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SOUTH DAKOTA

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. P. Rothrock, State Geologist

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REPORT OF INVESTIGATIONS

No. 10

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THE ISABEL–FIRESTEEL COAL AREA

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By

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THE ISABEL–FIRESTEEL COAL AREA

INTRODUCTION

Location and geographic relations:

The Isabel-Firesteel coal area is in northwestern South Dakota (Fig. 1 and Fig. 2). It lies along the divide between Grand and Moreau Rivers, mostly in northwestern Dewey County, but it also extends westward into Ziebach County. Isabel, in the western part of the area, is approximately 90 miles northwest of Pierre.

The area occupies the southeastern part of the South Dakota coal field which extends northward and westward from this area to comprise parts of Corson, Dewey, Harding, and Meade Counties.

Purpose of the Report:

The coal of this area has recently attracted attention because of the quality of the fuel as compared to that of nearby areas and because of its nearness to markets. Development of power mining machinery and its successful use in stripping operations in other fields has aroused general interest in areas where open pit methods may be used. Much of the coal of this area may be so recovered.

This report has been prepared primarily to acquaint operators and owners of coal properties of possible value of their coal and with the geological conditions bearing on coal recovery in the area. It is also intended to present to interested persons the results of investigations of character and quality of the coal.

Field Work:

A reconnaissance was made in the field season of 1929 when several days were spent in this and the surrounding area. Most of the two months field season of 1930 was spent in this area. All parts of the area were investigated and outcrops were plotted by odometer readings with the exception of two small but important areas which were surveyed with plane table and telescopic alidade to show outcrops and topography.

Acknowledgements:

The writer is greatly indebted to residents, owners, and operators for courtesies and cooperation beyond those commonly extended to the geologist in the field. Much data thus kindly given has been of material assistance in preparation of this report. Able assistance was rendered in the field by Mr. Harold Norbeck in the reconnaissance of 1929 and by Mr. Lyle D. Espe in 1930. Mr. Espe also served as instrument man. Chemical analyses of coals of the area not previously published were made by members of the corps of the State Chemical Laboratory at Vermillion through the cooperation of the State Chemist, G. G. Frary.

PHYSIOGRAPHY AND GEOGRAPHY

The Isabel-Firesteel area lies near the eastern boundary of the Great Plains, the boundary between the Great Plains and the glaciated plains being Missouri River. The area forms the divide between Grand River to the north and Moreau River to the south. The surface, for the most part, is gently rolling, except along the eastern margin where a few low but conspicuous buttes capped by sandstone of the upper Fox Hills are present. Butte topography extends beyond this part of the area to the east and southeast.

Slopes in the area are mostly gentle, the average being about 50 feet per mile, although

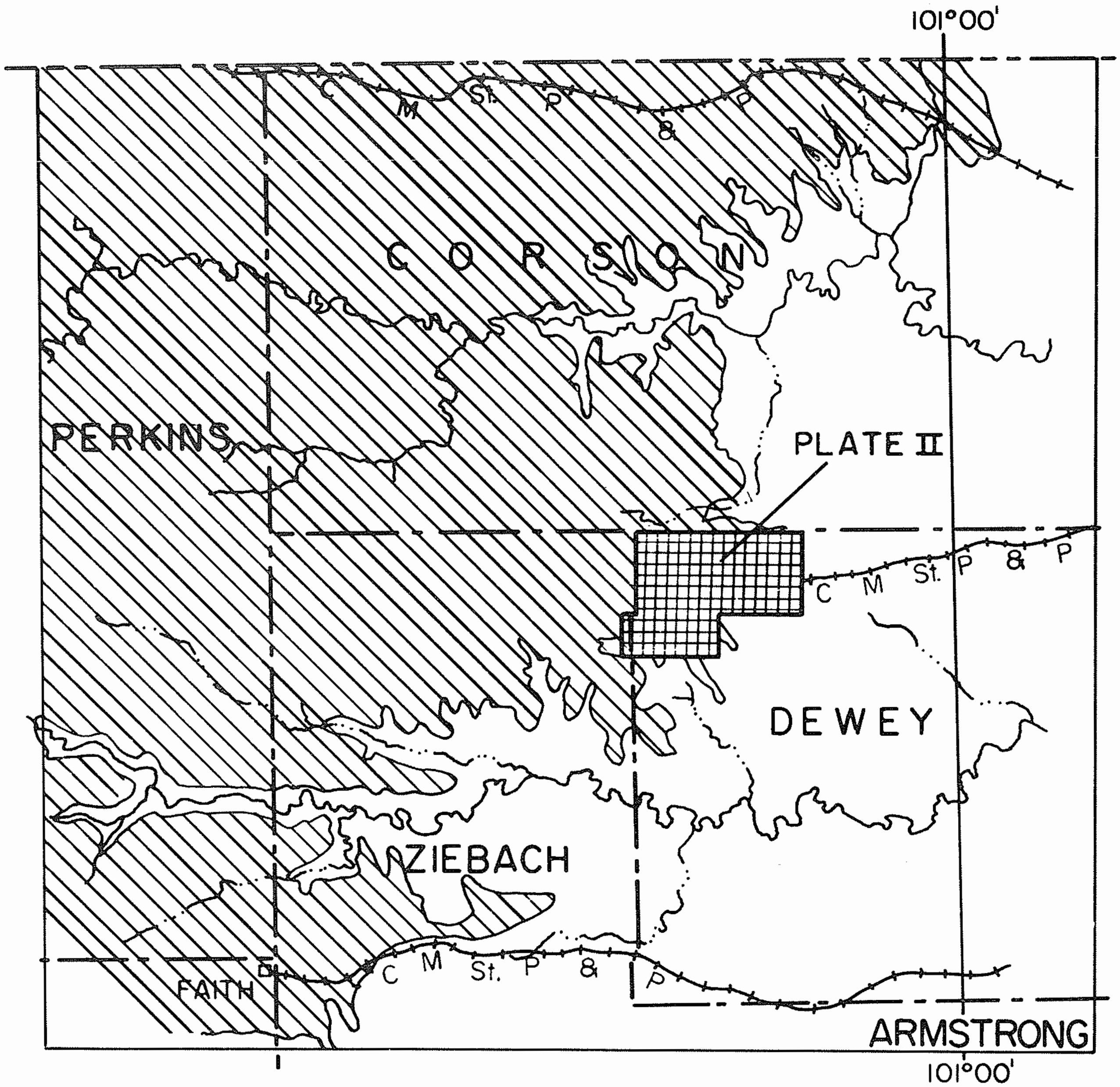


Fig. 1. Index map showing location of the Isabel-Firesteel coal area. Shaded area underlain by coal bearing formation.

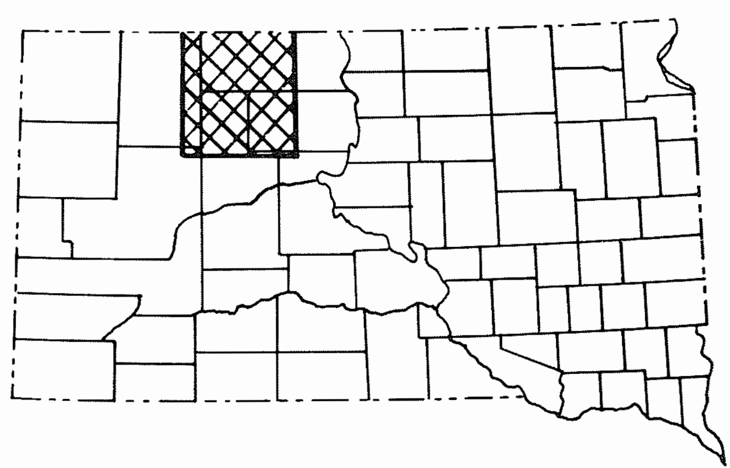


Fig. 2. Index map showing location of area shown in Figure 1, within the State of South Dakota.

lesser slopes of 20-25 feet per mile, and greater slopes of 100 feet per mile are fairly common. Divides are gently rounded or flattish. Valley walls slope gently to the valley bottoms which for the most part are concave rather than flat in cross-section.

The greatest altitude (2360 feet above sea level) is at Firesteel. The lowest place in the area is approximately 1350 feet. The maximum relief is thus approximately 1000 feet.

Drainage

Drainage is to Grand and Moreau Rivers. North of a line through Isabel and Firesteel drainage is to the Grand whereas south of this line is to the Moreau river. Throughout most of the year drainage is underground as shown by the fact that all streams of the area are intermittent. The northern slopes of the divide are drained by northward draining tributaries to Firesteel Creek whereas the southern slopes are drained by Red Earth, Meadow and Red-Water Creeks and their tributaries. Water holes in which water stands through the dry season are common along valley bottoms. During wet weather and during spring thaws water running down the grass covered valley bottoms cuts through the protective sod and scour occurs at these places. Pits up to eight or ten feet deep are thus formed. Those noted are less than 20 feet across and less than 50 feet long.

Artificial reservoirs made by damming small valleys to impound water for the use of stock are common. One small artificial lake, Lake Isaac Walton, was recently made by damming a small valley in Sec. 17, T. 17 N., R. 23 E.

Culture

Towns:

Isabel and Firesteel are the towns of the area. The former with a population of 450 (1930 census) is in the southwestern part and the latter with 94 inhabitants (1930 census) is in the east central part of the area. The remainder of the area is sparsely populated.

Railways:

The area is served by a branch of the Chicago, Milwaukee and St. Paul railway which passes from Mobridge through Firesteel to the terminal at Isabel. This branch connects at Trail City, east of the area, with another which has a terminal at Faith about 40 miles southwest of Isabel. At Mobridge, 40 miles east, connection is made with the main line of the Chicago, Milwaukee, St. Paul and Pacific Railway; thus furnishing rail transportation to Lemmon and other points northwest and to Aberdeen and other points east of Missouri River.

Highways and Roads:

The area is crossed by highways and roads, which, when improvement is complete, will be adequate for the needs of the area. All roads are earth roads and improved earth grades which are satisfactory in dry weather, but passible with difficulty or impassible in wet weather. State Highway 65 passes through both Isabel and Firesteel, making highway connection between Camp Crook at the western boundary of South Dakota and Mobridge on Missouri River. It is now gravel surfaced from Mobridge to a point about five miles east of Firesteel. The remainder of the road is graded. At Mobridge Highway 65 connects with a network of highways serving eastern South Dakota. State Highway 18 connects with Federal Highway 12 to the north and Federal Highway 212 to the south through Isabel. In the area, most parts may be reached readily by secondary roads, in part graded, and by unimproved trails.

Water Supplies

Wells:

Water is obtained over the area from bored and drilled wells at depths ranging from 20 to 600 feet. In many places supplies sufficient for domestic and farm use are obtained at depths less than 150 feet. Underground water from most wells in the area has been found to contain dissolved salts in sufficient quantities to render it unsatisfactory for boiler use.

Reservoirs:

Small reservoirs made by damming small valleys are in general use in the area to impound water for stock.

STRATIGRAPHIC GEOLOGY

General Statement:

The surface formations of the Isabel-Firesteel area consist entirely of beds of the Fox Hills of Cretaceous age, Lance of Cretaceous age or Eocene age, residuum from Tertiary formations, and some Pleistocene and recent deposits. The greater portion of the area is underlain by Fox Hills and Lance. Older Cretaceous and still older Paleozoic formations known elsewhere in South Dakota from exposures and drillings doubtless occur below the outcropping formations. The surface formations of the area are shown in the columnar section (Plate I) in their relation to other deposits of Dewey and Ziebach Counties.

Fox Hills

Strata of the Fox Hills formation are the oldest outcropping in the Isabel-Firesteel area. These are found at the surface only in the southern and eastern parts of the area mapped, where they border the coal bearing Hell Creek member of the Lance, (Plate II). Although the beds are largely grass covered or are covered by residuum and slope mantle, outcrops in and near the area suggest division into two members, a lower banded member and an upper member composed of massive sandstone. It is the uppermost of these which is most commonly seen and which forms the caps of conspicuous buttes lying to the east and southeast of the area.

Distribution:

The Fox Hills outcrops at the surface at lower elevations in the eastern tier of sections of T. 17 N., R. 23 E., and extends also into sections 26, 27, 28, 33, 34, 35, and 36. It also appears at the surface in deeper valleys in Secs. 11, 12, 13, 14, 16, and 18, T. 16 N., R. 22 E., and in Sec. 13, T. 16 N., R. 21 E.

Stratigraphic details.—As previously stated the Fox Hills of this area is grass covered for the most part and outcrops are few and discontinuous. The upper part of the formation which outcrops appears to be divisible into two members, a lower banded shale and sandstone member on which in many places, lies a member composed of beds dominantly sandstone.

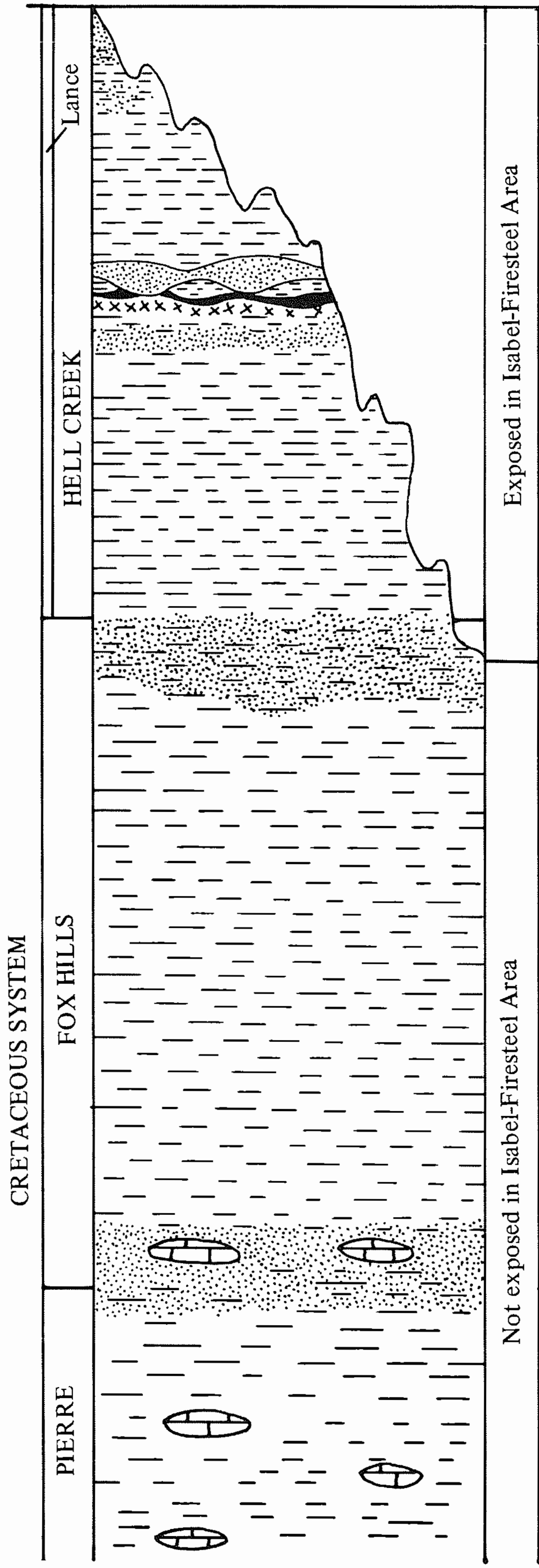
The banded member of the Fox Hills is composed of alternating layers, one inch to one foot thick, of buff, drab, gray and brown shale and sandstone. These layers of alternating colors and shades give the member its banded appearance. The beds vary in texture from shale, which is commonly silty, through silts, up to fine sand. Beds of sand, however, contain considerable silt. Bedding commonly approaches horizontality in outcrops, although some of the sandy layers are cross laminated.

The table of succession which follows is representative of the banded member of the Fox Hills.

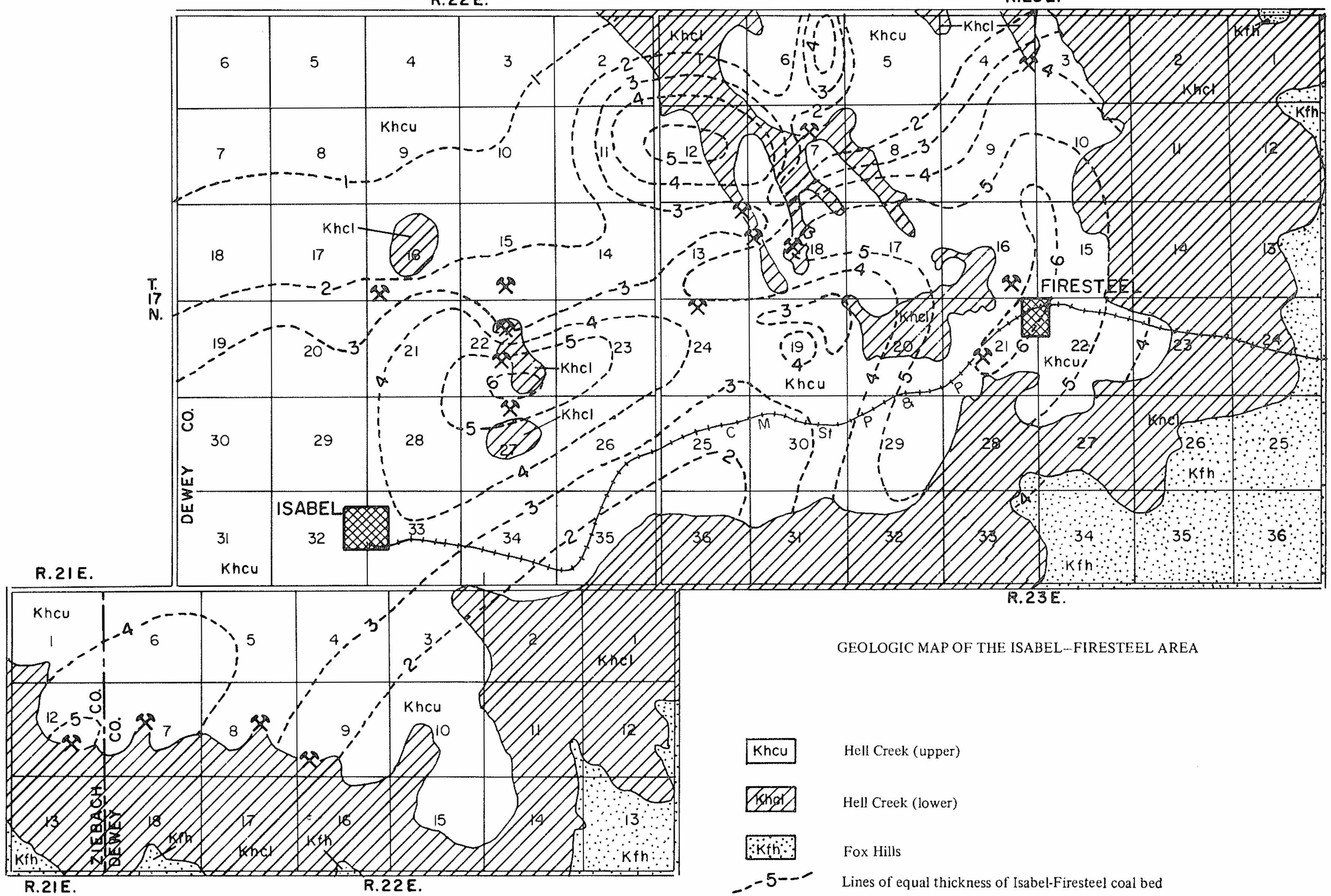
Section of the Banded Member of the Fox Hills

Exposed at East Side of State Highway No. 65 and below in cutbank at the east side of the creek in the S.E.¼, S.E.¼, Sec. 21, and the S.W.¼, S.W.¼, Sec. 22, T. 16 N., R. 22 E.

COLUMNAR SECTION
of
Rocks of Dewey County, South Dakota
Showing the position of those exposed in the Isabel-Firesteel area.



		AREA Thickness Feet
Lance / Hell Creek	Buff, dull brown, drab and gray clay, clay shale, shale and agrillaceous sandstone. Isabel-Firesteel coal bed, 136 feet (average) above the base.	180-300
Fox Hills	Yellow, buff and brown sandstone and sandy shale. Upper and lower portions most sandy.	200-300
Pierre	Dominantly dark gray to black shale, grades into silty beds in upper 200 feet. Silty beds grade without break into the overlying Fox Hills. Total thickness of formation about 1440 feet.	500±



GEOLOGIC MAP OF THE ISABEL--FIRESTEEL AREA

Khcu	Hell Creek (upper)
Khcl	Hell Creek (lower)
Kfh	Fox Hills
--5--	Lines of equal thickness of Isabel-Firesteel coal bed

		Feet
9.	Soil	1
8.	Sandstone, buff and gray, friable, finely cross-bedded, concretionary cementation in places	5
7.	Shale, fairly dark, brownish-gray to chocolate brown, brittle, fine and testured. Contains some beds of buff, fine textured, thin bedded sand	9
6.	Sandstone, drab and buff, thin bedded; limonite streaked in places. Horizontally banded with drab and gray. Some bedding planes covered with small, brown leaflike impressions	9
5.	Shale, drab brown to brown, interbedded with drab sandstone; both shale and sandstone thin bedded, alternating in beds ranging between 3 inches and 1 foot in thickness. Becomes increasingly silty and sandy toward the top	3
4.	Sandstone, buff and drab, uncemented. Fine and silty. Contains limonite concretions	5½
3.	Shale, reddish brown and gray, thin bedded and brittle in lower part. Tough and gumbo-like in upper part	1¼
2.	Sandstone, drab, very friable, silty. In beds to 1 ft. thick separated by thin beds of shale, 1 to 3 inches thick which give the zone a banded appearance	3
1.	Shale, silty, drab. In beds about one foot thick alternating with thin very silty and sandy brown beds. These give the zone a horizontally banded appearance.	4
	Total Exposed	40¾

The uppermost sandstone bed of this section (8) apparently belongs to the sandstones which overlie the banded member.

The upper member of the Fox Hills consists of sandstone, clay and shale, which appears to be lenticular in character. In most places beds at this horizon are covered by grass and residual materials and the character must be inferred from wells penetrating the beds and from outcrops which are at considerable distances from the area. Part of the sandstone beds, however, are more or less strongly cemented to form the caps of conspicuous buttes. These buttes, however, are mostly to the east and southeast of the area.

These sandstone beds consist commonly of buff and gray beds of more or less greenish cast. The lower sandstone beds tend to be buff and friable whereas higher beds are most likely to be cemented into hard gray micaceous sandstone with conchoidal fracture.

The grains of which these sands are composed are fine in texture, ranging between 1/16 and 1/2 millimeter in diameter. The greater portion range between ¼ and 1/8 millimeter in diameter.

The bulk of the sand is composed of sharply angular grains of quartz with here and there a grain which shows considerable rounding. Glauconite of medium to dark green color is abundant, particularly in friable beds. Both muscovite and biotite are abundant in most outcrops.

The hard gray micaceous sandstone is absent in many places in the outcrop and records of several wells suggest the absence of all sandstone at this position in many places in the area.

Thickness:

About thirty-five feet of banded Fox Hills and possibly 20 to 25 feet of friable sandstone, including 12-15 feet of hard gray sandstone are exposed in the area.

Fossils:

Leaves of deciduous trees and impressions of branches of coniferous trees occur in the hard sandstone which composes the butte caps along the eastern side of the area. Elsewhere, as along the Grand and Moreau Rivers, oyster beds in glauconitic sandstone occur at an horizon believed to be at approximately the same stratigraphic position. Near Dupree glauconitic sandstone beds at a similar position contain other brackish water fossils.

Stratigraphic relations:

The Fox Hills grades upward into the Hell Creek without stratigraphic interruption. Where glauconitic sandstone lenses and beds containing oysters and other brackish water forms are present, the boundary is drawn by the survey to include these in the Fox Hills on the grounds that these represent shoreline deposits made during the retreat of the Fox Hills sea and because in some places they also contain a few marine Fox Hills fossils. Where non-fossiliferous shales and silts lie at the boundary of Fox Hills and Lance as in many well logs of the area, the boundary can be drawn only approximately.

Correlation:

The upper Fox Hills is correlated with beds of the same age widely exposed along Grand and Moreau Rivers and along tributaries to these streams. The sandstone beds which lie here and there above the banded shale, silt, and sandstone beds, are correlated with the brackish water beds of Fox Hills age which elsewhere contain *Ostrea glabra* and other brackish water forms.

Lance Formation

(Hell Creek Member)

General Statement:

The Hell Creek Member of the Lance is the surface formation over the greater portion of the Isabel-Firesteel area. It is composed of gumbo-like clays, gumbo-like sands, lignitic shale, siliceous shale, carbonaceous shale, and coal.

Distribution:

The Hell Creek member of the Lance covers the greater portion of the Isabel-Firesteel area as mapped. Hell Creek beds underlie all of the area with the exception of the small parts under which the Fox Hills is the surface formation, as described in earlier sections.

The boundary between Hell Creek and Fox Hills is shown on the geological map of the area (Plate II). In most places it is concealed by grass and residual material but it has been determined accurately as possible by projection of dip of upper Fox Hills beds, from well records from the character of residual surface materials, and from outcrops.

Lithological Details:

The Hell Creek member of the Lance in the Isabel-Firesteel area, as elsewhere, consists of clays, lignitic and carbonaceous shale, sandstone, coal and some thin beds of limonite. In many places coal has been burned and baked clay or shale and ashes remain after burning.

Neutral and dull shades of gray, buff, drab, and brown are prevailing colors of the Hell Creek. Where clay and shale have been baked in the burning coal, brick red and yellow stand out in striking contrast with other outcropping beds.

The Hell Creek of this area appears to be divisible into two parts, a lower and an upper, on the basis of the Isabel-Firesteel coal, which has been interpreted by this survey as a single bed.

Below the Isabel-Firesteel coal, the Hell Creek consists mostly of shale, or clay and shale. Near the base, however, thin sandstones probably occur in many places as discontinuous lenses. Thin sandstones occur also among the beds immediately below the Isabel-Firesteel coal bed. The basal beds of this succession are mostly covered in the area but their character is well illustrated near the Moreau River where they are exposed in a ravine and on the side of an adjacent butte approximately at the southeast corner of Sec. 26, T. 2 N., R. 21 E. These beds and the upper portion of the underlying Fox Hills are shown in the table of succession which follows:

Section of the Lower Hell Creek and the Underlying Fox Hills
Exposed in a ravine and an adjacent butte at approximately the
Southeast Corner of Sec. 26, T. 20 N., R. 21 E.

		Feet
Lower Hell Creek:		
19.	Soil, brown, sandy	1- 2
18.	Sandstone, buff to gray, cross laminated, limonite streaked here and there, small sticks and stems on bedding planes	18-20
17.	Limonite, stick and stem impressions very abundant	1/18
16.	Shale, highly lignitic, brown to black, contains considerable glance coal. Thinly laminated	1
15.	Shale, drab brown, limonite bed 1/5–1/4 feet thick, three feet from top	5
14.	Limonite, concretionary	1/6–¼
13.	Shale, hard, brown, very brittle	3
12.	Shale, brown, lignitic, sticks and stems numerous	1
11.	Shale, hard, brittle, silty	1½
10.	Sandstone, drab, thin bedded to massive, contains thin, brown, lignitic partings on the bedding planes. Limonite abundant in one inch beds. Limonite concretions up to one foot in diameter, in upper 6 feet. Dinosaur remains have been removed from this bed by Denver Museum	16
9.	Shale, sandy, brown, lignitic, limonite concretions in base. Contains fairly large plant fragments	3
8.	Sandstone, massive, drab, fine-textured, silty. Limonite concretions in upper 2 feet and in thin ledges up to 2 inches thick in lower foot	9
7.	Shale, sandy, drab and brown. Contains thin sandstone lenses	3
6.	Sandstone, buff. Interbedded with lignitic shale in layers one inch thick. Contains some glance coal and resin	1
Upper Fox Hills:		
5.	Shale, lignitic, brown. Sticks and small plant fragments abundant. *Ostrea glabra* abundant in top 4 inches	12
4.	Shale, brown, silty and sandy. Weathers gumbo-like into irregularly polygonal fracture fragments. Few 3 inch horizontal limonite stained bands present	13
3.	Sandstone drab gray, fine textured, silty, micaceous. Crossbedded. Contains limonite concretions. Cemented in places to form ledges and lenticular concretions, some of which are oriented flatwise, others parallel to the cross lamination	7- 8
2.	Shale, banded buff and brown. Bands ½-1 foot thick. Hard	12
1.	Shale, brown, somewhat weathered, gumbo-like. Probably buff and brown banded shale	20±
	Total	106 5/6 to 110 11/12

There is the possibility that the succession of the foregoing table comprises most of the beds lying below the position of the Isabel-Firesteel coal bed.

In many places in the Isabel-Firesteel area the succession below the coal appears to be entirely shale, which is recorded from well drillings as blue shale. The upper portion of these beds is typically exposed in the east wall of the small valley which drains northward through

Sec. 22, T. 17 N., R. 22 E. These beds are described in the table of succession which follows:

Section of Hell Creek beds immediately below the Isabel-Firesteel coal bed and associated beds. Exposed in the East Valley wall in S.W.¼, S.E.¼, Sec. 22, T. 17 N., R. 22 E.

	Feet
7. Soil, brown	2/3-¾
6. Shale, baked, "scoria," brick red	5
5. Ashes, gray, represents Isabel-Firesteel coal bed	1±
4. Clay, brown to gray, gumbo-like	5
3. Sandstone, drab gray, fine	5
2. Shale, thinly laminated, brown, contains sticks and stems	4½
1. Sandstone, drab gray, fine textured, friable, massive. Contains much clay	5
Total	26 1/6–26¼

The Isabel-Firesteel coal bed, which divides the Hell Creek of the area, appears to be the most persistent bed of the area. The bed occurs at most places within the line of outcrop where its position has been penetrated. In many places black, highly carbonaceous shale or "blackjack" is associated with the coal lying immediately below, within or on the coal. A detailed description of this coal bed is given in a special section in later pages.

Beds of the Hell Creek member above the Isabel-Firesteel coal bed consist of lenses of clay, shale, sandstone, and some beds of limonite. Sands are commonly light gray, drab or buff in color, whereas clays are gray, buff or drab and brown.

The succession above the coal is variable. In many places brown clay shale, probably bluish gray when not weathered, lies on the coal. Although it is absent in some places, possibly in many places, locally it reaches a thickness of 30 feet. The shale is absent at the southwestern part of a mine exposure in the S.E.¼, N.W.¼, Sec. 22, T. 17 N., R. 22 E., whereas at the eastern part, it is one foot thick. The shale lies without apparent stratigraphic break on the Isabel-Firesteel coal bed or on carbonaceous shale ("blackjack") closely associated with the coal bed.

The lowermost beds of sand and sandstone above the coal are light gray, drab, and brown. They are composed of fine quartz sand grains between which considerable amounts of clay are present. The clay renders the sand sticky or gumbo-like when wet but fairly hard and compact when dry. Presence of clay and the resulting behavior of the sand when moist is probably responsible for the local term "packsand."

Bedding of the sandstone is horizontal in many cases. Cross lamination, however, is commonly seen.

Light gray concretions, due to cementation of the sand, are characteristic. They consist of flattened ovoid masses ranging from a few inches up to three or four feet in diameter and up to one and one half feet in thickness. Orientation is parallel to the bedding in most cases, but elsewhere, the concretions have been observed to lie with greatest diameters parallel to cross lamination. Both bedding and cross lamination continue from the matrix through the concretions.

The lowest beds of sand lying above the Isabel-Firesteel coal bed may be continuous, but they probably are discontinuous lenses, in some cases of considerable size. Here and there the base of the lowest sandstone rests on the coal, whereas in other places the base lies on the shale and clay previously described. In the latter places shale and clay beds from less than a foot in thickness up to more than 30 feet intervene between coal and sandstone (Fig. 3). The relations between the sandstone and the underlying coal and shale are unconformable and indicate cutting by running water after deposition of the shale and prior to deposition of the sandstone.

The sandstone reaches a thickness of 50 feet (?) in exposures in the N.W.¼, N.W.¼, Sec. 27, T. 17 N., R. 22 E.

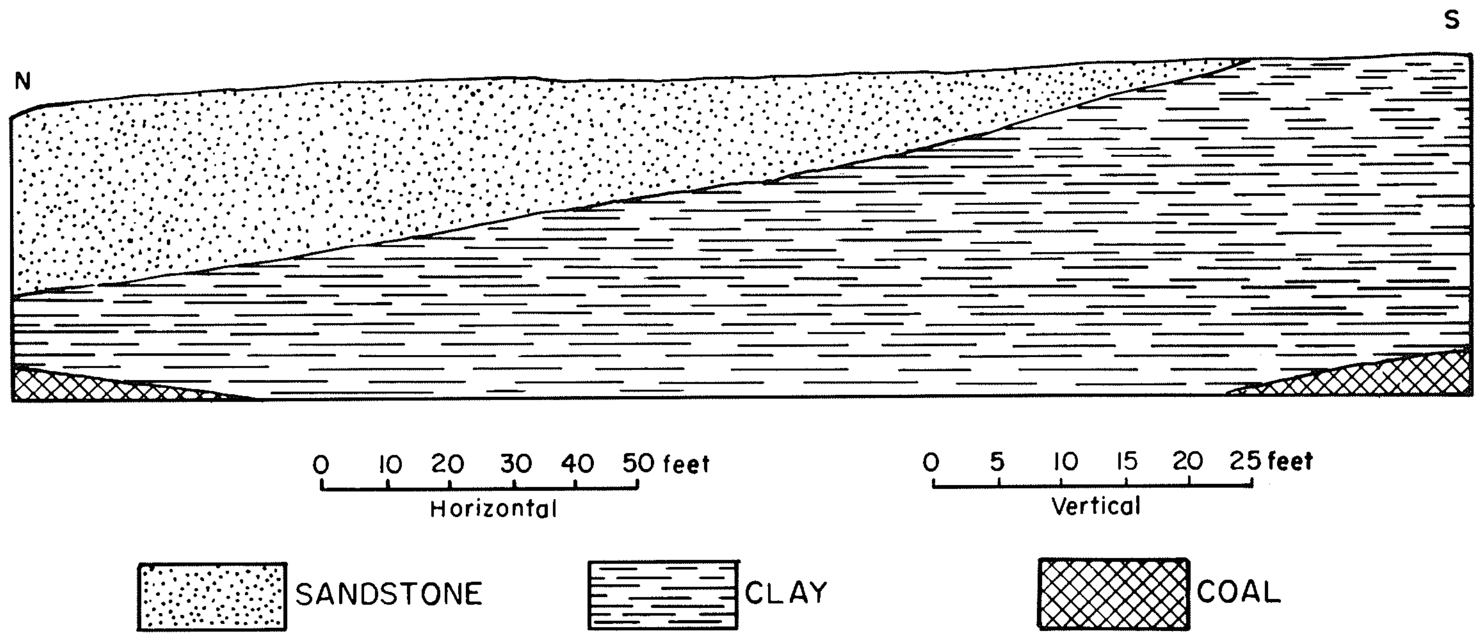


Fig. 3. North-South Section of Hammerly Mine in the S.E.¼, N.W.¼, Sec. 18, T. 17 N., R. 23 E., showing unconformity between sandstone and clay above Isabel-Firesteel coal bed.

Overlying these beds of sandstone are strata composed of clay, shale, shale and sandstones which are similar in character to those immediately above the coal.

The character of the beds comprising the Hell Creek strata above the Isabel-Firesteel coal is described in the tables of succession which follow. The first is a description of the coal and overlying beds in an abandoned mine in the S.E.¼, S.W.¼, Sec. 22, T. 17 N., R. 22 E.; the second in the abandoned strip pit of the Midwest Fuel Company in N.E.¼, S.W.¼, Sec. 22, T. 17 N., R. 22 E. and the third in the Hammerly mine in the S.W.¼, N.E.¼, Sec. 18, T. 17 N., R. 23 E. (Fig. 3).

Section of the Hell Creek Beds
Showing the Isabel-Firesteel coal bed and overlying beds.
Exposed in abandoned mine in the S.E.¼, S.W.¼,
Sec. 22, T. 17 N., R. 22 E.

	Feet
6. Soil, buff, sandy	1
5. Sandstone, buff to gray in lower part, brown in upper part, brown in places in lower part; massive, cross laminated. Cross bedding dips eastward. Contains large flattish gray calcareous concretions. Rests on coal at east side of mine and at southwest side	8
4. Shale, brownish gray, hard. Contains sticks and stems and glance coal. Pinches out at southwest and east ends of mine	0-1
3. Coal, Isabel-Firesteel bed, black, vertically jointed	3
2. Shale "blackjack," black, carbonaceous	¼
1. Clay, dark gray, exposed	¼
Total	12½–13½

Section of the Hell Creek Beds
Exposing Isabel-Firesteel coal and overlying beds in
abandoned strip mine of the Midwest Fuel Company,
N.E.¼, S.E.¼, Sec. 22, T. 17 N., R. 22 E.

	Feet
5. Soil, rusty brown	1
4. Sandstone, drab gray, rusty brown in places. Contains light gray sandstone concretions up to a maximum diameter of more than 4 feet, 5 feet above base	9
3. Clay shale, brown, weathered, somewhat silty. Lignitic in places	5
2. Shale, lignitic brown and "blackjack." Thinly laminated with stick and stem fragments	1
1. Coal, black, vertically jointed–exposed	2½
Total	18½

Section of the Hell Creek Beds
Exposing Isabel-Firesteel coal bed and overlying beds
in Hammerly mine. S.W.¼, N.E.¼, Sec. 18, T. 17 N., R. 23 E.

	Feet
5. Soil, sandy	1
4. Sandstone, drab gray, fine silty, friable, large lenticular concretions of light gray sandstone sparingly present, maximum thickness exposed at north end of mine	15

3. Shale, drab brown, bedding obscure, irregularly jointed. Joints limonite stained. Limonite concretions up to 8 inches in upper part. Stick and stem fragments sparingly distributed through lower part, also glance coal here and there in masses up to ¾ inches by 8 inches. Maximum thickness at south end of exposure 6-26
2. Shale, "blackjack," black, highly carbonaceous ¼-1
1. Coal, Isabel-Firesteel bed, black, vertically jointed, much glance coal; exposed 3

Total height of exposure 30

The uppermost Hell Creek beds of the area are penetrated by a well bored on the Walter Twito lot east of the schoolhouse in Isabel. The beds here consist of sandstone and shale. The lowest beds penetrated lie possibly 40-50 feet above the Isabel-Firesteel coal bed. The succession at this place is tabulated below in the log of the well borings checked by the writer by samples.

Log of Walter Twito Well
In Lot East of Schoolhouse in Isabel, S. Dak., showing
Hell Creek strata beginning 40-50 feet above the
Isabel-Firesteel coal bed.

4. Sandstone, drab, fine	19
3. Shale, blue at top, dark gray to black below	16
2. Sand, friable	1
1. Shale, blue at top, green at bottom	7
Total	43

Thickness:

The Hell Creek beds of the area reach a thickness between 180 and 300 feet. Numerous well drillings record a thickness of 86 to 200 feet of beds intervening between the Isabel-Firesteel coal and the first important sandstone bed which is accepted as the top of the Fox Hills. The average interval between the coal and the upper Fox Hills sandstone is 136 feet. In many places in the area, as in Isabel and in the well at the schoolhouse in Firesteel, 80 to 90 feet, however, of Hell Creek lie above the coal bed. A thickness of 90 to 100 feet however, appears to be the maximum thickness of beds above the coal. Lesser thicknesses prevail because of removal of beds by erosion.

Fossils:

Hell Creek fossils consist of land and swamp forms of reptiles. Plant remains have also been identified from the member. A few unidentified fragments of reptile bones have been collected from the Isabel-Firesteel area. A tooth of a large carnivorous dinosaur was found in the Isabel-Firesteel coal bed in the Raymond Mine by Mr. Fred W. Krumrei, Isabel, South Dakota.

Correlation:

The Hell Creek of the Isabel-Firesteel area is correlated with beds of the same character and position which outcrop from this locality westward into Montana and northward into North Dakota.

Tertiary

Deposits of Tertiary formations do not occur in place in the Isabel-Firesteel area but residuum believed to be from the Fort Union and White River formations have been observed here and there. Boulders of brown quartzite containing impressions of branches of trees are particularly abundant south of Isabel although they occur in many places. These have also been observed in northern Perkins County where they occur in the Fort Union formation. Masses of silicified wood very similar to that which occurs in the Fort Union has been observed in many places in the Isabel-Firesteel area. At the tops of gently rounded hills in the Sec. 4, T. 17 N., R. 23 E., and vicinity residual boulders occur which are composed of a coarse sandstone. Most of the grains and pieces of which these boulders are composed consist of transparent quartz but there are also grains of milky quartz and some pebbles of yellow and brown chert. Pieces reach a maximum diameter of one half inch in the boulders observed. Careful comparison of these boulders have been made with samples from Fox Ridge, in northern Meade County, from the big badlands of the White River, and from the Slim Buttes, and elsewhere. These comparisons indicate that these boulders and residuum are basal Chadron in age.

The residual quartzite, petrified wood, and Chadron residuum suggest the former extent of the Fort Union (Eocene?) and White River (Oligocene) deposits from the areas of outcrop over and probably beyond the Isabel-Firesteel area to the eastward.

Pleistocene

Sand and gravel deposits occur on flat topped butte-like terraces lying 50 feet or more above drainage along a tributary to Firesteel Creek northeast of Isabel in Secs. 10 and 15, T. 17 N., R. 22 E., (Plate II). These deposits have been investigated by E. P. Rothrock, State Geologist. They are composed of pebbles of iron oxide, quartz, sandstone and quartzite, in a matrix of sandy clay and sand. Most of the material ranges in size between ¼ and ½ inch although small boulders of sandstone and quartzite occur.

These deposits were made in the valley bottoms of ancient streams which were at grade 50 feet or more above the present drainage. Their age is presumably Pleistocene. The gravels suggest that at least 750 feet of White River, Fort Union, and Lance had been removed from the area before their deposition.

Recent

Alluvial deposits in valley bottoms, slope mantle and soil are the notable deposits which have been made and are now being made over the area in the Recent. These deposits are for the most part silty and sandy clays which are deposited in valley bottoms as alluvium and over slopes as slope mantle and elsewhere as soils or residual nature.

STRUCTURE

Introductory Statement:

Structure is the arrangement of rock layers. The term, as commonly used, has reference to the beds and dips in rocks and to open breaks or joints and to breaks in rocks or faults along which differential movement has taken place. The structure of the Isabel-Firesteel area consists of a regional dip of beds on which minor folds have been developed. These lesser structures are in turn modified by lesser foldings, joints and faults.

Regional Structure:

The strata of the Isabel-Firesteel area is part of a larger regional dip which is in a direction somewhat west of north.[1] The lengthening of the outcrop of the Isabel-Firesteel coal bed along northward flowing streams is illustrative of the effect of this regional dip.

Minor Structures:

Minor structures of the area consist of small anticlines and synclines which apparently

[1]Ward, Freeman, *The Structure of Western South Dakota,* South Dakota Geol. and Nat. Hist. Survey, Circ. 25, Structure Map, 1925.

trend in a direction at right angles to the regional dip. Those investigated are of low magnitude, and anticline in Sec. 20, T. 17 N., R. 23 E., rising somewhat more than 40 and 60 feet above adjacent synclines.

The Isabel-Firesteel coal bed partakes of the folding described and also shows many folds of a lesser order. These smaller folds consist of anticlines, synclines and domes on the larger features and vary only a few feet above and below the average dip of the coal bed. Although these structures are commonly observed in the coal bed they involve beds both immediately above and below the coal (Plate III). Folding of coal beds is of considerable importance because it determines in large measure the depth of coal beneath the surface.

Faults:

Faults observed in Hell Creek beds closely associated with the Isabel-Firesteel coal bed probably involve other Hell Creek and older strata. Those of the area are not commonly seen because of inadequate exposures. In the west trench of the Firesteel Coal Co., Inc., in the S.E.¼, Sec. 16, T. 17 N., R. 23 E., three were observed in a distance of 1150 feet (Plate III). These are of small magnitude, the maximum throw being only 3 or 4 feet, and the least being one foot. However, they involve beds both above and below the coal bed. Faulting on a small scale occurs, also in the abandoned mine in N.E.¼, S.W.¼, Sec. 21, T. 17 N., R. 23 E., where two were observed by a former member of the Survey.[1] These faults have throws of two feet.

Faulting on a larger scale than that observed may occur under cover in the area since several faults of greater throw occur in Hell Creek and Fox Hills beds a few miles southwest of the area in Sections 11 and 26, T. 16 N., R. 20 E., and also northwest of the area at approximately the southeast corner of Sec. 26, T. 20 N., R. 21 E.

COAL

Historical Statement:

The coal of the Isabel-Firesteel area was discovered before settlement of the area in 1910. It had been opened up and was in use by cattle men previous to that time. Pioneer residents of the area state that coal was mined by settlers in 1910 in Sec. 22, T. 17 N., R. 22 E., at a site of the now abandoned pit of the Midwest Fuel Company. Since that time the coal has been opened on the outcrop in many places and supplies of coal for local use have been obtained almost wholly within the area.

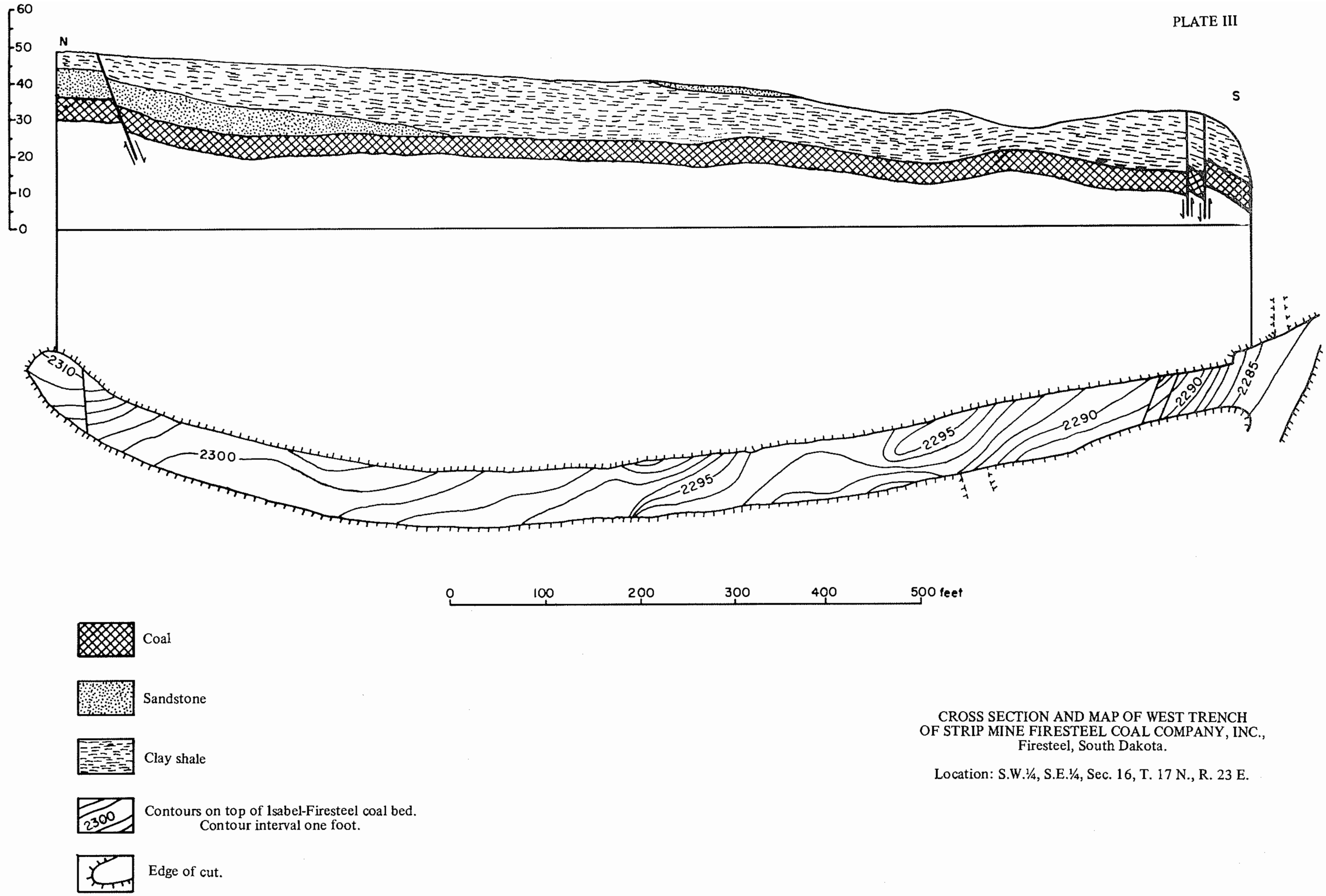
Location and Extent:

Coal underlies the greater portion of the Isabel-Firesteel area as mapped (Plate II). The boundary has been determined as accurately as possible by plotting of outcrops both natural and artificial, by plotting outcrops of burned shale or "scoria," and by plotting of well and other subsurface data showing the occurrence of coal. The map (Plate III) shows this boundary to lie at a distance ranging between one and one half and three miles from the eastern boundary of the mapped area. At a point approximately one and one fourth miles east and three-fourths miles south of Firesteel and boundary lies in an east by northeast direction to a west by southwest direction to a point in Sec. 3, T. 16 N., R. 22 E., southward into Sec. 15, T. 16 N., R. 22 E. From this location it continues off the map to the westward. Within this boundary coal is probably present except under small areas in which it has been removed by erosion in valleys north of Grand River–Moreau River divide and in a few places where coal is absent, possibly because of non-deposition or because of removal by erosion during Lance time.

In many places the boundary is extended from outcrops and subsurface data but elsewhere it has been drawn on the basis of topography. Along the east and southeast portion of the boundary in T. 17 N., R. 23 E., it is believed to be accurate within ¼ mile. From the western boundary of the mapped area to the S.W.¼, S.W.¼, Sec. 9, the boundary

[1] Russell, W. L., Unpublished report to C. R. Munson on coal in Sec. 21, T. 17 N., R. 23 E., 1924.

PLATE III



CROSS SECTION AND MAP OF WEST TRENCH
OF STRIP MINE FIRESTEEL COAL COMPANY, INC.,
Firesteel, South Dakota.

Location: S.W.¼, S.E.¼, Sec. 16, T. 17 N., R. 23 E.

is probably equally accurate. The remainder of the southern boundary is subject to considerable error. The coal, thus delimited, underlies an area of approximately 51 square miles, of which 35 square miles are underlain by coal of minable thickness.

Number of beds:—The minable coal of the Isabel-Firesteel area lies entirely in the Hell Creek member of the Lance. Examination of coal where exposed in mines, together with natural outcrops of coal and baked shale ("scoria") indicating former presence of coal, and correlation of coal in well borings, indicates that the important coal of the area is a single bed, the Isabel-Firesteel bed. Outcrops of coal which are in close proximity to other outcrops of coal or "scoria" lie at elevations of sufficient variation to suggest, in the absence of continuous outcrops, more than one coal bed. In every case where the relations could be ascertained in the field variations in altitude of minable coal of the area is due to structure of one coal bed.

Two coal beds are reported to have been penetrated in a well in the N.W.¼, N.W.¼, Sec. 15, T. 17 N., R. 23 E. Two beds have also been reported in two wells in the S.E.¼, S.E.¼, Sec. 9, T. 17 N., R. 23 E. The coal beds at the first location are reported to be separated by an interval of 60 feet and in the latter 25 feet. The uppermost bed occupies the position of the Isabel-Firesteel bed and is correlated with it. The lower is a second bed not known from outcrops or in mines.

A coal bed is reported to lie 30 feet below the Isabel-Firesteel bed in Sec. 22, T. 17 N., R. 22 E. Test borings made by employees of the Midwest Fuel Company are reported not to have penetrated a second bed. Its existence is, therefore, considered doubtful. Previous investigations report the occurrence of as many as four coal beds south of Isabel.[1] This number was probably suggested by discordance in elevations of outcrops. As previously stated, these variations in altitude may be explained by structure of one coal bed.

Thickness:

The Isabel-Firesteel coal bed varies in thickness between one and seven feet. On the map (Plate III) lines have been drawn through all points under which coal is of equal thickness. Thus a line is drawn connecting all points under which coal is known or presumed to be five feet thick. Other lines connect four-foot coal, three-foot coal, two-foot coal and one-foot coal. Coal lying between the three and four foot lines thus ranges between three and four feet in thickness. Where thickness has been accurately determined from numerous mines and trustworthy drilling data at relatively small intervals the lines designating thickness are fairly accurate. Elsewhere they are estimates of probable thickness and are subject to error. Nevertheless, variations considerably greater or less than the thickness estimated are not likely to be found.

PHYSICAL CHARACTER

The coal of the Isabel-Firesteel area, in common with other coals of the Hell Creek member of the Lance in South Dakota, is black in color. The streak (color of the powdered coal) is dark chocolate brown. In many cases, when artifically fractured across the bedding of the coal, a brownish tinge has been observed, due probably to pulverizing along the fractured surface. The dry coal is brittle, although the coal is fairly brittle even when freshly mined and in a wet condition. In color and brittle character it thus differs from lignite which is fibrous, tough, and woody.

In freshly exposed mine outcrops the coal is vertically jointed. The joints, where they have been observed, are commonly in two sets which intersect at angles approaching 90°. Coal jointed in this manner is commonly called block coal.

Interval Makeup:

Horizontal lamination is distinct in the fresh or well preserved coal and may be readily

[1]Ward, F. and Wilson, R. A., The Possibilities of Oil in Western Dewey County, S. D. Geol. and Nat. Hist. Survey, Circ. 9, p. 6, 1922.

observed in the coal as it occurs in the mine. The lamination is due to horizontal arrangements of three varieties of ingredients, glance coal, dull coal, and fusain.

The glance coal is jet black, brittle and has conchoidal fracture. When dry and somewhat weathered it has a brilliant and somewhat glassy luster. It is seen on vertically broken pieces of coal as lenses or bands interlaminated with dull coal. The bands of glance coal vary from a small fraction of an inch up to an inch or more in thickness. The material, in its parallel arrangement and character, suggests much compressed stems, branches, and trunks of trees. It has also been observed as stumps of trees standing upright in the coal bed. In many cases the grain of wood can be seen without the aid of a magnifier. Glance coal is believed to be the coalified stems, branches, and trunks of coal making plants.

Dull coal occurs in this, as in other coals, in this lusterless black laminae. It forms the matrix in which the other ingredients are enclosed. The laminae are oriented parallel to the bedding. They vary in thickness from microscopic to one-half inch layers. The dull coal is believed to be the coalified remains of the tougher and more durable portions, wood fibers, seed coats, and the like, of the plant matter from which this coal has been formed.

Fusain, "mineral charcoal," or "mother of coal," in the Isabel-Firesteel coal, as in other coals, has much the appearance of ordinary charcoal. It is commonly scattered on bedding planes in fragments less than one-half inch in diameter. Fusain is black or gray-black in color and has the silky luster peculiar to charcoal. It is thought to be the remains of wood which, before enclosure in the coal making plant matter, was exposed to the air sufficiently long for slow oxidation to take place. Some writers suggest that the substance is the result of rapid oxidation or burning, perhaps due to forest fires in the coal making period.

Resin:—Fossil resin occurs in considerable abundance in the Isabel-Firesteel coal as pale yellow bodies. These bodies are sub-spherical or ovoid in cross section. They vary from microscopic size up to 5/16 of an inch in diameter. Particles smaller and larger than those observed doubtless occur also. Resin bodies of sufficient size to be seen with the naked eye are abundant in certain parts of the seam and partially or nearly absent in others. The position of abundant bodies in the bed differs from place to place. In some cases they are so abundantly scattered through the coal that there is an average distance of less than one inch between them. Samples of coal collected near Isabel, probably S.W.¼, Sec. 22, T. 17 N., R. 22 E., were subjected to destructive distillation by a graduate student in chemistry laboratory at the University of South Dakota.[1] In ten samples a minimum of 1.125% of resin and a maximum of 3.125% was found. The average resin content of these ten samples was 2.3%, which amounts to 46.8 pounds of resin per short ton computed on this basis.

The resin is pale yellow, transparent, and very brittle. It melts readily in a test tube with a pine-like odor. According to Abell[2] the resin fuses at 207°C. The resin has been removed from the coal by Abell by solution in ethyl alcohol and recovered by evaporation. After repeating this process of solution and evaporation three times, the residue was again dissolved in alcohol and the solution was poured into cold water in which most of the resin precipitated out. Resin recovered by this process melted at about 200°C.[3]

The resin is true resin concentrated into small masses from the woods and plant matter from which the coal has been formed.

Pyrite:

Pyrite occurs sparingly in irregular shaped masses which are for the most part small. It also occurs in thin sheets along joints. However, it is rarely observed in this coal.

Marcasite:

Marcasite also occurs very sparingly in small subelliptical masses up to ¼ inch in

[1] Abell, E. E. (Miss) The Carbonization of South Dakota Lignite, University of South Dakota, unpublished thesis, p. 16, 1926.
[2] Abell, *Ibid.*, p. 33.
[3] Abell, *Ibid.*, p. 33.

diameter. It decomposes readily on exposure to the air.

Slacking characteristics:

All South Dakota coals in common with low rank coals of the west, slack appreciably on drying, particularly when alternating wet and dried. An empirical accelerated laboratory slacking test has been devised by the United States Bureau of Mines[1] to obtain an index of low rank coals indicative of their slacking properties. Two samples of coal from the Isabel-Firesteel area were tested by this method.

The test consists in drying a sample of coal 500-600 grams in weight which is broken into pieces between one and one and three-fourths inches in diameter. It is oven dried under a flow of air approximately 24 hours, immersed in water for one hour, and again dried for 24 hours. The coal is then screened over a 0.263 inch, (approximately one quarter inch) mesh screen for one minute. The percentage which passes the sieve is the first cycle slacking index. The oversize may be immersed in water for one hour, and dried for twenty-four hours for the second cycle index. The process may be repeated as many times as desired or until the sample passes completely through the sieve.

The accelerated slacking test was made on two samples, one from S.E.¼, Sec. 16, T. 17 N., R. 23 E., and one from S.W.¼, Sec. 22, T. 17 N., R. 22 E. In collection one quart glass topped mason fruit jars were used. These contain somewhat less coal than the standard coal sample cans used by the United States Bureau of Mines.

The tests on the samples from the Isabel-Firesteel area were made by the writer in the laboratories of the South Dakota Chemical Laboratory.

Samples were first sieved under a sieve with 1.05 inch square openings. The oversize was brushed to remove all fine loose material. Since the coal is somewhat brittle a blank sieving over a 0.263 (¼ inch) sieve was made. Samples were weighed and dried for 24 hours in an electric oven, through which air was drawn constantly, the temperature in the oven being maintained at 31°C.

The samples were then covered with water for one hour at room temperature and dried for 24 hours as before. After drying, the samples were sieved over a 0.263 (¼ inch) sieve. The percentage of undersize was computed as the first cycle slacking index. The process was subsequently twice repeated for the second and third cycle indices. Since slacking is due to the breaking up of the coal by wetting and drying, the percentage of blank sieving is properly subtracted from the first cycle index, the blank sieving result being due to friability and brittleness of the coal.

Results:

Results of slacking tests on the Isabel-Firesteel coal area shown in the table (Table I) which follows and in the diagram (Fig. 2). Comparison of slacking indices of coal from the Isabel-Firesteel area with those of numerous other coals made by the United States Bureau

TABLE I

Slacking Indices of Isabel-Firesteel Coal

Location	Sample No.	1st Cycle*	2nd Cycle	3rd Cycle
N.E.¼, S.E.¼, Sec. 22, T. 17 N., R. 22 E.	1	(6.9) 7.4	18.3	38.5
S.W.¼, S.E.¼, Sec. 16, T. 17 N., R. 23 E.	2	(20.8) 21.5	32.6	49.2
Average		(13.9) 14.5	25.5	43.9

* Figures in parentheses are corrected for blank sieving.

[1]Fieldner, A. C., Selvig, W. A., and Frederic, W. H., Accelerated Laboratory Test for Determination of Slacking Characteristics of Coal; U. S. Bur. Mines, Rept. of Investigations No. 3055, pp. 1-24, 1930.

of Mines[1], suggest that the average tendency of the Isabel-Firesteel coal to slack is considerably less than that of lignite, similar to that of sub-bituminous coal elsewhere, but greater than that of most bituminous coal. The first cycle index of the sample from Isabel (Sample No. 1, Table I) is low, even for sub-bituminous coal, whereas that of the sample from Firesteel (Sample No. 2, Table I) is typical of sub-bituminous coal. Although it is desirable that further studies of slacking properties of these and other South Dakota coals be made, the tests made are at least indicative of the tendency to slack as compared with other coals.

The United States Bureau of Mines suggests the classification of coals into six groups based on first cycle slacking indices.[2] This classification and the position of the Isabel-Firesteel coal in it are shown in the accompanying diagram (Fig. 4), which indicates that this coal is a slight to moderately slacking coal.

CHEMICAL CHARACTER

Although physical properties afford important information regarding the quality, rank and comparative fuel values of coal, chemical composition furnishes perhaps the most satisfactory basis for comparison of one coal with another. Coal, regardless of rank and quality, is composed of a limited number of substances chief of which are water as moisture, volatile or gaseous matter, fixed carbon, ash, and sulphur. The moisture, volatile matter and fixed carbon may be further resolved into hydrogen, carbon, nitrogen, and oxygen. Chemical ingredients of coal may be determined and stated as proximate analyses in which moisture, volatile matter, fixed carbon, ash and sulphur are determined. The same constituents may be stated as an ultimate analysis in which the elements hydrogen, nitrogen, carbon, oxygen, and sulphur are determined. The proximate analysis is most commonly used, as the quality and combustion properties of the fuel are, in the main, readily obtainable from this form of analysis. This is true because the elements are expressed in combinations which represent as closely as possible the chemical grouping of the elements in the coal. The proximate analysis has also the advantage of being more readily obtainable than the ultimate analysis.

Sampling:

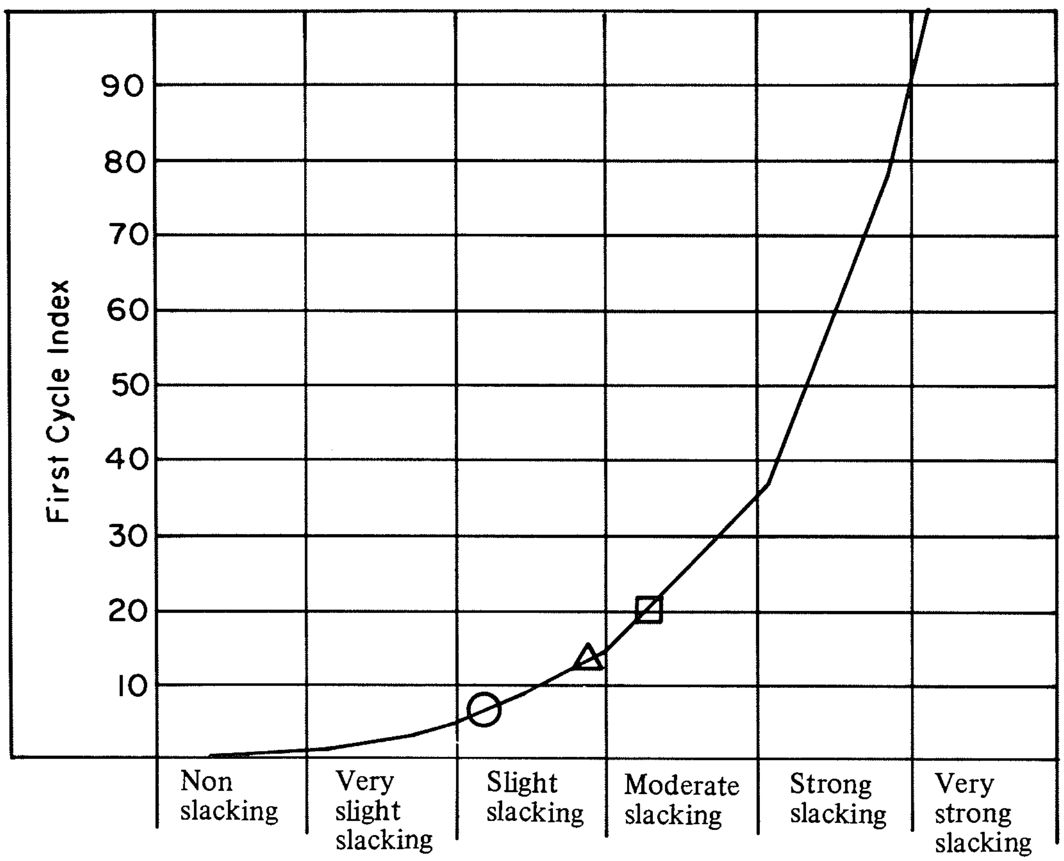
Samples of coal from the Isabel-Firesteel area were collected for chemical analysis early in September, 1930, when stripping operations were in progress at most of the mines. In collection of samples the standard procedure of the United States Geological Survey and the United States Bureau of Mines was followed as closely as possible. In the mine a clean face of coal was selected or a face was cleaned of dirt and foreign substances. An area about a foot in width was cut from the top of the coal bed to the bottom, as deep as necessary to expose fresh coal. In some cases, where the face had been exposed for some time, it was necessary to trench the coal in this manner to a depth of a foot or more. Down the center of this area coal was removed to a depth of two inches and a width of six inches and was permitted to fall on a collecting cloth. All materials such as blackjack, pyrite, and shale which would ordinarily be discarded in mining were rejected.

The sample was then crushed on a clean iron plate until no pieces larger than one half inch remained. The crushed coal was thoroughly mixed and quartered. It was remixed and quartered again if necessary. The remaining sample was placed in a glass topped quart mason fruit jar, sealed and labelled.

Analyses of these samples were made by Mr. Claude Dalbom of the staff of the State Chemical Laboratory at Vermillion through the kind cooperation of the director, Mr. G. G. Frary.

The analyses are tabulated in four forms as follows: A. Coal as received in the Laboratory; B. Air dried; C. Dry or moisture free; D. Moisture and ash free. The first (A) is important since it shows the constitution of the coal as it is mined and as it is transported if it is hauled from the mine immediately on mining. The second (B) shows the ratio of

[1] Fieldner, A. C., Selvig, W. A., and Frederic, W. H., *op. cit.*
[2] Fieldner, A. C., Selvig, W. A., and Frederick, W. H., *op. cit.*



⊙ N.E.¼, S.W.¼, Sec. 22, T. 17 N., R. 22 E.

⊡ S.W.¼, S.E.¼, Sec. 16, T. 17 N., R. 23 E.

△ Average

Fig. 4. Slacking Properties of Isabel-Firesteel Coal.

constituents after the fuel has been dried in air. The third (C) and the fourth (D) forms are valuable for comparative purposes since they show the substances actually involved in the combustion of the fuel, the third (C) with ash and sulphur present, the fourth (D) with ash removed. The fourth (D) with the exception of sulphur, is the coal substance without impurities.

In the table which follows (Table 2) these analyses of the Isabel-Firesteel coal are tabulated together with two others from the same area.

Moisture:

Analyses show that the Isabel-Firesteel coal contains moisture ranging between 33.28 per cent and 41.43 as received. The average moisture contained in this coal as received is 36.84 per cent. The moisture content of the fuel as received is thus representative of coals from the Hell Creek member of the Lance, as it occurs in South Dakota.[1] It is also similar in moisture content to black coals which occur in South Dakota in the basal part of the Ludlow member of the Lance.[2] Moisture content is also similar in amount to the black coal of Fort Union age in South Dakota.[3] The percentage of moisture as mined is considerably less than that contained in the typical brown lignites,[4] of the Ludlow member of the Lance which occurs in Harding and Perkins Counties. It is very close to average moisture content of North Dakota coal.

Drying of the Isabel-Firesteel coal in air reduced the moisture content to approximately one third of that contained in the coal as received. After drying in air the moisture ranges between 12.46 and 14.02 per cent and averages 13.23 per cent.

Ash:

The ash of coal is the most important impurity in coal. It consists of the non-combustible portion of the coal. In most coals it consists of silicates, chiefly silicates of alkalies which are commonly potash and soda. Other compounds are commonly present also. The amount and chemical character of the ash are very important; the first because of the fact that ash is non-combustible and the second because the chemical character determines the fusibility of the ash and hence the formation of clinker.

The ash of the Isabel-Firesteel coal varies in amount between 5.38 and 7.59 per cent as mined whereas moisture free coals of the area contain between 8.33 and 12.58 per cent. The average ash content as received is 6.22 per cent and that contained in water free samples averages 9.86 per cent. The lowest ash content shown in analyses (Table 2) is unusually low for coals of the Great Plains coal province and for South Dakota. The highest is not unusually high. The average ash content is considerably lower than that of the average South Dakota coal, and approximates that of the average North Dakota coal.[5]

Ash from several samples of coal of the Isabel-Firesteel area has been recovered by burning the coal in the laboratory. This ash is light and fluffy and light gray in color. Some has a slightly pinkish cast due probably to small amounts of iron. Although fusion tests have not been made, users report that this coal does not form clinkers in ordinary domestic use. The ash fuses under the blow pipe with difficulty.

Volatile Matter:

Volatile matter consists of the gaseous constituents of the coal. In nine analyses of coal from the Isabel-Firesteel area variation, for the most part, is within rather narrow limits. In analyses of the coal as received (Table 2) volatile matter varies between 23.69 and 26.42 per

[1] Searight, W. V., Preliminary Report on the Coal Resources of South Dakota, S. D. Geol. and Nat. Hist. Survey, Report of Investigations No. 3, p. 26, Table 1, and p. 32, 1930.
[2] Searight, W. V., *op. cit.*, pp. 27-29, Table II.
[3] Searight, W. V., *op. cit.*, p. 30, Table III.
[4] Searight, W. V., *op. cit.*, p. 30, Table III.
[5] Babcock, E. J. and Odell, W. W., Production and Briquetting of Carbonized Lignite, U. S. Bur. of Mines, Bull. 221, p. 3, 1923.

TABLE II

PROXIMATE ANALYSES OF ISABEL–FIRESTEEL COAL[1]

Location[2]	Form of analysis[3]	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Values B.t.u.[4]
1	A	35.35	25.75	33.51	5.38	0.434	7,134
	B	12.94	34.68	45.13	7.25	0.585	9,628
	C	......	39.83	51.84	8.33	0.672	11,059
	D	......	43.45	56.55	.....	0.733	12,034
2	A	39.71	23.69	29.02	7.59	0.397	6,359
	B	13.53	32.98	41.61	10.88	0.569	9,118
	C	......	39.30	48.12	12.58	0.658	10,545
	D	......	44.95	55.05	.....	0.753	12,062
3	A	36.03	24.78	32.02	7.16	0.522	6,845
	B	13.38	33.56	43.36	9.70	0.709	9,268
	C	......	38.74	50.06	11.20	0.819	10,699
	D	......	43.63	56.37	.....	0.922	12,049
4	A	37.15	24.75	31.86	6.25	0.534	6,819
	B	12.46	34.47	44.37	8.70	0.744	9,498
	C	......	39.38	50.68	9.94	0.850	10,848
	D	......	43.72	56.28	.....	0.944	12,009
5	A	41.43	24.31	29.96	5.42	0.492	6,404
	B	14.02	35.68	43.98	6.32	0.722	9,598
	C	......	41.50	51.15	9.25	0.839	10,934
	D	......	44.79	55.22	.....	0.907	11,850
6	A	39.57	24.14	30.86	5.42	0.453	6,632
	B	13.34	34.62	44.26	7.78	0.650	9,508
	C	......	39.95	51.07	8.98	0.750	10,974
	D	......	43.89	56.11	.....	0.824	12,050
7	A	34.05	24.54	34.83	6.58	0.502	7,157
	B	12.94	32.39	45.98	8.69	0.663	8,047
	C	......	37.20	52.81	9.98	0.762	10,852
	D	......	41.33	58.67	.....	0.846	12,055
8	A	34.96	30.33	28.80	5.91	0.30	7,144
	C	......	46.63	44.29	9.08	0.46	10,984
9	A	33.28	26.42	34.04	6.30	0.62	7,275
	C	......	39.60	51.02	9.44	0.82	10,912

[1] Coal from all locations, except 8 and 9, were analyzed by Claude Dalbom, State Chemistry Laboratory, Vermillion, S. D. No. 8, Charles Bentley, analyst, South Dakota School of Mines, No. 9, B. A. Dunbar, analyst, South Dakota State College of Agriculture and Mechanics, Experiment Station.

[2] Locations:
(1) N.E.¼, S.W.¼, Sec. 22, T. 17 N., R. 22 E.
(2) S.W.¼, S.E.¼, Sec. 16, T. 17 N., R. 23 E.
(3) S.E.¼, S.W.¼, Sec. 15, T. 17 N., R. 22 E.
(4) S.E.¼, N.W.¼, Sec. 7, T. 16 N., R. 22 E.
(5) S.W.¼, S.E.¼, Sec. 16, T. 17 N., R. 23 E.
(6) S.E.¼, N.W.¼, Sec. 18, T. 17 N., R. 23 E.
(7) N.E.¼, N.W.¼, Sec. 32, T. 17 N., R. 22 E.
(8) Robbins Mines, Isabel, South Dakota.
(9) N.E.¼, S.W.¼, Sec. 21, T. 17 N., R. 23 E.

[3] A. As received. B. Air Dried. C. Moisture free. D. Moisture and ash free.

[4] Heating values except no. 8 computed, H = 121.23.

cent, with one exception which contains 30.33 per cent. The average volatile matter is 25.41 per cent from which the maximum variation, with the exception of the sample noted, is less than 2 per cent. Volatile matter ranges in moisture free samples between 37.20 and 39.60 per cent, again, with the exception of one sample which contains 46.63 per cent dry. The average volatile matter in dry samples is 40.24 per cent. This is probably very slightly more than that present in the average South Dakota coal.

Fixed Carbon:

The fixed carbon in coal consists of the carbon contained with the exception of that which enters into the composition of the volatile matter. The percentage of fixed carbon in the Isabel-Firesteel coal is fairly constant as indicated by analyses of the coal as received (Table 2) in which it varies between 28.80 per cent and 34.83 per cent and averages 31.66. The fixed carbon content in the dry coal varies between 44.29 and 52.81 per cent. This latter figure is distinctly higher than that of average South Dakota coal, both brown and black.[1] Fixed carbon is approximately 3.5 per cent greater than that of the South Dakota coals which most closely approach it in age and character. It contains between about 7 per cent and 8 per cent more fixed carbon than averages of other South Dakota coals.

Fuel Ratio:

The fuel ratio of a coal is the ratio of volatile matter to fixed carbon. It is expressed as the quotient of fixed carbon divided by volatile matter. The average fuel ratio of the Isabel-Firesteel coal as determined from analysis is 1.25. This figure is higher than that of averages for other coals of South Dakota (Fig. 5). From the graphic representation of the fuel ratio of the Isabel-Firesteel coal and other coals it is noted that the fuel ratio is considerably higher than the average of coals from the Ludlow member of the Lance, ($\frac{c}{v}$ = .92) and Fort Union ($\frac{c}{v}$=1.01). The fuel ratio is approximately that of the best coal of the Kemmerer field, Lincoln County, Wyoming ($\frac{c}{v}$ =1.22). It appears to be intermediate in fuel ratio between coals of the lignite bearing Ludlow and the Carboniferous coals of Franklin County, Illinois ($\frac{c}{v}$ =1.45).

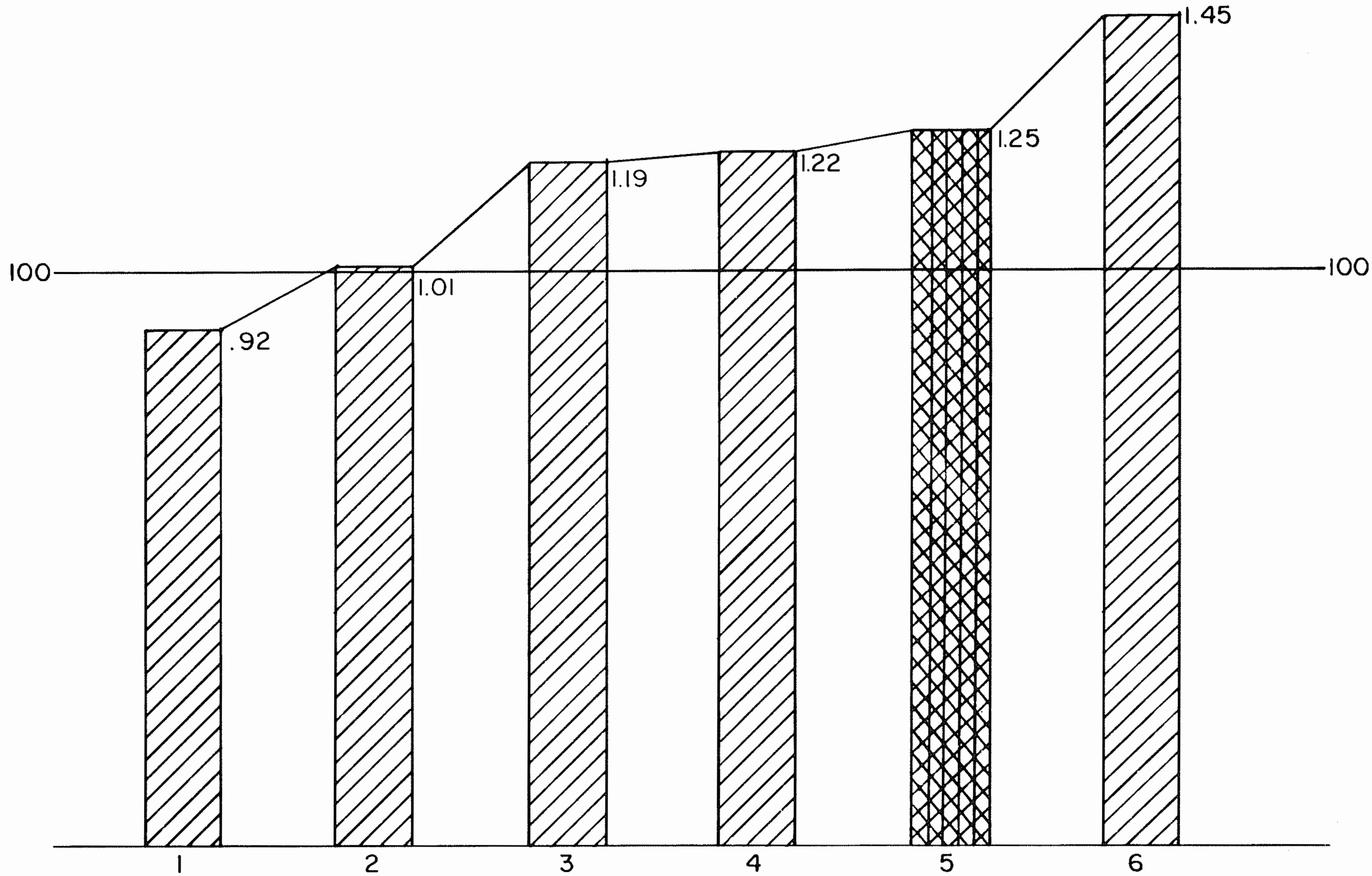
Sulphur:

Sulphur, which occurs in coal commonly as sulphides in the form of pyrite and marcasite is an important impurity. It is an impurity which affects in particular certain industrial uses of coal particularly the manufacture of producer gas. It also influences the fusibility of ash. The sulphur content of the Isabel-Firesteel coal is exceptionally low, the highest percentage being only .82 per cent. The average sulphur content in Isabel-Firesteel coal is 0.47 and in dry samples 0.74 per cent. These figures are low compared with coals of Fort Union age[2] in South Dakota and very low as compared with coals of Ludlow age[3] which average 1.25 per cent sulphur as received and 2.00 per cent moisture free. Sulphur content of coal from the Isabel-Firesteel area is low compared with eastern coals, the average of 21 analyses from Franklin County, Illinois being 1.45 per cent as received and 1.60 dry. The average for Iowa coal is given as 4.65 per cent as received.[4]

Heating Value:

Heating value of coal is expressed in British thermal units or in calories. A British thermal unit (B.t.u.) is the amount of heat required to raise one pound of water one degree

[1] Searight, W. V., *op. cit.*, pp. 26-31, 1930.
[2] Searight, W. V., *op. cit.*, p. 30.
[3] Searight, W. V., *op. cit.*, pp. 27-29.
[4] Lees, J. H., and Hixon, A. W., Analyses of Iowa coals, Iowa Geol. Survey, Vol. XIX, p. 519, 1908.



1. Coal of the Ludlow member of the Lance (lignite), South Dakota. 2. Coal of Fort Union. 3. Averages of Iowa coal. 4. Kemmerer field, Wyoming. 5. Isabel-Firesteel. 6. Franklin County, Illinois.

Fig. 5. Fuel Ratio of South Dakota and Other Coals

Fahrenheit. A calorie is the quantity of heat required to raise the temperature of one gram of water one degree centigrade. Calories can be computed from British thermal units by multiplying B.t.u. by 0.252.

Calorimeter determinations of heating values of Lower Hell Creek coals including one of the Isabel-Firesteel coal were published in an earlier paper.[1] These determinations indicate that this coal is high in heating value, compared with other coals of the state and of the nearby region.

Calorimeter tests of heating values were not made on coal samples collected during the 1930 season. Since it is desirable that these be known, computation of values from proximate analyses have been made. Values thus obtained are thought to approach those obtained by calorimeter fairly closely.

In these computations values have been obtained by the Lord method. In this method the calorific value (H) of the organic matter of the coal is determined by subtraction of the heating value of contained sulphur. This organic matter residual in coal is the coal substance exclusive of moisture, ash and sulphur. Quoting from Lord:[2]

> "If the percentage of the ash, the moisture and the sulphur be subtracted from 100, the remainder would be approximately the organic matter in the coal and if the calorific value of the sulphur be subtracted from the calorific value of the coal as determined, the remainder should be the calorific value of the organic matter present. Calculating this to unity gives the value designated by 'H'. . . ."

Thus: $$H = \frac{\text{calorific value} - (\text{sulphur in pounds x 4050})}{100 - (\text{Moisture} + \text{Ash} + \text{Sulphur})}$$

The value of H by this forumla is in British thermal units. Substituting values from an analyses of coal from the Isabel-Firesteel bed[3] and solving for H, the value of H is 121.23. The value H being known, the heating value of coal of similar chemical properties may be determined from approximate analysis by reversing the computation; thus:

$$\text{B.t.u.} = 121.23\ [1.00 - (\%\ \text{Moisture} + \%\ \text{ash} + \text{sulphur}\%)] + (\text{Pounds of sulphur x 4050}).$$

In order to check the accuracy of heating values obtained by this method analyses of Lower Hell Creek coals of similar chemical and physical properties, and known calorific values obtained by calorimeter were used. Computed values using H = 121.23 were checked against values obtained by calorimeter with results as follows: (Table III)

These comparisons (Table III) indicate that computed heating values do not vary greatly from determined values even for coal analyses of samples which are possibly from different beds but are of similar character.

The computed heating values (H = 121.23 in Table II, p. 24) are all from the same bed and are therefore probably nearer actual values than those of Table III which vary between 0.5 per cent and 2.7 per cent. The B.t.u. value of the Isabel-Firesteel coal as received (A) is probably within one per cent of actual calorimetric values. The error in moisture free (C) values is possibly greater but probably is not greater than 2.5 per cent and in most cases is little more than one per cent.

The heating value of the Isabel-Firesteel coal bed is high for South Dakota and for nearby areas as indicated by calorimetric determinations of one sample and the computation of eight others from proximate analyses (Table II). The coal as received (Table II—A) yields between 6359 and 7275 B.t.u. and averages 6863 B.t.u. In nine samples, four have a B.t.u. value greater than 7000. After air drying (Table II—B) the heating value is raised to an

[1]Searight, W. V., Preliminary report on the coal resources of South Dakota, South Dakota Geol. and Nat. Hist. Survey, Report of Investigations No. 3, p. 25, 1930.
[2]Lord, N. W., Coal, Geol. Survey of Ohio, Fourth Series, Bull. 9, 1908, p. 267.
[3]Searight, W. V., *Ibid.*, p. 26, Analysis 1.

TABLE III

ANALYSES OF HELL CREEK COALS[1]

Name and Location[2]	Form of Analyses[3]	Moisture	Proximate: Volatile Matter	Fixed Carbon	Ash	Sulphur	Heating Values: Calorimeter	Computed H=121.23	Difference between Values: B.t.u.	Per cent
1	A	34.96	30.33	28.80	5.91	0.30	7,144	7,143	......	....
	C	......	46.63	44.29	9.08	0.46	10,984	10,985	......	....
2	A	34.90	27.57	32.69	4.84	0.30	7,101	7,281	191	2.7
	C	......	42.35	50.22	7.43	0.46	10,907	11,185	278	2.5
3	A	34.98	25.34	31.15	8.53	0.31	6,854	6,822	32	0.5
	C	......	38.97	47.91	13.12	0.48	10,541	10,639	198	1.9
Averages	A	34.95	27.75	30.88	6.43	0.30	7,033	7,082	49	0.7
	C	......	42.65	47.47	9.88	0.47	10,811	10,936	125	1.1

[1] Analyses 1, 2, and 3 are of samples of lower Hell Creek coals.
[2] Name and location:
(1) Robbins Mine near Isabel.
(2) Kennedy Mine near Gopher
(3) Anderson Mine near Gopher
[3] Form of Analyses: (A) As received; (C) Moisture free.

average of 9238 for the seven samples computed. The lowest B.t.u. value of air dried coal is 8047 and the highest 9628, sample 9 with the highest as received value being omitted. The heating value of moisture free samples (Table II–C) averages 10867 B.t.u. and that of the moisture and ash free samples (Table II–D) averages 12016 B.t.u.

The coal thus averages more than 1000 B.t.u. per pound as received more than the average of lignite from the Ludlow member of the Lance.[1] The average as received is 138 B.t.u. less than that of coal from the Fort Union formation[2] of South Dakota. The data on coal of the latter formation, however, is based on relatively inadequate data and is possibly somewhat too high.

Pronounced variations in heating values of the coal are probably due to weathering of the coal bed. Weathering takes place most readily where cover is thin or where the cover is composed in large part of sandstone. In the analyses (Table II) the lowest heating values are for coal under very thin cover and the highest under most cover, that of No. 9, Table II, being under 49 feet of cover.

Rank:

By rank of coal is meant the position of the coal in the series of changes which take place in the coal making process. In these changes there is a loss in moisture, oxygen and volatile matter and commonly a gain in fixed carbon and sulphur and a probable increase in ash. The term "grade" refers to relative freedom of the coal from ash and sulphur. In the table which follows, the commonly accepted ranks of coal are tabulated, together with their chemical and physical characteristics.

The Isabel-Firesteel coal should apparently be placed in this classification as subbituminous coal. In the descriptions of chemical and physical character in earlier sections, it was noted that the coal is black rather than brown, although it has a brown streak. It is brittle rather than tough and woody. In spite of the moisture content as

[1] Searight, W. V., *op. cit.*, pp. 27-29, 1930.
[2] Searight, W. V., *op. cit.*, p. 30, 1930.

TABLE IV

PHYSICAL AND CHEMICAL CHARACTERISTICS OF COAL

(After Fieldner and Davis)

Chemical Characteristics			Physical Characteristics
Coal	Approximate per cent normal mine moisture	Ratio of fixed carbon to volatile matter	
Lignite	30-45	....	Distinctly brown; either markedly clay-like or woody in appearance. Falls into pieces on exposure to weather.
Subbituminous	18-30	......	Black; no distinct woody texture; disintegrates and loses moisture on exposure to weather, but less rapidly than lignite.
Bituminous	3-15	3	But slightly affected by exposure to weather.
Semi-bituminous	3-6	3-7	But slightly affected by exposure to weather.
Semi-anthracite	3-6	6-10	But slightly affected by exposure to weather.
Anthracite	2-3	10-60	But slightly affected by exposure to weather.

received, which falls within that of lignite, the coal slacks only moderately (Fig. 6). The fuel ratio, moreover, is high as that of good subbituminous coal. In moisture content the coal is similar to lignite but in other physical and chemical properties, it is closely related to subbituminous coal.

Overburden:

Overburden on the Isabel-Firesteel coal is of particular importance in this area since open pit or stripping methods have been used almost exclusively in the past in recovery of the coal and since underground mining does not appear to be commercially practical, at least over the greater portion of the area. No portions of the overburden are known to be of such character that explosives need be used in their removal.

Character:

The overburden on the coal consists of clay, shale, and sandstone, all of a character permitting ready removal with power machinery.

The beds of clay and shale consist, for the most part, of compact, siliceous, fairly hard material. Bedding is rarely conspicuous and under the steam shovel or dragline bucket there is little or no tendency for the material to break away in sheets along natural partings. The argillaceous beds, however, are broken into irregularly polygonal blocks only a few inches in diameter by joints which aid materially in excavation. The material stands fairly well in

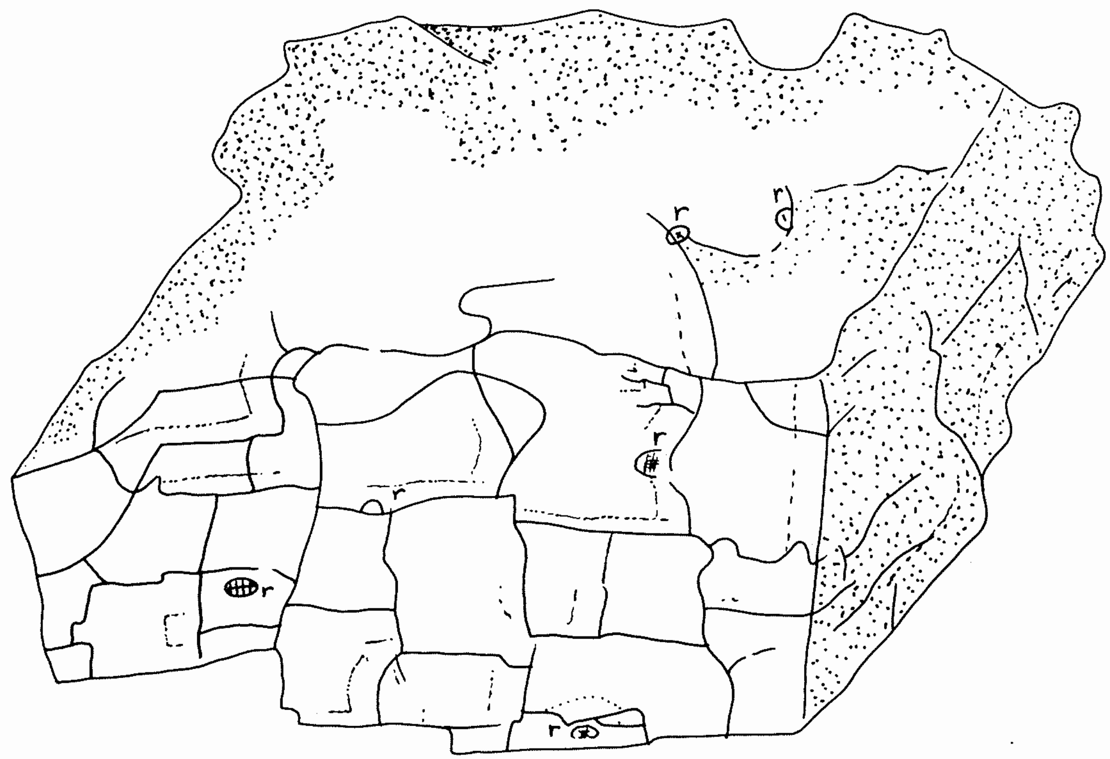


Fig. 6. Block of Isabel-Firesteel coal showing orientation and size of cracks after five years exposure to room temperature. Natural size. r—resin bodies.

steep walls along cuts so that caving into open pits should not cause unusual concern.

Associated with and lying on the coal in many places is hard, compact, carbonaceous shale or "blackjack". This material is fairly tough and, therefore, removable with somewhat greater difficulty than other shales and clays above the coal. It responds readily, however, to the steam shovel and heavy dragline bucket.

Sandstones overlying the coal consist mostly of light colored drab buff and gray sandstone. Considerable clay in the interstices between sand grains is commonly present. This gumbo like clay renders the sandstone soft and somewhat plastic when crushed but fairly tough and hard when dry. The somewhat plastic character when wet is probably responsible for the local term "packsand".

The sandstones are not cemented. Concretions of cemented sandstone occur in many places, however. These are commonly less than 3 feet in diameter and less than one foot thick.

No beds of limestone or other dense rocks occur in the overburden of the coal. A bed of hard sandstone, one foot thick, is reported to lie on the coal in the N.E.¼, S.W.¼, Sec. 21, T. 17 N., R. 23 E., where it appears to be a local development.

Thickness of overburden:

Overburden on the coal ranges between zero and 80 to 90 feet. Because of relief on the surface and variable attitude of the coal below the surface, the thickness of overburden is variable even within relatively short distances. In many places the dip of the coal is 120 feet or more per mile. At this dip, under a flat horizontal surface, coal under ten feet of the overburden at one point would lie approximately 33 feet below the surface 1000 feet away, in the direction of dip. If the coal lay horizontally and the surface slopes at 120 feet per mile the overburden increases at the rate of about 23 feet in 1000 feet of horizontal distance up the slope. In cases where slope of the surface and dip of the coal are opposite, the thickness of the overburden increases rapidly even though dip and slope are both of low angle.

The general dip of the coal in the area is known. The minor structures, however, have not been determined except in rather limited areas. The general thickness of overburden was readily determined but thickness of overburden in detail has been determined only in small areas where outcrop or test pits and borings are numerous.

The thickness in the area has been tabulated section by section as accurately as data permits, (Table V). Since the thickness of cover as related to the thickness of coal is of prime importance has been tabulated in ratios of cover thickness to coal thickness.

Tonnage:

The total tonnage of coal of the Isabel-Firesteel area including only the coal of greater thickness than 2½ feet has been computed at 137,580,000 tons. In computing a tonnage of 1700 tons has been estimated per acre foot which is approximately the tonnage of coal with specific gravity of 1.25. The acreage by sections has been tabulated and appears on Table V.

Favorable Stripping Areas:

The most favorable stripping areas are shown on maps (Fig. 7 and Fig. 8). One lies near Firesteel in Secs. 16, 17, 18, 19, 20, 21, T. 17 N., R. 23 E. The second lies northeast of Isabel in Secs. 22 and 27, T. 17 N., R. 22 E. The probable thickness of coal underlying this area is shown on the geologic map of the area (Plate II). The portion of these areas lying under a cover of five feet or less to one of coal is indicated on the detailed maps. The tonnage of coal has been computed and appears in Table V.

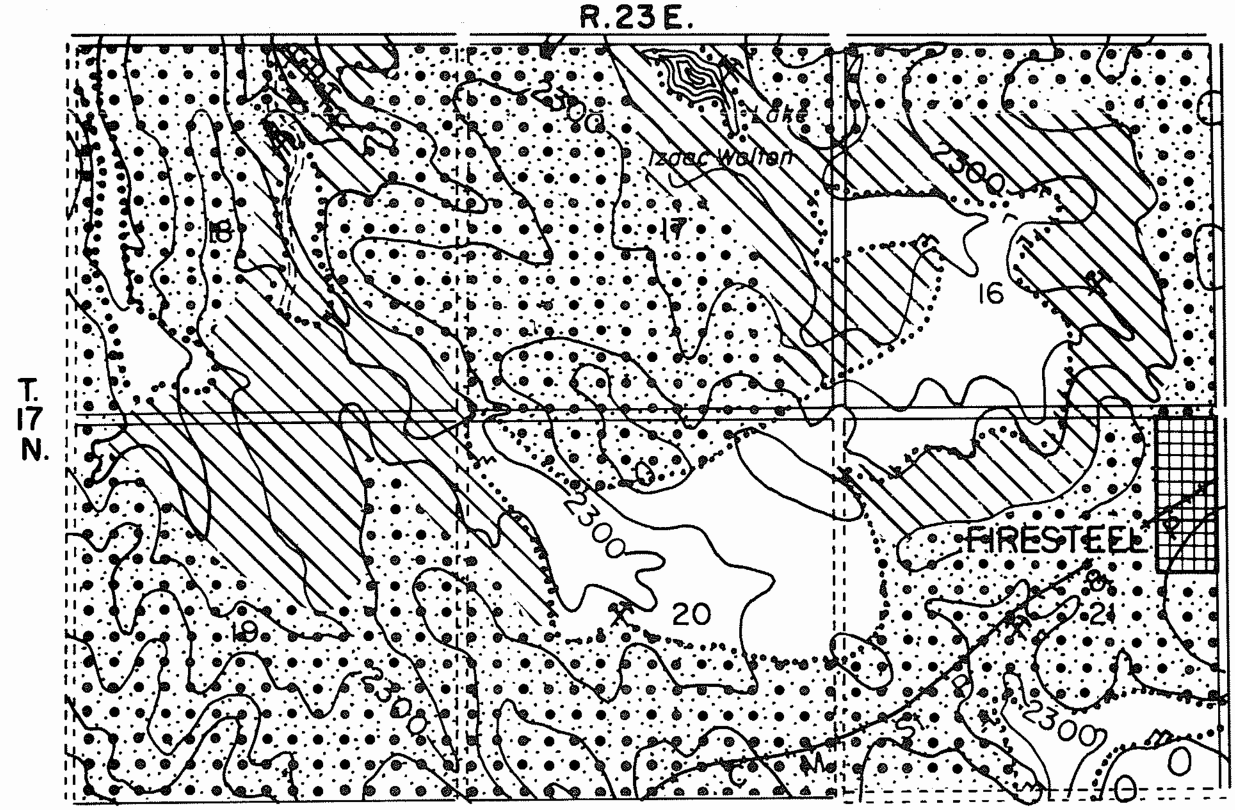


Fig. 7. Map of Firesteel vicinity.

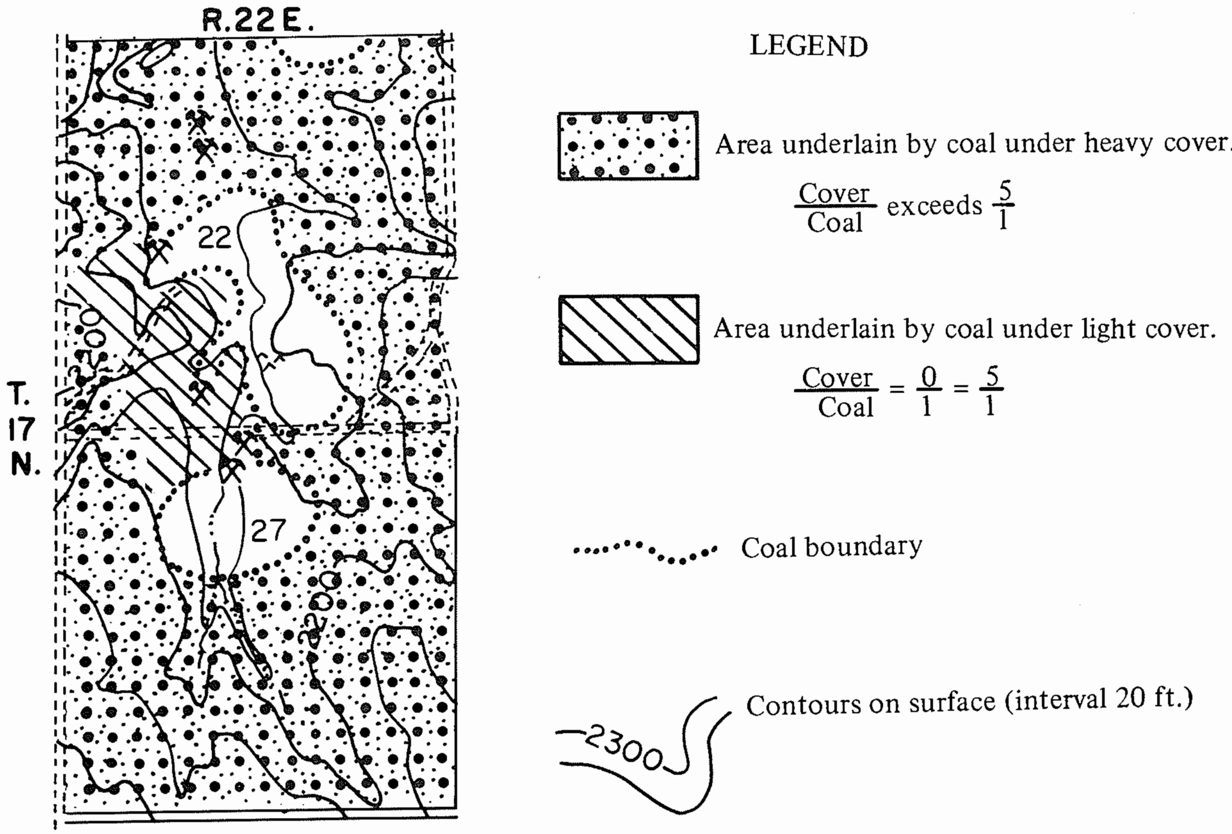


Figure 8. Map of Isabel vicinity

TABLE V

THICKNESS, TONNAGE*, AND OVERBURDEN

LOCATION			THICKNESS	TONNAGE AND OVERBURDEN									
				Cover uncertain or confidential		Cover $\frac{0}{1}$ to $\frac{5}{1}$		Cover $\frac{5}{1}$ to $\frac{10}{1}$		Cover greater than 10-1		Total over 2½ feet.	
Sec. (1)	Twp. N. (2)	Range E. (3)	(4)	Acres (5)	Tons Thousands (6)	Acres (7)	Tons Thousands (8)	Acres (9)	Tons Thousands (10)	Acres (11)	Tons Thousands (12)	Acres (13)	Tons Thousands (14)
1[a]	16	21	4-[b]	560	3808	......	......	......	......	......	......	560	3808
12	16	21	4-5½	240	1632[o]	......	......	......	......	......	......	240	1632[o]
13	16	21	......	....	......	......	......	......	......	......	......	0	0
1	16	22	......	....	......	......	......	......	......	......	......	0	0
2	16	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
3[a]	16	22	2½-3[a]	80	374	......	......	......	......	......	......	80	374
4	16	22	2½-3½[b]	560	2856	......	......	......	......	......	......	560	2856
5	16	22	3-4[b]	640	3808	......	......	......	......	......	......	640	3808
6	16	22	4-4½	640	4352	......	......	......	......	......	......	640	4352[o]
7	16	22	4-5	320	2176	......	......	......	......	......	......	320	2176[o]
8	16	22	2½-4	400	2380	......	......	......	......	......	......	400	2380
9[a]	16	22	2½-3½[b]	280	1190[o]	......	......	......	......	......	......	280	1190[o]
10	16	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
11	16	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
12-13	16	22	......	....	......	......	......	......	......	......	......	0	0
13-14	16	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
16-18	16	22	......	....	......	......	......	......	......	......	......	0	0
1[a]	17	22	2½-4½[b]	30	153	......	......	......	......	......	......	30	153
2[a]	17	22	2½-4[b]	120	510[o]	......	......	......	......	......	......	120	510[o]
3-10	17	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
11	17	22	2½-5	440	3318	......	......	......	......	......	......	440	3318
12	17	22	3-5½	400[c]	3060[c]	......	......	......	......	......	......	400	3060
13	17	22	2½[b]-4½	620	3689[x]	......	......	......	......	......	......	620	3689[x]
14[a]	17	22	2½-3½[b]	320	1360[o]	......	......	......	......	......	......	320	1360[o]
15	17	22	2½-3	120	510	......	......	......	......	......	......	120	510[o]
16[a]	17	22	2½-3½	60	255	......	......	......	......	......	......	60	255

Table V--continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
17-18	18	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
19[a]	17	22	2½-3½[b]	480	2448	......	......	......	......	......	......	480	2448
20[a]	17	22	2½-3½[b]	400±	2038	160±	818	......	......	......	......	560	2856
21	17	22	2½-5	640	4352	......	......	......	......	......	......	640	4352
22	17	22	2½-6¼	....	......	120±	1020	400	2958	......	......	520	3978
23	17	22	3-5[b]	640	4896	......	......	......	......	......	......	640	4896
24	17	22	3-4½[b]	620	2689	......	......	......	......	......	......	620	2689
25[a]	17	22	2½-4[b]	280	1190[o]	......	......	......	......	......	......	280	1190[o]
26	17	22	2½-5[b]	560	3332[x]	......	......	......	......	......	......	560	3332[x]
27	17	22	3-6	440	2856	80±	680	......	......	......	......	520	3536
28	17	22	3½-5½[b]	640	4896	......	......	......	......	......	......	640	4896
29	17	22	3½[b]-4[b]	640	3808	......	......	......	......	......	......	640	3808[o]
30	17	22	3[b]-3½[b]	640	3264	......	......	......	......	......	......	640	3264
31	17	22	3[b]-4[b]	....	......	......	......	......	......	640	3264	640	3264[o]
32	17	22	3-4	....	......	......	......	......	......	640	3264	640	3264[o]
33	17	22	2½-4	640	3808	......	......	......	......	......	......	640	3808[x]
34	17	22	2½-4[b]	360	1530	......	......	......	......	......	......	320	1530[o]
35[a]	17	22	2½[b]-3[b]	20	80[o]	......	......	......	......	......	......	20	80[o]
36	17	22	Less than 2½	....	......	......	......	......	......	......	......	0	0
1[a]	17	23	d	d	......	......	......	......	......	......	......	d	d
2	17	23	d	d	......	......	......	......	......	......	......	d	d
3[a]	17	23	2½-4½[b]	200	1360	......	......	......	......	......	......	200	1360
4	17	23	2½-5[b]	260	1547	......	......	......	......	......	......	260	1547[x]
5	17	23	Less than 2½	....	......	......	......	......	......	......	......	0	0
6	17	23	2½-4	320[c]	1911[x]	......	......	......	......	......	......	320	1911[x]
7	17	23	2½-4 2/3	180[c]	1021[x]	......	......	......	......	......	......	180	1021[x]
8	17	23	2½-5	240	1632	......	......	......	......	......	......	240	1632
9	17	23	2½-6[b]	640	4896	......	......	......	......	......	......	640	4896
10[a]	17	23	4[b]-6[b]	320	2720	......	......	......	......	......	......	320	2720
11-14	17	23	......	....	......	......	......	......	......	......	......	0	0
15	17	23	5[b]-6[b]	400	3400	......	......	......	......	......	......	400	3400[o]
16[a]	17	23	5[b]-6	....	......	240	2040	160	1360	......	......	400	3400[o]
17	17	23	3-5½	....	......	160	1088	360	2898	......	......	520	3978
18	17	23	3-5	....	......	160±	1088	280	1804	......	......	440	2992
19	17	23	3-4	480±	1360±	160±	1088±	......	......	......	......	640	1334[o]
20	17	23	3-5[b]	280±	2176	40±	272±	......	......	......	......	320	2448
21[a]	17	23	5½[b]-7	....	......	120±	1122±	440±	3366±	......	......	480	4488[o]

Table V–continued

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
22[a]	17	23	4[b]-6[b]	560	4760	......	......	......	......	......	......	560	4760
23[a]	17	23	3[b]-4	120	612[o]	......	......	......	......	......	......	120	612[o]
24-26	17	23	......	....	......	......	......	......	......	......	......	0	0
27[a]	17	23	4[b]-5[b]	80	544	......	......	......	......	......	......	80	544
28[a]	17	23	5[b]	80	680	......	......	......	......	......	......	80	680
29	17	23	4-5½[b]	620	4216[o]	......	......	......	......	......	......	620	4216[o]
30[a]	17	23	2½-4[b]	520	2652	......	......	......	......	......	......	520	2652
31[a]	17	23	2½-4[b]	80	408	......	......	......	......	......	......	80	408
32[a]	17	23	4[b]-5[b]	100	765	......	......	......	......	......	......	100	765
33-36	17	23	......	....	......	......	......	......	......	......	......	0	0

*Tonnage at 1700 T per acre foot (G. estimated at 1.25)
[o]–Computed on basis of lower thickness
[x]–Computed at thickness of 3½ feet
[a]–Area uncertain
[b]–Thickness estimated
[c]–Thickness of cover is confidential
[d]–Data too uncertain for computation