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A REVIEW OF THE GEOLOGY AND COAL RESOURCES OF THE PERMANENT RIVER COAL FIELD, ALASKA

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PERMANENT

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A REVIEW OF THE GEOLOGY AND COAL RESOURCES OF THE BERING RIVER COAL FIELD, ALASKA

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INTRODUCTION

Location and extent

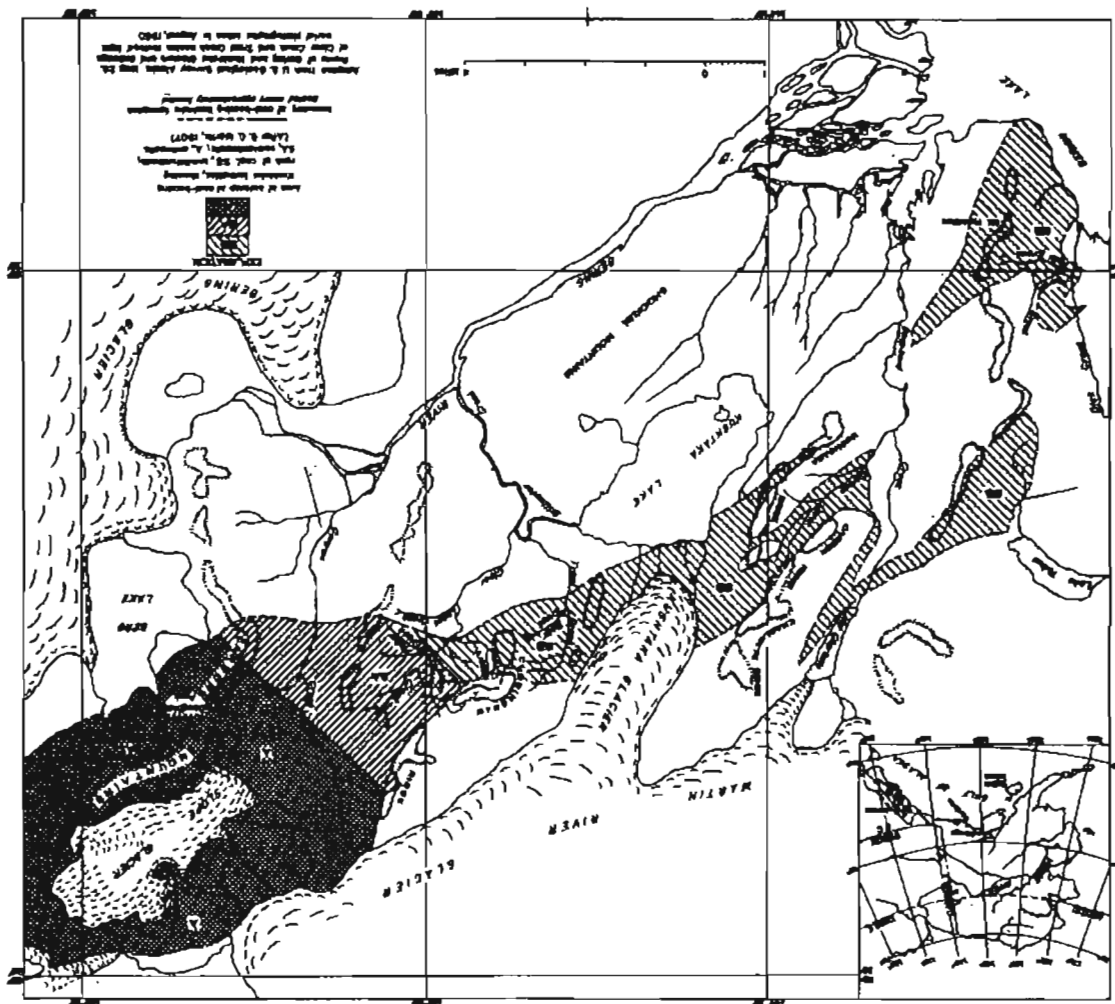
The Bering River coal field is in south-central Alaska, about 50 miles southeast of Cordova and 12 miles northeast of the coastal village of Katala. It lies between latitudes $60^{\circ}15'$ and $60^{\circ}30'$ N., and longitudes $143^{\circ}45'$ and $144^{\circ}20'$ W. (fig. 1). Known coal-bearing rocks are exposed in a belt roughly 21 miles long and 2 to 5 miles wide trending northeast from the east shore of Bering Lake. (See figs. 1 and 2.)

History of investigations

The Bering River coal field was discovered in 1896, and practically all of it was covered by coal claims entered under the law of 1904 (Fisher, 1912, p. 12).

The first extensive study of the area was made by the U. S. Geological Survey in 1905 and 1906, when the known coal-bearing area was mapped topographically and geologically, and many coal beds were measured and sampled (Martin, 1908).

In 1907 Storrs (1910, pp. 2326-2345) made an engineering study of the Cunningham group of coal claims in the basins of Trout and Clear Creeks. His report includes a large number of coal analyses, brief descriptions of numerous coal exposures, proposed plans for development, and estimates of mining and development costs. In 1909 brief examinations of the Cunningham property were made for the General Land Office by Kennedy (1910, pp. 1039-1040) and for the Forest Service by Wingate (1910, p. 1043), for the purpose of determining whether the area should be classified as coal or noncoal land. As these two engineers did not agree, C. A. Fisher, a mining geologist of the U. S. Geological Survey, was sent to the area in the same year and made a detailed examination of the property (Fisher, 1910, pp. 1073-1092), in the course of which he opened and measured 201 coal prospects. As a result of this study he classified all 33 claims of the Cunningham group as coal land, the basis of such classification being the observed or inferred presence of a coal bed of workable thickness within 3,000 feet of the surface.



In 1912 a general examination of the most promising parts of the entire Bering River coal field was made by C. A. Fisher, W. R. Calvert, R. Y. Williams, and S. S. Smith, mining geologists and engineers, to determine the best localities from which samples could be taken for testing by the U. S. Navy. The geology of the field and its relations to coal mining were summarized by Fisher and Calvert (1914, pp. 29-50), and the mining conditions encountered in obtaining the sample were described by Williams (1914, pp. 12-28). The Navy sample, totalling about 600 tons, was obtained from four tunnels on Trout Creek.

Coal beds in various parts of the field were measured and sampled by J. A. Holmes in 1911, W. A. Selvig in 1912, G. W. Evans in 1915, and Capt. W. P. T. Hill in 1920, 1921, and 1922. (Cooper, 1946, pp. 104-107.)

In 1920 a detailed report on the property of the Bering River Coal Company on Carbon Creek was prepared by G. W. Evans (1920). This report summarizes existing and proposed developments, lists detailed information on many coal

exposures, and gives the results of coking and washing tests.

Purpose and scope of present report

This report is an attempt to review and integrate the results of several examinations of the Bering River coal field, including some that have been published only in Congressional Hearings and probably are not widely known, and to evaluate these results insofar as possible in the light of present conditions. No new field studies have been made by the writer. The purpose of the present report is to make more readily available the considerable amount of information already in existence on an area that continues to attract considerable interest as a possible source of both anthracite and coking coal.

STRATIGRAPHY

The general succession of rocks in the region including the Bering River coal field, according to Martin (1908, p. 24), is as shown in the following table:

General section of rocks in the Controller Bay region

Age	Formation	Character of rocks	Thickness (feet)
Quaternary		Stream deposits, lake sediments, moraine deposits, marine silt and clay	
Tertiary or later		Diabase and basalt dikes	
Tertiary	Tokum	Sandstone Shale	500 2,000+
	Kushtaka	Arkose with many coal beds	2,500 ¹
	Stillwater	Shale and sandstone	1,000 ¹
	Katalla ¹	Conglomerates, sandstones, and shales Sandstone Shale, concretionary Sandstone Shale	2,500 500 2,000 1,000 500+
Pre-Tertiary		Graywacke, slates, and igneous rocks	

¹The position of the Katalla formation with reference to the other Tertiary formations is not definitely established. (See following discussion.)

The Stillwater formation was described by Martin (1908, p. 30) as consisting of shale and sandstone without known characteristic beds. The base of the formation was not recognized.

The Kushtaka formation, according to Martin (1908, p. 31): " * * * consists predominantly of coarse arkose, although some sandstone and much shale are present. It contains a large but unknown number of coal beds. Marine conditions are not known to be represented.

"The thickness exceeds 2,000 feet, the exact total not being known."

A generalized section of the coal-bearing strata given by Fisher (1910, p. 1077) has a total thickness of about 3,500 feet.

In discussing stratigraphic relations Martin (1908, p. 31) stated that:

"The Kushtaka formation overlies the Stillwater formation, probably conformably, although as the contacts are in many places faults the exact relations are none too well known." In the same report (p. 37) Martin admits the possibility that the sandstone and shale at the base of the Katalla formation may be equivalent to the Tokun formation, which would place the Katalla stratigraphically above the Kushtaka formation. Later work in adjoining areas by D. J. Miller (Manuscript in preparation) indicates that the lower part of the Katalla formation is equivalent to the upper part of the Tokun. Furthermore, according to a personal communication from D. J. Miller, re-examination of fossils collected by Martin from areas mapped as Stillwater has raised the possibility that the Stillwater formation may represent a part of the Katalla formation, in which case it also would be stratigraphically above the Kushtaka formation.

The Tokun formation was described by Martin (1908, pp. 35-36) as follows:

"These beds overlie the Kushtaka formation conformably, the transition apparently representing a change from fresh-water to marine conditions. The formation is at least 2,500 feet thick, the lower 2,000 feet consisting chiefly of sandy shales * * *. The shales * * * are overlain by a bed of sandstone several hundred (possibly 500) feet thick. This sandstone is well exposed in the hills northeast of Lake Tokun and west of Lake Charlotte. The beds overlying this sandstone contain some shale, but are not well exposed."

IGNEOUS ROCKS

According to Martin (1908, p. 41), small basic dikes and sills are very abundant in the Tertiary rocks, north and east of Stillwater Creek. Most of them are less than 1 or 2 feet thick, and none could be traced more than a

short distance. Although basalt is the predominant rock, sills at three localities were described as diabase. These include: three sills, interlayered with coke and ranging in thickness from 2 to 8 feet, at the south end of Carbon Mountain; a sill of unspecified thickness at the base of the falls near the head of Clear Creek, which has coked the upper 12 inches of a 17-foot coal bed; and a 4-foot sill underlying a 4-foot coal bed on the east bank of Clear Creek about 3 miles above its mouth. Other basic dikes are shown on Martin's geologic map at several points on the east slope of Carbon Mountain.

STRUCTURE

The structure of the rocks of the Bering River coal field, particularly as reflected in the physical condition of the coal seams, is by far the most important factor bearing on the potential economic value of the coal deposits. Thickness measurements and analyses of many samples of coal from all parts of the field leave no doubt that the area contains a large amount of both anthracite and coking coal of excellent quality in beds that are at least locally of minable thickness. The actual value of these deposits is dependent on their being minable in sufficient quantity and at low enough cost to warrant their exploitation.

The principal structural features of the region were outlined by Martin (1908, pp. 42-43) as follows:

"The pre-Quaternary rocks of this region have a general northeast strike; have steep dips, which are northwestward throughout the greater part of the region; and are faulted. The northeast strike and northwest dip are the dominant structural features of the region. The strike varies from the northeast most markedly between Kushtaka Lake and Berg Lakes, where it is east and west, and at points in and north of the valley of Burl Creek, where it is northwest.

"Monoclinial northwest dip holds throughout the greater part of the region east of Kushtaka Glacier and Kushtaka Lake. In the northeast part of this region the structure is not as simple as the uniform strike and monoclinial dip seem to indicate. The folds are in part overturned, in places complexly so, and a complicated system of overthrust faults * * * adds to the complexity of the structure, which gradually increases from southwest to northeast.

"The structure between Kushtaka Lake and Shepherd Creek is somewhat more simple than in the eastern district described above. In the greater part of this region the folds are open, and strike northeast, and the dip northwest, although southeast dips occur in several areas and there is considerable variation in strike along the valley of Shepherd Creek. * * * At least four faults traverse this area. An overthrust near the crest of the southern end of Kushtaka Ridge has cut out the Kushtaka formation and brought the Tokun and Stillwater formations in contact with each other. Another fault of somewhat uncertain character extends along the western side

of and about half way down Kushtaka Ridge. Along the eastern side of the valley of Shepherd Creek, from a point near the northern end of Lake Charlotte to $1\frac{1}{2}$ miles below the lake, two faults bound a block of southeastward-dipping Kushtaka formation between northwestward-dipping rocks of the Tokum formation. An anticline has its axis on Carbon Creek, and another, which is probably a prong of the former, on Queen Creek. Between these a synclinal mass of the Tokum formation lies transversely across the crest of Kushtaka Ridge."

Martin measured a large number of coal exposures in all parts of the field, for most of which he gave the attitude of the bedding. Although dips were recorded in all four quadrants, they were preponderantly to the northwest, at angles ranging from 20° to 80° and averaging about 40°. At only one point, at elevation 1,450 feet on Barrett Creek (see fig. 2), did he mention a fault cutting the coal. At two other points, on the east bank of Canyon Creek 2 miles above its mouth, and in a tunnel on the west side of Kushtaka Lake, he mentioned coal beds pinching out, but did not state whether as a result of faulting or of stratigraphic thinning.

The foregoing description of the structure by Martin agrees generally with the findings of later investigators, who confined their studies largely to the basins of Clear, Trout, and Carbon Creeks, where they found the structure to be characterized by moderate to steep northwest dips, varied in a few places by tight folds, generally of unknown extent.

In addition to the four major faults shown on Martin's map (1908, pl. 8), Fisher and Calvert (1914, p. 34) reported: " * * * faults of lesser dimensions are exceedingly numerous, some representing a stratigraphic displacement of several hundred feet.

"Every tunnel of any consequence encounters one or more of these lesser breaks. In the northeastern part of the field the Davis mine has struck at least six of these faults in 500 feet of entry. The McDonald mine at the opposite end of the field near Bering Lake discloses similar conditions, and the prospect tunnels in the intervening area encountered the same difficulty."

They referred specifically to two faults--one a strike fault below the falls on the middle fork of Barrett Creek, which they inferred to have considerable displacement "as it appears to cut practically the entire middle group of coals," and the other a transverse fault that trends up the valley of Trout Creek. The Trout Creek fault was inferred from the fact, revealed during intensive prospecting by the Navy expedition, that several thick coal beds exposed on the west side of the creek were not present on the projection of their strikes east of the creek. A discrepancy in the attitude of the strata--almost flat strata on the east side of the creek opposite steeply dipping strata on the west side--also suggested major faulting. After examining many tunnels and outcrops Fisher and Calvert (1914, pp. 34-35) concluded that " * * * every part of the field, except possibly the ridge lying between Trout Creek

and Kushtaka Glacier, is traversed by an intricate system of fault lines, making underground development everywhere tedious and costly and in many places almost, if not quite, impracticable, except where the extraction of only a limited amount of coal is contemplated."

Storrs (1910, p. 2340) noted a zone of intense faulting on Barrett Creek and expressed the belief that " * * * the region to the northwest was raised very greatly relative to the region to the southeast, and the lower coal seams in the northwestern sections are, in my judgment, the same seams as those to the southeast." Fisher and Calvert (1914, p. 34), also noted a strike fault of considerable displacement on Barrett Creek but concluded (p. 36) that no duplication of coal beds had been produced by faulting in this area.

Probably more important than the major folding and faulting, in effecting the quality of the coal, have been the shearing, crushing, and repeated small-scale faulting that characterize most of the known coal exposures in the field. Steep dips and fold axes may determine the method of mining to be used, and major faults may limit the extent of mining from a given entry, but the small-scale features, such as shearing and crushing, may so adversely affect the quality of the coal and the cost of mining as to preclude successful development. These features are discussed in detail under "Prospective mining conditions".

COAL

Areal extent

The area underlain by the coal-bearing Kushtaka formation was estimated by Martin (1908, p. 65) to be about 50 square miles, of which roughly the eastern half contained mainly anthracite and the western half mainly semi-bituminous coal. Martin also estimated that an additional 20 square miles may be underlain by coal "at a greater or less depth" beneath the overlapping Tokum formation. The principal coal-bearing areas lie in a belt extending northeastward from Bering Lake and include the ridge culminating in Mt. Hamilton; the valley of Carbon Creek and the east slope of Kushtaka Ridge; and the upper drainage basins of Trout, Clear, and Canyon Creeks; and Carbon Mountain. (See fig. 2)

Stratigraphic position

According to Martin (1908, p. 66), the coal beds of the Bering River field are distributed throughout the entire thickness of the Kushtaka formation and are also restricted to it, the overlying Tokum and underlying (?) Stillwater formations being entirely barren. Fisher (1910, pp. 1076, 1088-1089) on the other hand, found several coal beds in areas supposedly underlain by the Stillwater formation, and therefore concluded that at least the upper part of the Stillwater was also coal-bearing. It is possible either that Fisher found coal undetected by Martin within the Stillwater formation, or that the formational contact as mapped by Martin should be moved farther south to include, within the Kushtaka formation, the southernmost coal beds found by

Fisher. In a later report Fisher (Fisher and Calvert, 1914, p. 32) expressed the opinion that "probably only the Kushtaka is coal-bearing."

The following conclusions on the stratigraphic position of the coal beds in the basins of Trout and Clear Creeks were stated by Fisher and Calvert (1914, p. 36):

"The coals are distributed throughout the entire thickness of the Kushtaka, and possibly into the upper part of the underlying Stillwater formations. It is believed that more than 20 beds of locally workable coal occur within the Kushtaka, but owing to the prevailing complexity of structure that exists in this field it is possible that some of the beds believed to be distinct are in reality duplications. These beds arrange themselves into three rather indefinite groups--a lower, a middle, and an upper.

"The evidence favoring the belief that these groups are distinct within themselves and not duplications caused by major strike faulting consists in the wide variation in stratigraphic interval between individual beds in the respective groups, especially when the lower is compared with the middle or the upper; also in the difference in the aggregate number of coal beds present in each group, even when these groups are examined at nearby places across the strike, as on Barrett Creek, and further in the absence of indications of disturbance of strata such as should be present if strike faulting sufficient to cause group duplication had taken place.

"The lower group contains eight beds of coal which are moderately thick and generally 100 to 800 feet apart; the middle group has nine beds closely grouped within about 400 feet of strata, and the upper group contains five beds of variable dimensions and slightly more widely separated than those of the middle group."

A study of a generalized stratigraphic section given by Fisher in an earlier report (1910, p. 1077) shows that the grouping mentioned above is indeed "rather indefinite." Of the 22 coal beds 3 feet or more in thickness, 14 are rather evenly distributed through about 900 feet of strata near the top of the formation, and the remaining 8 beds are widely scattered, either singly or in pairs, through 2,700 feet of underlying strata.

Physical and chemical properties

Martin (1908, pp. 81-92) found that all unweathered samples of coal from the part of the field east of Canyon Creek possessed the physical characteristics of anthracite, and that fuel ratios based on proximate analyses of coal from that part of the field confirmed its classification as anthracite.

The coal of the rest of the field, which Martin classified on the basis of fuel ratios as semi-anthracite in the middle district and as semi-bituminous in the western district (see fig. 2), "is all of a friable nature, the least crushed of it somewhat resembling part of the softer bituminous coals of the Eastern States." Storrs (1910, p. 2330) noted that the coal of the middle

district that had not been crushed had a conchoidal fracture.

For analyses of coals of the Bering River field the reader is referred to U. S. Bureau of Mines Technical Bulletin 682, which contains most of the previously published analyses as well as many previously unpublished analyses of coal from all parts of the field (Cooper, 1946, pp. 60-68, 101-107). These analyses show the coal of the field to range in heating value from 12,000 to 15,000 B.t.u., as received, and in rank from anthracite in the eastern part, through semianthracite in the middle part, to low-volatile bituminous in the western part. The low-volatile bituminous coal corresponds to the semi-bituminous coal described by Martin.

As a result of field coking tests, Martin (1908, p. 82) concluded that practically all the coal of the field classed as semibituminous was of good coking quality. Storrs (1910, p. 2329) and Fisher and Calvert (1914, p. 38) concurred in this conclusion. However, the results of tests reported by Evans (1920, pp. 18-20) indicate that the Carbon Creek coal does not make a satisfactory coke in a beehive oven or in byproduct ovens of conventional type.

Tests by the Navy Department (1914, pp. 62-83) showed that the coal from Trout Creek, even after washing to reduce the ash content to a comparable figure, had a somewhat lower boiler efficiency than run-of-mine Pocahontas coal, on which comparative tests were made. Furthermore, it formed a large amount of dense clinker on the furnace grates, which made it unsuitable for Navy use.

In cleaning the Bering River sample the ash content of the dry coal was reduced from 14.06 percent as received to 5.42 percent. This involved a loss of 49 percent of the fuel as mined.

Prospective mining conditions

The following geologic factors were listed by Martin (1908, pp. 92-93) as affecting the cost of mining in this region: topographic position, steep dips and complicated structure, variability in thickness and possible lack of persistence of coal beds, occurrence of explosive gas and large amounts of underground water, and the friable character of the coal. His comments on these factors, supplemented by observations of later workers, are summarized in the following paragraphs.

Topographic position of the coal

Martin (1908, p. 92) pointed out that the region is one of considerable relief, that many of the coal beds crop out in the bottoms of valleys, and that all the beds, if persistent for a sufficient distance, could be reached by tunnels at the level of the valley floors. He concluded that shaft or slope mining would not be necessary for many years, or until all the coal above the general drainage level had been exhausted.

In discussing proposed developments on Trout and Clear Creeks Storrs (1910, pp. 2333-2334) stated:

"The ultimate development of the Cunningham lands will undoubtedly call for several crosscut tunnels, such as proposed by Mr. W. L. Hawkins in his report on this property and shown on plate IV, from near Sta. 9 on Clear Creek; the others probably being one on Trout Creek, one to the southeast from some point on Clear Creek south of Sta. 299, and two from the Clear Creek Valley, one to the northwest and one to the southeast from near Sta. 276. At the present time [November 1907] however, sufficient data as to the field is not available to justify the commencement of any of these tunnels with assurance of their being at the proper locations."

Storrs further recommended that test slopes be sunk from the out-crops of certain prominent seams on the west side of Clear Creek valley to prove the dip and continuity of the coal before the crosscut tunnels were started. Fisher and Calvert (1914, pp. 40-41) stated that coal seams of the upper group that crop out on Moore and Barrett Creeks could possibly be reached by a water-level tunnel from Clear Creek, but that beds of the lower group, exposed on the lower courses of Moore and Barrett Creeks and along Clear Creek, dip so steeply that the greater part of their coal tonnage is below water level.

Attitude of the coal

The relations of folding and faulting to mining operations were discussed to some extent in this report under the heading of "Structure." Martin (1908, p. 93) stated that in certain areas of the field faults and overturned folds would probably prevent the successful mining of the coal, particularly in the structurally complex eastern part of the field. Fisher and Calvert gave the faulted and disturbed condition of the coal beds as one of the objectionable features of the coal in the Clear Creek basin (1914, p. 41), mentioned complex structure as adversely affecting coal exposures at two localities on the east side of Trout Creek (1914, p. 48), and concluded that the coal examined in the valleys of Carbon Creek and its tributaries, Ocean and Leeper Creeks, is in a zone of too complex structure to warrant development on a large scale (1914, p. 45). They also mentioned (1914, p. 45) two areas where conditions seemed to warrant further prospecting. One of these described as a possibly undisturbed area that lies in a fault block on the east side of Kushtaka Ridge, and the other as an apparently unfaulted area on the northwest side of Carbon Creek, which is underlain by the upper part of the Kushtaka formation and should therefore contain coal. According to Evans (1920, pp. C, 70), however, development work on the north side of Carbon Creek was not too encouraging, but work on the south side of Carbon Creek revealed at least one coal bed that showed promise of being exceptionally persistent, and gave reason for believing that a small mine could be developed.

Considerable care should be taken in this region in interpreting the attitude of bedding from distant views or aerial photographs. Beds exposed along the strike may appear to have a uniform monoclinical dip, but when exposed across the strike

may be found to be compressed into tight overturned folds.

Persistence of the coal

Coal exposures in the Bering River field consist for the most part of isolated natural outcrops and prospect openings along the main stream courses, the intervening areas are covered with soil, moss, and other vegetation. Few coal beds have been traced more than short distances, so that little is known of the maximum extent of individual coal beds. Martin (1908, p. 68) mentioned one anthracite seam on the east side of Carbon Mountain that was reportedly traced for 2 miles. A seam on the west side of Carbon Mountain, which he described as "apparently very persistent," was measured at two points about a third of a mile apart and was tentatively correlated with the above-mentioned seam on the east side of the mountain, about half a mile distant. Fisher and Calvert (1914, p. 47) reported that an 8-foot seam on the west side of Trout Creek was traced for 600 feet along the surface, within which distance it thinned to 16 inches and became dirty. A 30-foot bed near the same locality was similarly found to thin to 18 feet and become softer "several hundred feet" to the southwest, and at about 1,000 feet from the original prospect tunnel to consist of only 4 feet of soft dirty coal. Several other coal beds in the field, particularly on Trout and Clear Creeks, have been followed underground for distances ranging from a few feet to 350 feet. Most of the tunnels terminated where the coal had pinched out or had been cut off by faulting.

A review of available reports indicates that change in thickness is a common feature of coal veins in the Bering River field. Not all the descriptions indicate the cause of the thickness change, but structural deformation, in the form of squeezing and faulting, and stratigraphic thinning are both represented. According to Fisher and Calvert (1914, p. 36) "in some places there is an actual thinning of the entire bed, and at others impure coaly shale or horsebacks reduce the thickness of the pure coal."

Martin (1908, pp. 68-74) described several examples of thickness change. The anthracite seam that was traced for 2 miles on the east side of Carbon Mountain was said to range in thickness from 9 to 25 feet, and a seam 200 feet below, from 4 to 11 feet. A coal bed on the east bank of Canyon Creek 2 miles above its mouth was described as containing 2 feet 9 inches of coal at one point but being very variable in thickness and pinching out higher in the bluff. In a creek on the west side of Carbon Mountain opposite the mouth of Canyon Creek two coal seams were reported, one ranging in thickness from 3 to 21 inches and the other from 14 to 24 inches. A third seam on the same creek ranged from 8 to 22 inches in thickness. A coal bed at the base of the falls on Clear Creek was found to thicken within a few yards from 8 feet 2 inches to about 16 feet. A 10-foot bed near the west shore of Kushtaka Lake was described only as "pinching out."

Storrs (1910, p. 2342) found a coal seam, on the crest of Cunningham Ridge opposite the head

of Trout Creek, containing 32 feet of "very soft shelly coal" with two large benches of coal and slate mixture that thinned to 4 feet within a distance of 60 feet to the southwest. He implied that this abnormal thickness change was probably related to a nearby faulted zone. Storrs (1910, p. 2344) also examined a 350-foot tunnel on the west side of Trout Creek and measured a maximum thickness of more than 60 feet of coal, which he believed to be a "pocket" caused by faulting.

Fisher and Calvert (1914, pp. 39-42) noted several examples of abrupt thinning of coal seams. They described one bed, above the falls on Clear Creek, as being more than 40 feet thick at one point but "perceptibly thinned" a short distance to the south by a shaly parting. Below the falls and 300 feet above the creek on the west side, a coal seam 45 feet thick was found, but less than 100 feet to the south it decreased to 25 feet "by the development of shaly members." On Trout Creek a coal bed opened by a 100-foot tunnel was found to have a "workable thickness" at the portal but to thin to 18 inches at the face. A second coal bed exposed in a 175-foot tunnel decreased in thickness from 5 feet at the portal to 3 feet at the face.

Presence of water and gas

Martin (1908, p. 94) predicted that underground water would be encountered in large amounts in any mine development "owing to the abundance of surface water and the deep fracturing of the rocks," and noted that gas had been encountered in several of the longer tunnels. In discussing faults Fisher and Calvert (1914, p. 34) pointed out that "they act as underground channels for the excessive amount of water that permeates every part of the rock section." Although Storrs mentioned encountering gas at only one locality (1910, p. 2339), he stated in a discussion of proposed mine developments (1910, p. 2328) that "large fans and systematic ventilation will be required, for considerable gas has already been encountered very close to the outcrops." He also referred to probable large quantities of water as one of the mining problems to be faced. Williams (1914, p. 25) noted that large quantities of methane were found in the two longest Navy-expedition tunnels.

Physical condition of the coal

Aside from its inherent physical properties, much of the coal of the Bering River field has acquired additional characteristics through the shearing and crushing that accompany structural deformation. Martin (1908, p. 81) noted that most of the coal exposures in the eastern part of the field show "only a soft, weathered mass of coal which gives little indication of anthracite character," its classification as such being based on analyses and numerous float specimens of hard bright coal. As none of the openings in that part of the field extended beyond the zone of weathering he was unable to determine whether the anthracite became hard and unbroken at depth. He described the coal of the rest of the region, classed as semianthracite and semibituminous,

as all being of a friable nature, many beds having been severely crushed and sheared. Storrs (1910, p. 2330) also found that "many of the seams show much crushing and shearing, and although the coals are hard, they are quite friable and have a flat, slippery fracture." Evans (1920, p. 17) noted that the friable character of the coal from most of the beds on Carbon Creek would be a handicap during shipping, but added that the tendency to break into small sizes would be offset to some extent by the coking tendency of the coal which would cause the smaller particles to agglomerate into large masses instead of falling through the grates.

In discussing the character of the coal with respect to mining conditions Williams (1914, p. 24) stated:

"In mining operations, judging from conditions thus far found, the loss of coal will be high. It is doubtful whether, under present mining methods, a recovery of over 25 percent will be possible from a number of the most favorable beds. It is believed that the coal of some beds will be found so soft and crushed that the coal will "flow" or "run" under pressure induced by the mining operations, so that it would be difficult to maintain pillars. It is possible that some modification of existing methods of mine packing could be applied that would insure a high percentage of recovery; but such a method would necessitate the quarrying of rock or the excavation of gravels on the surface and delivery into the mine of the packing material and would render the cost of mining high."

Fisher and Calvert (1914, pp. 36-37) described the coals of the Cunningham claims as follows:

"They are prevaillingly soft and friable, with a pronounced foliated structure and graphitic luster. In at least 90 percent of the beds the coal has been badly crushed and shearing planes are highly developed. A few beds appear to be moderately firm, but such beds are generally closely associated with faulting, where the pressure causing deformation has been released. The soft, friable condition of the coal is not a surface aspect due to weathering, as has generally been supposed, but is deep seated. In different parts of the field where development work has been carried on, the coals that are soft and friable at the surface do not increase perceptibly in hardness underground."

In commenting on the friability of the coal Martin (1908, p. 94) noted that if this condition persists at depth it would seriously affect the market value of the anthracite because of the high proportion of fine coal that would be produced in mining that would result from crushing during transportation. Both Martin and Storrs (1910, p. 2330) expressed the belief that the semibituminous coals would not be so seriously affected by this condition when used as steam or coking coals. However, impairment of the combustion qualities would not be the only effect of the high proportion of slack resulting from the crushed, friable condition of the coal. In loading the pulverized coal at the mine face more impurities from the roof and partings would be unavoidably mixed with the coal than would happen in coarser material. Williams (1914, p. 25) noted that in each of the four tunnels from which the Navy coal sample was taken the hanging

wall consisted of soft, slippery shale that grades downward into the coal. He pointed out that such a roof is difficult to hold, especially in a region of broken strata, and expressed the belief (1914, p. 26) that the coal would require washing because of impurities within the beds, the prevailing soft nature of the coal, and the probable admixture of roof material.

The efficiency of separation by wet cleaning of coal begins to drop sharply below the 2-millimeter size, and very little separation is effected below the 1-millimeter size. Washing of the Bering River coal, consisting of a large proportion of slack, would therefore probably involve excessive fuel loss, except possibly by an expensive flotation process.

Another effect of the high proportion of slack would be the retention of much of the large amount of extraneous moisture that would be expected in most of the coal mined in the area. This excess water would be particularly troublesome in winter, when it would require the installation either of expensive drying equipment at the mine, or of facilities for thawing or otherwise removing the frozen coal at the unloading point.

A general impression of the condition of the coal in different parts of the field may be gained from the following summary of descriptions of individual exposures extracted from the reports reviewed.

Clear Creek. --Storrs (1910, pp. 2339-2340) mentioned 10 coal exposures along Clear Creek, but referred to the condition of only 5 of them. Of these, three were described as hard bright coal, one showed the effect of crushing in the form of a "flat, slippery fracture", and one was "so faulted that no section could be taken." Fisher and Calvert (1914, pp. 38-39) described three coal outcrops along Clear Creek, all of which were badly broken or crushed, and two contained "cannon-ball" nodules of hard impure coaly material.

Barrett Creek. --On lower Barrett Creek Storrs (1910, p. 2340) noted five coal outcrops, which he described as "badly disturbed and faulted, none of them showing in minable shape." On a west fork, above the falls, he measured 13 beds, ranging in thickness from 3 to 17 feet, of which one was described as "shelly," two as faulted, one as containing "sulfur kidneys," and four as "very soft." Fisher and Calvert (1914, pp. 38-39) examined what is probably the same series of beds, which they described as "bright and relatively clean, but, without exception, badly crushed into a molybdenitic structure. Shaly bodies, commonly known as 'horsebacks', are frequent in the thicker beds." On the headwaters of the east branch of Barrett Creek Storrs (1910, pp. 2340-2341) noted "very disturbed measures" in which all the coal examined was "soft" or faulted and unminable."

Moore Creek. --Along the main course of Moore Creek, Storrs (1910, pp. 2341-2342) examined eight coal outcrops. Of the four he described, two were of hard bright coal, one was a coal and slate mixture, and one was badly faulted. On the

eastern headwaters five seams were noted, of which three were badly faulted and soft, and two were hard and presumably undisturbed. On a western headwater he found four coal seams--one 25 feet thick--that were all of soft coal or greatly disturbed.

Of four beds described by Fisher and Calvert (1914, p. 40) on Moore Creek, three were crushed or sheared and one was referred to only as "clean coal." In the saddle in the crest of Cunningham Ridge at the head of Moore Creek they reported two thick beds of soft, crushed coal.

Trout Creek. --Storrs (1910, p. 2343) examined eight coal exposures on the headwaters of Trout Creek. He described a 32-foot bed as "soft shelly coal," an 18-foot bed as containing slate and dirt streaks, and a third bed as a "disturbed outcrop." No description was given of the other five beds. In the main Trout Creek valley he made specific note of 25 coal exposures; of these 7 were described as faulted, 2 as soft coal (presumably crushed), 3 as part hard and part soft (crushed?) coal, and 5 as hard bright coal. The condition of the other eight exposures was not given.

Of nine coal beds examined on Trout Creek by Fisher and Calvert (1914, pp. 41-43, 46-48), seven were described as badly crushed and sheared or soft. The other two beds were hard and bright where first examined but where found to thin and become soft and dirty within short distances.

Bear Creek. --Storrs (1910, p. 2345) described three coal beds on Bear Creek, of which one consisted of hard bright coal and two were in part hard and bright and in part soft and dirty. Fisher and Calvert (1914, p. 48) did not describe individual outcrops on Bear Creek but remarked that coal beds where found were badly crushed.

Kushtaka Ridge. --Fisher and Calvert (1914, p. 43) described one coal bed, exposed in a tunnel on the east slope of Kushtaka Ridge, as soft and crushed, and two beds as being partly hard and partly crushed. They also mentioned seeing several other coal openings in a disturbed zone, in which the coal was generally soft and crushed.

Carbon Creek. --On Carbon Creek and its tributaries Fisher and Calvert (1914, pp. 43-44) described four coal outcrops, of which all appeared to be of good quality, but one was soft and friable and another was in a closely folded and faulted zone.

Bering Lake. --Fisher and Calvert (1914, p. 46) reported that the McDonald mine, on the east shore of Bering Lake, was opened on a 6-foot bed of impure coal that was cut by several minor faults. The mine output was estimated to contain more than 90 percent slack coal. Two beds opened south of the mine were said to be soft and crushed.

Canyon Creek. --The only available description of coal on Canyon Creek is that given by Fisher and Calvert (1914, pp. 45-46) of an 11-foot bed exposed in a tunnel on Canyon Creek about 2.7 miles above its mouth. The bed was soft and friable and, except for the upper 3 or 4 feet, too

dirty to be minable. Other coal outcrops on Canyon Creek were measured by Martin but not described.

Carbon Mountain. --No detailed descriptions of coal outcrops on Carbon Mountain are available, but general statements by Martin and others indicate that the coal of the eastern part of the field is characteristically crushed and friable.

CONCLUSIONS

Available information leaves little doubt that coal of high quality, including both coking coal and anthracite, is present in great aggregate amount in the Bering River field. As the coal beds are exposed only in scattered short tunnels and isolated outcrops, little is known of their over-all continuity. Examinations of hundreds of exposures, however, and a few attempts at tracing coal veins along the outcrop as well as underground, have revealed a tendency for the coal to change thickness within comparatively short distances, either by thinning of the beds or by thickening of rock partings.

Probably overshadowing in importance the original extent and continuity of the various coal beds is the fact that in a large proportion of the exposures examined the coal has been greatly disturbed, either by complex faulting or by crushing and shearing resulting from structural deformation. Such conditions will, in many places, complicate if not preclude the successful mining of the coal, particularly where shearing of the coal has been accompanied by the introduction of impurities from the enclosing strata.

In view of the above conditions, which seem typical of all parts of the field that have been studied, the prospects of proving a large reserve tonnage of economically minable coal in a single block are not encouraging. Smaller blocks, possibly ample to keep a small mine in operation for several years, may be present in several parts of the field, particularly on Carbon, Trout, and Clear Creeks. Any such block should be thoroughly tested by both surface and underground prospecting before any large investment in surface plant is made.

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