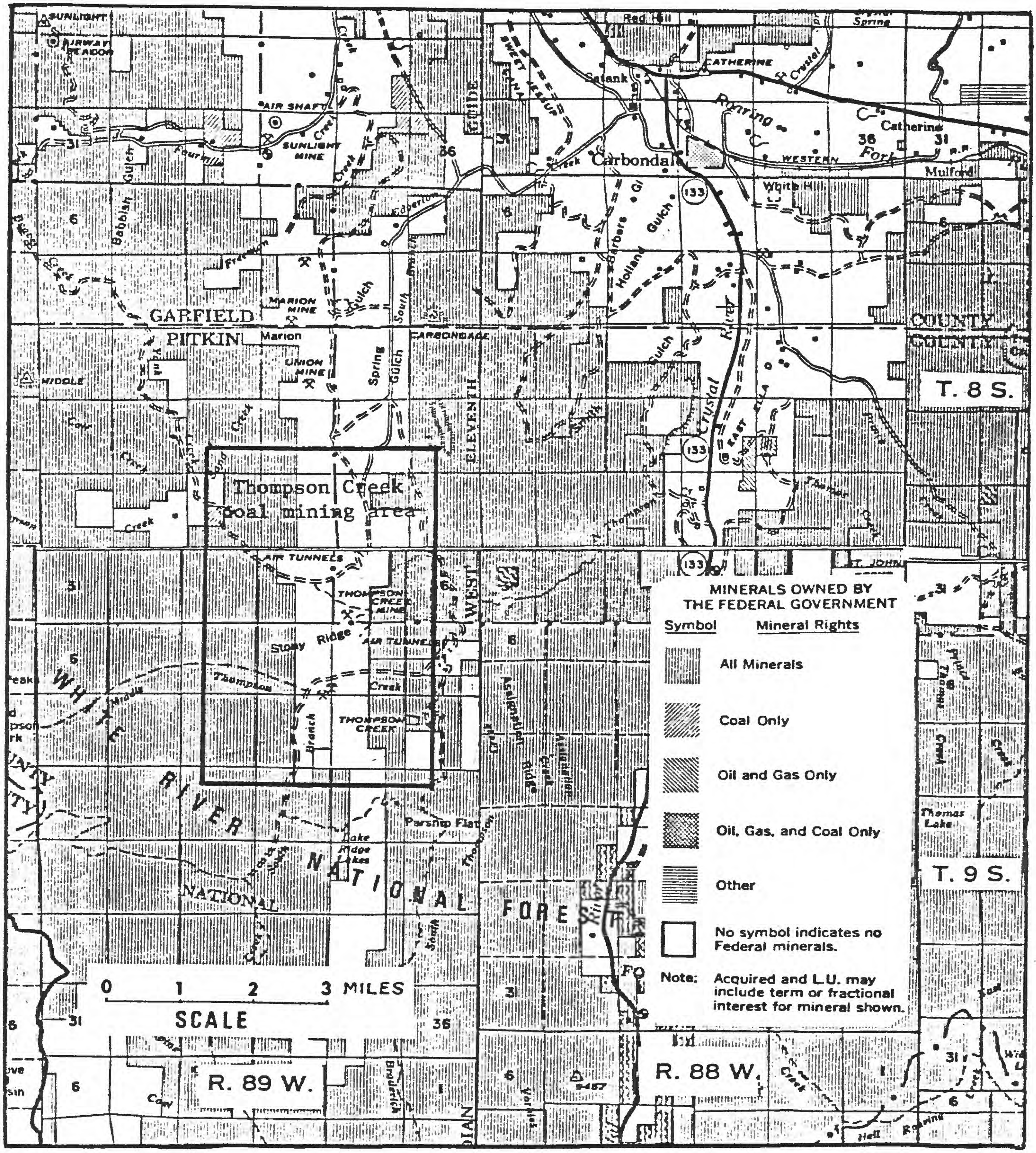

Figure 3:- Surface-minerals management map of Thompson Creek coal mining area and vicinity, as assembled from U.S. Bureau of Land Management Surface-Minerals Management Quad NW-21 (Glenwood Springs, March, 1975) and Quad NW-27 (Paonia Resevoir, 1974).

Topography

The rectangular outline of the Thompson Creek coal mining area is shown on the Stony Ridge topographic quadrangle map (fig. 4). Altitudes range from about 7,200 feet above sea level on North Thompson Creek at the east edge of the outlined area, to 9,815 feet above sea level near the west-central edge. Thus, the relief of the area is about 2,600 ft, and most of this relief is expressed by the steep valley walls of North and Middle Thompson Creeks.

The mean altitude of the mining area is about 8,500 feet above sea level, and much of the western half of the area is above 9,000 feet.

Climate

In parts of western Colorado characterized by rugged topography, high relief, and abrupt differences in altitude, climate is a function of altitude rather than of latitude and large variations in climatic conditions occur within short distances. Consequently, it is difficult to estimate the expected climate of the Thompson Creek mining area from records for weather stations in the vicinity. However, some indication of what to expect in terms of average yearly or monthly temperature, precipitation,and snowfall,can be obtained from weather records for Glenwood Springs and Crested Butte (see fig. 5). Weather records are listed in Appendix A. They are summarized in the following paragraphs.

The nearest weather station is at Glenwood Springs, about 16 miles north of the Thompson Creek coal mining area. The station is located at an altitude of 5,823 feet above sea level.

At Glenwood Springs, normals for the period from 1931 to 1960 are as follows: the average temperature was 71° F in July, the warmest month of the year, and 25° F in January, the coldest month. Average precipitation was maximum (1.80 inches) in January and minimum

Figure 5.--Diagrammatic relief map of part of western Colorado, showing locations of weather stations (Glenwood Springs and Crested Butte) with respect to Carbondale mining area.

(1.19 inches) in June; and average annual precipitation was 18.03 inches. Average annual snowfall was 62.4 inches for the 26-year period prior to 1931 and 74.2 inches for the period 1931-1950, and maximum snowfall occurred during the months of December, January, and February. Normals for the period 1931-1960 show that the average annual temperature was 48°F; average monthly temperatures for November, December, January, February, and March were 36.4°, 27.4°, 24.8°, 29.7°, and 37.9°F, respectively, indicating that average monthly temperatures were below freezing for a 3-month period (December, January, and February).

The weather station at Crested Butte, at an altitude of about 8,900 feet above sea level, is about 34 miles southeast of the Thompson Creek mining area. Weather records for Crested Butte contrast sharply with those for Glenwood Springs. At Crested Butte, normals for the period 1931-1960 show (a) the average temperature was 58°F in July, the warmest month of the year, and 13.5°F in January, the coldest month; (b) average precipitation was maximum (2.68 inches) in January and minimum (1.31 inches) in June; and (c) average annual precipitation was 23.00 inches. Average annual snowfall was 166.8 inches for the 19-year period prior to 1931 and 173.4 inches for the period 1931-1951, and maximum snowfall occurred during the months of December, January, February, and March. Normals for the period 1931-1960 show that the average annual temperature was 36°F; and average monthly temperatures, November-March, were 25.7°, 16.8°, 13.5°, 16.3°, and 22.6°F, respectively, indicating that average monthly temperatures were below freezing for a 5-month period (November-March).

The mean altitude of the Thompson Creek coal mining area is about 8,500 feet above sea level, and much of the western half of the area is above 9,000 feet. These altitudes contrast rather sharply with the altitude of the weather station at Glenwood Springs (5,823 feet) and are about the same or less than that of the station at Crested Butte (8,900 feet).

In terms of temperature, precipitation, snowfall, and freezing periods, climatic conditions in the Thompson Creek coal mining area should be similar to those in the Crested Butte area, and climatic records for Crested Butte should provide an indication of the expected climate in the Thompson Creek mining area.

Drainage

Eastward-flowing North and Middle Thompson Creeks drain the Thompson Creek coal mining area (see fig. 4). These creeks merge about 1 mile east of the mining area, to form Thompson Creek. Thompson Creek flows eastward and is tributary to the Crystal River (see fig. 6). Boundaries of the basin drained by the Crystal River, and other major rivers in the general area, are also shown on figure 6.

The Stony Ridge topographic quadrangle map indicates that, within the coal mining area, both North and Middle Thompson Creeks are perennial. However, west of the "Thompson Creek Mine" site on North Thompson Creek in sec. 34/35, T. 8 S., R. 89 W., and with exception of Yank Creek, all tributaries to North Thompson Creek are indicated on the topographic map as being intermittent.

Surface water supply

A considerable amount of water is required for hydraulic mining. Even though some of the water required could be conserved by recycling, one measure of hydraulic mining potential is the initial availability of an adequate water supply proximal to mining. North Thompson Creek is the most immediate source of surface water for hydraulic mining in the vicinity.

In 1963, a USGS gaging station was installed on North Thompson Creek in sec. 28, T. 8 S., R. 89 W., about 0.5 mile downstream from Yank Creek (see Stony Ridge topographic quadrangle map). Surface water supply records for that station have been kept since 1964. Earlier, in 1950, a USGS gaging station was installed on Thompson Creek in sec. 28, T. 8 S., R. 88 W. (near the Crystal River); however, records for that station were discontinued in 1968.

The locations of those gaging stations, and of others in the general area, are shown on the map of the Crystal River drainage basin (fig. 6). Surface water supply records for the gaging station on North Thompson Creek, and for the station on Thompson Creek, are listed in Appendix B.

Surface water supply records for the gaging station on North Thompson Creek are summarized in table 1. From data in table 1, it can be derived that, for the period 1964-1970, (a) average total annual discharge was 6,340 cfs,

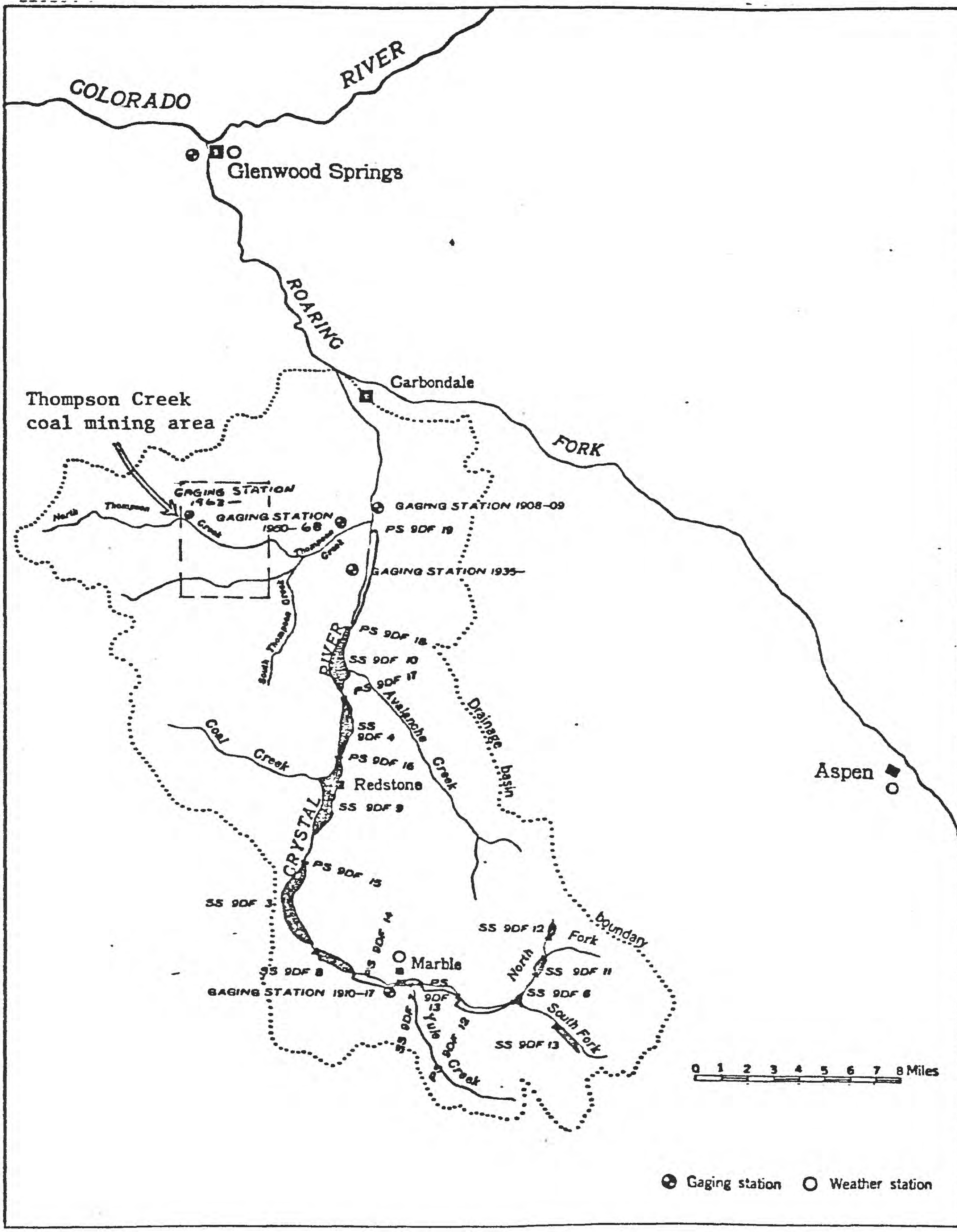

Figure 6: - Map showing the drainage basin of the Crystal River, Colorado, after Lawrence (USGS Circular 292, 1953; Plate 1)

Table 1.--Summary of surface water supply records for U.S. Geological Survey gaging station on North Thompson Creek in sec. 28, T. 8 S., R. 89 W., Pitkin County, Colorado water years 1964-1970.

[Discharge in cubic feet per second (cfs); 1 cfs = 7.48 gallons per second (gps) or 448.8 gallons per minute (gpm). Water year (1964) begins October (1963) and ends September (1964)]

Water Year	Total Discharge	Maximum Discharge monthly		Maximum Discharge daily		Minimum Discharge monthly		Minimum Discharge daily		Remarks
		month	total	date	total	month	total	date	total	
1964	5,814	May (1) June(1) Apr.(3)	3,456 1,608 281	5/22(1) 5/24-25(2)	221 215	Sept.	26.40	9/9	0.30	No gage-height record Nov.17-Apr.22
1965	8,946	June(1) May (2)	3,960 3,118	6/12(1) 5/22(2)	250 231	Oct.	37.00	9/1-2	.80	No gage-height record Nov.6-Apr.15
1966	4,310	May (1) Apr.(2)	2,046 979	5/9 (1) 5/10(2)	93 90	Sept.	23.20	9/26-30	.40	No gage-height record Nov.26-Mar.19
1967	3,255	May (1) Apr.(2)	1,297 677	5/26(1) 5/27(2)	69 62	Sept.	41.95	9/6-7	.09	No gage-height record Dec.8-Mar.15
1968	7,458	June(1) May (2)	3,329 2,882	6/1 (1) 5/31(2)	233 231	Oct.	33.77	10/15	.73	No gage-height record Oct.31-April 1
1969	5,319	May (1) Apr.(2)	2,383 1,404	4/24(1) 5/2-3(2)	129 124	Sept.	64.20	9/3	.73	No gage-height record Nov.7-Mar.27
1970	9,267	May (1) June(2)	4,976 2,866	5/20(1) 5/22(2)	272 270	Aug.	80.8	8/31	1.0	No gage-height record Nov.2-Apr.27

(b) maximum discharge during a 2-month period, which included either April or June and always included May, accounted for an average of 77 percent of total annual discharge; and (c) discharge during the month of May alone accounted for an average of 47 percent of that total. However, daily discharge during the months of August, September, and October, is apt to be less than 1 cfs (449 gpm) and freezing conditions should prevail during 5 months of the year (November-March).

Much of the stream flow in North Thompson Creek is derived from snow melt during April, May, and June and stream flow during other months of the year is apt to be minimal. Consequently, if sustained hydraulic mining is contemplated and if surface water from North Thompson Creek is to be used for that purpose, storage of melt water will be required in order to insure adequate water supply during dry months.

Yearly fluctuations in surface water supply during normally wet months are indicated by the following example: the winter of 1976-77 was characterized by unusually light snow fall. Mine sites along North Thompson Creek were visited during the course of a field survey conducted May 19-24, 1977. On May 20, stream flow at North Thompson Creek was reported to be about 25 cfs (13,220 gpm). This amount is about one-eighth the normal expected (see table 1).

Surface water supply records for the gaging station on Thompson Creek show the same pattern as do those for the station on North Thompson, except that volume of discharge is considerably greater; for water years 1965-1968, average annual discharge was 13,838 cfs; total discharge during the two peak months (May and June) averaged 9,942 cfs or 72 percent of average yearly total. Total discharge during the two minimum months averaged 410 cfs or about 3 percent of the average yearly total. Some of the water flow in Thompson Creek is diverted for irrigation purposes in the valley of the Crystal River.

Mine-water supply

Underground mines in the vicinity of North Thompson Creek have been in operation for many years and the mine workings are currently in the process of being rehabilitated. Some of the mine workings are at or near the ground-water table and waters enter such workings from (a) updip surface recharge areas; (b) subsurface percolation from North Thompson Creek; and (c) percolation downward along permeable fault zones. During the course of the field survey (May 19-24) it was mentioned that during a dewatering phase (discontinued April 1976) about 150,000 gal/day was pumped from Mine No. 1; and normal overflow discharge continues at a rate of about 85,000 gal/day. Mine No. 3 has a normal overflow discharge of about 25,000 gal/day. Mine waters belong to the mining company and could be stored without restriction; the volume of discharged water should be adequate for hydraulic mining requirements, with provisions for water storage and recycling of water.

It should be noted also that mine-water quality is reported to have improved since dewatering. In fact, mine-waters are currently being filtered (which does not remove any dissolved impurities) and used as the drinking water supply at the mine site.

COAL GEOLOGY

A geologic map of the bedrock and structure of the Thompson Creek coal mining area illustrates some features of the geologic setting of mines and coal beds (see fig. 4, (separate). The geologic map is positioned geographically within the 1:24,000-scale Stony Ridge topographic quadrangle map in order to incorporate pertinent structural information in places west of the mining area, and to indicate the continuity of exposed coal-bearing rocks into Area 3, to the north and to the south of the Thompson Creek mining area itself (see fig. 1).

Stratigraphic sections of coal-bearing rocks (i.e., the lower part of the Williams Fork Formation) in the Thompson Creek mining area, are shown on figure 7 (in pocket). The line of sections emphasizes the continuity of units of coal-bearing rock; the datum for the line of sections is the top of the Rollins Sandstone Member of the Iles Formation. The stratigraphic relations between the lower and the upper coal zones and the stratigraphic distances between the zones are also indicated on figure 7. The index map on figure 7 shows the locations of the sections illustrated on figures 7, 8, 9, 10, and 11.

Sections illustrating the position and correlation of coal beds A, B, C, and D, in the lower coal zone, are shown on figure 8. As shown on figure 8, coal bed A maintains a rather uniform thickness throughout the Thompson Creek area. Coal bed B also underlies the entire area but its thickness is more variable. Stratigraphic intervals between coal bed A and overlying coal beds in the lower coal zone vary considerably.

Sections illustrating position and correlation of coal beds in the upper coal zone are shown on figure 9. The coal bed identified as the Sunshine is apparently continuous but overlying coal beds are difficult to trace and correlate; for example, the Anderson coal bed seems to pinch out to the south of locality 3 (see index map, fig. 7).

Coal sections of the principal coal beds (A and B) in the lower coal zone, are shown on figure 10. The sections illustrate variations in type of coal and variations in number, thickness, and spacing of non-coal partings in the coal beds at various locations.

As shown on figure 11, similar data are recorded for coal sections of the principal coal beds (Sunshine and Anderson) in the upper coal zone.

In constructing and arranging the figures described above, the objective is to provide a means of following the coal-bearing rocks through increasing levels of detail.

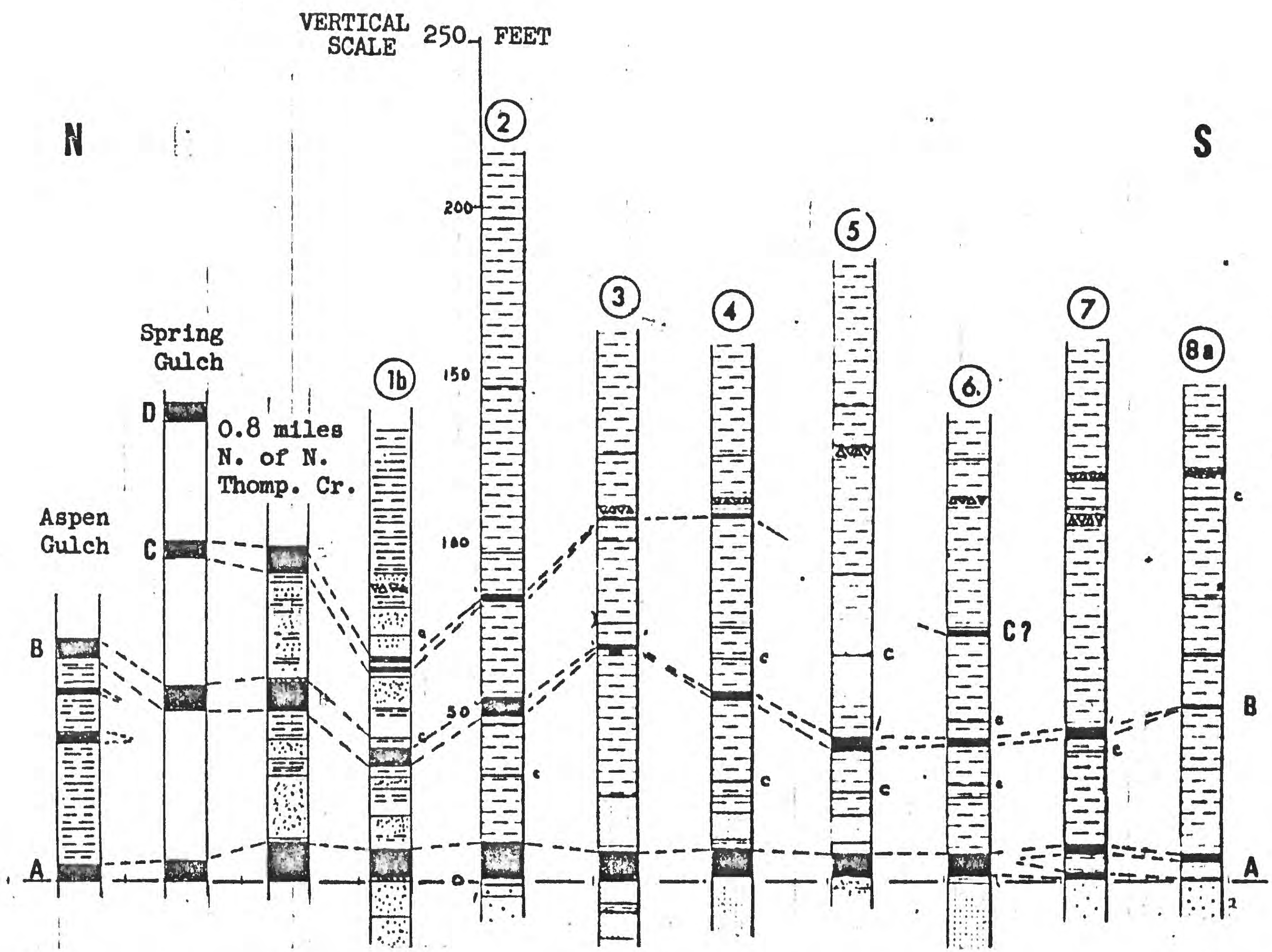

Figure 8 :- Correlation of coal beds A, B, C and D, lower coal zone, Thompson Creek coal mining area, Pitkin County, Colorado. Datum is top of Rollins Sandstone Member of the Iles Formation. Locations of sections are shown on figure 7. Small letter "c" beside section indicates position of coal and (or) bone bed < 1 foot thick.

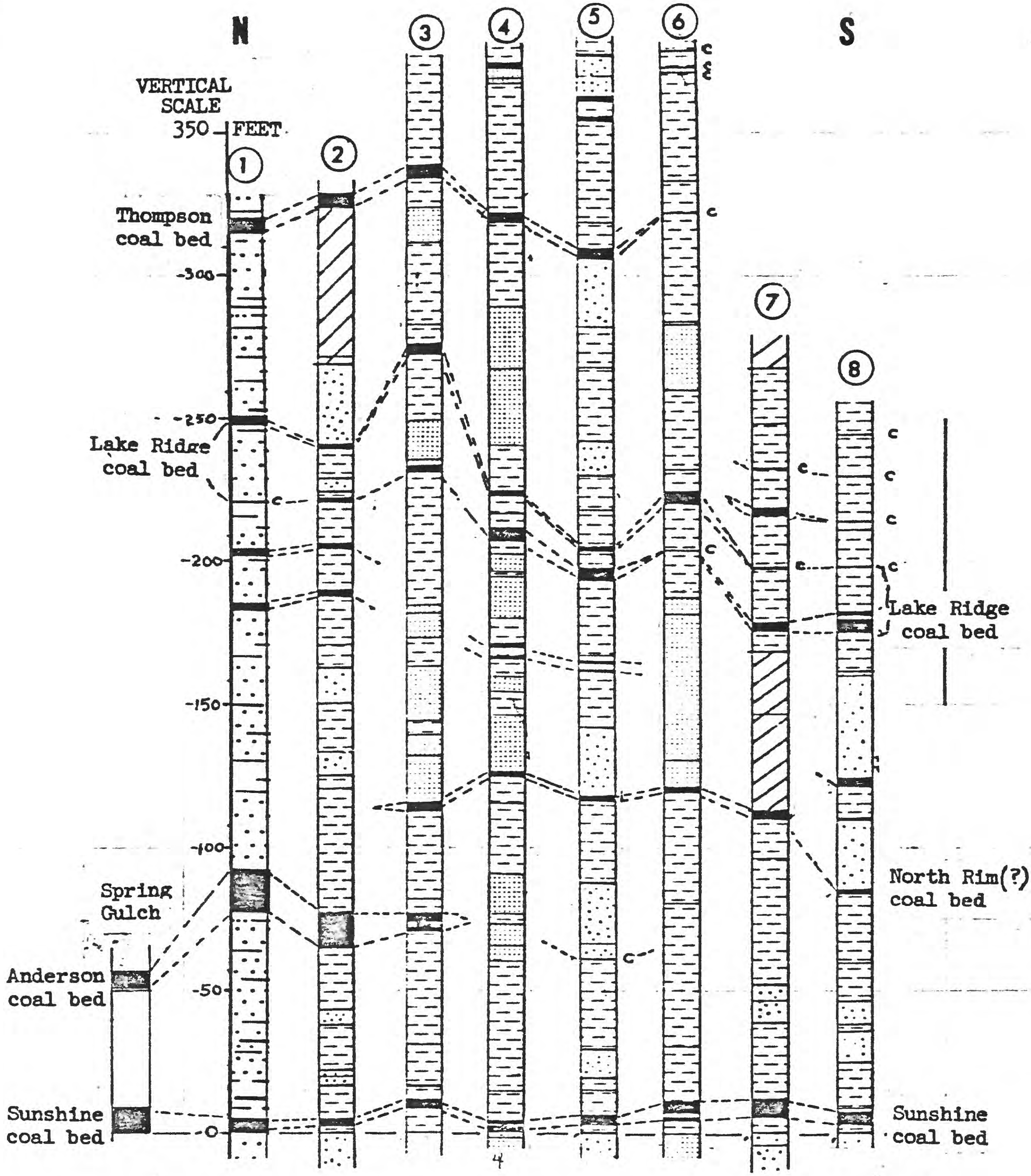

Figure 9:- Correlation of coal beds in the upper coal zone, Thompson Creek coal mining area, Pitkin County, Colorado. Datum is top of upper sandstone bed of the Bowie Shale Member of the Williams Fork Formation. Docations of sections are shown on figure 7 . Letter "c" beside section indicates position of coal bed < 1 foot thick.

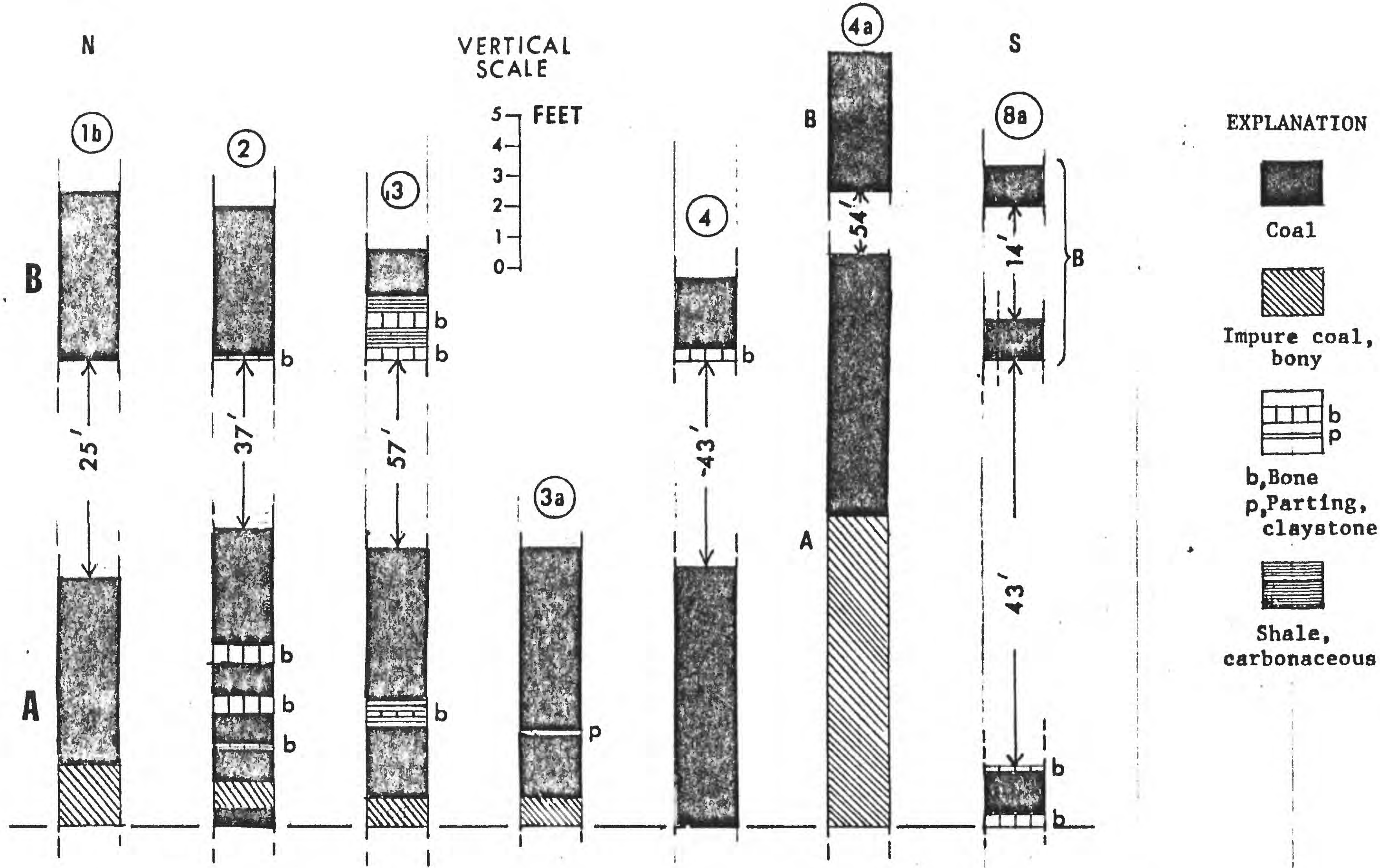

Figure10:-North-south line of coal sections, coal beds A and B, lower coal zone. Locations of sections are shown on index map on figure 7.

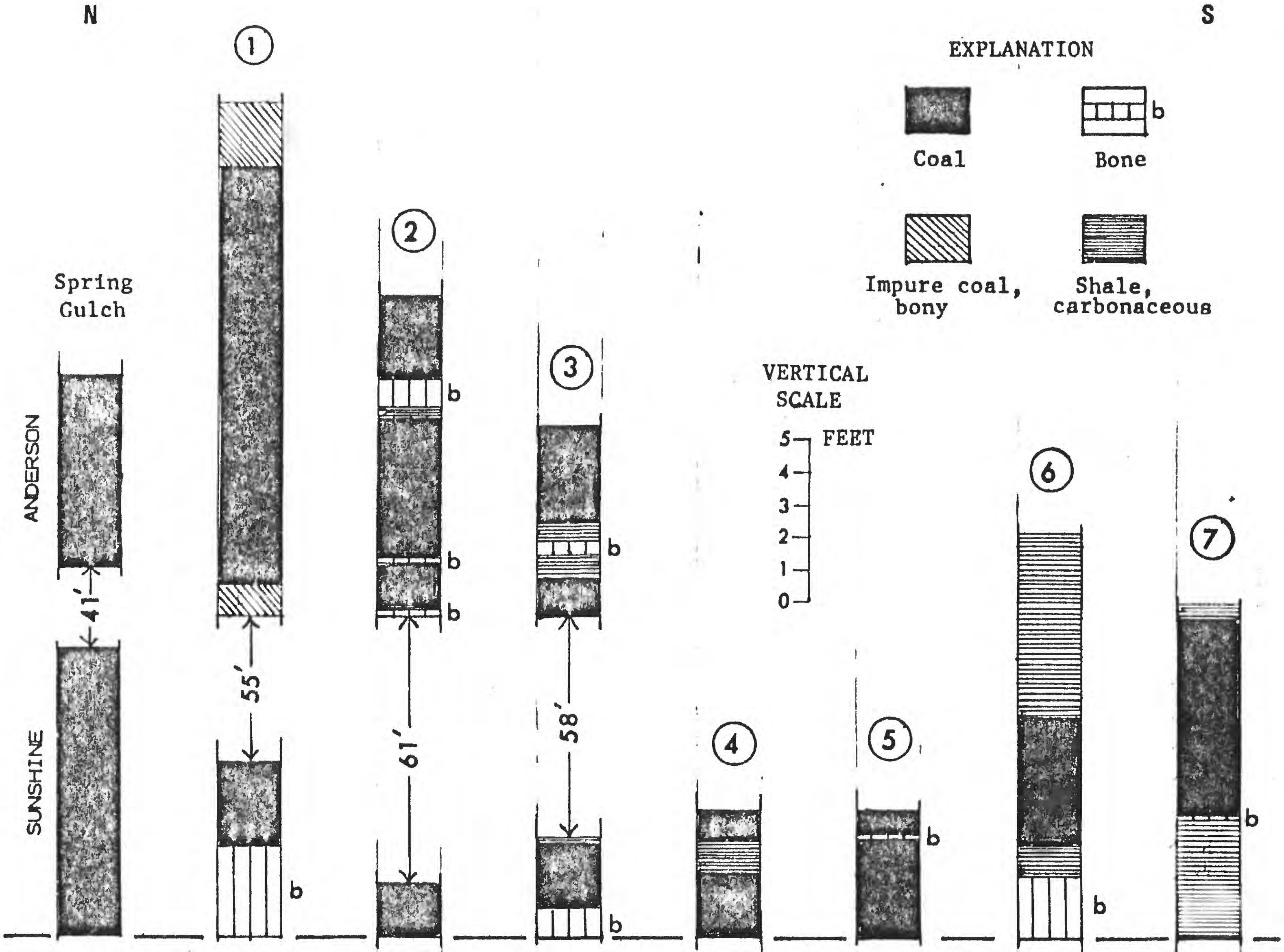

Figure 11:- North-south line of coal sections, Sunshine and Anderson coal beds, upper coal zone. Locations of sections are shown on index map on figure 7.

Basic sources of geologic data, and acknowledgments

The Thompson Creek coal mining area (Area 2) is part of the Carbondale coal field (Area 3). Geologic mapping on vertical aerial photos of the Carbondale area was done by U.S. Geological Survey geologists (J. R. Donnell, E. R. Landis, and W. E. Hallgarth) during 1952-53, and a geologic map of the Carbondale area, on planimetric base and at a scale of 1:31,680, was placed on open file (Donnell, 1962). The geologic map (fig. 4, this report) was constructed from the open-file map by transferring geologic data to the new topographic quadrangle map base. Additional general geologic information was obtained through discussions with J. R. Donnell and E. R. Landis (oral commun., 1977); their interest and support of this project work is hereby gratefully acknowledged.

Most of the illustrated geologic data is from logs and records of exploratory drilling done in 1954-56; these logs and records belonged to the Anschutz Coal Co. We wish to thank Andrew Allen, President, and Albert M. Keenan, Chairman of the Board, Anschutz Coal Co., for permission to use the data and for their interest in our work. During the brief field survey, we received wholehearted cooperation from many company officials involved, and hereby express our appreciation to John Mullins, Mine Manager; Robert Lauman, Chief Mining Engineer; Ray Steed, Geologist; and Lee Kuhre, Manager of Environmental Control, for their efforts on our behalf.

A comprehensive report by Collins (1976) on the coal deposits of the Carbondale, Grand Hogback, and southern Danforth Hills coal fields, eastern Piceance basin, Colorado, is a basic reference. In that report is a 1:250,000-scale geologic map (pl. 1) of the coal fields which shows stratigraphic nomenclature used to identify rock units mapped.

Another basic reference, the report of Murray (1966) on the stratigraphy and structural geology of the Grand Hogback monocline, Colorado, also includes geologic data on the Carbondale coal field; a 1:63,360-scale geologic map (pl. I) of the Grand Hogback monocline shows the stratigraphic nomenclature used by Murray.

Considerable geologic information was taken from the preliminary geologic map (1:250,000 scale) of the Leadville $1^{\circ}x2^{\circ}$ quadrangle, northwestern Colorado (Tweto and others, 1976), which includes the Grand Hogback and Carbondale coal fields.

Stratigraphy

Stratigraphic nomenclature used by various authors for Upper Cretaceous and lower Tertiary rocks in the Thompson Creek mining area is summarized on figure 12. The nomenclature used by Collins (1976) is used in this report because, at a large map scale (1:24,000), subdivision of formations containing thick sequences of coal-bearing rocks allows for more precise definition of the stratigraphic positions of the coal beds (see figs. 4, 7, and 12).

Events leading to or involved with deposition and preservation of coal are indicated in the following descriptions of the rocks in the Thompson Creek mining area.

Mancos Shale

The Mancos Shale (Upper Cretaceous) includes deposits of dark-gray marine shale and minor amounts of limestone which are widely distributed throughout Colorado, New Mexico, and eastern Utah. The shales and limestones of the Mancos were deposited in a Late Cretaceous epicontinental sea.

Iles Formation

In the late stages of Mancos Shale deposition, eastward regression of the sea from northeastern Utah and northwestern Colorado was interrupted by many temporary westward transgressions as recorded by marine strata resting on nonmarine strata (Zapp, 1960, p. B246). Typically each regressive-transgressive cycle resulted in deposition of intermixed marine and nonmarine siltstone and sandstone along a strand line (i.e., the line of maximum marine retreat or advance).

Regionally, the Iles Formation, as separated from the underlying Mancos Shale, includes the strand line deposits of siltstone and sandstone and intervening deposits of marine shale of the Mancos Shale variety. Collins (1976, p. 23) notes that the Iles Formation-Mancos Shale contact "is everywhere placed at the bottom of the first significant sandstone unit in the Mancos."

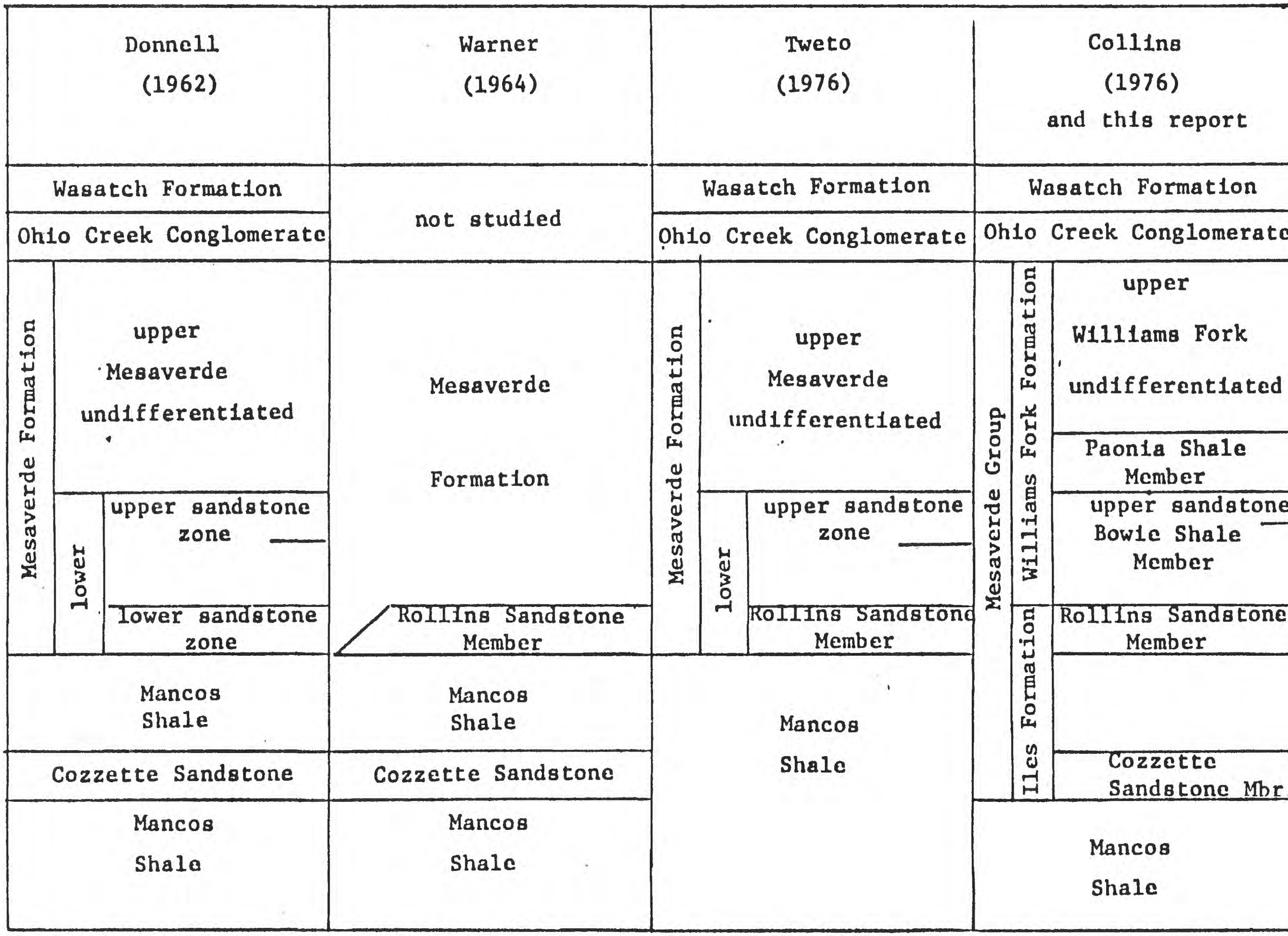

Figure 12:- Stratigraphic nomenclature used by various authors for Upper Cretaceous and lower Tertiary rocks in the Thompson Creek mining area.

In the Thompson Creek mining area the Cozzette Sandstone, consisting of a 20-foot-thick sandstone about 1,000 feet below the Rollins Sandstone Member of the Iles, is the first significant sandstone unit in the Mancos; accordingly, the Cozzette is the base of the Iles in that area (see Collins, 1976, p. 23). The intervening rocks between the Cozzette and the Rollins are predominantly dark-gray marine shale; the shale unit is best described as a marine tongue of the Mancos.

Rollins Sandstone Member.--The Rollins Sandstone Member includes intermixed marine and nonmarine sandstone and siltstone deposited during a regressive phase. In the Thompson Creek mining area, according to the usage of Collins (1976), the Rollins is the topmost member of the Iles. The importance of the Rollins is that its accumulation set the stage for subsequent deposition and preservation of coal as represented by the lower coal zone of the Williams Fork Formation (see fig. 7).

Williams Fork Formation

Murray (1966, p.81-82) noted that the Williams Fork Formation was named by Hancock (1925) to identify about 1,000 feet of alternating Upper Cretaceous sandstone, sandy shale, and coal beds exposed near the confluence of Williams Fork and Yampa Rivers, about 30 miles north of Meeker, Colorado; in that area the Williams Fork is underlain by the Iles Formation and the Trout Creek Sandstone is the topmost member of the Iles. The Trout Creek and Rollins Sandstone Members are thought to be equivalent (Warner, 1964, p. 1099).

The Williams Fork Formation thickens to the south. In the Thompson Creek mining area, and as measured along North Thompson Creek, the total thickness of the Williams Fork is 3,915 feet (see Collins, 1976, table 1, p. 22).

Bowie Shale Member.--The Bowie Shale Member of the Williams Fork is shown on figure 4. The member is 800-1,000 feet thick; the lowermost part of the member contains the lower coal zone of this report. The upper sandstone is the topmost unit (see fig. 7).

In the Thompson Creek mining area the Bowie contains a variety of other rocks in addition to shale and coal (see fig. 7). The middle and the upper sandstone units of the Bowie are laterally persistent and are suggestive of strandline deposits, but the rock types contained in the Bowie are repeated vertically in crude cyclic sequence and some of the coal beds are laterally discontinuous. Variations in stratigraphic levels and intervals between coals are common. Such features are characteristic of deltaic deposits.

Paonia Shale Member.--In the Coal Basin to the south of the Thompson Creek mining area, the Paonia Shale Member consists of a sequence of nonmarine sandstones, siltstones, shales, and coal beds overlying the Bowie Shale Member (Collins, 1976, p. 28). Collins (1976, p. 28) noted that the Paonia is difficult to trace north of Coal Basin, but he felt that it can be traced as far north as North Thompson Creek. On that basis, the Paonia is treated as a member of the Williams Fork Formation (see fig. 4). The unit is about 600 feet thick and the contact with the overlying upper part of the Williams Fork is indefinite. The lower part of the unit contains the upper coal zone of this report (see fig. 7).

In the upper coal zone, as compared to the lower coal zone, the lateral discontinuity of coal beds and variations in stratigraphic levels and intervals between coals are more pronounced (see figs. 8 and 9). The rocks of the upper coal zone probably are deltaic deposits.

Upper Williams Fork (undifferentiated).--In the Thompson Creek mining area the upper part of the Williams Fork Formation is about 2,300 feet thick. The upper part includes nonmarine deposits of sandstone, siltstone, sandy shale, mudstone, shale, and thin coal.

Ohio Creek Conglomerate

The Ohio Creek Conglomerate (Paleocene) overlies the Williams Fork. At North Thompson Creek, the Ohio Creek Conglomerate consists of about 90 feet of sandstone containing chert, quartzite, and quartz pebbles.

Wasatch Formation

The Wasatch Formation (Paleocene and Eocene) conformably overlies the Ohio Creek. The Wasatch includes nonmarine deposits of conglomerate, sandstone, siltstone, mudstone, and shale. In the field, the rocks of the Wasatch are distinguished by their bright varicolored appearance.

In the Thompson Creek mining area and immediately to the west, the upper Wasatch has been removed by erosion. Further west, however, and in sec. 17, T. 7 S., R. 90 W., about 9 miles southwest of the Thompson Creek area, the thickness of the Wasatch and the Ohio Creek combined is estimated to be about 5,100 feet (Murray, 1966, table 5, p. 93).

Structure

Within the Thompson Creek mining area, the predominant structure is the westward dipping Grand Hogback monocline, which forms the eastern margin of the Piceance basin. The strata exposed in the Thompson Creek area form the uppermost part of this monoclinal fold.

As indicated on figure 4, exposed coal beds and associated rocks dip westward about 30° (2,760 ft/mile). To the west of the coal-bearing exposures, the westward dip of overlying strata decreases progressively, and the pitch of Tertiary strata along the west margin of the Thompson Creek area averages about 15°W. (see fig. 4).

Structure contours drawn on the base of coal bed A (fig. 4) suggest that the elevation of coal bed A descends below 6,000 feet along the west margin of the Thompson Creek area. About 3 miles west of the area, as interpreted from well logs, the elevation of coal bed A rises to about 6,000 feet above sea level. The configuration of the 6,000-foot structure contour shown on figure 4 suggests that a shallow syncline occurs between the Thompson Creek area and the wells. The configuration also suggests that the axial trend and plunge of the syncline is to the northwest.

Thickness of overburden

Thicknesses of overburden on coal bed A, as determined by subtracting structure contour values from topographic contour values, increases rapidly and progressively westward away from the outcrop (see fig. 4). Coal bed A is under more than 1500 ft of overburden at distances within about one-half mile west of the outcrop, and overburden increases to a maximum of about 3000 ft in western parts of the mining area.

The overburden factor may limit the extent of underground mining westward, down the dip of the coal beds. Mining problems caused by overburden pressures tend to become more severe when overburden exceeds 1500 ft.

Faulting

As used here, faulting refers to the process in which rocks are displaced by fracturing during structural breakage. A fault is a fracture or zone of fractures along which rocks have been displaced on one side relative to the other.

Although faults involving detectible displacement were not observed during the surface geologic mapping of the Thompson Creek mining area, several west-trending faults cutting the coal-bearing rocks were mapped to the north and south of the area. It is the authors' belief that the extensive vegetation and surficial cover on bedrock in interstream areas has obscured all major and minor faults that break to the surface if, indeed, any are present.

Within the subsurface of the Thompson Creek mining area, two major fracture systems cutting coal beds and associated rocks were encountered in the area during past mining. These fracture systems are described and illustrated in a report by Keenan and Carpenter (1960). Displacements along faults are generally less than 60 feet; the strike of one set of faults is west and the other is north.

As described by Keenan and Carpenter (1960), faulting of pitching coal beds produces complex geometry. Applied geology, as an economic tool, is required in order to determine the extent, pattern, and frequency of faults, and if mining problems resulting from coal-bed displacement and roof breakage are to be resolved successfully, geologic data on faulting must be incorporated into mining plans and operations.

Faulting generally adds to mining costs and may also influence coal quality. For example, otherwise strongly coking coal in the immediate vicinity of a fault has been found to have weaker coking characteristics (Keenan and Carpenter, 1960, p. 235). This adverse effect might be caused by oxidation of the fractured coal owing to greater porosity and permeability of coal in fault zones.

MINING

Underground mining of coal in the Thompson Creek mining area dates back to 1887. Total production of coal mines is tabulated in Appendix C (see table C-3). Large-scale production mining continued until 1966.

Thompson Creek mines Nos. 1, 2, and 3, with portals in both the north and south walls of North Thompson Creek, were active from 1955 to 1966. Mines No. 1 and No. 3 were reopened in 1975, for longwall recovery of the pitching coal.

Coal resources

Estimates of original resources contained in coal beds more than 42 inches thick, in townships that include the Thompson Creek mining area, are summarized in Appendix C (table C-4). The estimates, made by Donnell (1962), do not indicate measured, indicated, or inferred resources; and no estimates of remaining resources are available.

ANALYTICAL DATA

Analytical data on chemical and physical properties of coal samples from the Thompson Creek mining area and vicinity are tabulated in Appendix C (table C-1). These data are summarized in Table 2. The coal beds sampled include correlative beds in the lower coal zone and those in the upper coal zone; the stratigraphic interval between the lower and upper coal zone is about 1,000 feet (see fig. 7).

In Appendix C, analytic data on the Thompson Creek coals are grouped according to localities 1 through 6 from north to south, respectively (fig. 13), with the line of localities being approximately parallel to the strike of the pitching coal beds involved.

The reason for this arrangement is that, from north to south, chemical and physical properties of correlative coals exhibit progressive and pronounced changes over relatively short distances along the strike of the beds. These changes are emphasized by the analytic data summarized in table 2, wherein locality 3 (vicinity of Thompson Creek mine site on North Thompson Creek) serves as a reference point, and distances north or south are measured from that locality (see also fig. 13).

Free swelling index (FSI)

The ASTM test method (D 720-67) determines the free swelling index (FSI) of a given coal sample and provides an approximate measure of its coking properties. The test does not provide a measure of coking quality.

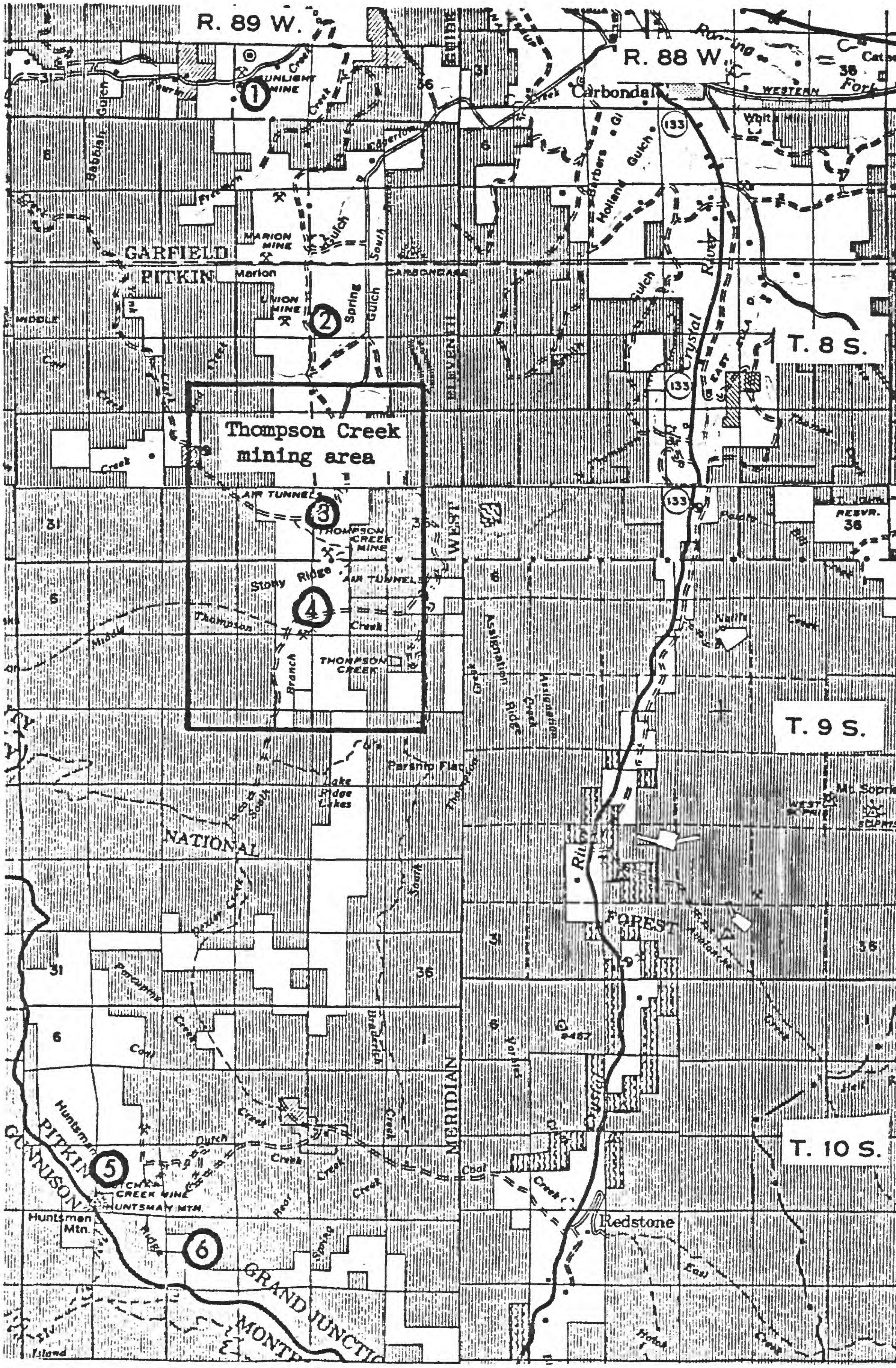

Figure 13:- Map showing localities of coal samples for which analytical data are available.

Table 2.--Summary of analytical data on coal samples from Thompson Creek mining area and vicinity north and south from table C-2, Appendix C

Locality[1/]	Mine area and coal bed	Distance from N. Thompson Creek (loc. 3)	Coal rank	Dry coal, percent				FSI	HGI
				Vol.	F.C.	H	O_2		
(1)	Sunlight mine "D" bed	5 mi N	HvAb	42.2	54.0	5.5	12.5	0-1	47
(2)	Aspen Gulch "B" bed	2.5 mi N	HvBb	37.3	55.5	5.3	7.9	1½	--
(3)	N. Thompson Cr.								
	A bed	(0)	Mvb	30.8	60.3	5.2	6.4	7	89
	Anderson bed	(0)	HvAb	32.4	59.5	5.1	5.4	7	71
(4)	Middle Thompson Anderson bed	1.5 mi S	Mvb	27.0	59.5	4.9	3.5	8½	--
(5)	Dutch Creek A-B bed	9 mi S	Mvb	23.0	68.6	4.8	2.3	9	110
(6)	Bear Creek A+B bed	10 mi S	Mvb	26.1	70.9	4.9	4.9	4	--

1/ Localities 1-6 are shown on figure 10.

In the test a sample of coal is heated to 820°C in a standard covered crucible, and the size and shape of the resulting "coke button" is compared to standard outlines which have been assigned index numbers from 1 to 9 in order of increased swelling and relative strength of coking.

As shown by the analytic data (table 2; and Appendix C) Thompson Creek coals in localities 3 and 4 have relatively strong coking properties as indicated by FSIs of 7 to 8½, and coals to the south (locality 5) have FSIs of 9 and 9+, indicative of the strongest coking coal. North of locality 3, however, FSIs of correlative coals show a marked decrease. At locality 2, for example, a sample of coal from bed B has an FSI of 1½, indicative of very weak coking properties. At locality 1, coal bed D is virtually noncoking.

From north to south (localities 1 to 5) the progressive increase in FSIs of correlative coals is accompanied by (a) decrease in percentage of volatile matter and oxygen, (b) increase in percentage of fixed carbon, and (c) hydrogen content remains about the same at all localities (see table 2). These changes illustrate some guides for separating coking coals from noncoking or weakly coking coals that were outlined by Johnson (1952, p. 1). As a general rule, coals may be eliminated as possible coking fuels if (a) oxygen content is greater than 11 percent, (b) the ratio of hydrogen to oxygen is less than 0.5, or (c) the ratio of fixed carbon to volatile matter is less than 1.3.

Hardgrove grindability index (HGI)

The ASTM standard test method for grindability of coal by the Hardgrove machine method (D 409-71) determines the relative grindability or ease of pulverization (i.e., <200 mesh) of a given coal sample as compared to samples of coals selected as standards. The specific purpose of the test is to determine relative ease of grinding finely enough to use as pulverized fuel.

In the test, initial sample sized fractions of 0.6 to 1.2 mm are used and 50 g of such sized particles are ground for 60 revolutions. The calculated weight of the material passing a No. 200 sieve (particle sizes <0.075 mm) is then plotted against weights of <200 mesh materials corresponding to HGIs of standard reference samples (40, 60, 80, and 100). In this method of calculation the higher the resulting HGI of the given sample of coal, the easier the coal was to grind. Coals that are easiest to grind have HGIs on the order of 100 to 110.

Correlative coals in localities 1 and 2 have relatively low HGIs (47-52), indicating that samples of such coals were relatively hard to grind. Coals in localities 3 and 4 were much easier to grind as indicated by HGIs of 69 to 89; and to the south (loc. 5) the coals have an HGI on the order of 110, which is somewhat off-scale in terms of extreme ease of grindability.

As a physical property of coal, however, grindability is complex and somewhat ambiguous. For example, Yancey and Geer (1968, p. 1-31) describe grindability as "-a composite physical property embracing other specific properties such as hardness, strength, tenacity, and fracture." But it is difficult to see how the HGI test for grindability can be in any way a measure of those specific properties because the initial sample-size fractions used are rather minute (0.6 to 1.2 mm). However, this does not preclude associating HGI data with test data for the other specific properties mentioned.

Many workers have noted an empirical correlation between HGI and ASTM rank of coal. For example, Brown and Hiorns (1963, p. 148; and fig. 9) compiled HGI data on American, British, and Indian coals and related HGI to rank as determined by percentage of volatiles. Results obtained indicate that coals containing 15-30 percent volatiles generally have HGIs >90, whereas coals containing 30-40 percent volatile exhibit HGIs from 90 to 40, respectively.

FSI, HGI, and content of volatile matter

Many workers have observed consistent relations between FSI, HGI, and percentage of volatile matter. These relations are that strongly coking coals generally have relatively high HGIs and contain 20-35 percent volatiles; weakly-coking coals generally have low HGIs and contain >35 percent volatiles. These relations are supported and illustrated by the analytic data for coals in the Thompson Creek mining area and vicinity.

From work establishing these relations, Donahue and Leonard (1967, p. 365) concluded that it is possible to estimate the magnitude of one property if the other two properties are known. Their graphic illustrations (fig. 4, p. 363; fig. 7, p. 364) of the relationship of VM (within selected ranges of FSI) to coal hardness (i.e., grindability) are summarized on figure 14.

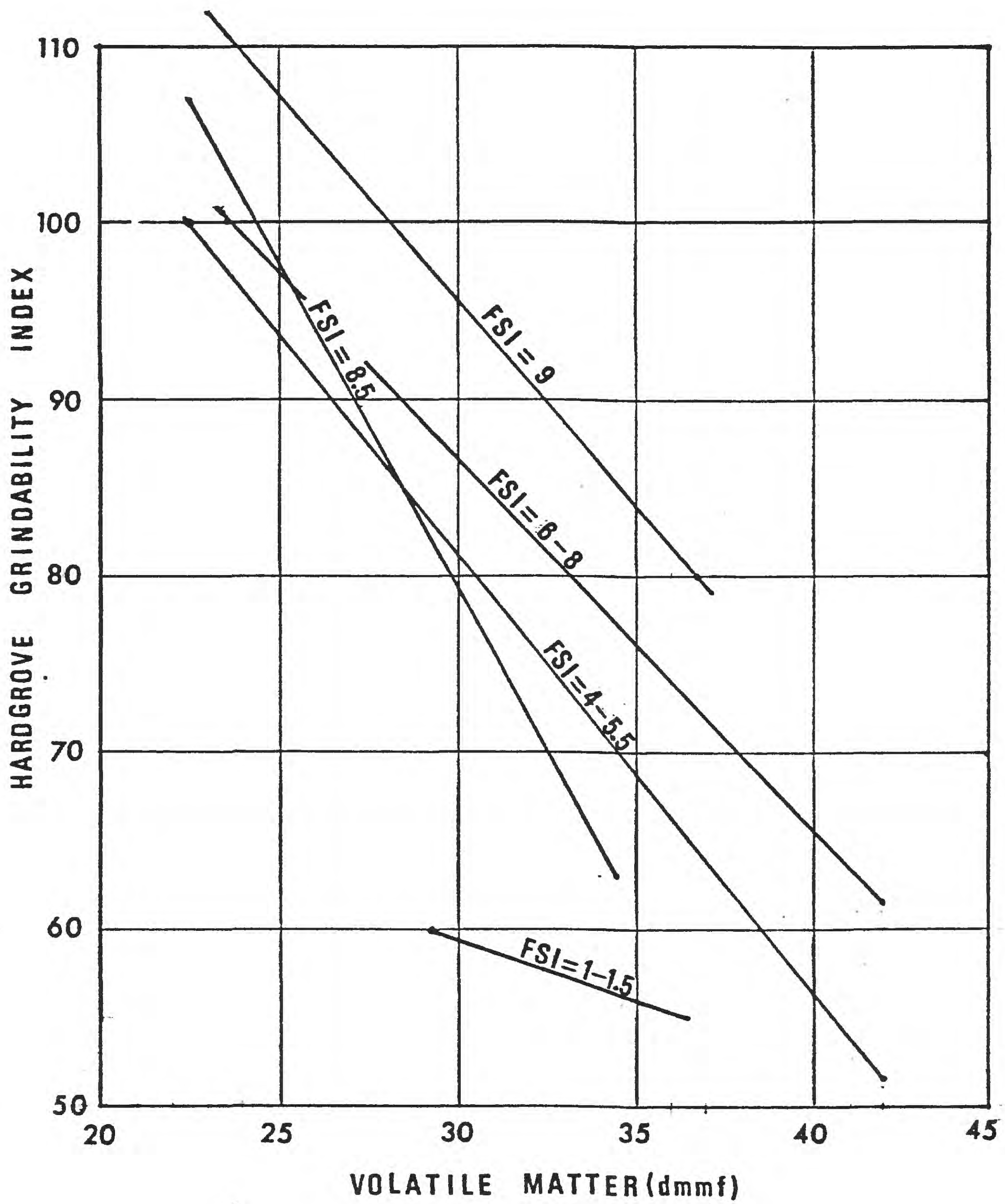

Figure 14 :- Empirical relationship of Hardgrove Grindability Index to percent-content of volatile matter for different levels of free swelling index (FSI). Source of data: Donahue and Leonard (1967, fig. 4, p. 363; fig. 5, p. 364).

Analytic data for Thompson Creek coals are not complete for all samples analyzed and either the FSI or the HGI was not determined. For such samples, the graph shown on figure 14 provides a means of estimating the magnitude of either FSI or HGI.

Coal hardness

Variations in hardness of coals have been cited as a factor affecting the control of productivity rates achieved in subsurface mining. The property is discussed in that context in a later section of this report (see "Subsurface Hydraulic Mining;" "Coal hardness").

Hardness as discussed here concerns the relations between FSI, HGI, and content of volatile matter (fig. 14), and references to hardness that Donahue and Leonard (1967, p. 364) make in the following quotation.

> "Figs. 4 and 5 [cf fig. 14] illustrate the relationship of VM, within selected ranges of FSI, to coal hardness. In Figs. 4 and 7, HGI can be estimated from the measured values of VM and FSI. It is apparent from Fig. 4 that for FSI values of 8 or less, decreases in VM are related to increasing coal softness (HGI). Generally, for any given VM content, increases in HGI are associated with increases in FSI. The hard, lower HGI coals, are generally weakly coking with FSI in the range of 1 to 1 1/2."

These statements indicate that Donahue and Leonard consider coal hardness and grindability to be similar or comparable physical properties.

Hardness is also a specific property of coal, and reference is commonly made to the dynamic hardness of vitrain layers as measured by Vickers and Shore scleroscope methods. Such measurements provide a means of examining changes in that property according to rank of coal (Brown and Hiorns, 1963, p. 127). In this connection, Yancey and Geer (1968, p. 1-25) compiled data on dynamic hardness of vitrain layers in coals of various types which are summarized as follows:

Type of coal	Volatiles (percent)	Shore hardness number[1/]	Vickers hardness number[2/]
Anthracite	6	122	54
Bituminous (noncaking)	41-42	107-109	24-29
Bituminous (caking)	40-44	105-107	22-26
Bituminous (coking)	21-36	44-65	9-16

1/ Shore number represents dynamic deformation by rebound.

2/ Vickers number shows static deformation, by size of indentation formed when load is applied to steel ball or diamond in contact with the coal.

The tabulation of dynamic hardness of vitrain layers in various types of coal indicates that vitrain layers in bituminous coking coals containing 21-36 percent volatile matter are relatively soft. But the tabulation implies that bituminous coals containing 37-40 percent volatiles may exhibit dramatic (and presumably progressive) increases in hardness of vitrain layers. However, variations in hardness of coal containing 37-40 percent volatiles may actually be a function of the coking strengths of the coals. Vitrain layers of weakly coking coal may be relatively hard, whereas vitrain layers of rather strongly coking coal may be relatively soft (see fig. 14).

With respect to hardness as a specific property, and as related to rank of coal and coking properties, Yancey and Geer (1968, p. 1-25) report: "Hardness is related to rank and has a minimum value by various means of measurement at about 85 to 90 percent carbon." Brown and Hiorns (1963, p. 127) report that "A minimum in hardness was also found at 90%C, and a maximum found at around 80%, supporting Van Krevelen's results."

Brown and Hiorns (1963, p. 127) also mention that: "Van Krevelen, for example, measured the change in Vickers microhardness with carbon content and found a minimum at 90%C which was interpreted as a minimum in binding forces [Ref.]."

COALIFICATION AND GEOTHERMAL METAMORPHISM

Deposits of Upper Cretaceous bituminous coal are widespread in the western United States and it must be assumed that, during Late Cretaceous time, swamps were extensive and conditions were optimum for the accumulation and preservation of coal-forming materials.

Deposition of coal and coal-bearing rocks commonly takes place in subsiding depositional basins and, in the past, substantial thicknesses of overburden rocks commonly accumulated on any coal before a later geologic event arrested further deposition.

Coalification may be described as a long-term metamorphic process in which peat and anthracite are end-members of a series, and intervening ranks of coal represent stages of metamorphism. The mechanisms of coalification involve pressure, heat, and geologic time. In the usual cycle of coal formation a given accumulation of coal-forming materials is converted to peat, the peat layer is buried to increasing depths, overburden pressures and confining pressures continue to increase, and heat increases. As the peat-coal layer continues to be depressed downward, pressure and heat combine to produce compaction and physical and chemical changes which alter the thickness, volume, structure, texture, and composition of the coal (i.e. metamorphism).

It is not within the scope or purpose of this report to attempt to classify pressure, heat, and geologic time as to their relative importance in the metamorphic process of coalification. It seems evident that all three are required for coalification to be effective in reaching the rank of low-volatile bituminous coal. Nonetheless, the evidence at hand strongly suggests that coalification involves long-term geothermal metamorphism which may be described as a natural, thermal distillation of volatile substances, including oxygen, from buried coal, over long periods of geologic time.

Thermal metamorphism

The rank of coals in the Thompson Creek mining area and to the south locally is higher than the regional rank (see fig. 15). Chemical changes involved in these local advances in rank include (a) decreases in percent-content of moisture, volatile matter, and oxygen, and (b) increases in Btu value and in percent-content of fixed carbon (see table 2 and Appendix C).

The most notable feature associated with these chemical changes is that most coals north of the Thompson Creek area are noncoking, whereas the coals in the area and to the south are strongly coking. These changes are also accompanied by physical changes; for example, coals north of the Thompson Creek area have relatively low HGIs, whereas coals in the area have relatively high HGIs and those to the south have extremely high HGIs. It should be emphasized that these chemical and physical changes occur over short distances along the strike of the coal beds (see table 2). This suggests that localized geologic events accelerated the coalification process.

Some regional and local geologic events germane to the coalification process, are as follows:

(1) Coals of the Thompson Creek area, and of the region shown on figure 15, were deposited in Late Cretaceous time about 75 million years ago. Subsequently, the lower zone of coals in the Thompson Creek area was buried by at least 9,000 feet of sediments of the Williams Fork and Wasatch Formations, and probably by an additional 3,000 feet or more of sediments of the Green River Formation of Eocene age, which have since been eroded off. Consequently, by late Eocene time about 40 million years ago the lower zone of coals was buried by 9,000 to 12,000 feet of rocks, and the coalification process had been underway for about 35 million years.

(2) Beginning in late Eocene time, about 45 million years ago, and continuing through middle Miocene time (18 million years ago), large-scale vertical movements took place in the northwestern part of the region shown on figure 15. This structural movement resulted in the development of the White River uplift and the Grand Hogback monocline (Murray, 1966, p. 193), a prominent structural feature exposing some 25,000 feet of steeply-dipping rocks. Structural relief of the monocline ranges from about 10,000 feet near Placita, Colorado, to about 27,000 feet

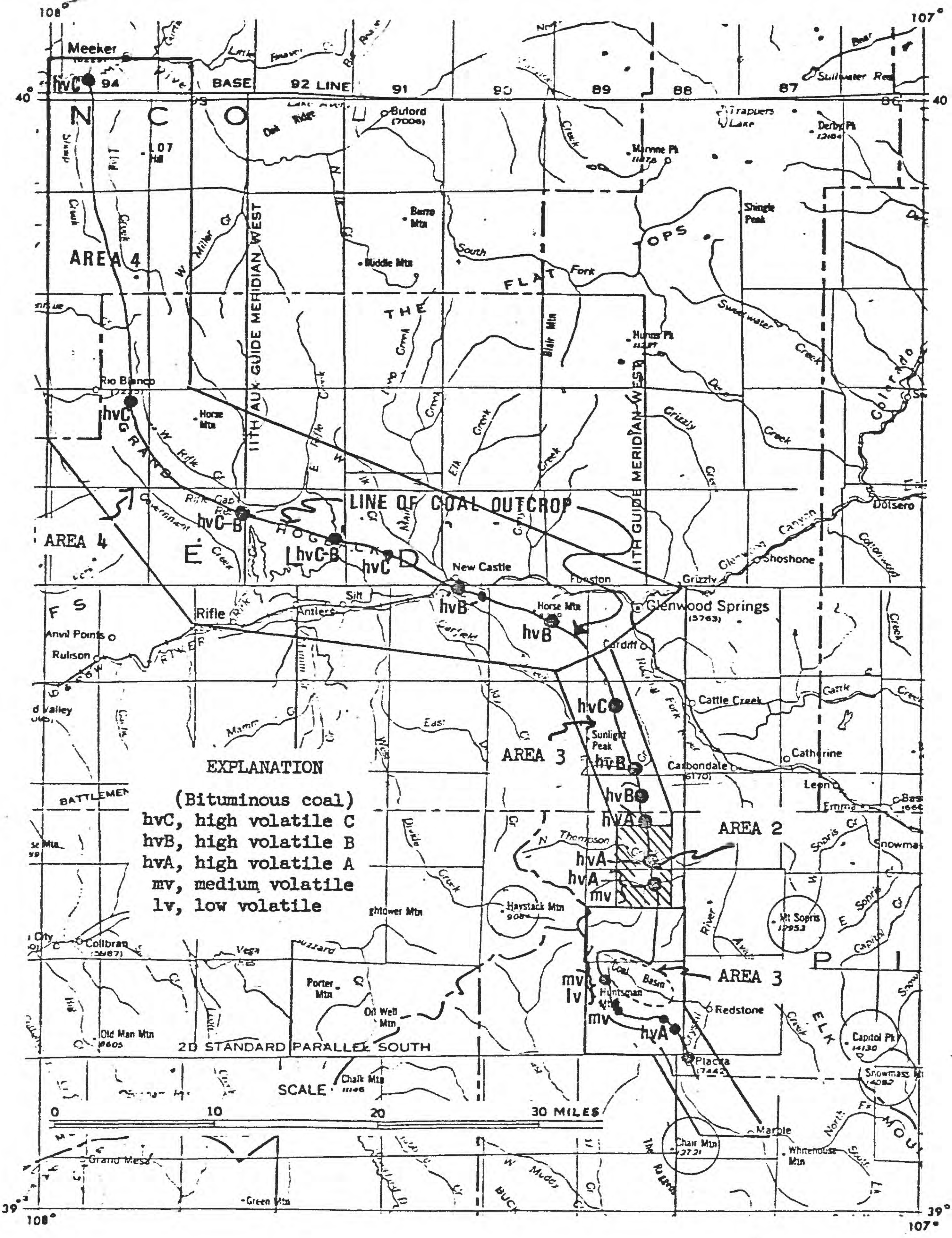

Figure 15:- Regional map showing localities and ASTM ranks of bituminous coal samples from Areas 2, 3 and 4.

near Rio Blanco (Murray, 1966, p. 192). This regional orogenic event arrested further deposition. The coalification process had by then advanced to a regional rank of HvC-HvB (see fig. 15).

(3) In Oligocene time 26-38 million years ago, and concurrent with the regional orogenic event described above, the rocks in the southwestern part of the region were intruded locally by igneous bodies of granodioritic and quartz monzonitic composition (Tweto and others, 1976). The temperature of comparable magma is estimated to have been about 800°C (see Wahlstrom, 1950, p. 154). The cooled intrusive bodies are now represented by prominent geographic features such as Haystack Mountain, Mt. Sopris, Chair Mountain, Snowmass Mountain, and Capitol Peak (see circled areas on fig. 15).

Subsurface laccolitic intrusions of quartz monzonite are also known to be present in the region; for example, beneath "Coal basin" (see fig. 15) where exploratory oil and gas wells penetrated at least 1,500 feet of quartz monzonite at depths of about 4,000 feet (Donnell, oral commun., 1977). The aeromagnetic map (fig. 16) of the region indicates that the buried intrusive under Coal Basin may be connected to the Mt. Sopris stock.

(4) During Pliocene and Miocene time (8-23 million years ago) lava flows of alkali basalt were extruded in the area east of Glenwood Springs-Carbonadle. Eroded remants of the basalt flows overlie the coal-bearing rocks in the area southwest of Glenwood Springs. These basalt flows seem to be responsible for the area of relatively high magnetic intensity shown on the aeromagnetic map (fig. 16) in the vicinity of Glenwood Springs.

(5) Thermal springs developed subsequent to the Pliocene vulcanism. Glenwood Springs and area to the south and southeast are well-known for numerous thermal springs (see fig. 17). Some of the hot springs are located in and adjacent to Oligocene-age intrusive bodies, and it would seem that their heat may be derived from nearby igneous rocks that are still cooling.

(6) Also shown on figure 17 are heat-flow contours. The contoured values indicate that, as measured from the surface, the flow of heat from the interior of the Earth is still abnormally high in the eastern half of the region shown on figure 17. In this respect, the average rate

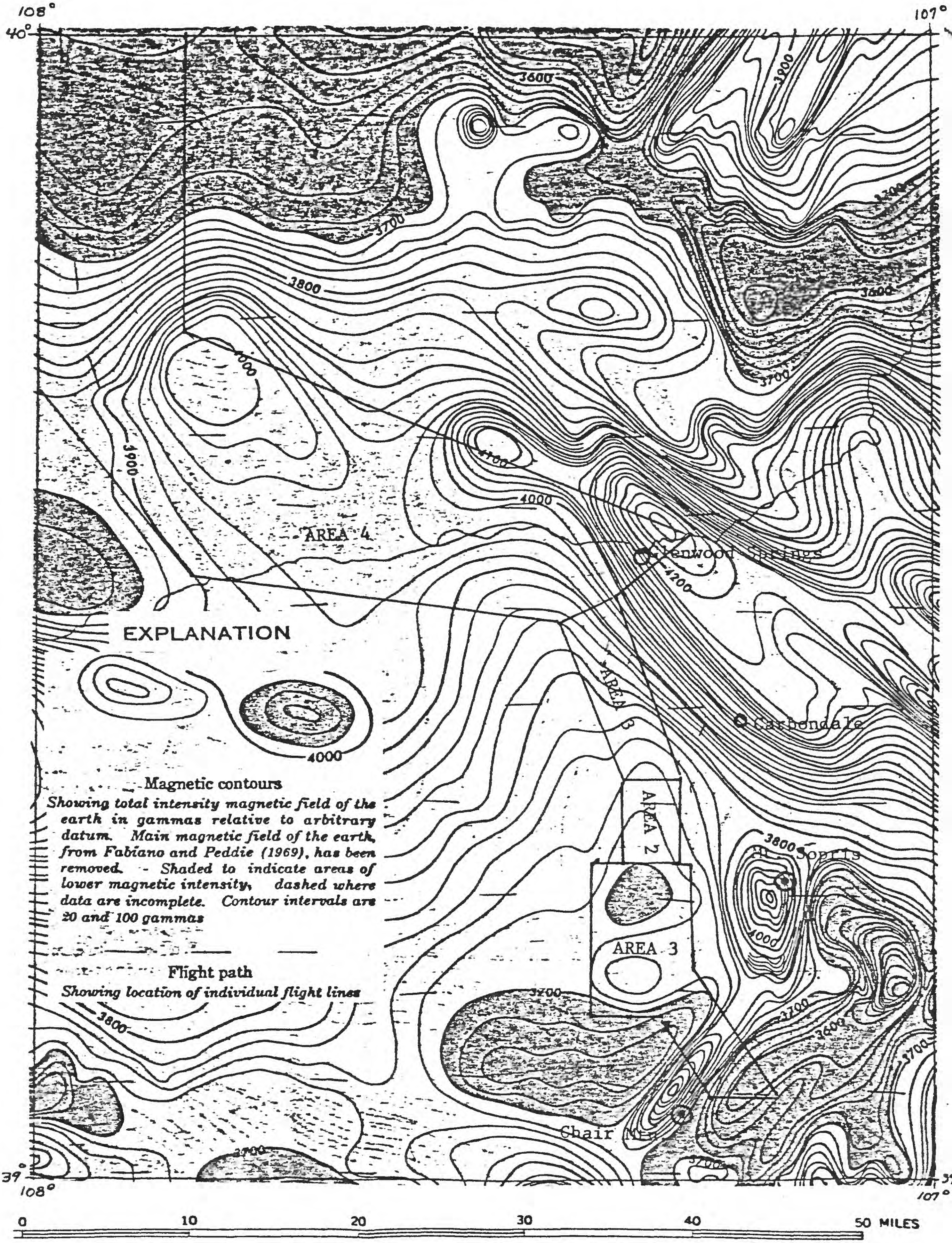

Figure 16 - Aeromagnetic map of part of western Colorado showing locations of Areas 2, 3, and 4 (Area 2 is Thompson Creek mining area), after Zietz and Kirby (1972: USGS Map GP-836).

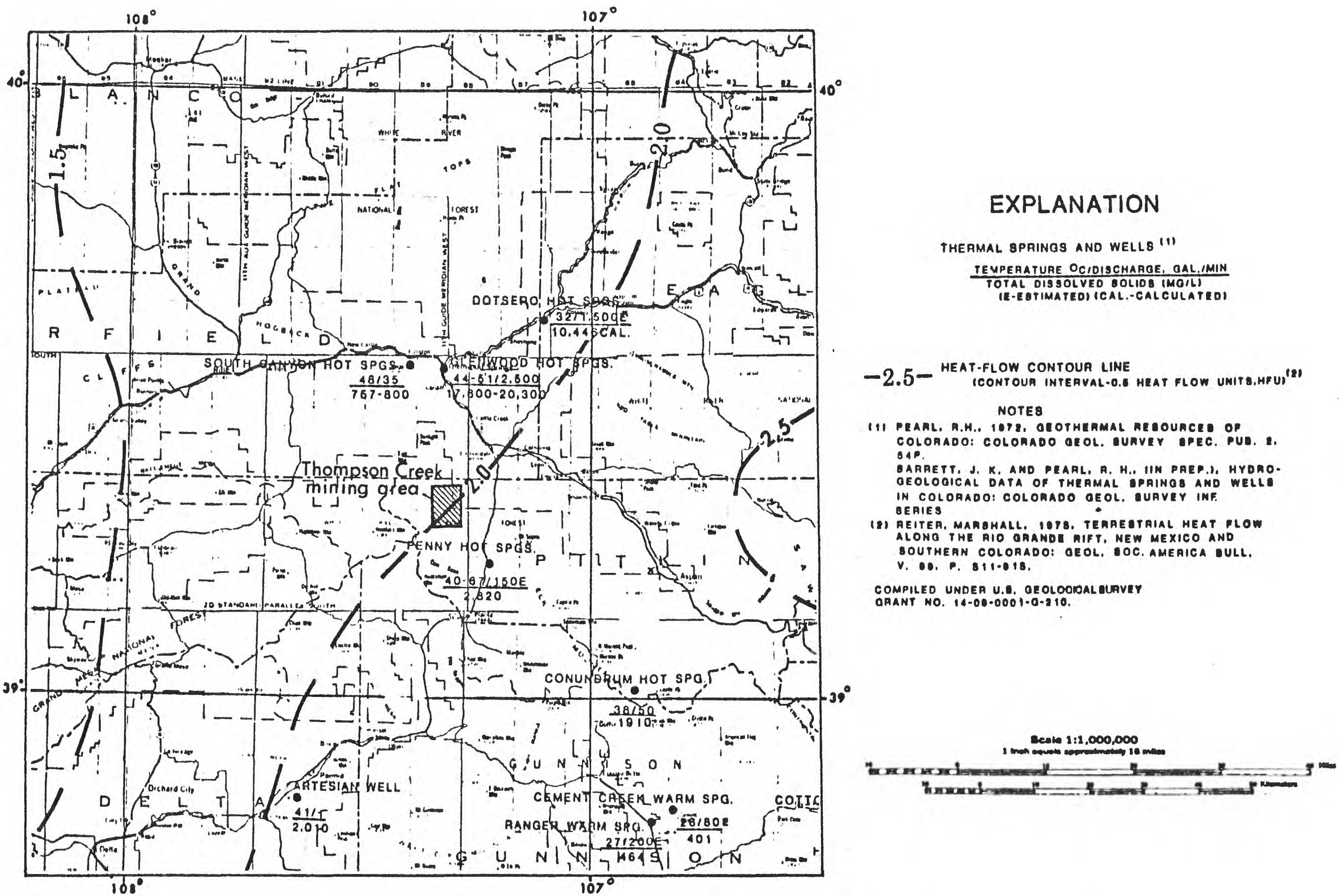

Figure 17 :- Map showing Thermal springs, wells and heat-flow contours in part of western Colorado. Data source: Barrett, J. K., Pearl, R. H., and Pennington, A. J., 1976, Map showing Thermal springs, wells and heat-flow contours in Colorado: Colorado Geol. Survey, Information series 4.

for the Earth is 1.5 x 10^{-6} cal/cm^2/sec. (Pearl, 1972, p. 4), which for convenience is referred to as 1.5 heat flow units (HFU). Any measurement in excess of 1.5 HFU usually indicates a geographically restricted heat source at fairly shallow depths (Pearl, 1972, p. 12). As shown on figure 17, a 2.0 HFU-contour passes through the Thompson Creek mining area and higher rates of heat flow are indicated in the region to the east and southeast.

7) A geothermal gradient map of part of western Colorado (fig. 18) shows that present-day geothermal gradients are steeper than normal (1.8^{o}F/100 feet) in an area including the Thompson Creek mining area and to the west. (The gradients were derived from annual surface temperatures and corrected bottom-hole temperatures of oil and gas wells.)

8) Point-locations of geothermal gradients shown on figure 18 correspond to locations of oil and gas wells. Logs of some of these wells were obtained, and data for each well commonly included the bottom-hole temperature encountered. One of the highest subsurface temperatures recorded in the area to the west of the Thompson Creek mining area is in sec. 36, T. 8 S., R. 91 W., where instruments in the California Co. No. 1 Hurd Govt. well recorded a bottom-hole temperature of 290^{o}F at a depth of about 12,600 feet. That location is about 3 miles northwest of "Haystack Mountain" (see figs. 15 and 18) where igneous rocks of Oligocene age are exposed (Tweto and others, 1976). The surface elevation of the No. 1 Hurd Govt. well is 9,815 feet near the top of the Williams Fork Formation (see fig. 19). As interpreted from electric logs, (a) about 50 feet of igneous rocks were penetrated from 3,770-3,820 feet, (b) the base of coal bed A was penetrated at a depth of about 4,400 feet (i.e., the elevation of the base of coal bed A is about 5,400 feet), and (c) the thickness of the Williams Fork Formation is probably about 4,600 feet, or about 700 feet thicker than measured along North Thompson Creek, about 8 miles to the east.

9) As shown on figure 19, geothermal gradients in the area west of the Thompson Creek area and northwest of the Haystack Mountain intrusive are steeper than normal, whereas, to the southwest and south, gradients are less than normal (i.e., 1.8^{o}F/100 feet). The steeper gradients suggest a geographically restricted heat source which is still effective, and may

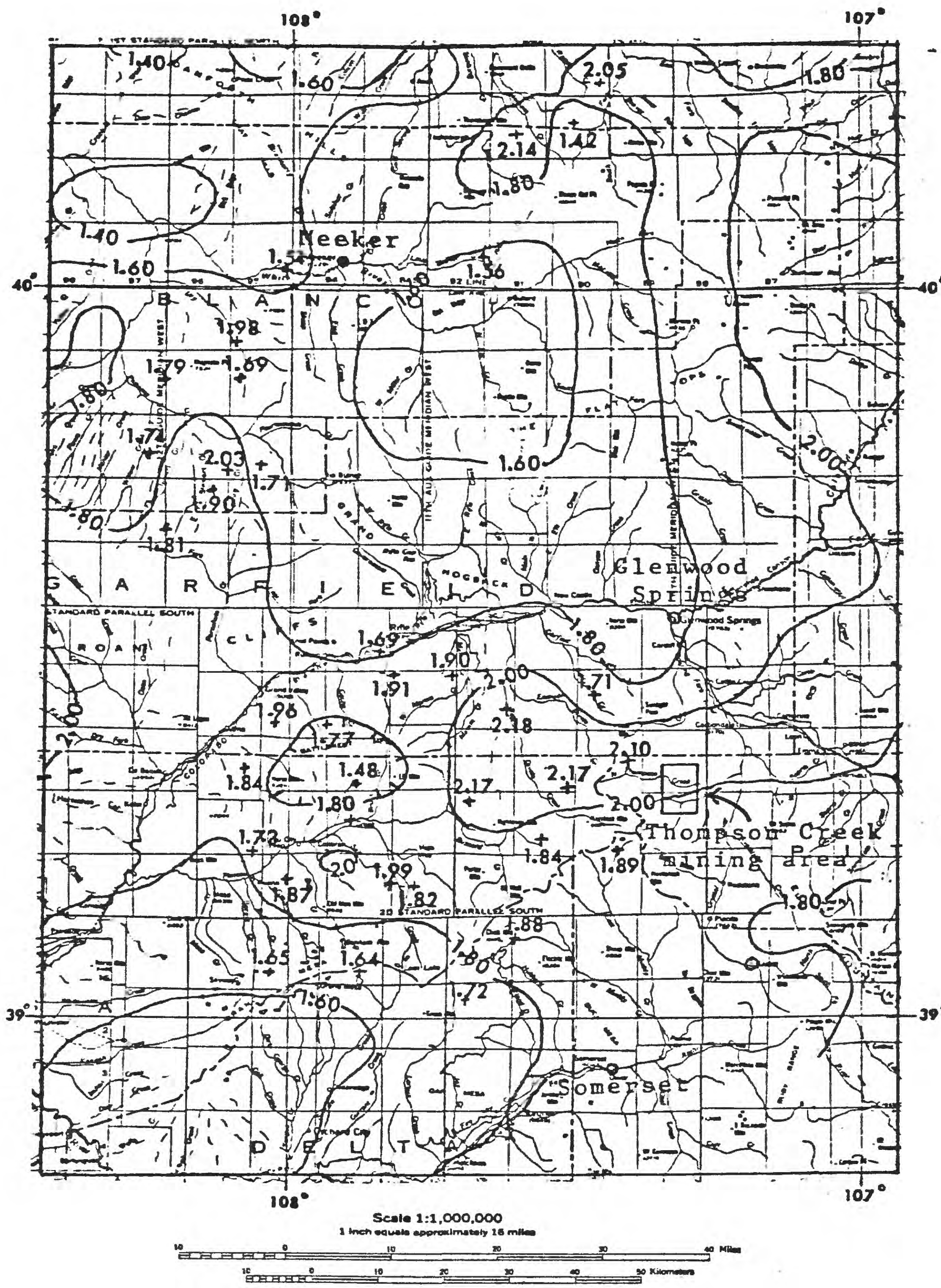

Figure 18:- Geothermal gradient map of part of western Colorado. Contour interval, 0.20°F/100 feet. Data source: computer-generated (1977) Geothermal gradient of Utah-western Colorado, portfolio map area No. 19, Geothermal Survey of North America, American Association of Petroleum Geologists.

have been more effective in past geologic time. In this respect it is of interest to note that the above-normal geothermal gradients, and the Haystack Mountain intrusive, occur in association with anticlinal structures trending northwest in the vicinity of Haystack Mountain, and the anticline northwest of Haystack Mountain exposes Upper Cretaceous rocks along the crestline (see fig. 19).

From the evidence at hand it seems highly probable that the local advances in rank of coal in the Thompson Creek mining area and to the south resulted from accelerated thermal metamorphism caused by very steep geothermal gradients during and following localized emplacements of magma masses in Oligocene time.

The span of geologic time between intrusion of igneous bodies and completion of regional coalification (at a regional rank of HvB-HvC) is difficult to estimate. Emplacement of the intrusions which caused the steep geothermal gradients and accelerated the coalification process may have continued from Oligocene into Miocene time ($\pm$25 million years ago). Vertical uplifting may not have been appreciable in the southeastern part of the region (fig. 15) until late Miocene time (11 million years ago). These age differences suggest a time span on the order of 14-20 million years during which accelerated thermal metamorphism could have been effective. It has been reported that coals of the southern Ruhr Basin in Germany reached Lvb rank (22 percent volatile matter) in about 12 million years, implying a temperature of about 210°C at depths of burial of about 7,000 feet with a corresponding geothermal gradient of 1°C/12 meters (see Teichmüller, 1966, p. 151).

Overburden rocks of Late Cretaceous age thicken slightly westward and the total thicknesses of overlying Paleocene and Eocene rocks are unknown because of erosion. It seems likely that emplacement of the Oligocene intrusives may have inhibited further deposition, because the intrusives are exposed in the cores of anticlines and because structural relief of the Grand Hogback monocline is nearly three times greater near Rio Blanco than it is near Placita, Colorado. The geographic position of the depositional axis of the overburden rocks is unknown, but is thought to have been some distance west of the Thompson Creek area. There is no evidence for local advances in rank (beyond the regional HvB-HvC values) having been caused by increased static pressure due to thicker overburden.

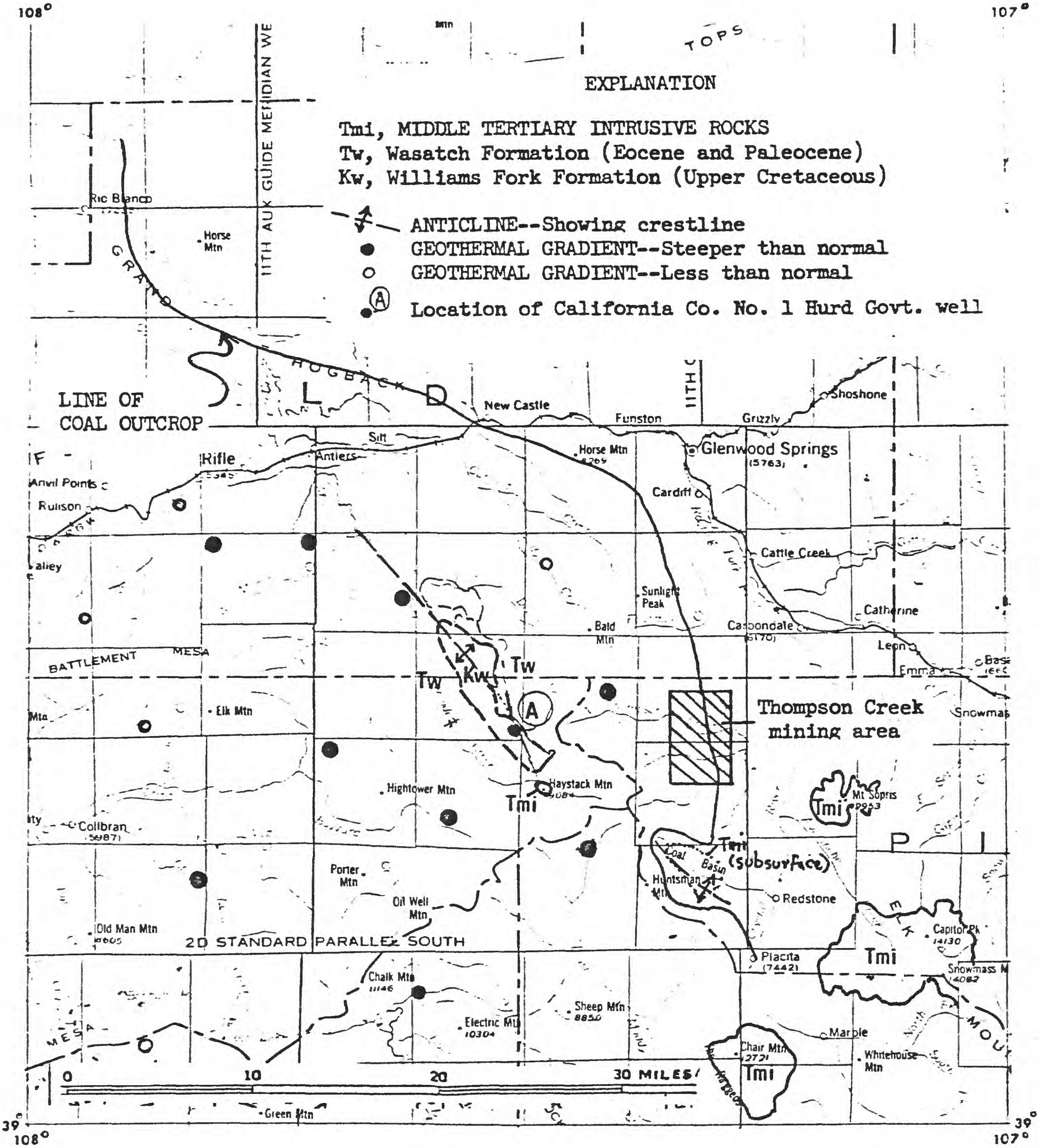

Figure 19 :- Map showing areal relationships between anticlines, intrusive rocks, and geothermal gradients in the vicinity of the Thompson Creek mining area. Geology after Tweto (1976; USGS Maps MF-760 and MF-788); as used here Williams Fork Formation (Kw) is equivalent to Mesaverde Formation.

In fact, the HvB rank of coals in the Somerset area corresponds to the regional rank, and the Somerset area is about 35 miles southwest of the Thompson Creek area (see fig. 1).

SUBSURFACE HYDRAULIC MINING

During the period 1958-1962, the Bureau of Mines conducted five field experiments with subsurface hydraulic mining of bituminous and anthracite coals using high-water pressure jet monitors. In chronological order the field trials involved the following coal beds:

1) Pittsburgh coal bed, near West Lebanon, Pennsylvania.
2) Bottom Red Ash (anthracite) coal, near Sugar Notch, Pennsylvania.
3) Roslyn No. 5 coal bed, Roslyn No. 9 mine, near Roslyn, Washington.
4) Coal bed "A," Thompson Creek Mine, near Carbondale, Colorado.
5) Roslyn No. 5 coal bed, Roslyn No. 10 mine, near Roslyn, Washington.

Some of the data on the coal beds mined, types of jet monitors used, production rates achieved, and difficulties encountered during the field trials, are summarized in table 3, and typical sections of the coal beds are shown on figure 20.

Subsurface hydraulic mining of coal has been practiced for some time in Russia, Poland, and Canada; most research on hydraulic mining methods, and practical experience in such mining, concern operations in those countries. A comprehensive four-volume report on the worldwide status of subsurface hydraulic mining was prepared by Cooley (1975) under contract with the U.S. Bureau of Mines. He listed (1975, v. 1, tables 9-1 and 9-2) some United States areas of pitching coal seams thought to have hydraulic mining potential. His tables include the areas listed in the introduction to this report.

Mechanisms of coal failure in hydraulic mining

The mechanisms of coal failure when mined hydraulically need brief description here, as such information serves as background to discussions of physical properties of coal that are thought to be measures of hydraulic mining potential. As described by Cooley (1975, v. 1, p. 5-4), the mechanisms are as follows:

Table 4.--Summary of data on coal beds on coal beds mined, jet monitors used, and results and experience obtained during field trials of subsurface hydraulic mining conducted by the U.S. Bureau of Mines.

Field Trial	Coal bed; description [1/]	Rank and coking strength	Pitch of bed	UGI	Friebility,[2/] percent	Jet monitor used	Max. production rates development mining	Max. production rates pillar mining	Remarks	References
(1)	Pittsburgh coal bed; hard; pronounced face and butt cleats; numerous streaks of impurities; hard binders	HvAb, moderate (FSI est 6)	flatlying	84	30 est	3/8"-3D nozzil 4000 psi 300 gpm	[1.6 tpm]		Coal bed 66" thick; 80' overburden	RI 5915; RI 7090; Palowitch (1964)
(2)	Bottom Red Ash coal bed; refuse bands of sandstone and sand slate	Anthracite	0-20°	37	30	0.394"3D nozzil up to 5000 psi 300 gpm (hydraulic jumbo)	[0.83 - 0.99 tpm]		Coal bed 13' thick;450 ft. overburden. Jet-cutting only 25 percent of total face time. Bottom bench of coal harder to mine than other portions of the bed including the refuse bands.	Palowitch (1964) RI 6610 RI 7120
(3)	Roslyn No. 5 coal bed Roslyn No. 9 mine; variable hardness; cleavage planes not pronounced	HvAb; weak	34-38°		42	0.148" D nozzil 4500 psi 40 gpm (developmental mining: monitor attached to roofjack)	0.10 tpm (5.7 tons/ man-shift) in hard coal 0.51 tpm (9.0 tons/ man-shift in softer coal	0.74 tpm (16.6 tons/ man-shift 0.42-1.91 tpm (with varying roof pressure)	Coal bed 58" thick; overburden ave. 500 ft Productivity depended on coal "hardness". Hydraulic mining more productive than conventional, in pillar mining.	RI 6276 Palowitch (1964)
(4)	Coal bed "A", Thompson Creek mine; containing three partings of variable thickness.	Mvb; strong (FSI 7-8)	26°	71-83	Est. 70 Ave.	0.148" D nozzil 4500 psi 40 gpm (monitor attached to jack)	[Range from 3.5 tons/ manshift in very hard coal to 46 tons/man-shift in soft coal. Ave: 23.3 tons/man-shift, 35% higher productivity than by conventional development mining. Ave. cutting rate: 0.39 tpm		Coal bed 101" thick: Est. 800 ft overburden Coal hardness varies but generally soft and friable Jet cutting only 31% of total face time "during 51 production shifts 2830 tons of coal was mined driving a pair of raises 350 ft. up the pitch". (Palowitch, (1964, p. 72)	Palowitch (1964)
(5)	Roslyn No. 5, Roslyn No. 10 mine; parting in lower pt. of bed; cleavage planes not pronounced	HvAb; weak	42°		42	Raise mining: 1/4"D nozzil 4000 psi 128 gpm Room mining: 3/8" D nozzil 4000 psi 230 gpm (remote controlled monitor)	[4.7 tons/man-shift in raise mining compared with 7.5 tons/man-shift by conventional. Jet cutting rate: 0.73 tpm] [5.2 tons/man-shift in room mining, compared with 8.5 tons/man-shift by conventional. Jet cutting rate: 0.55 tpm]		Coal bed 64" thick: 900 ft overburden Roslyn No. 5 coal harder in No. 10 mine than No. 5 coal in No. 9 mine. Jet cutting, raise mining, only 12% of total face time. Remote controlled jet cutting, room mining, only 19% of total face time; trouble with single-acting roof jacks	RI 6685 Palowitch (1964)

1/ Typical sections of the coal beds mined are shown on figure 21, this report.

2/ Friability data from Yancy (1932) USBM Tech. Paper 512.

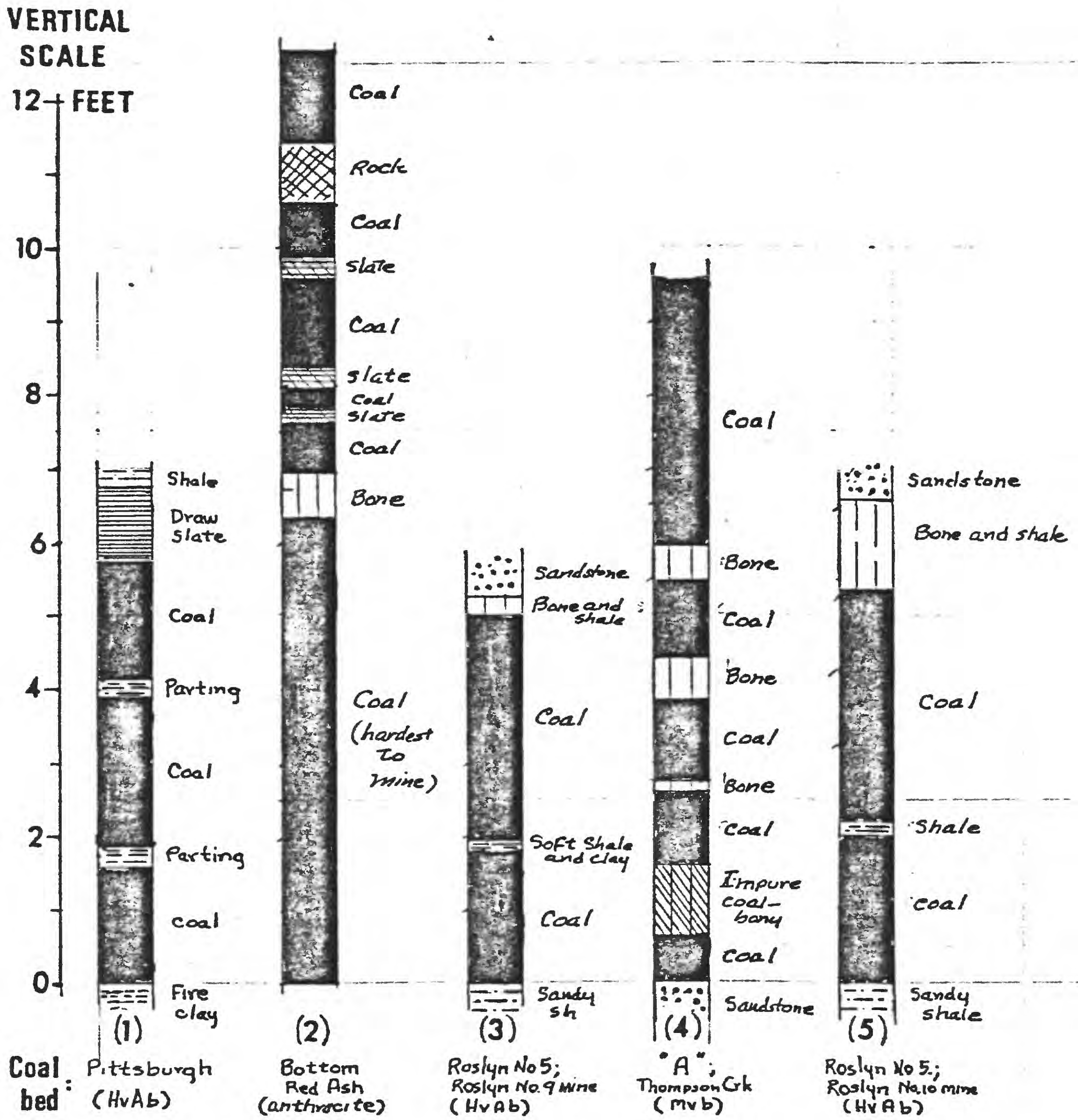

Figure 20: Typical sections of coal beds mined hydraulically in USBM field trials of subsurface hydraulic mining. Sources of data: section (1), USBM RI-7090; (2), RI-6610; (3), RI-6276; (4), this report; and (5), RI-6685.

"When a high pressure jet is directed against coal, there are two main mechanisms of failure of the material. The first is granular erosion and the second is fracture (called hydrobreaking) under shear or tensile stresses aided by water permeation into pores and cracks. The erosion mechanism is quite inefficient because it breaks coal into very small grains with high specific energy because of the large surface area produced per unit volume. Hydrobreaking disintegrates coal into larger pieces with lower specific energy. Therefore coal disintegration by a continuous jet of small diameter (less than 5 mm) is best accomplished by cutting slots of minimum total volume with rapidly traversing jet, followed by breakage of the coal between slots by the action of water pressure, gravity, roof pressure stresses, mechanical methods, or combinations. Jet cutting of slots should be accomplished with a standoff distance from nozzle to coal of less than 100 nozzle diameters, if possible."

Coal properties that influence hydrobreaking production rates are described by Cooley (1975, v. 1, p. 5-5) as follows:

"The primary properties of coal affecting its ease of disintegration are the coal hardness (which is related to compressive strength) and its permeability to water (which is affected by porosity, joints, cleats, lamination planes, plasticity, the state of stress, and the direction of water permeation). In general, coals with an intermediate degree of metamorphism are easier to break than coals of low or high rank, but there are exceptions. Breakage of coal from a free surface is generally more effective if the jet is directed approximately parallel to the plane of cleats and laminations. If the jet is directed at 90^{o} to the cleat plane, the breakage rate is decreased by 55 to 65 percent.

"As a first order approximation, it was initially found that the minimum jet pressure required to cut coal effectively should exceed a value of about one half the compressive strength or 50 times the Protod'yakonov hardness number F (which is approximately 1 percent of the unconfined compressive strength). However, exceptions to this rule were found and therefore a water infusion test method was developed in the USSR to measure the ability of coals to be broken by a monitor jet."...

Coal hardness

Cooley (1975, v. 1, p. 5-5) reports that, in Russian experience, hardness is a physical property of coal that affects its ease of disintegration and thereby influences hydrobreaking production rates in subsurface hydraulic mining. Variations in production rates achieved during United States field trials of hydraulic mining were also attributed to variations in coal hardness (see table 3, this report).

As a specific physical property of coal, hardness refers to the dynamic microhardness of vitrain layers; measurements are made by Vickers and Shore scleroscope methods; and such data commonly are used as a means of comparing changes in that property with different ranks of coal (Brown and Hiorns, 1963, p. 127). Yancey and Geer (1968, p. 1-25) compiled data on specific values for dynamic hardness of vitrain layers in coals of various types; their data are summarized as follows:

Type of coal	Volatiles (percent)	Shore hardness number 1/	Vickers hardness number 2/
Anthracite	6	122	54
Bituminous (noncaking)	21-42	107-109	24-29
Bituminous (caking)	40-44	105-107	22-26
Bituminous (coking)	21-36	44-65	9-16

1/ Shore number represents dynamic deformation by rebound.

2/ Vickers number shows static deformation, by size of indentation formed when load is applied to steel ball or diamond in contact with the coal.

The tabulation of hardness of vitrain layers in coals indicates that, characteristically, Mvb and HvAb coking coals have minimum hardness, but the tabulation emphasizes that relatively slight changes in composition or in coking strength effect appreciable changes in the hardness of vitrain layers (which commonly comprise the bulk of the coal seam).

Hardness has also been related to carbon content of coal, in that minimum hardness is found at about 85 to 90 percent carbon and maximum hardness, at about 90 percent (Yancey and Geer, 1968, p. 1-25; Brown and Hiorns, 1963, p. 127). These findings again emphasize the fact that relatively slight changes in coal composition can result in rather drastic changes in hardness.

In Russian usage, the term "hardness" seems to be synonymous with (unconfined compressive) strength of coal as derived from measurements of strength in kg/cm^2. In this respect, Cooley (1975, v. 1, p. 3-2) defines hardness as follows:

> hardness--the resistance of a material to crushing. Usually Soviet data on coal and rock is reported in terms of the Protod'yakonov hardness "F," which is approximately 1 percent of the unconfined compressive strength in kg/cm^2.

However, the definition introduces some ambiguity as to (a) the specific properties of coal involved, (b) methods used in laboratory testing, and (c) the interpretive value of test results as a basis for predicting the hydraulic mining potential of the parent body of coal.

As a specific property, the (unconfined) compressive strength of coal has been tested in U.S. laboratories, and measurements commonly are expressed in lb/in^2 (psi). Equivalents to Protod'yakonov hardness "F" numbers might be derived through conversion of lb/in^2 to kg/cm^2 (e.g., multiply by 7.03×10^{-2}) wherein 1 psi is approximately equivalent to 0.07 kg/cm^2. But a quantitative approach of that nature, if applied in predicting hydraulic mining potential, is subject to qualification on both sides, Russia and the United States. For example, in context with a discussion of variations in compressive strength of coal, Brown and Hiorns (1968, p. 128) refer to Protodyakonov (sic) as having shown "by empirical tests, that strength varies by as much as 30 percent over the width of a coal seam." On our side, for example, it has been found that laboratory measurements of unconfined compressive strengths of coal samples do not relate directly to compressive strengths of the parent bodies of coal; in fact, results of laboratory testing show that (a) compressive strength increases markedly as the size of the sample tested decreases, and (b) compressive strength measured when the crushing load is applied across, or perpendicular to bedding planes is generally less than measured when load is applied along, or parallel to bedding planes (see Yancey and Geer, 1968, table 1-6). To illustrate increases in compressive strength with decreasing sample size, with load applied perpendicular to bedding planes, results obtained by Rice and Enzian (1929) are tabulated as follows:

Coal	Size of specimen	Compressive Strength (lb/in^2)
Bituminous	54 in.	310
	30 in.	820
	12 x 12 x 18 in.	1,150
	10 in. - 12 in.	2,010
	7 in. - 8 in.	2,170
	2½ in. - 4 in.	2,490

Nonetheless, a general relationship between compressive strength and coal rank has been noted, in that minimum strength is commonly reached at 20 to 25 percent volatile matter (Yancey and Geer, 1968, p. 1-26).

The following quotation from Brown and Hiorns (1963, p. 130) is of interest here:

> "The variation of compressive strength with rank of British coals was given by Pomeroy and Foote, and a plot of strength against volatile matter shows the customary minimum at 20 to 25 percent dry, ash-free volatile matter (cf., fig. 4) for compression both perpendicular and parallel to the bedding planes [Reference]. They also obtained figures for cleat frequency for the nine coals tested, and a plot of their data shows that compressive strength falls off as cleat frequency increases."

The definition of hardness provided by Cooley (i.e., the resistance of a material to crushing) suggests that hardness is also a function of "grindability" which has been described as "a composite physical property embracing other specific properties such as hardness, strength, tenacity, and fracture" (Yancey and Geer, 1968, p. 1-31).

The ASTM standard test method most commonly used is the Hardgrove machine method (D 409-71) which determines the relative grindability or ease of pulverization of a given coal sample, as compared to samples of coals selected as standards; results are expressed as an HGI number which is inversely proportional to the ease of pulverization of the sample tested. But again, the use of HGIs as a basis for predicting hydraulic mining potential is subject to qualification.

The ASTM standard test method (D 409-71) uses initial sample-size fractions of 0.6 to 1.2 mm. The purpose of the test is to determine the relative ease with which such rather minute size-fractions can be ground fine enough to use as pulverized fuel (i.e., <200 mesh). But it will be noted that the minute dimensions of the initial sample-size fractions used are considerably smaller than are the dimensions involved in, for example, cleat spacing--and it is evident that the HGI for a given coal sample is by no means a direct measure of overall strength, tenacity, or fractured condition of the parent block of coal.

With allowance for connotative differences between crushing versus pulverization, the HGI does provide a direct measure of the <u>granular erosion potential</u> of a target coal to be mined hydraulically. But HGIs are not direct measures of <u>hydrobreaking</u> potential.

Unfortunately, granular erosion is rated as a very inefficient mechanism of coal failure (Cooley, 1975, v. 1, p. 5-4), and it would seem that the degree of granular erosion achieved is somewhat incidental to the success, failure, or effectiveness of hydraulic mining. It follows that, unless hydrobreaking of coal at the face can be accomplished effectively by combined action of water pressure, gravity, roof pressure stresses, and mechanical methods, a hydraulic mining operation will not be successful.

Friability of coal

Although specific data on friability were not found in the literature for the Thompson Creek coals, observations made during the course of the field survey indicated that locally, friability of coal bed A in the vicinity of locality 2 (see index map on fig. 7) seemed lower than that of coal bed A in other localities where coal bed A could be examined, whereas, the friability of coal bed B and that of the Anderson coal bed seemed consistently high.

Friability of sized coal is the complement of size stability, and both are recognized as composite physical properties embracing specific properties such as toughness, elasticity, fracturing, and strength. These composite physical properties are expressed by the degree of breakage that occurs in mining, screening, and subsequent handling and, in testing, by the degree to which a given coal will shatter on impact. In these respects, friability and size stability are measures of hydrobreaking potential.

The ASTM drop shatter test method (D440-49), for example, determines the relative size stability of lump coal (size fractions up to 4 in. diameter). Results are expressed in percent, and friability (in percent) is equal to 100 minus size stability. In a similar way, the ASTM tumbler test method (D441-45) determines the relative friability of 1.06-1.50 inch size-fraction coal by tumbling for 1 hour, as a simulation of breakage on handling. After tumbling, weight-percentages of resulting size fractions are determined, factored, totaled, and subtracted from 100 to arrive at percent-expressions of friability. By this method, for example, coal determined to have a friability of 70 percent is considerably more friable than coal having 30 percent friability.

The Bureau of Mines has made friability tests for various types of coals from various parts of the United States. For example, as reported in U.S. Bureau of Mines Technical Paper 512 (Yancey, 1932), some 235 friability determinations were made for coals from Washington, Pennsylvania, West Virginia, Maryland, Kentucky, Illinois, North Dakota, Montana, and Wyoming; the data reported are summarized as follows:

Friability values of mine samples of coal

Rank of coal	Number of tests	Average friability (percent)	Range (percent)
Low- and medium-volatile bituminous	27	70.4	90.6 - 53.5
High-volatile bituminous	87	43.3	83.9 - 14.1 (splint)
Anthracite	36	33.2	51.6 - 24.0
Subbituminous A (<20 percent moisture)	40	30.2	56.1 - 20.7
Subbituminous B (>20 percent moisture)	29	20.3	31.1 - 11.5
Lignite	16	12.1	16.7 - 8.6

Methods and procedures for determining the friability values tabulated above are described in detail in U.S. Bureau of Mines Technical Paper 512; it should be noted, however, that (a) tumbling was for a 3-hour period rather than for the presently recognized ASTM standard of 1 hour; (b) initial size fractions used were 1.05-1.50 inch; and (c) the formula used to determine percent friability was as follows:

$$\text{Friability, percent} = 100 \times \frac{D - d}{D}, \text{ where:}$$

D = average diameter of pieces before test

d = average diameter of pieces after test

General relationships of friability to various aspects of coal composition were noted and reported by Yancey (1932, p. 37-39); these relationships include:

1) Coals having less than about 3 percent moisture content (a.r.) tend to have the highest friability.
2) Friability decreases as moisture content increases.
3) Friability increases with increasing Btu values for bituminous coal; on average, the sharpest increase in friability occurs for coals having Btu values >14,000.
4) On the average, friability increases as fixed carbon content increases to 75 percent; coal containing 75 percent fixed carbon has about 70 percent friability.

Even though there is a general relationship between friability and rank of coal, coals of the same rank may vary widely in friability. For example, Yancey and Geer (1968, p. 1-31) report that Bureau of Mines tests have shown that "the high-volatile A bituminous coals of Alabama range in friability from a low of 17 percent to a high of 60 percent."

In locality 2 (Thompson Creek mining area) it was observed on mining that coal bed A exhibited some tendency to break into lump-sizes. At that locality, the rank of coal bed A seems borderline between Mvb and HvAb (see fig. 21).

Yancey (1932, p. 35) noted that HvAb coal from the Pittsburgh coal bed in southwestern Pennsylvania has the well-known property of withstanding mining without excessive degradation, and the average friability of such coal is 31.1 percent; in contrast, Lvb coal from the Pocahontas No. 3 bed of West Virginia has friability as high as 70 percent, and it was difficult to obtain a sample of such coal of sufficient size for testing.

In connection with difficulties encountered in sampling the Pocahontas No. 3 coal for friability testing, Yancey (1932, p. 35) quotes from field notes made by Thomas Hendricks, geologist, U.S. Geological Survey, as follows:

> "In sampling Pocahontas coal No. 3 at different places and noting its character at many points, I have come to the conclusion that it is very nearly impossible to secure lumps of the 1 inch to 1½ inch size used in the friability test for more than about 60 percent of a section of the coal bed. The development of vertical jointing and horizontal planes of parting is so great in parts of the bed as to make it extremely difficult to break out a small lump. However, some parts of a single section of the bed are sufficiently solid to yield small lumps. Thus it is apparent that the testing is on the less friable parts of the bed only, and that the remainder of the bed must be considerably more friable.
>
> "In addition to this difficulty, only about 60 to 70 percent of the coal extracted from a mine comes from advance workings. The remaining 30 to 40 percent is left as pillars. When extracted, this pillar coal is distinctly more friable than coal from advance workings. The increase in friability in pillar coal is not constant but depends on such factors as the size of the pillars, the amount of the overburden, the spacing of the pillars, and the age of the pillars as such. It would be extremely difficult to make a standard comparison between coal from a heading and the somewhat crushed coal of the pillars."

Qualitatively, friability of coal can be estimated from the lump size produced on mining, and in this connection Yancey (1932, p. 35) reports that, from observations in other coal fields, "mine operators know that they obtain less lump size from pillar coal than from advance workings."

Cleats and cleating

A specific purpose of the field survey was to observe cleats and cleating in Thompson Creek coals because such features are measures of hydrobreaking potential. By way of background:

1) Cleating, as expressed by intersecting sets of vertical fractures cutting layered coal, is a form of jointing and cleats are universal features of bituminous coals just as joints are universal features of sedimentary rocks.

2) Cleat-sets commonly intersect at approximately 90 degrees. Cleats belonging to one of these sets commonly are more planar and better developed than are those belonging to the other. In mining, cleats belonging to the better developed set commonly are referred to as "face cleats," as distinguished from "butt cleats" which identify the other set. As a term, (face) cleat is somewhat ancestral, dating back to the time when pick-and-shovel coal miners first recognized that bituminous coal was easiest to mine when the face of the coal was parallel to the direction of the better-developed cleat set because, when hit with a pick, the coal spalled off the face along lines parallel to that cleat direction.

3) In areas where the coal beds have been folded, and are now inclined, the direction of face cleats commonly is approximately perpendicular to fold axes, or perpendicular to the strike of the coal bed. But the vertical-fracture aspect of cleating is preserved, in that cleat-planes are also inclined so as to remain perpendicular to the (inclined) layers of coal that they cut, and this feature is commonly cited as evidence that cleating pre-dates folding.

4) Face cleats generally are most pronounced, most apparent, and most closely spaced as vertical planes cutting layers of bright coal.

On the basis of brief observations of cleats and cleating in the Thompson Creek coals, it was found that, in general, cleating is well developed in the Anderson coal bed and in coal bed B. Variations in cleating development were noted for coal bed A. In the vicinity of locality 2 (see index map, fig. 7) it was difficult to determine which cleat-set was better developed.

Cleat spacing

Quantitative determinations of cleat spacing and cleat development in various types of coal require careful examination under laboratory conditions. The only report of data of that nature that was found in the literature concerned data obtained from systematic studies of face cleat frequency made for some bituminous coals in England. However, Dr. Francis T. C. Ting, Associate Professor of Geology, West Virginia University, Morgantown, West Virginia, is currently conducting research on the origin and spacing of cleats in coal beds. A recent visit with Ting provided opportunity for discussion of cleat spacing in context with hydrobreaking potential, and in subsequent correspondence he (written commun., 1977) shared some preliminary results of his research work.

With respect to some general aspects of cleat spacing in coals, Ting noted that although variations in cleat spacing are controlled by rank and petrographic composition of the coal, cleat frequency increases with increasing rank, reaching a maximum for Lvb coal; but within the same coal bed at the same mine face, dull coal layers tend to have fewer cleats than bright coal layers, and the number of cleats per a standard horizontal measurement varies from bed to bed and even within the same coal. More specifically, Ting (written commun., 1977) has found that Lvb coals have the most numerous cleats per a standard 10 centimeter measurement, and that cleat spacing is on the order of 1 to 2 millimeters. Dull coal layers of an Mvb coal bed in West Virginia have approximately three cleats per 10 centimeters (i.e., cleat spacing is about 30 mm) whereas the bright coal layers contain more than 80 cleats per 10 centimeters (about 1 mm spacing). For Pittsburgh coal in West Virginia, a dull layer has 2-3 cleats per 10 centimeters whereas a bright coal layer at the same mine face has 75 cleats per 10 centimeters.

Of particular interest is Ting's (written commun., 1977) discovery of primary and secondary sets of face cleats. The following details some of his findings. Primary cleats usually cut through all coal layers, whereas secondary cleats either terminate at the contact of bright and dull layers or exhibit apparent offset (no lateral movement). The spacing of primary sets of cleats is uniform and more widely spaced than the spacing of secondary sets which are irregular and more closely spaced. Generally coal tends to break along primary cleats into large blocks, with the size of the blocks being governed by petrographic composition and rank.

The degree of primary cleat development is a primary measure of hydrobreaking potential.

The research work of Ting supports, illustrates, and adds geographic dimension to results obtained from systematic studies of cleat frequency in the Yorkshire coal field in England. Data reported and illustrated by Williamson (1967; fig. 8.33 after Macrea and Lawson, 1954, fig. 2) are summarized as follows:

Cleat frequency and spacing in bituminous coals,
Yorkshire coal field, England

Seam	Coal types[1/]	Number of cleats per horizontal foot: Range	Number of cleats per horizontal foot: Average	Average cleat spacing
1	Bright coal(3)	8 - 48	19	0.6 in. (15 mm)
	Dull coal(1)	7	7	1.7 in. (43 mm)
	Inferior coal(2)	4 - 15	10	1.2 in. (30 mm)
2	Bright coal(1)	15 - 70	43	0.3 in. (8 mm)
	Cannel coal(1)	12	12	1.0 in. (25 mm)
3	Bright coal(1)	13 - 18	16	0.8 in. (19 mm)
	Inferior coal(3)	20 - 35	30	0.4 in. (10 mm)
4	Bright coal(3)	12 - 20	17	0.7 in. (18 mm)
	Interbanded coal (chiefly dull) (1)	9 - 13	11	1.1 in. (28 mm)
5	Bright coal(1)	12 - 24	18	0.7 in. (17 mm)
	Interbanded coal (chiefly dull) (1)	10	10	1.2 in. (30 mm)
6	Bright coal(1)	12 - 24	18	0.7 in. (17 mm)
	Interbanded coal (chiefly dull) (1)	10	10	1.2 in. (30 mm)

[1/] Number in parentheses following coal type refers to the number of layers of that type of coal for which cleat determinations were made.

Hydrobreaking potential

Coal before mining is under a confined overburden pressure applied perpendicular to bedding planes. During and after mining, and with particular reference to pillars, pressure is directed to such support areas and maximum pressures can be measured or estimated. As a general rule, the static pressure of 1 foot of overburden is approximately equivalent to 1 psi.

In response to directed overburden pressures, blocks of coal such as pillars isolated by mining become more susceptible to coal failure. As a result of the directed pressures, incipient friability and cleating are increasingly enhanced, and the coal remaining in pillars is easier to mine hydraulically than coal remaining in virgin mine faces.

This difference in ease of mining is illustrated by the achieved production rates and experiences recorded during hydraulic mining of the Roslyn No. 5 coal bed in the Roslyn No. 9 mine (see table 3; field trial No. 3).

In connection with the hydrobreaking potential of different types of coal, it is of particular interest to note that, in terms of production rates achieved during hydraulic mining, coal bed A (Mvb) in the Thompson Creek mining area exhibited by far the greatest potential (averaging 23.3 tons/man-shift); moreover, this rate was achieved during raise mining, using only the small jet monitor (see table 3; field trial No. 4). These circumstances serve to emphasize the relatively high hydrobreaking potential of Mvb coking coal. It should also be emphasized that, in the area where coal bed "A" was mined hydraulically, the bed is characterized by three partings of variable thickness as noted in the USBM field trial and as illustrated by coal section no. 2 on figure 10. This circumstance would have made coal bed A harder to mine in that locality. However, the occurrence of three partings represents a localized condition (see fig. 10) and it would seem that the full hydraulic mining potential of coal bed A may not have been realized during the USBM field trial.

Variable "hardness" of coal bed A was reported in the locality where the USBM field trial of hydraulic mining was conducted (see table 3). In previous sections of this report (see "Coal hardness") it was noted that statistically Mvb-HvAb coking coals containing 21-36 percent volatiles exhibit minimum hardness of vitrain layers, and minimum hardness is also found at about 85 to 90 percent carbon. Variations in the composition of layers comprising coal beds A and B in the center part of the Thompson

Creek mining area are shown on figure 21. But the variations in hardness encountered on hydraulic mining of coal bed A in locality 2 could also be attributed to the numerous hard bony partings present in the bed, and perhaps in part to the relatively high ash content of the constituent layer of impure coal. Such circumstances could have obviated minimum hardness of constituent vitrain layers.

During brief field survey, a face of coal bed A was visited in Thompson Creek mine no. 1. The face was struck repeatedly with a hammer, with the expectation that the coal would be easily fractured from the face in keeping with theory concerning minimum hardness of Mvb coal. The coal resisted hammer attack. Coal bed B was also visited at locality 2; coal bed B was highly fractured, and cleating was well developed. Hammer strikes showed a tendency for vertical layers of coal to fall off all parts of the exposed coal bed. As shown on figure 21, coal bed B in locality 2 is essentially a single bench of coal of slightly better quality than coal bed A as indicated by comparing volatile, ash, and carbon content.

In hydraulic mining, with a high-pressure jet, hydrobreaking takes place mainly along existing cleat and fracture planes. Breakage is generally most effective when jet cutting is directed parallel to the cleat because it has been found that when jet cutting is directed perpendicular to cleat planes (as, for example, in undercutting the coal bed) the hydrobreakage rate is decreased by 55 to 65 percent (Cooley, 1975, v. 1, p. 505). The principal exception to this generalization seemingly occurs where there are rock partings because the overall effectiveness of the jet cutting-hydrobreakage process is apparently governed locally by the number, spacing, and thickness of rock-partings.

As shown on figures 10, 11, and 21, rock partings occur as horizontal layers within a coal bed and are interbedded with bright coal. Such partings may be shale, clay, slate, "draw slate," bone, and bony impure coal which is distinguished from layers of bright coal (vitrain).

The rock partings interrupt cleat spacing and development in the vitrain layers and thereby interrupt the fracture pattern exploited by hydrobreaking. It follows that the number, thickness, and spacing of the layers of rock and impure (durain) coal determine the degree to which the fracture-cleat pattern in bright coal is interrupted, which in turn determines the degree of hydrobreaking potential.

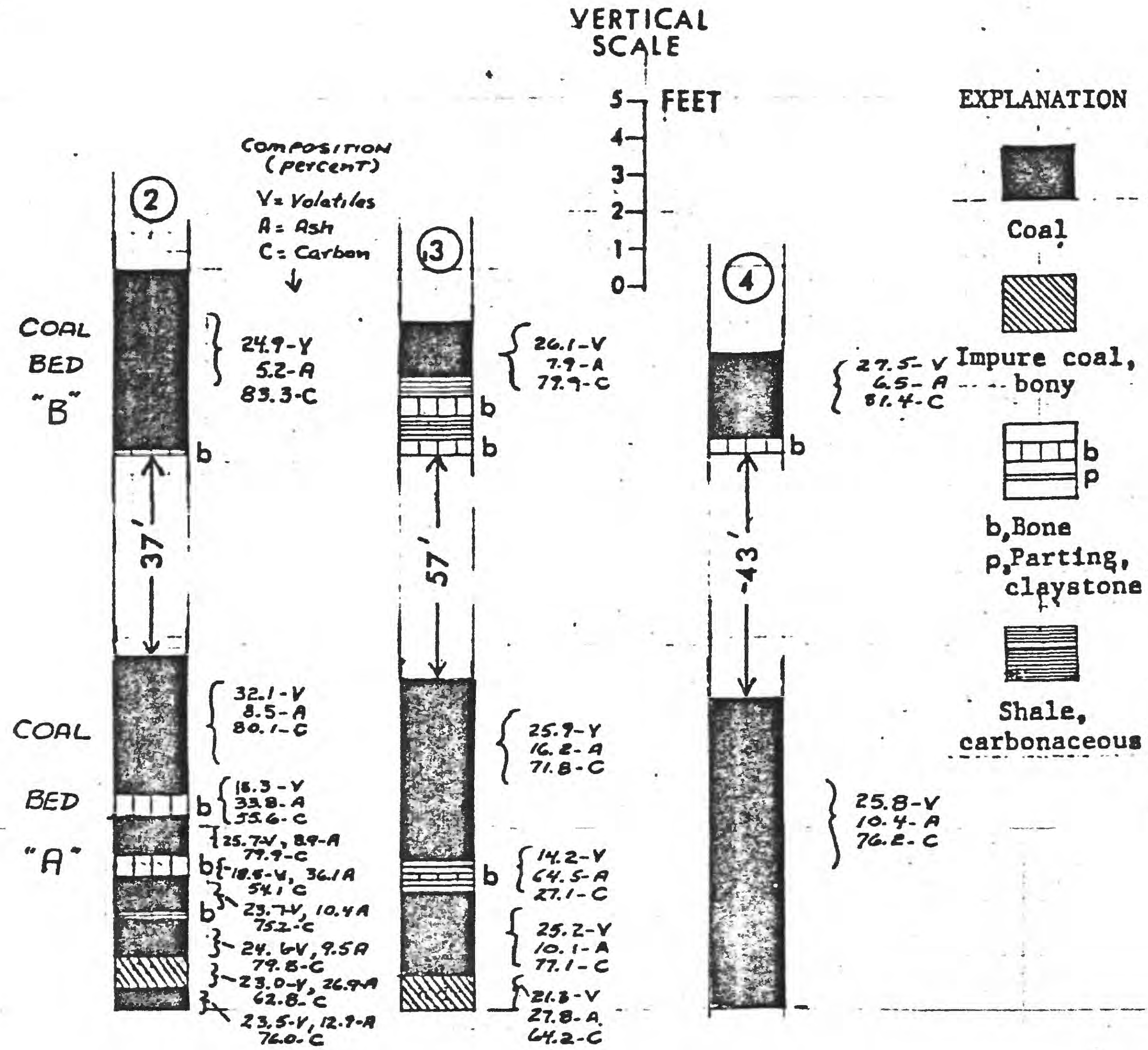

Figure 21:- Variations in the composition of layers comprising coal beds "A" and "B", center part of Thompson Creek mining area. Locations of coal sections are shown on the index map on figure 7. Analytical data obtained from cored coal samples.

The overall hydrobreaking potential of a coal is a function of the degree the coal is permeable to water. Permeability is affected by porosity, friability, cleat development, rock partings, plasticity of coal, faulting, state of stress, and the direction of water permeation in pitching coal. In most areas to be hydraulically mined it seems likely that a coal would be mined out, or the mine abandoned before an adequate appraisal of permeability could be made. In this respect, it is of interest to note the evolution of Russian research and experience as reported by Cooley (1975, v. 1, p. 5-5 and 5-6) in the following quotation:

> "As a first order approximation, it was initially found (Ref. 661) that the minimum jet pressure required to cut coal effectively should exceed a value of about one half the compressive strength or 50 times the Protod'yakonov hardness number F (which is approximately 1 percent of the unconfined compressive strength). However, exceptions to this rule were found and therefore a water infusion test method was developed in the USSR (Ref. 450, later superseded by Ref. 666) to measure the ability of coals to be broken by a monitor jet. The method requires drilling a hole in the coal seam, installing a hydroseal (or packer), infusing water under pressure, and measuring the pressure required to fracture the seam and the pressure variation with time. The specific water absorption of the seam is determined and correlated with the monitor jet pressure required for effective breakage. Since water is infused in all directions into the seam, an average value of specific water absorption is obtained which allows for anisotropic permeability."

The U.S. Bureau of Mines conducted water infusion tests of the Bottom Red Ash anthracite bed (see Malenka, 1968, RI-7120). The technology developed for testing anthracite should also apply to water infusion testing of blocks of bituminous coal. Results obtained from water infusion tests should provide the best measure of hydrobreaking potential.

HYDRAULIC MINING POTENTIAL OF THOMPSON CREEK COALS

Statistically, strongly coking medium volatile bituminous (Mvb) coals are relatively soft; cleating tends to be well developed and closely spaced; and such coals have minimum compressive strength. These properties and conditions indicate high granular erosion and hydrobreaking potential. The occurrence of Mvb coal in beds pitching 26-33 degrees also favors hydraulic mining methods. On that basis, Thompson Creek coals in central and southern parts of the mining area have high hydraulic mining potential.

During USBM field trial No. 4 (see table 3) the average production rate achieved in hydraulically mining coal bed A was 23.3 tons per man-shift; this was 35 percent higher than the productivity rate of conventional mining. As compared to production rates achieved in hydraulic mining of coals elsewhere, the production rate for coal bed A (Mvb) was by far the highest (see table 3) --even though only a small jet monitor was used and a minimal amount of water (40 gpm) was expended.

Adequate water supply for subsurface hydraulic mining in the Thompson Creek area is a matter of primary concern because (a) surface water supply seems marginal to requirements for hydraulic mining, (b) surface water flow fluctuates drastically throughout the year, and (c) ownership of surface water rights is uncertain. Fortunately, however, a considerable volume of mine water has accumulated in abandoned parts of the Thompson Creek mines. This (mine) water supply should be adequate for hydraulic mining, if stored and recycled waters are used.

Hydraulic mining of pitching coals at levels above adjacent ground or creek levels would of course be easier than mining at levels below, for example, the ground water table. This tends to place areal limits on the parts of the coal deposit that are most easily mined.

The coking coals of the Thompson Creek area can be mined effectively by hydraulic mining methods. However, it may be difficult to sustain large-scale hydraulic mining operations or to achieve high-volume production by that method alone, because of inadequate water supply.

Overall mining plans might incorporate hydraulic mining with longwall and(or) room-and-pillar mining operations, to insure more efficient long-term recovery of remaining resources of pitching coal. Thus, hydraulic mining might provide a supplimental, additional, or alternative method of recovering coal, for example:

1) Small-scale hydraulic mining operations might be conducted in favorable parts of a mine or mine complex without interference to longwalling or room-and-pillar operations in other parts.

2) Some pillar coal could be recovered by hydraulic mining.

3) Hydraulic mining is more flexible and adaptable than longwalling; consequently, some coal not otherwise recoverable may be recovered by hydraulic mining methods.

4) As compared to coal bed A, coal beds B and Anderson have higher hydrobreaking potential but thickness variations are more pronounced and they tend to be laterally discontinuous. Hydraulic mining methods would be most adaptable to those conditions.

APPENDIX

Weather Records, Glenwood Springs weather station, El. 5,823

Type of record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
A. Temperature (°F)													
1. Normals for the period 1931-1960	24.8	29.7	37.9	47.6	56.3	64.3	71.1	69.0	61.6	51.0	36.4	27.4	48.1
2. Mean, record prior to 1931(26 years)--	23.0	28.1	37.0	45.5	53.6	61.4	66.8	65.7	58.3	47.8	36.0	24.3	45.6
3. Means, 1931-1951 (21 years)---------	24.0	29.7	38.1	48.1	56.6	64.0	71.3	69.3	61.8	51.1	36.6	27.5	48.2
B. Precipitation (in)													
1. Normals for the period 1931-1960---	1.80	1.75	1.53	1.90	1.36	1.19	1.36	1.67	1.41	1.40	1.21	1.45	18.03
2. Means, 1931-1952(22)-	1.91	1.94	1.72	2.04	1.45	1.30	1.49	1.74	1.46	1.39	1.23	1.61	19.28
3. Means, record prior to 1931 (28-33 years)	1.29	1.00	1.45	1.27	1.19	.81	1.31	1.65	1.34	1.17	.99	1.16	14.63
C. Mean Snowfall:													
1. Record prior to 1931 (26)	16.6	11.8	8.1	2.0	.4	.0	.0	.0	.4	1.7	5.6	15.8	62.4
2. 1931-1950	22.9	15.5	8.5	1.9	.3	T	.0	.0	.0	1.1	6.4	17.6	74.2

Weather Records, Crested Butte, El. 9 Station pre 1931-1945: 8,950
El, 9 Station 1946- 8,867

Type of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
A. Temperature (^{o}F)													
1. Normals 1931-1960	13.5	16.3	22.6	33.4	44.2	52.3	58.0	56.9	50.1	40.3	25.7	16.8	35.8
2. Means, prior to 1931 (19)	12.2	15.2	22.8	32.5	43.4	52.3	57.0	54.8	46.8	35.4	24.0	18.2	34.6
3. Means, 1931-1950	12.7	16.5	22.2	33.6	44.2	51.9	57.8	57.0	49.9	40.2	25.5	16.7	35.7
B. Precipitation (in)													
1. Normals 1931-1960	2.68	2.56	2.36	1.73	1.31	1.43	1.95	2.27	1.66	1.43	1.52	2.10	23.00
2. Means, prior 1931 (20)	2.68	2.18	2.46	1.74	1.58	1.37	2.19	1.98	2.42	1.23	1.40	2.18	23.41
3. Means, 1931-1952	2.41	2.36	2.18	1.68	1.22	1.56	1.95	2.38	1.76	1.30	1.38	2.22	22.40
C. Snowfall													
1. Means, prior 1931 (19)	36.2	28.0	28.4	16.5	6.8	1.1	.0	.0	1.1	6.8	15.7	26.2	166.8
2. Means, 1931-1951	32.9	32.0	31.1	15.7	4.7	.5	T	T	1.0	6.3	18.6	30.6	173.4

APPENDIX B

9-0828. North Thompson Creek near Carbondale, Colo.

Location.--Lat 39°19'47", long 107°19'58", in sec.28, T.8 S., R.89 W., on right bank 0.4 mile downstream from Yank Creek and 8½ miles southwest of Carbondale.

Drainage area.--26.8 sq mi.

Records available.--October 1963 to September 1965.

Gage.--Water-stage recorder. Altitude of gage is 8,120 ft (from topographic map).

Extremes.--Maximum and minimum discharges for the water years 1964-65 are contained in the following table:

Annual maximum discharge (*), peak discharges above base (160 cfs), and annual minimum discharge

Water year	Maximum				Minimum daily		
	Date	Time	Discharge (cfs)	Gage height (feet)	Date	Discharge (cfs)	Gage height (feet)
1964	May 17, 1964	1830	* 322	4.05	Sept. 9, 1964	0.30	-
1965	May 21, 1965	1830	292	3.87	-	-	-
	June 12, 1965	-	* 312	3.97			

1963-65: Maximum discharge, 322 cfs May 17, 1964 (gage height, 4.05 ft), from rating curve extended above 190 cfs; minimum daily, 0.30 cfs Sept. 9, 1964.

Remarks.--Records good except those for winter periods, which are poor. Transbasin diversions above station by Thompson Creek feeder ditch for irrigation in West Divide Creek basin.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1963 TO SEPTEMBER 1964

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1	1.[illegible]	2.2					2.2	22	100	13	.60	.80
2	.80	2.0					2.2	22	10[illegible]	12	.70	.80
3	.70	2.2					2.0	19	116	10	6.4	.60
4	.80	2.6					2.[illegible]	17	107	9.[illegible]	2.2	.60
5	.60	3.[illegible]					2.[illegible]	12	95	8.[illegible]	2.5	.70
6	.60	2.6					2.0	12	92	7.2	1.0	.60
7	.60	2.4					2.0	14	95	6.8	.70	.50
8	.60	2.2				1.0	2.0	13	109	9.[illegible]	.60	.40
9	.60	2.[illegible]					2.2	14	83	8.[illegible]	.60	.30
10	.60	2.0					2.4	27	73	8.5	.70	.40
11	.6[illegible]	2.[illegible]					2.4	33	68	6.8	.70	.40
12	.60	1.8					2.2	44	63	6.[illegible]	1.[illegible]	.40
13	.60	1.8					2.[illegible]	61	53	6.[illegible]	7.2	.40
14	.60	1.[illegible]					3.[illegible]	7[illegible]	42	7.6	2.2	.50
15	.6[illegible]	1.8	1.0	.80	.80		6.[illegible]	113	39	6.[illegible]	1.6	.60
16	.6[illegible]	1.6					10	151	39	6.0	1.9	.60
17	.7[illegible]	1.2					11	199	39	5.2	2.8	.40
18	.7[illegible]	1.4					1[illegible]	197	39	4.[illegible]	1.3	.40
19	.7[illegible]	1.4					11	193	31	3.1	3.1	1.0
20	5.6	1.4					10	193	26	2.5	5.6	1.6
21	4.4	1.4					12	2[illegible]7	25	2.8	2.2	1.4
22	2.8	1.[illegible]					14	221	29	2.2	.9[illegible]	1.2
23	1.9	1.2				1.6	22	215	24	2.2	.70	1.2
24	3.4	1.4					30	215	22	1.9	1.3	1.2
25	3.1	1.4					25	211	19	.80	3.1	1.2
26	1.9	1.4					22	2[illegible]3	17	.70	3.6	1.4
27	1.[illegible]	1.4					16	2[illegible]1	16	.50	6.4	1.8
28	1.[illegible]	1.4					17	175	17	.50	3.1	1.6
29	1.[illegible]	1.2					17	147	16	.50	1.3	1.6
30	1.3	1.[illegible]			------		17	125	15	.60	1.[illegible]	1.6
31	3.1	------			------		------	1[illegible]7	------	1.[illegible]	.90	------
TOTAL	43.5	52.7	31.0	24.80	23.20	43.6	281.2	3,456	1,608	158.80	67.70	26.40
MEAN	1.43	1.76	1.00	.80	.80	1.31	9.37	111	53.6	5.12	2.18	.88
MAX	5.6	3.[illegible]	-	-	-	-	30	221	116	13	7.2	1.8
MIN	.60	1.[illegible]	-	-	-	-	2.[illegible]	12	15	.50	.60	.30
AC-FT	86	105	61	49	46	81	558	6,85[illegible]	3,190	315	134	52
(†)	0	0	0	0	0	0	0	0	455	90	0	0

CAL YR 1963: TOTAL MEAN MAX MIN AC-FT †
WAT YR 1964: TOTAL 5,813.90 MEAN 15.9 MAX 221 MIN .30 AC-FT 11,532 † 545

† Diversions, in acre-feet, by Thompson Creek feeder ditch; furnished by State engineer of Colorado.
Note.--No gage-height record Nov. 17 to Apr. 22.

9-0828. North Thompson Creek near Carbondale, Colo.--Continued

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1964 TO SEPTEMBER 1965

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1	1.5	1.6					10	63	107	42	12	.80
2	1.2	1.9					11	90	105	41	10	.80
3	1.1	1.9					10	93	109	38	11	1.3
4	1.0	1.8					9.0	88	109	35	8.5	1.3
5	.90	1.8					8.0	88	109	34	7.2	2.2
6	.90	1.8					5.5	64	120	31	6.8	7.2
7	1.0	1.8					8.0	52	130	29	5.6	3.1
8	1.0	1.8				.80	5.5	50	140	30	5.2	5.2
9	1.0	1.8					4.0	41	180	29	4.4	6.8
10	1.0	1.8					5.0	37	160	26	4.0	3.4
11	1.3	1.8					4.0	36	200	29	4.4	3.4
12	1.0	1.6					3.7	40	250	50	3.7	6.8
13	1.0	1.6					3.4	60	200	44	3.7	5.6
14	1.0	1.6					4.0	71	180	32	3.1	2.5
15	1.0	1.6	1.4	1.0	.80		5.2	56	170	23	5.2	2.2
16	1.0	1.6					6.0	74	180	22	3.7	1.9
17	1.3	1.6					8.0	131	170	20	3.7	2.2
18	1.0	1.6					10	167	155	20	10	8.0
19	1.0	1.6					15	169	146	20	11	14
20	1.0	1.6					23	183	132	18	6.8	11
21	1.0	1.4					28	219	127	17	4.8	9.0
22	1.3	1.4				2.0	30	231	120	14	3.7	10
23	1.6	1.4					37	205	113	13	3.4	14
24	1.6	1.4					42	149	113	12	2.8	16
25	1.3	1.4					42	116	109	16	2.2	13
26	1.3	1.4					38	104	92	12	1.6	12
27	1.6	1.4					31	86	74	11	1.0	11
28	1.3	1.4					30	78	64	12	1.0	11
29	1.6	1.4			---		35	83	53	10	1.9	14
30	1.6	1.4			---		50	92	43	10	4.0	11
31	1.6	---			---		---	102	---	12	1.6	---
TOTAL	37.00	48.2	43.4	31.0	22.40	44.00	521.3	3,118	3,960	752	158.0	210.70
MEAN	1.19	1.61	1.40	1.00	.80	1.42	17.4	101	132	24.3	5.10	7.02
MAX	1.6	1.9	-	-	-	-	50	231	250	50	12	16
MIN	.90	1.4	-	-	-	-	3.4	36	43	10	1.0	.80
AC-FT	73	96	86	61	44	87	1,030	6,180	7,850	1,490	313	418
(†)	0	0	0	0	0	0	0	0	0	536	0	0

CAL YR 1964: TOTAL 5,815.30 MEAN 15.9 MAX 221 MIN .30 AC-FT 11,530 † 545
WAT YR 1965: TOTAL 8,944.00 MEAN 24.5 MAX 250 MIN - AC-FT 17,740 † 536

† Diversions, in acre-feet, by Thompson Creek feeder ditch; furnished by State engineer of Colorado.
Note.--No gage-height record Nov. 6 to Apr. 5.

09082800 NORTH THOMPSON CREEK NEAR CARBONDALE, COLO.

LOCATION.--Lat 39°19'47", long 107°19'58", in sec.28, T.8 S., R.89 W., Pitkin County, on right bank 0.4 mile downstream from Yank Creek and 8.5 miles southwest of Carbondale.

DRAINAGE AREA.--26.8 sq mi.

PERIOD OF RECORD.--October 1963 to September 1970.

GAGE.--Water-stage recorder. Altitude of gage is 8,120 ft (from topographic map).

AVERAGE DISCHARGE.--7 years, 17.4 cfs (12,610 acre-ft per year).

EXTREMES.--Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (160 cfs), water years 1966-70

Date	Time	Disch.	G.H.	Date	Time	Disch.	G.H.	Date	Time	Disch.	G.H.
May 9, 1966	1630	*113	2.97	May 22, 1968	2030	251	3.64	May 2, 1969	[illegible]	16?	3.09
				May 31, 1968	2000	*302	3.85	July 21, 1969	163?	*2??	3.??
July 31, 1967	1500	*150	3.22								
				Apr. 24, 1969	2100	169	3.16	May 22, 1970	2230	*36?	4.00

Annual minimum daily discharge, water years 1966-70

Wtr yr	Date	Discharge	Wtr yr	Date	Discharge
1966	Sept.26-30, 1966	.40	1969	Sept. 3, 1969	.75
1967	Sept. 6, 7, 1967	.09	1970	Aug. 13, 31, 1970	1.0
1968	Nov. 29, 1967	.60			

Period of record: Maximum discharge, 365 cfs May 22, 1970 (gage height, 4.00 ft), from rating curve extended above 170 cfs; maximum gage height, 4.05 ft May 17, 1964; minimum daily discharge, 0.09 cfs Sept. 6, 7, 1967.

REMARKS.--Records fair except those for winter periods, which are poor. Transbasin diversions above station ... Thompson Creek feeder ditch for irrigation in West Divide Creek basin.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1965 TO SEPTEMBER 1966

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	10	3.8	2.0	1.8	1.6	1.6	22	83	47	8.5	2.5	1.3
2	10	3.6	2.0	1.8	1.6	1.5	27	85	39	7.6	2.5	.96
3	8.0	3.4	2.0	1.8	1.6	1.4	24	85	32	6.0	6.4	.9?
4	6.8	3.4	2.0	1.8	1.6	1.3	22	86	29	5.6	10	1.2
5	6.4	3.4	2.0	1.8	1.6	1.4	21	88	27	4.0	7.2	.8?
6	5.6	3.2	2.0	1.8	1.6	1.6	20	83	24	4.4	5.2	.78
7	5.2	3.2	2.0	1.8	1.6	1.7	20	83	23	3.7	4.4	[illegible]
8	5.2	3.0	2.0	1.8	1.6	1.7	22	88	25	3.4	3.7	.7?
9	4.8	3.2	2.0	1.8	1.6	1.6	28	93	22	2.8	3.7	.7?
10	4.4	3.0	2.0	1.8	1.6	1.7	31	90	21	2.8	3.7	.68
11	4.0	2.8	2.0	1.8	1.6	1.8	29	78	19	3.4	3.7	.64
12	3.7	2.8	2.0	1.8	1.6	2.2	26	71	18	4.0	5.2	.80
13	3.4	2.5	2.0	1.8	1.6	2.4	23	63	16	4.0	?.7	1.3
14	3.7	2.8	2.0	1.8	1.6	2.8	23	55	12	2.8	[illegible]	1.8
15	3.7	2.6	2.0	1.8	1.6	3.2	24	52	12	2.2	?.7	1.6
16	3.7	2.4	2.0	1.8	1.6	3.2	29	56	12	1.6	?.5	[illegible]
17	4.4	2.4	2.0	1.8	1.6	3.0	33	60	12	1.6	?.7	[illegible]
18	7.6	2.6	2.0	1.8	1.6	2.6	34	61	10	1.9	3.1	[illegible]
19	7.2	2.6	2.0	1.8	1.6	2.6	32	60	9.5	2.5	?.4	[illegible]
20	7.2	2.4	2.0	1.8	1.6	2.9	30	56	9.0	2.2	?.6	[illegible]
21	6.8	2.2	2.0	1.8	1.6	2.9	31	58	9.5	1.3	4.8	.6?
22	6.4	2.2	2.0	1.8	1.6	2.7	26	60	9.0	2.2	4.4	.7?
23	6.0	2.2	2.0	1.8	1.6	2.5	25	58	7.2	2.5	3.7	.7?
24	4.8	2.4	2.0	1.8	1.6	2.4	27	52	6.8	2.2	3.4	.60
25	4.2	2.6	2.0	1.8	1.6	3.0	34	50	6.0	2.2	2.5	.58
26	4.0	2.4	2.0	1.8	1.6	6.0	52	49	6.0	.80	2.5	.40
27	4.0	2.2	2.0	1.8	1.6	10	66	47	6.8	.80	1.9	.40
28	3.8	2.0	2.0	1.8	1.6	15	61	47	9.5	1.0	1.8	.40
29	3.8	2.0	2.0	1.8	-----	20	63	47	8.5	.60	1.8	.40
30	3.8	2.0	2.0	1.8	-----	19	74	47	9.5	.50	1.8	.40
31	3.8	-----	2.0	1.8	-----	20	-----	55	-----	.90	2.5	-----
TOTAL	166.4	81.3	62.0	55.8	44.8	145.7	979	2,046	497.3	90.00	118.1	23.7?
MEAN	5.37	2.71	2.00	1.80	1.60	4.70	32.6	66.0	16.6	2.90	3.81	.77
MAX	10	3.8	2.0	1.8	1.6	20	74	93	47	8.5	10	1.6
MIN	3.4	2.0	2.0	1.8	1.6	1.3	20	47	6.0	.50	1.8	.40
AC-FT	330	161	123	111	89	289	1,940	4,060	986	179	234	46
(T)	0	0	0	0	0	0	0	0	372	0	0	[illegible]

CAL YR 1965 TOTAL 9,127.10 MEAN 25.0 MAX 250 MIN .80 AC-FT 18,100 † 536
WTR YR 1966 TOTAL 4,309.60 MEAN 11.8 MAX 93 MIN .40 AC-FT 8,550 † 372

† DIVERSIONS, IN ACRE-FEET, BY THOMPSON CREEK FEEDER DITCH (FURNISHED BY STATE ENGINEER OF COLORADO).
NOTE.--NO GAGE-HEIGHT RECORD NOV. 26 TO MAR. 19.

[illegible]

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1966 TO SEPTEMBER 1967

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	.80	1.0	1.8	1.2	1.8	2.4	9.0	30	33	6.5	5.5	3.4
2	1.0	1.9	1.6	1.2	1.8	2.6	10	26	32	5.5	5.0	.82
3	1.4	1.6	1.6	1.0	1.8	2.6	16	24	32	7.0	4.5	.55
4	1.8	1.4	1.4	1.0	1.8	2.4	20	22	34	7.0	5.0	.19
5	1.8	1.4	1.0	1.2	1.8	2.2	22	20	31	6.5	6.0	.10
6	2.0	1.3	1.6	1.0	1.6	2.2	21	19	30	5.5	6.5	.09
7	1.8	1.0	2.2	1.0	1.6	2.2	22	21	27	6.0	6.0	.09
8	1.8	1.0	2.0	.90	1.4	2.7	24	29	25	9.0	9.0	.64
9	1.8	1.4	1.6	.90	1.6	2.2	24	36	27	6.5	6.5	2.7
10	2.0	1.8	1.2	1.0	1.8	2.0	22	45	19	5.0	6.5	1.3
11	2.2	1.9	1.4	1.0	2.0	2.2	26	50	19	5.5	6.5	1.9
12	3.4	1.6	1.6	1.2	2.0	2.4	26	57	27	6.5	6.0	2.5
13	3.4	1.8	1.8	1.2	2.0	2.4	23	49	19	4.0	4.5	2.5
14	4.0	1.6	1.6	1.2	2.0	2.2	22	36	21	4.0	3.7	1.3
15	3.7	1.8	1.4	1.2	1.8	2.2	19	33	18	5.5	2.5	.72
16	4.0	2.0	1.4	1.2	1.8	2.6	18	37	22	6.5	2.5	.64
17	3.7	2.0	1.4	1.2	1.8	4.5	18	44	17	13	1.9	.64
18	2.2	2.0	1.4	1.0	1.8	7.0	21	52	14	10	1.3	.55
19	1.6	1.8	1.4	1.0	1.8	7.0	30	52	13	5.0	1.6	1.6
20	1.6	1.8	1.6	1.0	1.8	5.0	29	52	17	3.7	1.6	1.6
21	1.6	1.9	1.6	1.2	1.6	4.0	23	51	19	3.1	1.6	1.3
22	1.3	1.9	1.4	1.2	1.6	5.0	22	51	15	2.8	1.0	1.0
23	1.6	1.3	1.4	1.4	1.8	8.0	21	50	13	3.4	1.0	.91
24	1.3	1.4	1.2	1.6	2.0	12	18	48	10	3.7	.91	1.3
25	1.3	1.6	1.4	1.6	2.0	12	18	54	9.7	3.7	.82	1.9
26	1.3	1.4	1.4	1.6	2.0	11	17	69	9.0	2.5	.82	3.1
27	1.0	1.2	1.2	1.4	2.2	10	22	62	8.5	2.2	.82	2.8
28	1.0	1.2	1.0	1.4	2.2	8.0	32	56	8.0	1.9	.82	2.8
29	1.3	1.4	.80	1.4	------	10	43	46	7.0	1.0	.82	1.9
30	1.0	1.6	.80	1.6	------	9.0	39	41	6.5	.91	.91	1.6
31	1.0	------	1.0	2.0	------	9.0	------	35	------	7.1	2.8	------
TOTAL	59.70	47.0	44.20	38.00	51.2	158.5	677.0	1,297	572.7	160.51	106.92	41.95
MEAN	1.93	1.57	1.43	1.23	1.83	5.11	22.6	41.8	19.1	5.18	3.45	1.40
MAX	4.0	2.0	2.2	2.0	2.2	12	43	69	34	13	9.0	3.4
MIN	.80	1.0	.80	.90	1.4	2.0	9.0	19	6.5	.91	.82	.09
AC-FT	118	93	88	75	102	314	1,340	2,570	1,140	318	212	83
(†)	0	0	0	0	0	0	0	0	460	0	0	0

CAL YR 1966 TOTAL 4,250.60 MEAN 11.4 MAX 93 MIN .40 AC-FT 8,430 † 372
WTR YR 1967 TOTAL 3,254.68 MEAN 8.92 MAX 69 MIN .09 AC-FT 6,460 † 460

† DIVERSIONS, IN ACRE-FEET, BY THOMPSON CREEK FEEDER DITCH (FURNISHED BY STATE ENGINEER OF COLORADO).
NOTE.--NO GAGE-HEIGHT RECORD DEC. 8 TO MAR. 15.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1967 TO SEPTEMBER 1968

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.0	1.2	1.2	1.4	1.4	1.4	15	25	233	19	9.0	2.2
2	.91	1.0	1.0	1.6	1.2	1.0	13	27	227	18	10	2.2
3	1.0	.70	.80	1.6	1.0	1.1	12	30	205	16	18	3.1
4	1.0	1.0	.90	1.5	1.1	1.5	11	41	197	17	9.7	2.8
5	1.6	1.4	1.0	1.6	1.2	1.9	10	44	209	15	8.0	2.5
6	2.8	1.2	1.0	1.7	1.3	1.9	10	46	203	15	10	2.2
7	3.1	1.2	1.1	1.5	1.3	1.9	11	40	175	12	12	1.9
8	1.3	1.0	1.2	1.3	1.3	1.9	12	33	154	12	10	1.9
9	.91	1.1	1.3	1.2	1.2	1.7	13	38	129	12	9.0	1.6
10	.91	1.2	1.5	1.3	1.1	1.6	12	43	114	12	14	1.6
11	.82	1.0	1.8	1.4	1.1	1.8	12	50	104	11	8.0	1.6
12	.82	.80	1.9	1.4	1.1	1.9	13	56	102	9.7	7.5	1.6
13	.82	1.0	1.9	1.4	1.1	1.6	15	54	111	8.5	5.5	1.9
14	.82	1.1	1.8	1.3	1.2	2.1	14	45	111	8.0	9.0	2.5
15	.73	1.3	1.6	1.2	1.3	2.2	13	43	107	9.7	10	3.4
16	.82	1.4	1.7	1.2	1.2	2.1	13	44	105	8.0	6.0	2.2
17	.91	1.4	1.8	1.2	1.1	2.1	13	44	104	7.5	4.5	2.5
18	.91	1.3	1.6	1.2	1.1	2.1	14	56	100	7.5	3.7	2.2
19	.82	1.1	1.6	1.2	1.2	2.1	13	72	96	6.5	3.4	1.9
20	.91	1.2	1.8	1.3	1.3	2.2	12	98	98	7.0	3.1	1.9
21	.82	1.3	1.8	1.4	1.3	2.3	12	148	87	5.5	3.1	2.2
22	.82	1.3	1.6	1.5	1.5	2.5	11	219	63	5.0	3.1	1.9
23	.82	1.3	1.6	1.6	1.6	2.6	11	183	57	6.5	6.0	1.9
24	.80	1.3	1.8	1.6	1.6	2.8	10	135	53	9.7	4.0	1.9
25	.80	1.2	1.8	1.6	1.6	3.1	10	124	45	9.7	3.4	1.9
26	.80	1.1	1.7	1.5	1.6	3.5	10	126	36	9.7	3.1	1.9
27	1.0	1.0	1.7	1.4	1.6	3.4	11	152	28	10	3.1	1.9
28	1.3	.80	1.7	1.3	1.5	3.4	12	187	28	12	3.4	1.6
29	1.3	.60	1.6	1.1	1.5	4.4	14	219	26	9.7	3.1	1.6
30	1.0	.90	1.4	1.3	------	5.5	20	229	22	10	2.8	1.9
31	1.4	------	1.3	1.6	------	9.0	------	231	------	12	2.5	------
TOTAL	33.77	33.40	46.50	43.4	37.6	78.8	372	2,882	3,329	331.2	208.0	62.4
MEAN	1.09	1.11	1.50	1.40	1.30	2.54	12.4	93.0	111	10.7	6.71	2.09
MAX	3.1	1.4	1.9	1.7	1.6	9.0	20	231	233	19	18	3.4
MIN	.73	.60	.80	1.1	1.0	1.0	10	25	22	5.0	2.5	1.6
AC-FT	67	66	92	86	75	156	738	5,720	6,600	657	413	124
(†)	0	0	0	0	0	0	0	0	403	231	0	0

CAL YR 1967 TOTAL 3,217.45 MEAN 8.81 MAX 69 MIN .09 AC-FT 6,380 † 480
WTR YR 1968 TOTAL 7,458.07 MEAN 20.4 MAX 233 MIN .60 AC-FT 14,790 † 634

† DIVERSIONS, IN ACRE-FEET, BY THOMPSON CREEK FEEDER DITCH (FURNISHED BY STATE ENGINEER OF COLORADO).
NOTE.--NO GAGE-HEIGHT RECORD OCT. 31 TO APR. 1.

09082900 NORTH THOMPSON CREEK NEAR CARBONDALE, COLO.--CONTINUED

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1968 TO SEPTEMBER 1969

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1.9	1.9	2.0	1.8	2.0	2.4	7.0	103	39	18	4.5	.91
2	1.9	1.9	2.0	1.8	2.0	2.2	7.5	124	33	16	3.7	.87
3	1.9	1.6	1.8	1.8	2.0	2.1	8.0	124	28	15	3.4	.73
4	1.9	2.5	2.2	1.9	2.1	2.0	9.0	111	23	14	3.1	1.0
5	2.8	1.9	2.1	2.1	2.2	1.8	10	100	22	13	2.8	1.3
6	2.5	1.3	2.0	2.0	2.3	1.6	12	93	25	11	2.2	.91
7	2.5	2.0	1.8	1.8	2.2	1.6	14	109	26	11	1.9	.82
8	3.1	2.0	1.8	1.6	2.1	1.6	12	93	20	9.7	1.6	.91
9	3.4	2.0	1.8	1.4	2.0	1.6	14	89	16	9.0	1.6	3.4
10	3.4	1.9	2.0	1.5	1.9	1.6	20	91	15	8.5	2.2	3.7
11	3.4	1.8	2.1	1.6	1.9	1.6	28	86	18	7.5	4.0	2.7
12	2.8	2.0	1.8	1.7	1.8	1.6	37	80	18	7.0	3.1	1.6
13	2.8	2.1	1.6	1.8	1.9	1.6	38	89	18	6.5	5.0	1.3
14	2.5	2.1	1.8	1.9	2.0	1.6	46	93	20	7.0	2.5	1.6
15	2.5	2.0	2.0	2.0	2.1	1.7	43	79	24	7.0	1.6	2.7
16	3.1	1.8	2.0	1.8	2.0	2.0	36	71	18	6.0	1.3	3.4
17	2.2	1.8	2.0	1.8	1.9	2.1	31	66	17	7.0	1.3	3.4
18	1.9	1.8	1.8	1.6	1.8	2.1	36	66	19	10	2.2	2.7
19	2.8	2.0	1.6	1.8	1.9	2.1	44	66	15	15	3.4	1.8
20	2.8	2.0	1.8	2.0	2.1	2.0	72	68	12	18	3.7	1.6
21	2.8	2.0	2.0	2.0	2.2	2.1	93	74	11	19	3.4	2.8
22	2.5	2.0	1.8	2.0	2.3	2.3	109	68	9.7	9.0	2.2	6.5
23	2.5	2.0	1.5	1.9	2.4	2.2	124	63	9.0	10	1.3	4.5
24	1.9	2.0	1.7	1.6	2.4	2.1	129	51	46	12	1.3	2.8
25	2.2	2.0	2.0	1.9	2.3	2.0	109	49	39	10	1.0	2.5
26	2.2	1.6	2.0	2.1	2.2	2.1	68	44	39	8.0	.91	2.2
27	1.6	1.7	2.0	2.1	2.2	2.3	53	49	34	9.7	.91	1.9
28	1.3	1.9	1.6	2.0	2.3	3.0	52	49	29	9.7	1.3	1.6
29	1.6	1.6	2.0	1.8	------	4.0	63	45	23	9.0	5.0	1.6
30	1.9	1.7	2.0	1.6	------	5.0	80	44	21	7.5	4.5	1.9
31	2.2	------	2.0	1.8	------	6.0	------	44	------	6.0	1.9	------
TOTAL	74.8	56.9	58.6	56.5	58.5	70.0	1,404.5	2,383	686.7	326.1	78.52	64.70
MEAN	2.41	1.90	1.89	1.82	2.09	2.26	46.8	76.9	22.9	10.5	2.54	2.16
MAX	3.4	2.5	2.2	2.1	2.4	6.0	129	124	46	19	5.0	6.5
MIN	1.3	1.3	1.5	1.4	1.8	1.6	7.0	44	9.0	6.0	.91	.73
AC-FT	148	113	116	112	116	139	2,790	4,730	1,360	647	156	128
(†)	0	0	0	0	0	0	0	188	569	79	0	0

CAL YR 1968 TOTAL 7,534.70 MEAN 20.6 MAX 233 MIN 1.0 AC-FT 14,950 † 634
WTR YR 1969 TOTAL 5,318.62 MEAN 14.6 MAX 129 MIN .73 AC-FT 10,550 † 836

† DIVERSIONS, IN ACRE-FEET, BY THOMPSON CREEK FEEDER DITCH (FURNISHED BY STATE ENGINEER OF COLORADO).
NOTE.--NO GAGE-HEIGHT RECORD NOV. 7 TO MAR. 27.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1969 TO SEPTEMBER 1970

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	2.5	3.1	2.5	2.0	2.1	2.5	2.4	23	133	31	4.0	2.8
2	2.2	3.2	2.5	2.1	2.1	2.7	2.2	26	118	29	3.7	6.3
3	3.7	4.2	2.4	2.1	2.1	2.7	2.0	30	113	26	3.7	2.8
4	5.0	4.8	2.4	2.1	2.1	2.6	2.2	42	109	22	4.5	1.8
5	6.0	5.0	2.4	2.1	2.0	2.5	2.2	54	100	18	3.7	12
6	6.5	5.0	2.4	2.0	2.1	2.5	2.4	76	98	15	4.5	11
7	6.0	4.8	2.3	2.0	2.1	2.6	2.4	84	114	29	6.0	7.3
8	8.5	4.6	2.2	1.9	2.0	2.7	2.8	86	146	17	3.7	3.7
9	8.0	4.4	2.1	2.0	1.8	2.7	3.2	76	128	17	3.1	2.5
10	8.0	4.2	2.3	2.3	2.0	2.5	3.8	89	156	28	2.2	1.6
11	7.5	3.8	2.4	2.3	2.1	2.4	3.8	143	146	23	1.9	1.3
12	7.5	3.6	2.3	2.3	2.1	2.4	3.8	181	128	23	1.3	2.5
13	9.0	3.4	2.2	2.2	2.2	2.5	3.6	177	109	17	1.0	21
14	9.0	3.2	2.2	2.2	2.2	2.4	3.4	167	109	13	1.3	13
15	6.5	3.0	2.2	2.2	2.1	2.3	3.4	164	102	11	1.6	9.8
16	7.0	2.8	2.2	2.1	2.0	2.3	3.6	193	95	9.7	2.5	3.4
17	7.0	2.6	2.2	2.1	1.9	2.4	3.8	237	87	8.5	1.6	2.8
18	9.0	2.3	2.3	2.1	1.8	2.4	3.8	258	89	8.0	1.3	2.5
19	8.5	2.3	2.3	2.1	1.8	2.3	3.6	265	87	7.5	1.3	2.2
20	7.0	2.6	2.3	2.1	1.8	2.2	3.4	272	87	7.0	2.2	1.8
21	11	2.8	2.3	2.0	2.0	2.3	3.4	262	82	6.0	5.0	1.4
22	7.0	3.0	2.3	2.0	2.2	2.4	3.4	270	80	6.5	4.5	6.4
23	7.5	2.9	2.3	2.1	2.2	2.3	3.2	265	76	15	2.8	6.3
24	6.0	2.9	2.3	2.1	2.1	2.2	3.2	235	69	7.5	1.9	6.4
25	5.5	3.0	2.2	2.0	2.3	2.2	6.0	217	63	6.0	1.9	3.4
26	4.0	2.8	2.2	2.0	2.3	2.3	15	217	41	10	1.6	2.9
27	4.5	2.6	2.1	2.0	2.2	2.2	23	199	56	8.0	1.9	[illegible]
28	3.1	2.4	2.0	2.1	2.2	2.2	22	179	49	9.7	1.6	[illegible]
29	3.0	2.3	1.9	1.8	------	2.2	21	167	41	9.7	1.9	[illegible]
30	3.0	2.5	1.8	1.6	------	2.3	22	160	35	5.5	1.6	[illegible]
31	3.0	------	2.0	2.0	------	2.4	------	162	------	5.0	1.0	------
TOTAL	192.0	100.1	69.5	64.0	57.9	74.6	184.2	4,976	2,866	448.6	90.8	[illegible]
MEAN	6.19	3.34	2.24	2.06	2.07	2.41	6.14	161	95.5	14.5	2.61	[illegible]
MAX	11	5.0	2.5	2.3	2.3	2.7	23	272	156	31	6.0	[illegible]
MIN	2.2	2.3	1.8	1.6	1.8	2.2	2.0	23	35	5.0	1.0	[illegible]
AC-FT	381	199	138	127	115	148	365	9,870	5,680	890	180	[illegible]
(†)	0	0	0	0	0	0	0	0	0	181	0	[illegible]

CAL YR 1969 TOTAL 5,489.92 MEAN 15.0 MAX 129 MIN .73 AC-FT 10,890 † 836
WTR YR 1970 TOTAL 9,267.40 MEAN 25.4 MAX 272 MIN 1.0 AC-FT 18,380 † 181

† DIVERSIONS, IN ACRE-FEET, BY THOMPSON CREEK FEEDER DITCH (FURNISHED BY STATE ENGINEER OF COLORADO).
NOTE.--NO GAGE-HEIGHT RECORD NOV. 2 TO APR. 27.

9-0830. Thompson Creek near Carbondale, Colo.

Location.--Lat 39°19'50", long 107°13'25", in sec.28, T.8 S., R.88 W., on right bank 800 ft upstream from Camp Foster Creek, 1 mile upstream from mouth, and 5 miles south of Carbondale.

Drainage area.--75.7 sq mi (revised).

Records available.--October 1950 to September 1960, October 1964 to September 1965.

Gage.--Water-stage recorder. Altitude of gage is 6,450 ft (from topographic map).

Average discharge.--11 years, 38.6 cfs (27,950 acre-ft per year).

Extremes.--Maximum and minimum discharges for the water year 1965 are contained in the following table:

Annual maximum discharge (*), peak discharges above base (200 cfs), and annual minimum discharge

Water year	Maximum				Minimum daily		
	Date	Time	Discharge (cfs)	Gage height (feet)	Date	Discharge (cfs)	Gage height (feet)
1965	May 3, 1965	-	250	-	Apr. 13, 1965	1.6	-
	May 18, 1965	1930	550	3.97			
	June 12, 1965	0430	* 630	3.87			
	July 12, 1965	1730	293	3.28			

1950-60, 1964-65: Maximum discharge, about 800 cfs between June 4 and 8, 1957; maximum gage height, 4.4 ft Aug. 27, 1955, from floodmarks; minimum daily discharge, 1.5 cfs Aug. 30 to Sept. 1, 1954.

Remarks.--Records fair except those for period of no gage-height record, which are poor. Small diversions for irrigation of hay meadows above station. Transbasin diversions above station through Thompson Creek feeder ditch to West Divide Creek.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1964 TO SEPTEMBER 1965

DAY	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.
1	4.8	8.5					10	150	229	162	36	11
2	4.5	8.5					11	187	220	162	31	11
3	4.4	8.0					10	200	244	151	33	12
4	4.2	8.0					8.4	190	250	147	28	12
5	4.0	8.0					4.8	180	238	140	24	14
6	4.2	8.0					3.6	170	272	134	23	20
7	4.4	8.0					4.4	150	316	122	20	12
8	4.3	8.0				4.0	4.0	141	324	126	18	12
9	5.2	7.5					6.4	98	332	113	16	14
10	6.0	8.0					5.2	83	316	100	15	11
11	7.6	7.5					2.0	77	355	114	17	11
12	7.2	7.5					2.0	83	482	162	15	14
13	6.8	8.0					1.6	100	410	132	15	14
14	7.2	8.5					3.2	150	405	93	13	11
15	8.0	8.5	5.0	4.5	4.0		4.4	130	405	76	15	11
16	9.2	8.5					5.2	200	385	71	14	11
17	8.5	8.5					9.0	260	395	67	14	10
18	8.[illegible]	8.5					18	340	375	65	26	17
19	8.0	8.0					26	400	360	66	29	29
20	8.[illegible]	7.5					40	380	336	58	18	26
21	8.[illegible]	7.0					57	345	324	54	15	19
22	8.[illegible]	6.5					61	395	300	46	13	18
23	8.5	5.5					70	400	276	42	12	22
24	9.[illegible]	6.5				5.0	80	328	293	38	11	28
25	8.5	7.0					75	262	300	41	10	29
26	8.0	6.0					70	211	253	36	10	28
27	8.[illegible]	5.5					65	176	208	33	9.0	25
28	8.2	5.5					70	158	188	32	9.0	26
29	8.5	6.0			------		85	162	178	30	10	30
30	8.5	5.5			------		100	178	160	30	14	24
31	9.[illegible]	------			------		------	211	------	36	11	------
TOTAL	215.7	223.5	155.	139.5	112.0	140.0	912.2	6,488	9,129	2,679	544.0	532
MEAN	6.96	7.45	5.00	4.50	4.00	4.52	30.4	209	304	86.4	17.5	17.7
MAX	9.2	8.5	-	-	-	-	100	400	482	162	36	30
MIN	4.2	5.5	-	-	-	-	1.6	77	160	30	9.0	10
AC-FT	428	443	307	277	222	278	1,810	12,870	18,110	5,310	1,080	1,060

CAL YR 1964: TOTAL 13,1[illegible] MEAN 35.9 MAX 250 MIN 2.0 AC-FT 26,060
WAT YR 1965: TOTAL 21,269.9 MEAN 58.3 MAX 482 MIN 1.6 AC-FT 42,190

Note.--No gage-height record Dec. 5 to Mar. 31.

09083000 THOMPSON CREEK NEAR CARBONDALE, COLO.

.TION.--Lat 39°19'50", long 107°13'25", in sec.28, T.8 S., R.88 W., Pitkin County, on right bank 600 ft upstream from Camp Foster Creek, 1 mile upstream from mouth, and 5 miles south of Carbondale.

..AGE AREA.--75.7 sq mi.

..IOD OF RECORD.--October 1950 to September 1960, October 1964 to September 1968 (discontinued).

..E.--Water-stage recorder. Altitude of gage is 6,450 ft (from topographic map).

..RAGE DISCHARGE.--14 years, 37.0 cfs (26,810 acre-ft per year).

..EMES.--Maximums and minimums (discharge in cubic feet per second, gage height in feet).

Annual maximum discharge (*) and peak discharges above base (200 cfs), water years 1966-68

Date	Time	Disch.	G.H.	Date	Time	Disch.	G.H.	Date	Time	Disch.	G.H.
May 7, 1966	2000	*21[illegible]	2.96	July 31, 1967	1900	200	-	May 31, 1968	-	*60[illegible]	-
								June 20, 1968	1900	[illegible]	3.49
May 26, 1967	0700	*220	3.30	May 22, 1968	2100	528	3.85				

Annual minimum daily discharge, water years 1966-68

Wtr yr	Date	Discharge	Wtr yr	Date	Discharge
1966	Aug. 25, 28-30, Sept.25-30, 1966	3.9	1968	Nov. 29, 1967	2.6
1967	Sept.17, 18, 1967	3.2			

Period of record: Maximum discharge, about 800 cfs between June 4 and 8, 195[illegible]; maximum gage height, 4.4 ft Aug. 27, 1955, from floodmarks; minimum daily discharge, 1.5 cfs Aug. 30 to Sept. 1, 1954.

..MARKS.--Records good except those for winter periods and those for periods of no gage-height record, which are poor. Small diversions for irrigation of hay meadows above station. Transbasin diversions above station through Thompson Creek feeder ditch to West Divide Creek.

..ISIONS.--WSP 1924: Drainage area.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1965 TO SEPTEMBER 1966

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	24	9.0	9.0	8.0	7.0	6.0	54	149	169	26	9.0	5.3
2	23	9.0	9.0	8.0	7.0	6.0	60	156	147	22	9.0	5.3
3	20	9.0	9.0	8.0	7.0	6.0	55	165	126	19	11	5.6
4	18	9.0	9.0	8.0	7.0	6.0	46	167	116	17	18	5.3
5	17	9.0	9.0	8.0	7.0	6.0	40	173	108	15	10	5.0
6	16	9.0	9.0	8.0	7.0	6.0	34	180	98	14	8.0	4.6
7	15	9.0	9.0	8.0	7.0	6.0	30	185	92	13	7.0	4.6
8	14	9.0	9.0	8.0	7.0	6.0	30	192	103	11	6.0	4.6
9	13	9.0	9.0	8.0	7.0	6.0	38	202	94	11	5.0	4.6
10	12	9.0	9.0	8.0	7.0	6.0	50	198	92	10	4.6	4.1
11	11	9.0	9.0	8.0	7.0	6.0	50	165	84	11	4.1	4.1
12	10	9.0	9.0	8.0	7.0	6.0	46	145	77	10	5.6	4.6
13	9.0	9.0	9.0	8.0	7.0	6.0	40	124	69	14	6.5	6.2
14	10	9.0	9.0	8.0	7.0	6.0	34	113	60	13	4.6	5.3
15	10	9.0	9.0	8.0	7.0	6.0	34	114	56	13	4.6	6.8
16	10	9.0	9.0	8.0	7.0	15	40	126	54	12	4.3	5.3
17	13	9.0	9.0	8.0	7.0	15	46	140	52	13	4.1	4.6
18	18	9.0	9.0	8.0	7.0	15	55	154	46	11	4.3	4.6
19	17	9.0	9.0	8.0	7.0	15	60	151	42	12	4.3	4.3
20	17	9.0	9.0	8.0	7.0	15	55	154	38	11	6.5	4.3
21	16	9.0	9.0	8.0	7.0	15	55	149	38	11	5.6	4.3
22	15	9.0	9.0	8.0	7.0	15	50	151	36	10	4.8	4.1
23	14	9.0	9.0	8.0	7.0	15	48	156	32	11	4.6	4.1
24	13	9.0	9.0	8.0	7.0	15	48	151	28	10	4.6	4.1
25	12	9.0	9.0	8.0	7.0	15	60	145	26	10	3.9	3.9
26	11	9.0	9.0	8.0	7.0	15	80	134	26	10	4.1	3.9
27	11	9.0	9.0	8.0	7.0	15	110	126	26	10	4.1	3.9
28	10	9.0	9.0	8.0	7.0	15	114	126	24	11	3.9	3.9
29	10	9.0	9.0	8.0	------	30	116	130	24	9.0	3.9	3.9
30	10	9.0	9.0	8.0	------	34	124	145	25	8.0	3.9	3.9
31	10	------	9.0	8.0	------	41	------	178	------	8.0	5.3	------
TOTAL	429.0	270.0	279.0	248.0	196.0	390.0	1,702	4,744	2,008	386.0	185.2	139.1
MEAN	13.8	9.00	9.00	8.00	7.00	12.6	56.7	153	66.9	12.5	5.97	4.64
MAX	24	9.0	9.0	8.0	7.0	41	124	202	169	26	18	6.8
MIN	9.0	9.0	9.0	8.0	7.0	6.0	30	113	24	8.0	3.9	3.9
AC-FT	851	536	553	492	389	774	3,380	9,410	3,980	766	367	276

CAL YR 1965 TOTAL 21,653.7 MEAN 59.3 MAX 482 MIN 1.6 AC-FT 42,950
WTR YR 1966 TOTAL 10,976.3 MEAN 30.1 MAX 202 MIN 3.9 AC-FT 21,770

NOTE.--NO GAGE-HEIGHT RECORD OCT. 10 TO MAR. 28.

0908[illegible] THOMPSON CREEK NEAR CARBONDALE, COLO.--CONTINUED

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1966 TO SEPTEMBER 1967

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.7	3.6	6.5	4.4	5.5	6.5	10	45	84	23	14	10
2	4.1	3.8	6.2	4.2	5.0	6.5	11	35	84	20	7.4	7.1
3	5.3	4.0	5.9	4.3	5.0	6.5	16	29	93	20	7.1	5.6
4	5.6	3.8	6.2	4.4	5.0	6.5	23	27	114	19	6.5	[illegible]
5	5.6	3.6	6.2	4.6	5.0	6.0	26	26	114	17	8.5	[illegible]
6	6.0	3.6	7.7	4.2	5.0	5.5	22	26	116	15	7.7	4.1
7	5.3	3.4	14	3.8	4.6	5.5	26	25	102	14	12	4.1
8	5.5	3.8	6.5	3.8	4.4	5.5	30	36	84	22	18	4.8
9	5.5	4.0	4.1	3.6	4.6	5.5	30	53	74	16	10	[illegible]
10	5.5	4.0	5.0	3.8	4.8	5.0	26	88	65	14	8.0	[illegible]
11	6.0	4.2	6.0	4.4	5.0	5.5	33	91	62	15	7.4	[illegible]
12	6.0	4.4	6.0	4.6	5.0	5.5	38	102	65	20	6.2	17
13	6.5	4.4	5.5	4.6	5.0	5.6	31	96	62	14	6.2	[illegible]
14	7.0	4.4	5.5	4.6	5.5	5.3	25	64	69	12	5.6	[illegible]
15	7.0	4.4	5.5	4.6	5.5	5.3	25	51	61	16	5.3	[illegible]
16	7.0	4.6	4.6	4.4	4.6	6.2	25	54	66	16	5.3	3.9
17	7.0	4.8	4.8	3.8	4.6	7.7	22	80	55	32	5.0	[illegible]
18	6.5	4.8	5.0	3.8	5.0	10	29	118	55	32	4.8	3.7
19	6.0	4.8	5.5	4.2	5.0	10	46	129	54	20	4.8	[illegible]
20	5.0	4.8	5.5	4.6	4.6	7.7	49	136	68	17	5.0	3.6
21	4.6	5.0	5.5	4.8	4.4	7.7	36	140	76	14	4.8	3.9
22	4.4	5.0	5.0	4.6	4.4	8.5	30	152	64	12	4.6	3.9
23	4.2	5.0	4.4	4.4	4.6	10	32	150	55	12	4.3	3.9
24	4.0	5.0	3.8	4.6	4.8	12	28	140	45	14	4.1	3.9
25	4.0	5.5	4.0	4.6	5.0	12	26	152	40	12	4.1	[illegible]
26	3.8	5.5	4.6	4.2	5.5	11	23	190	36	10	4.3	[illegible]
27	3.6	5.0	4.8	6.2	5.5	10	28	170	34	9.5	4.3	[illegible]
28	3.6	5.0	4.6	4.8	5.5	10	45	152	33	8.0	4.6	[illegible]
29	3.6	5.5	3.6	4.6	------	12	70	127	31	7.4	4.6	[illegible]
30	3.6	6.0	4.2	4.8	------	11	70	98	26	7.1	4.6	[illegible]
31	3.6	------	4.4	5.5	------	10	------	88	------	11	7.4	------
TOTAL	159.3	135.7	171.1	135.3	138.4	242.0	931	2,870	1,987	491.0	206.5	[illegible]
MEAN	5.14	4.52	5.52	4.36	4.94	7.81	31.0	92.6	66.2	15.8	6.66	[illegible]
MAX	7.0	6.0	14	5.5	5.5	12	70	190	116	32	18	[illegible]
MIN	3.6	3.4	3.6	3.4	4.4	5.0	10	25	26	7.1	4.1	[illegible]
AC-FT	316	269	339	268	275	480	1,850	5,690	3,940	974	410	[illegible]

CAL YR 1966 TOTAL 10,464.4 MEAN 28.7 MAX 232 MIN 3.4 AC-FT 20,750
WTR YR 1967 TOTAL 7,623.0 MEAN 20.9 MAX 190 MIN 3.2 AC-FT 15,120

NOTE.--NO GAGE-HEIGHT RECORD OCT. 6 TO DEC. 1, DEC. 29 TO MAR. 8.

DISCHARGE, IN CUBIC FEET PER SECOND, WATER YEAR OCTOBER 1967 TO SEPTEMBER 1968

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	3.9	5.2	4.0	4.2	3.6	4.5	20	30	480	61	18	[illegible]
2	3.9	5.0	3.5	4.6	3.5	4.5	19	40	460	52	17	[illegible]
3	3.9	4.3	3.2	4.8	3.7	4.5	16	44	440	47	25	[illegible]
4	4.1	6.5	3.2	4.7	3.9	4.8	14	59	400	45	16	[illegible]
5	4.6	5.9	3.9	4.6	3.7	5.4	14	80	420	45	14	[illegible]
6	4.6	5.4	4.2	4.8	3.8	6.0	14	93	360	43	16	[illegible]
7	4.6	5.6	4.6	4.2	4.0	5.8	12	88	292	37	18	[illegible]
8	4.3	5.0	5.0	4.0	4.0	5.9	12	75	220	36	16	[illegible]
9	4.3	5.2	5.0	3.8	3.9	5.6	11	90	224	36	17	[illegible]
10	4.6	5.3	5.3	3.8	3.8	5.4	12	110	196	34	29	[illegible]
11	4.3	4.7	5.6	4.1	3.8	6.2	14	140	185	32	21	[illegible]
12	4.3	4.2	5.6	4.3	4.4	5.6	18	130	193	30	20	[illegible]
13	4.3	4.8	5.3	4.3	4.3	5.2	20	110	214	29	16	[illegible]
14	4.3	4.8	4.8	4.3	4.2	6.5	18	110	228	26	19	7.1
15	4.3	5.3	4.8	4.1	4.5	6.2	19	95	220	25	25	[illegible]
16	4.1	4.7	4.8	4.1	4.3	6.0	20	90	217	23	16	[illegible]
17	4.3	4.7	5.0	4.1	4.2	6.5	20	81	217	20	14	[illegible]
18	4.3	4.3	4.8	4.1	4.3	6.4	20	98	244	19	12	[illegible]
19	4.6	4.5	4.8	4.1	4.2	6.4	19	140	232	19	11	7.1
20	4.6	4.6	5.0	4.1	4.5	6.2	18	202	248	17	10	6.9
21	4.6	4.4	5.0	4.1	4.6	6.0	18	292	240	16	10	7.1
22	4.6	4.4	4.6	4.1	4.7	6.5	17	440	205	16	9.5	[illegible]
23	4.6	4.5	5.0	4.1	4.8	7.4	16	374	182	18	15	[illegible]
24	4.6	3.9	5.0	4.1	4.8	8.0	16	240	168	16	14	[illegible]
25	4.8	4.3	5.0	4.1	4.7	9.5	16	190	138	17	10	[illegible]
26	5.0	3.7	5.0	4.3	4.6	9.5	16	185	114	18	9.0	[illegible]
27	4.6	3.1	5.0	4.3	4.6	9.0	16	240	93	18	9.0	[illegible]
28	5.3	2.8	4.8	4.3	4.5	9.5	16	296	91	21	10	[illegible]
29	5.6	2.6	4.8	4.0	4.5	12	18	380	93	16	9.0	[illegible]
30	4.3	3.2	4.6	3.7	------	14	23	440	74	17	8.5	[illegible]
31	5.9	------	4.0	4.1	------	17	------	480	------	20	8.0	------
TOTAL	140.1	136.9	145.2	130.3	122.4	222.0	502	5,462	7,078	869	462.0	[illegible]
MEAN	4.52	4.56	4.68	4.20	4.22	7.16	16.7	176	236	28.0	14.9	[illegible]
MAX	5.9	6.5	5.6	4.8	4.8	17	23	480	480	61	29	[illegible]
MIN	3.9	2.6	3.2	3.7	3.5	4.5	11	30	74	16	8.0	[illegible]
AC-FT	278	272	288	258	243	440	996	10,830	14,040	1,720	916	[illegible]

CAL YR 1967 TOTAL 7,579.1 MEAN 20.8 MAX 190 MIN 2.6 AC-FT 15,030
WTR YR 1968 TOTAL 15,481.9 MEAN 42.3 MAX 480 MIN 2.6 AC-FT 30,710

NOTE.--NO GAGE-HEIGHT RECORD JAN. 29 TO MAR. 7, MAY 29 TO JUNE 6.

Table C-1.--Analytic data on coal samples, Thompson Creek coal mining area and vicinity

Locality[1]	Mine-location Coal bed	Source	Size and kind of coal sample[2]	Moisture (as rec'd)	Proximate[2], percent, Dry coal: Vol.	F.C.	Ash	Sulfur	Ultimate[2], percent, Dry coal: Hydrogen	Carbon	Nitrogen	Oxygen	Calorific value (Btu): as received	dry	Ash softening temp., °F	Free Swelling Index[2] (FSI)	Hardgrove Grindability Index (HGI)
(1)	Sunlight mine																
	"D" bed	RI 5270	3"x3/8"-T	4.4	42.2	54.0	3.8	0.9	5.5	76.1	1.9	12.5	13,010	13,600	2,650	----	48
	"D" bed	RI 5221	1 1/2"x1/4"-T	6.2	42.6	54.0	3.4	0.6	5.5	76.1	1.9	12.5	12,840	13,680	2,670	1	47
	D	Collins (1976)	stockpile sample	6.7	40.6	58.7	1.7	0.6	5.2	77.7	2.0	13.1	12,779	13,697	2,460	0	---
(2)	Aspen Gulch "B" bed?	Collins (1976)	mine sample	3.1	37.3	55.5	7.2	0.6	5.3	77.3	1.8	7.9	13,176	13,598	2,700	1 1/2	---
	Marion Gulch Sunshine(?)	RI 5270	1 1/2" lump-T	3.8	40.2	56.1	3.7	0.5	5.4	77.9	1.8	10.7	13,530	14,060	2,160	----	---
		do.	1 1/2"x1/2"	3.9	39.9	55.0	5.1	0.5	---	----	---	----	13,260	13,810	2,230	----	52
		do.	1/2"x0	4.2	38.9	54.6	6.5	0.5	---	----	---	----	12,970	13,540	2,420	2 1/2	---
(3)	Thompson Cr. No. 1																
	A bed	RI 5270	ROM	2.6	30.8	60.3	8.9	1.0	5.2	76.5	2.0	6.4	13,750	14,110	2,500	7	89
		RI 6086	ROM	3.5	30.3	55.6	14.1	1.2	4.9	72.8	1.9	5.1	12,830	13,300	2,870	8	83
	No. 2 mine																
	A bed	RI 6086	ROM	3.1	29.5	58.2	12.3	1.1	---	----	---	----	13,220	13,640	2,470	8	86
	No. 3 mine																
	Anderson bed	RI 5270	ROM	3.6	32.4	59.5	8.1	0.7	5.1	79.0	1.7	5.4	13,590	14,100	2,440	7	71
	do.	RI 6086		2.3	34.9	57.5	7.6	0.6	---	----	---	----	13,900	14,230	2,420	8	69
(4)	Middle Thompson Cr.																
	"Middle Thompson prospect"	Collins (1976)		3.0	27.0	59.5	13.5	1.3	4.9	74.6	2.0	3.5	12,982	13,383	2,730	8 1/2	---
	"Anderson"	do.		5.1	33.6	57.4	9.0	0.6	5.3	77.1	2.0	6.1	13,150	13,857	2,495	8 1/2	---
(5)	Dutch Creek																
	"B" bed	IC 8497		4.9	23.0	68.6	8.4	0.6	4.8	81.9	2.0	2.3	13,780	14,480	2,250	9	110
	Dutch Creek No. 1																
	"B" bed	Collins (1976)	mine sample	1.56	22.6	69.8	7.6	0.7	4.8	81.8	2.0	2.9	14,322	14,555	2,460	9+	---
	"B"	do.	do.	1.7	22.0	66.8	11.2	0.5	4.6	79.4	1.8	2.5	13,759	13,997	2,370	9+	---
	"B"	do.	do.	2.13	23.1	69.6	7.3	0.6	4.8	82.4	2.0	2.8	14,297	14,604	2,340	9+	---
	Dutch Creek No. 2																
	Dutch Creek bed	do.	do.	2.58	28.6	67.2	4.2	2.4	5.3	83.3	1.8	2.9	14,455	14,841	2,240	9	---
	Dutch Creek bed	do.	do.	3.08	21.2	74.9	3.9	0.6	5.2	85.3	2.0	2.9	14,697	15,167	2,300	9	---
	No. 3, L.S. Wood																
	"B" bed	do.	do.	4.0	22.6	69.6	7.8	0.8	4.9	83.3	1.9	1.5	13,940	14,521	2,370	9+	---
(6)	No. 4, Bear Creek																
	"B" bed	do.	do.	3.8	26.1	70.9	3.0	0.6	4.9	84.7	2.0	4.9	14,397	14,966	2,465	4	---
	B bed	do.	do.	5.1	24.5	69.3	6.2	0.5	4.7	81.8	2.0	5.0	13,661	14,395	2,500	4 1/2	---

1/ Localities 1 through 6 are shown on figure 13, this report.

2/ For samples collected by Collins (1976): proximate and free swelling index (FSI) done by Coal Laboratory of Eastern Associated Coal Corp., Pittsburgh, C. W. Lype, Chief Chemist; ultimate and high temperature ash analyses by U.S. Bureau of Mines.

APPENDIX C

Table C-2.--ASTM classification of coals by rank

Class	Group	Fixed Carbon Limits, percent (Dry, Mineral-Matter-Free Basis): Equal or Greater Than	Fixed Carbon: Less Than	Volatile Matter Limits, percent (Dry, Mineral-Matter-Free Basis): Greater Than	Volatile Matter: Equal or Less Than	Calorific Value Limits, Btu per pound (Moist,[b] Mineral-Matter-Free Basis): Equal or Greater Than	Calorific Value: Less Than	Agglomerating Character
I. Anthracitic	1. Meta-anthracite	98	...	...	2	...	...	nonagglomerating
	2. Anthracite	92	98	2	8	...	...	
	3. Semianthracite[c]	86	92	8	14	...	...	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	...	...	Commonly agglomerating[e]
	2. Medium volatile bituminous coal	69	78	22	31	...	...	
	3. High volatile *A* bituminous coal	...	69	31	...	14 000[d]	...	
	4. High volatile *B* bituminous coal	...	...	...	...	13 000[d]	14 000	
	5. High volatile *C* bituminous coal	...	...	...	...	11 500	13 000	
						10 500	11 500	agglomerating
III. Subbituminous	1. Subbituminous *A* coal	...	...	...	...	10 500	11 500	nonagglomerating
	2. Subbituminous *B* coal	...	...	...	...	9 500	10 500	
	3. Subbituminous *C* coal	...	...	...	...	8 300	9 500	
IV. Lignitic	1. Lignite *A*	...	...	...	...	6 300	8 300	
	2. Lignite *B*	...	...	...	...	...	6 300	

[a] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[b] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile *C* bituminous group.

Table C-3.-- Total production of coal mines, Thompson Creek mining area.

DATA [1] SOURCE	MINE, LOCATION, (Operator (last or latest))	COAL BED	OPENED	CLOSED	TOTAL PRODUCTION (short tons)	REMARKS
(1)	Spring Gulch Sec. 15,22,23,26 and 27, T. 8 S., R. 89 W. (C. F. and I. Steel Corp.)	Sunshine, Allen, Anderson	1887	1916	3,372,385	"Coal is of coking quality" Coal thickness: Sunshine, 12.0 ft.; Allen, 5.5 ft.; Anderson, 9.0 ft.
(1)	Thompson Creek No. 1 Sec. 34,35, T. 8 S., R. 89 W. (Anschutz Coal Corp.)	A & B	1951	1966 (Re-opened, 1975)	1,079,166	"Coal is of coking quality" Coal thickness: 8.0 ft. (A bed)
(2)	Thompson Creek No. 2 Sec. 34, T. 8 S., R. 89 W. (Anschutz Coal Corp.)		1953	1966	226,893	
(1)	Thompson Creek No. 3 Sec. 34, T. 8 S., R. 89 W. (Anschutz Coal Corp.)	Anderson	1955	1966 (Re-opened, 1975)	672,206	"Coal is of coking quality" Coal thickness: 9.0 ft.
(2)	Union Sec. 15, T. 8 S., R. 89 W.		1896	1902	142,765	

[1] Sources of data:
(1) Jones and Murray (1976)
(2) Collins(1976)

Table C-4.--Estimated original resources (in thousands of short tons) in coal beds more than 42 inches thick, Thompson Creek mining area and vicinity 1/.

Coal Zone	Location, coal bed	Overburden (ft) 0-1,000	1,000-2,000	2,000-3,000	Totals
	T. 8 S., R. 89 W., Pitkin County:				
Lower	Coal bed A	5,745	8,845	16,389	30,979
	Coal bed B	3,854	5,392	10,278	19,524
	Coal bed C	2,426	2,974	6,984	12,384
	Coal bed D	1,130	1,875	2,275	5,280
	Total, lower zone	13,155	19,086	35,926	68,167
Upper	Sunshine	6,300	10,179	10,980	27.459
	Anderson	6,132	5,536	1,638	13,306
	Thompson	1,493	399	----	1,892
	Total, upper zone	13,925	16,114	12,618	42,657
	T. 9 S., R. 89 W., Pitkin County:				
Lower	Coal bed A	5,505	11,145	12,632	29,282
	Coal bed B 2/	9,383	5,287	8,454	23,124
	Total, lower zone	14,888	16,432	21,086	52,406
Upper	Sunshine	17,534	22,283	15,228	55,045
	North Rim	4,799	4,350	----	9,149
	Lake Ridge	548	660	2,818	4,026
	Total, upper zone	22,881	27.293	18,046	68,220
	Township total	37,769	43,725	39,132	120,626

1/ Source of data: Donnell(1962). Resource estimations do not conform to Geological Survey standards, but they are the most complete and accurate data available for the area as of December 1, 1977.

2/ Figures listed are totals for "upper split, lower B", "lower split lower B" and "Upper B", combined.

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