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HENRY LANDES, State Geologist

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The Coal Fields of Southwestern Washington

By HAROLD E. CULVER

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LETTER OF TRANSMITTAL.

Governor Ernest Lister, Chairman, and Members of the Board of Geological Survey:

GENTLEMEN: I have the honor to submit herewith a report entitled "The Coal Fields of Southwestern Washington," by Harold E. Culver, with the recommendation that it be printed as Bulletin No. 19 of the Survey reports.

Very respectfully,

HENRY LANDES,

State Geologist.

University Station, Seattle, Jan. 2, 1919.

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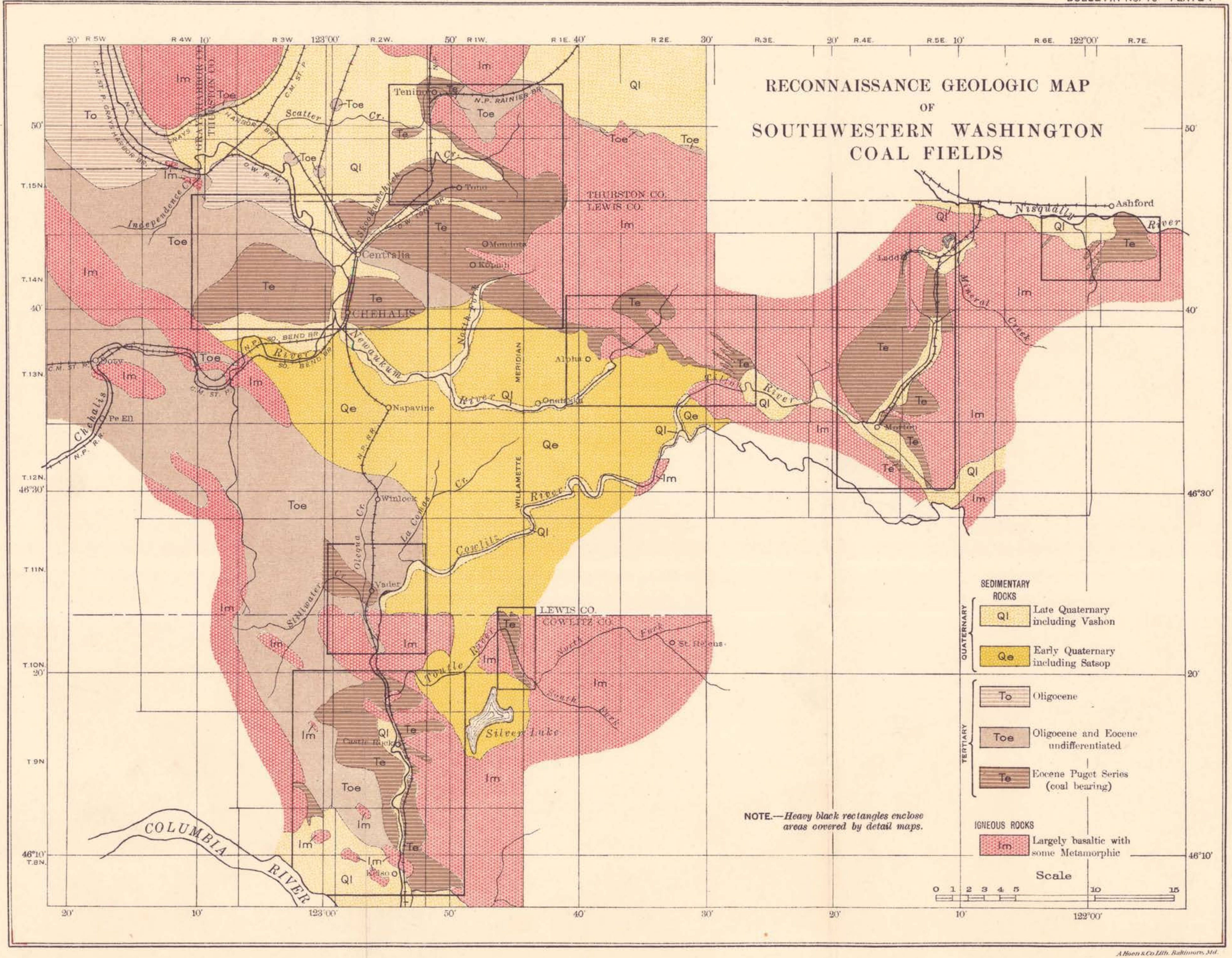

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CHAPTER I.

INTRODUCTION.

GENERAL STATEMENT.

Until recently the coal fields of southwestern Washington have been of interest because of the ease with which the local demands for industrial and household fuel could be met, rather than for the volume of production.

In addition to the increased demand for local coals, the recent advances in the development of processes of coal preparation which make use of subbituminous and lignite coals have stimulated the coal mining industry in this area and emphasized the need of more accurate data on the character of the coal seams and the extent of the field.

The earlier geologic work on these coal fields involved the careful measurement and description of known seams with but little attempt to determine the areal or structural features. A bibliography of the literature on the geology of this area so far as it has come to the attention of the writer is added in the appendix.

The aim of the present study was to collect and correlate as far as possible the available data from all sources, to verify and supplement them by field work, and thus to make readily accessible whatever facts might be of value in commercial or scientific fields.

A base was compiled from the original land survey plats, the soil maps, and the topographic sheet of the Chehalis quadrangle. Mines, prospects, and exposures were tied in to section corners as far as possible by pace and compass traverses, and plotted on the base. The field work comprised a hasty survey of the various districts with practically no detailed study. In general only the known or easily accessible exposures were examined, the requirements being to obtain data sufficient for a general classification map over a relatively large area.

With few exceptions the mines which were in operation while the field work was in progress were visited, the seams measured and sampled for analysis and the methods of mining noted. The discussion of this last named feature, however, has been made as brief as possible since the methods followed in this district are quite similar to those in use in other districts of the state. For detailed description of these the reader is referred to Bulletins 3, 9 and 10 of the Washington Geological Survey publications. A number of small operators are represented in the field and individual practice in mining and preparation of the coal vary somewhat in details. The factors of greater thickness of seams, relative simplicity of structure of the coal-bearing strata, and physical character of the coal make the mining problems simpler in this field than elsewhere in the state.

Naturally a difficult area to study because the extensive alluvial deposits and the vigorous vegetation combine to hide the rocks most effectually, the lack of accurate locations has made the structural interpretations doubly hard. While plant and animal remains are fairly common, their character is such as to render them of little value as horizon markers. The lack of detailed study over large areas makes it impossible to verify any but the major features of either structure or stratigraphy, so that future study will doubtless show some areas now classed as igneous to be sedimentary, and vice versa.

GEOGRAPHY.

The region under consideration includes the south central portion of Thurston County, most of Lewis County and a strip through Cowlitz County, along the Cowlitz River to the Columbia. (See Figure 1).

This area may be roughly described as comprising two adjoining rectangles; the western, 55 miles north and south by about 40 miles east and west; the eastern, 20 miles north and south by 30 miles east and west. The first contains most of Townships 8 to 16 North, in Ranges 5 West to 2 East; the second includes Townships 12 to 15 North in Ranges 3 to 7 East, Willamette Meridian. Farther to the east and entirely separated from the area above described lie two small fields which do not appear on the general reconnaissance map, Plate I, but are mapped as Plate XXIII.

The eastern portion of the area is served by the Tacoma Eastern Railway (Chicago, Milwaukee & St. Paul Railroad) with terminus at Morton, on the edge of the fertile bottom lands of the upper Cowlitz Valley. The more thickly settled western portion is traversed by the Northern Pacific, Great Northern, Oregon-Washington Railroad & Navigation Company and the Chicago, Milwaukee & St. Paul lines. Of the many towns in this part of the area, Centralia is the largest, while Chehalis, the county seat of Lewis County, Kelso, and Castle Rock are important centers. The growing demands of these places and of neighboring cities have been an important factor in the development of the coal mining industry in southwestern Washington.

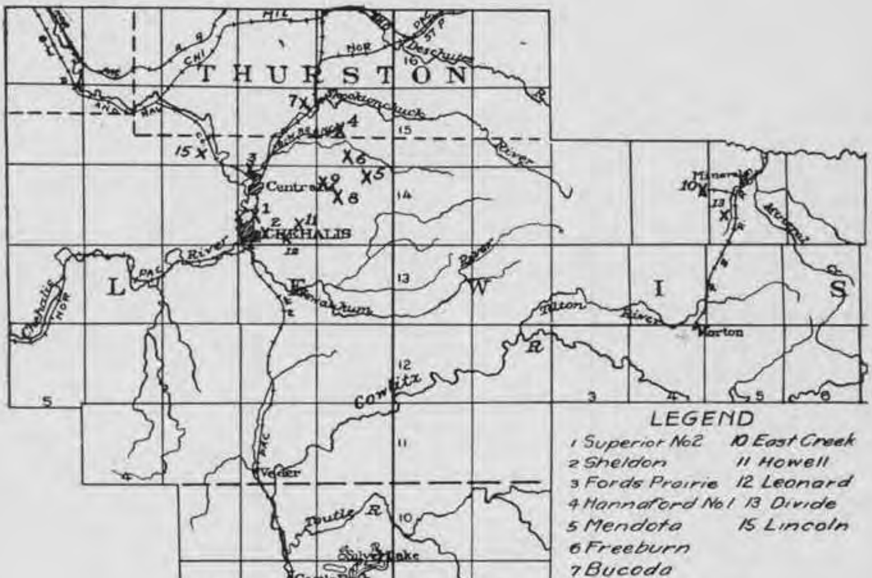


FIG. 1. Map showing the location of coal mines recently in operation in southwestern Washington.

ACKNOWLEDGMENTS.

The examination of the field has occupied a total of about four months, having been carried on at intervals from August, 1913, to August, 1918. In the earler reconnaissance work the writer was assisted by F. M. Handy and Charles Landes, in the later by Sheldon L. Glover.

The writer is glad to credit the technical description of mining methods employed in this field to Joseph Daniels, Associate Professor of Mining, University of Washington, who kindly assisted in the examination of mines in operation during the second week of September, 1917.

For valuable data on the methods of preparing and burning powdered coal the writer is under obligation to Mr. W. J. Santmyer, Advising Steam Engineer for the Puget Sound Traction, Light and Power Company.

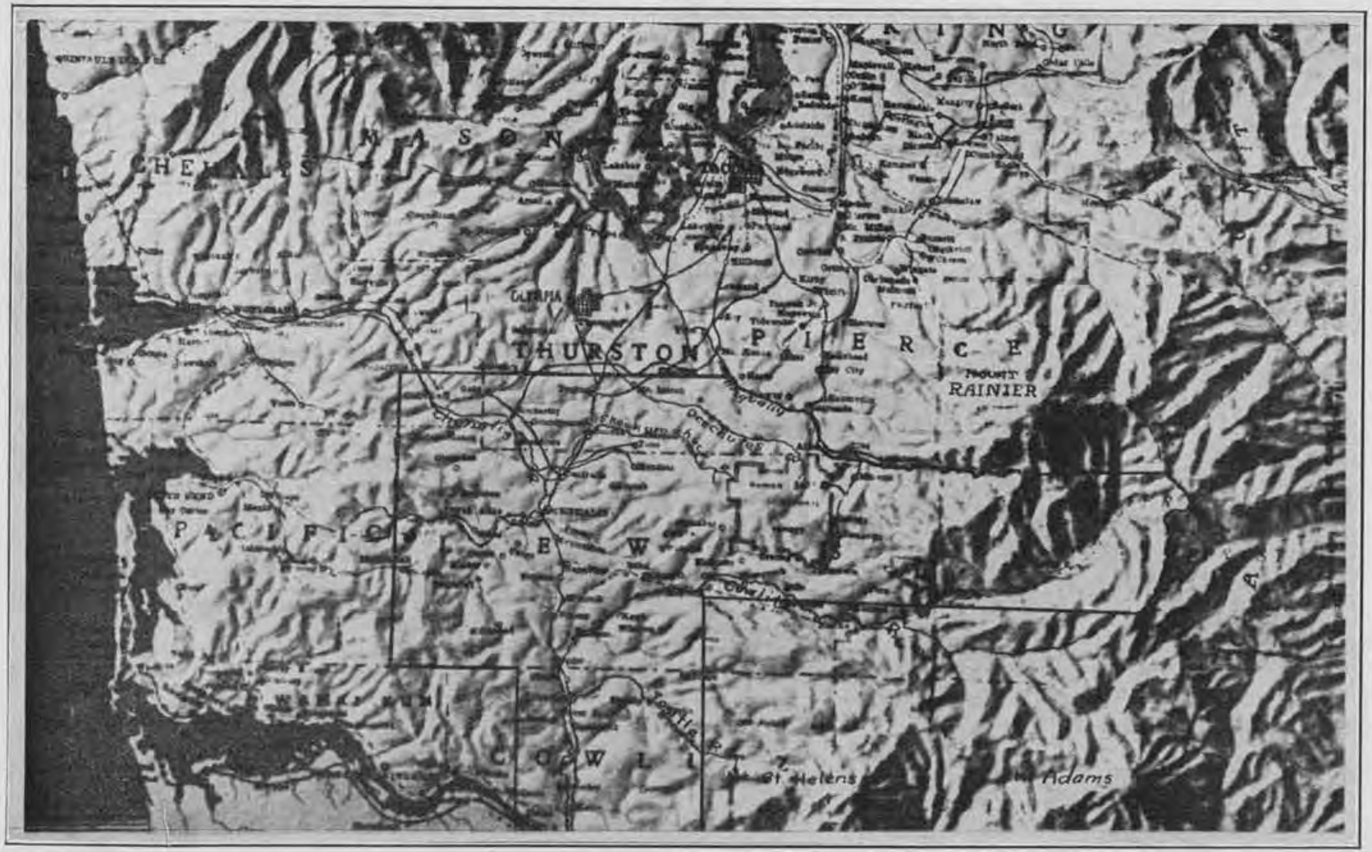
For the determination of certain Tertiary and Pleistocene boundaries as well as for numerous suggestions as to preparation of the manuscript the writer is indebted to his colleagues, Charles E. Weaver, Associate Professor of Geology, and Morris M. Leighton, Assistant Professor of Geology, at the University of Washington.

To the mining men throughout the field the writer wishes to express his appreciation for unfailing courtesy and able assistance.

TOPOGRAPHY AND DRAINAGE.

The area examined in this survey extends from the foothills of the Cascade Mountains on the east to the western edge of the Cowlitz Valley and exhibits several topographic types.

The major topographic element of the eastern portion is a rugged spur of the Cascades extending southwesterly from Mt. Rainier, with the valleys of the Nisqually and Cowlitz rivers to the north and south respectively. (See Plate II). The rock masses have been deeply dissected; steep slopes are characteristic and all but the major streams have excessive gradients. Maximum elevations in this portion are above 4,000 feet. Followed westward through the Rainier National Forest, this spur shows less relief, a more mature topography appearing. Practically all the surface is forested so that exposures of bed rock are infrequent. (See Plate III).



Photograph of a relief model of western Washington, made by the Burgie Relief Map Establishment, Rochester, N. Y., showing the relation of the field surveyed to the surrounding area. Scale about 23 miles to the inch.

The streams are in well developed channels and commonly have built flats or benches of limited extent. These for the most part are fertile and cultivated. In the western portion of the area under discussion the many tributaries merge, their low divides giving place to the alluvial flats of major streams. The bottom lands are limited in extent, rarely more than three miles wide, and frequently interrupted by low ridges or knobs.

Southward through Cowlitz County this last mentioned type of topography prevails although the low ridge-like hills are of more frequent occurrence, the intervening flats grading into the broader flood plain of the Columbia River.

That part of Thurston County included in this report shows a marked modification of the lowland topography through the action of glacial agencies. The relief and irregularities of surface normally developed by weathering and stream erosion are all but obliterated by the heavy filling of drift over an area of some two hundred square miles in the northern portion of the field. At the extreme northwest corner of the field studied, in the vicinity of Bordeaux, the drift boundary is marked by the maturely eroded basalt elevation known as the Black Hills, which are about 1,500 feet high. At the western edge of the area examined the lowlands are replaced by the Willapa Hills, comprising basalt ridges with intervening valleys largely underlain by Tertiary sediments.

The drainage of this region is well developed for the most part, the few undrained areas being of very limited extent. The Puget Sound, Grays Harbor and Columbia River watersheds are separated by divides which in part traverse this area, meeting near the western boundary of the Rainier National Forest.

The Deschutes and Nisqually rivers drain the northeastern portion of the area into Puget Sound. That part of the Columbia watershed lying within the area is drained by the Cowlitz River and its tributaries, the Cispus, Tilton, Toutle, and Coweman. The Chehalis River with its tributaries, the Black, Skookumchuck and Newaukum, carries the waters of the central and western portion of the area to Grays Harbor.

Views showing typical vegetal covering in southwestern Washington. An important factor in geological field work in this region is the heavy forest covering which effectually conceals the underlying rocks over large areas.

HISTORY OF MINING IN SOUTHWESTERN WASHINGTON.

The earliest recorded coal discovery in this field was in 1833 by Dr. Tolmie, an Englishman in the employ of the Hudson Bay Company, who examined coal prospects in the Cowlitz and Toutle rivers near their junction. In his daily journals Tolmie reported his observations on the coal seams and associated rocks, taking structure data as follows: In the first "coal mine" (located probably in the south half of Sec. 34, T. 10 N., R. 2 W.) the "direction of the strata to the Pole was N. 70° W., dipping about 20°. The channel for 500 yards below and 200 yards above was rocky." The next location (probably a mile or so up the Toutle) showed similar lignitic strata trending northeast-southwest, dipping about 25°. These were covered by layers of reddish sandy clay "similar to those of the Cowlitz." The second "coal mine" was probably located about section 16 of the same township, and here he found a "layer of carboligenous matter 3 or 4 feet thick, laminated and very friable," at the base of a cliff of gravels 200 feet high. The next recorded location was in the same part of the area, in 1848. There is no record of the coal in any of these locations having actually been mined. Later, in 1855, coal was discovered in the valley of the Skookumchuck River near the town of Seatco, now called Bucoda, but it was not until the seventies, a quarter of a century later, that a company was organized to exploit the property. Convict labor from the state penitentiary located at Seatco was utilized and 10,000 tons of coal were mined before the removal of the penitentiary to Walla Walla led to the abandonment of the enterprise some years later.

Beginning about 1890 extensive prospecting was carried on in all parts of the field. It was found that the area underlain by coal was much more extensive than had been realized. In a decade coal had been found and claims located over a large area from near the headwaters of the Cowlitz River on the east to the upper Satsop in the northwest and the Columbia on the south. Many of these prospects became the scene of active exploratory work but the only producing properties were those whose location afforded rail transportation or a local market. The reports of the coal mine inspector of this time show the organization of companies to operate mines near Bucoda, Centralia, Chehalis, Castle Rock and other towns of this region.

An examination of the coal areas emphasizes the large number of such enterprises started and the extent of the exploratory work. Certainly much capital and honest endeavor went into the attempts at development that were made. With relatively few exceptions, however, these companies were foredoomed to loss or failure through the lack of adequate scientific direction for the work. Throughout most of the area rock exposures are so infrequent that only by extensive study can the underground structure be learned. The lack of similarity between this and any other coal areas had aided in making the task of exploration one of baffling difficulties. Doubtless, also, the large number of the coal beds and the high content of carbonaceous matter throughout the Puget series, together with the localized character of the deposition of these rocks, has been the cause of much of the unfortunate waste in the exploratory work.

In some cases a study of structural relations as revealed in the attitude and areal distribution of the different rocks should have made manifest the improbability of profitable exploitation. In other cases, careful preliminary tests would have shown that certain of the coals were not of sufficiently high grade to make their exploitation of value. Again, an understanding of the fundamental processes of coal formation would have prevented some hopeless exploration for coal that never existed. Thus the early history of the coal mining industry in this section is chiefly a record of earnest but haphazard prospecting followed by unscientific attempts at development.

As has been indicated, there is great difficulty in getting information in regard to most of the mining operations of former years. The older geologic reports contain some data, the coal mine inspector's reports have some, much can be gained from the mining men themselves, but a great deal is locked up in the pits, tunnels, and shafts, whose rotting timbers prohibit re-examination.

CHAPTER II.

GENERAL GEOLOGY.

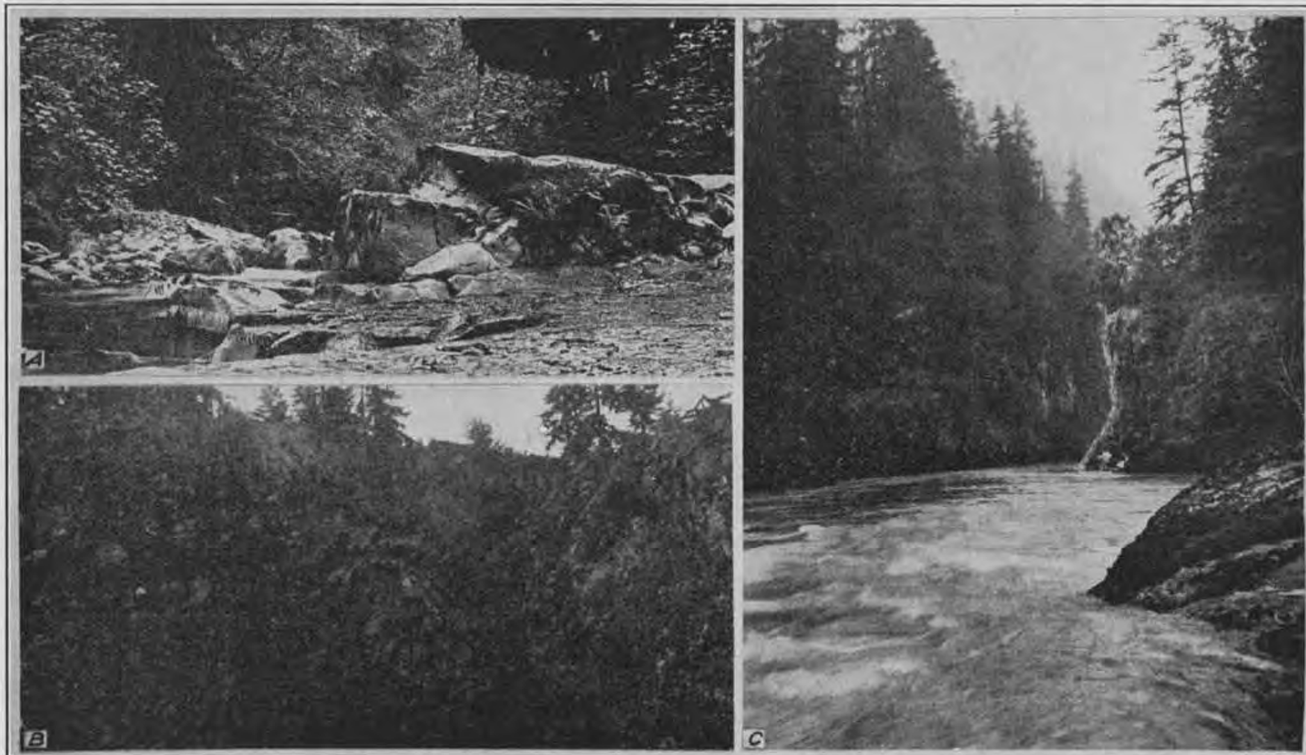
GENERAL STATEMENT.

Rocks of diverse character are found in the area covered in this report, all three of the great rock groups, igneous, sedimentary and metamorphic being represented, but in relations not yet well understood. The igneous rocks comprise various types of breccias, tuffs, andesites, and basalts. The last two are of most frequent occurrence and in the field were not usually distinguished. Consequently, unless otherwise stated, the term basalt is used in this report in its field sense, covering all types of dark, igneous rocks of dense or porphyritic texture.

The sedimentaries include conglomerates, sandstones, shales, and dolomitic limestones. The conglomerates are of rare occurrence, local in distribution, and are probably in part stream-laid. The limestones were found in but two localities and have very limited areal extent. The sandstones and shales are abundant, occur in thick series and are of marine, estuarine, and in some instances possibly of fresh-water origin. In general they are composed of material poorly assorted both as to size and mineral constituents, but exhibit variations between arkosic sands and pure shales.

The metamorphic rocks have limited areal extent and include some rocks of possibly sedimentary origin in which the crystallization is so prominent as to exclude them from the sedimentary class. They are provisionally regarded as conglomerates and graywackes, somewhat metamorphosed. It is probable that the limestones mentioned above should be placed with these rocks stratigraphically.

The determination of the position of these strata in the geologic column depends upon their correlation with rocks in adjoining areas, to the north and west and east. This correlation is based in part upon the fossil content of certain of the beds and in part upon similarity in lithology and structure. Because of the limited data available in these lines at the present the age determination must be regarded as tentative.



TYPICAL EXPOSURES OF IGNEOUS ROCKS.

A. Basalt dike intruded into sandstone. Newaukum River. The greater resistance of the igneous rock causes it to project above the sediments in the stream channel.

B. Columnar structure in a basalt flow. Meskill quarry. The columns radiate from a point near the original outer surface of the mass.

C. A gorge-like portion of the Cowlitz channel where the river is cutting through an intrusive andesite. Near Mayfield.

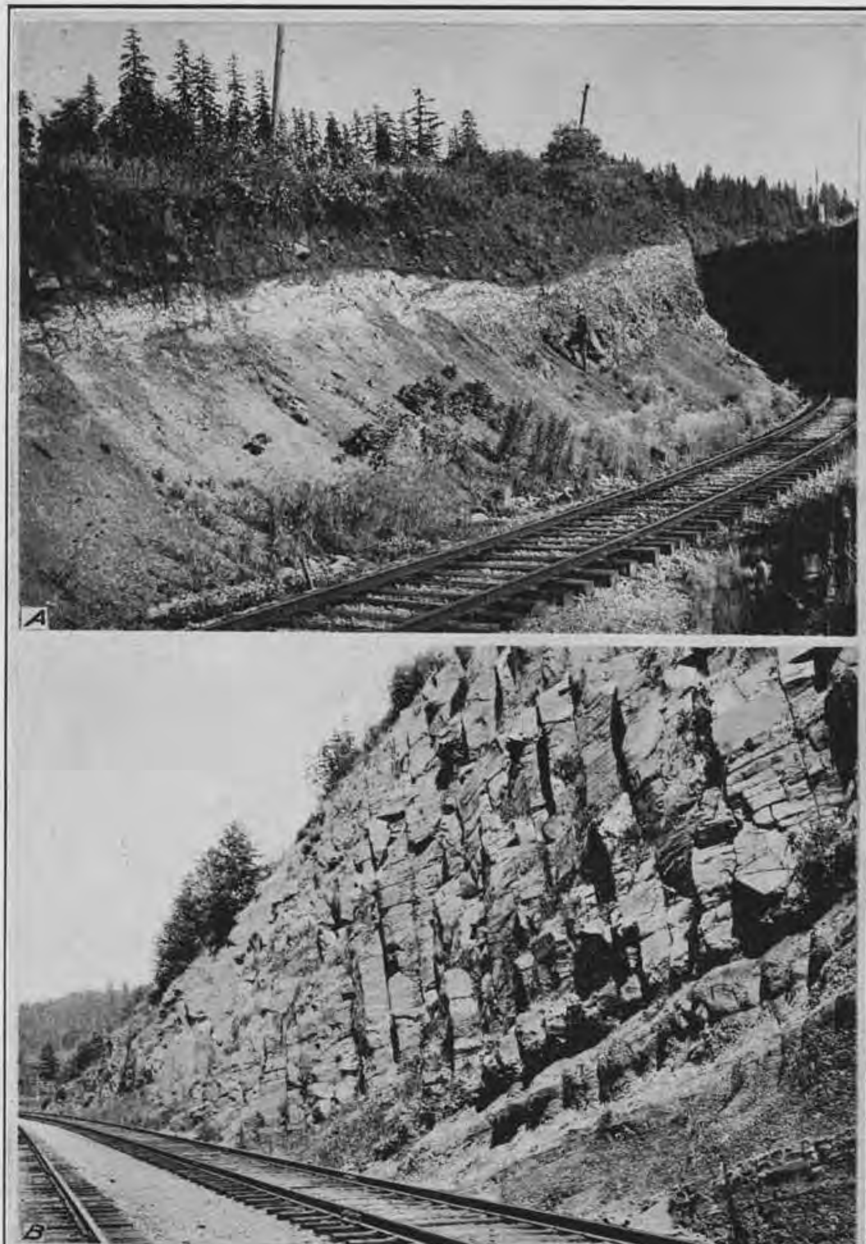
IGNEOUS ROCKS.

Throughout most of the field, in fact in all parts except in a narrow strip from Vader northward to Tenino, igneous rocks are found to underlie relatively large areas. In rare instances carbonaceous beds, and indeed coal seams, are found in the midst of igneous masses, but in the main the presence of igneous rocks precludes the possibility of finding workable coal seams. In mapping the igneous areas, the location of the boundaries has been for the most part only approximate. Without doubt sedimentary strata will be found within the areas mapped as igneous, but it is believed that the sediments so found are not associated with coal seams of value.

Both intrusive and extrusive types of igneous rocks are found. In the western portion of the field most of the igneous masses are of relatively small dimensions and because of the deformation in which they have been involved the area covered by any one mass is not large. As a result exposures frequently show small masses of both igneous and sedimentary rocks. In many cases the former are evidently interbedded flows, in others undoubtedly dikes, (See Plate IV), but in the majority of cases conclusive evidence of their relations to the sediments has not been obtained. No indication of age greater than that of the Tertiary sediments was noted.

East of Silver Lake, in the southeastern portion of the field, is an area nearly if not quite exclusively igneous. These masses are considered to be of relatively recent age. Similarly, east and southeast of Mineral Lake, in the northeast part of the field, the rocks are in large part igneous. These consist of flows and intrusives in undefined relations to the sediments.

The igneous rocks show considerable variation in character but may be classed roughly into basaltic lavas and pyroclastics. The former greatly predominate, but tuffs and agglomerates are common in the western part of the field, especially in the lower Cowlitz Valley. These usually show a rough stratification, which in the finer tuffs is pronounced. The basaltic rocks show wide variation in texture from nearly glassy rocks to those containing abundant wellformed crystals. Under the microscope some of these show predominant hornblende, others olivine, others augite, while rarely the feldspars are in equal amount with the mafic minerals. In color



A. Highly weathered vesicular basalt overlain by coarse Pleistocene gravels. Near West Adna. Because of the rough stratification assumed during the weathering process such basalt masses may easily be mistaken for thin-bedded sandstone.

B. Shales of the Puget series overlain by basalt. Near Castle Rock. But for the superior resistance of the overlying basalt this shale series would not stand above the general valley floor.

these rocks are quite uniformly dark, nearly black, but with a faint bluish or grayish tinge. On weathering they usually show a change to buff or tan in early stages, but with more complete alteration the yellow of limonite becomes more and more pronounced.

The basalt flows often show a porous structure, the vesicles frequently being so abundant as to give the rock a spongy aspect. In fresh exposures these porous masses may show a filling by secondary minerals such as calcite, quartz, opal, zeolites, etc. In some cases of weathering these vesicular layers assume a peculiar bedded structure, breaking down into granular sand-like masses and then may easily be mistaken for strata of impure sandstone. Such a case is seen in a cut on the Chicago, Milwaukee & St. Paul Railroad, a few miles west of West Adna. (See Plate V, A).

Spheroidal structure is seen infrequently in fresh exposures, but on weathered surfaces becomes prominent. Columnar structure, however, is very common and some excellent examples of this interesting feature of basaltic rocks are found. The columns are usually straight but occasionally, in masses which have cooled unevenly, the joint planes converge toward a point which is near the original outer surface of the mass. Fine examples of this are seen in the vicinity of Meskill. (See Plate IV B and Plate V B). Columns are usually about two or three feet in diameter and 20 to 30 feet long. Those in the augite andesite of the Skookumchuck in Sec. 14, T. 15 N., R. 1 E., are several times as large.

NEWAUKUM SERIES
(Pre-Puget in Age).

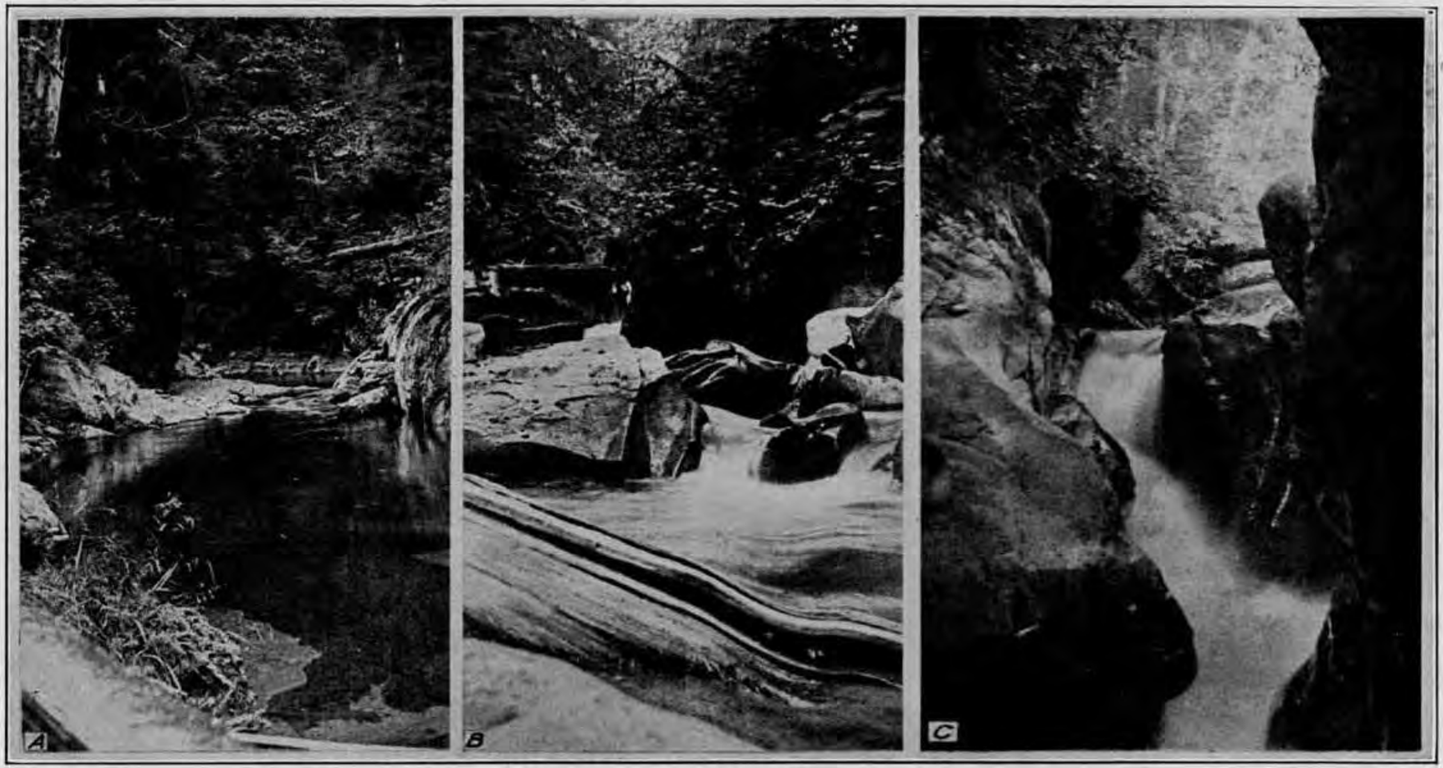
The oldest rocks found in the area are those in the northeastern part, typically exposed in the channel of the North Fork of the Newaukum River in Sec. 19, T. 14 N., R. 1 E. (See detail map, Plate XVI). Here the conglomerate base of the sandstone series associated with the coal (See Figure 3a), is underlain, possibly unconformably, by a breccia of red volcanic fragments in a dense black matrix grading into graywacke below, and it, in turn, by a dense resistant conglomerate. The distinction between these two series is based upon the fact that the upper conglomerate, which is thought to belong to the coal series, in common with those rocks, is markedly less well cemented than the rocks below, and, in addition, contains pebbles of graywacke similar to that below.

In other exposures the rocks of this older series show considerable variation from the sequence and indeed from the lithologic character noted above. In places the red breccia is absent; again, a bed of dense siliceous shale, nearly a black slate in character, replaces the graywacke. In still other places lenses of limestone are interbedded with the graywacke-conglomerate series. Time did not permit detailed study of this formation which lies almost wholly outside the area of the coal-bearing strata. A report upon the stratigraphy and structure of the Newaukum series will be made separately upon the completion of a more detailed field and laboratory examination of these rocks.

The origin of the conglomerate phases of this older series constitutes a distinct problem in the stratigraphic history of this area. For present purposes, however, it is necessary only to point out certain of the characteristics of these rocks. In matrix there is not even approximate uniformity; here it is sandy, here of graywacke character, here arkosic, and more commonly it is best described as porphyritic. The constituent pebbles are varied; porphyries, quartzites, basalts, slates, granites, etc., have contributed fragments. The degree of cementation is apparently quite uniform and the conglomerates are dense, resistant rocks most commonly found causing falls and rapids. (See Plate VI).

Stratigraphically these rocks appear to be below the coal-bearing series and distinctly above certain graywackes, while commonly there is found in close association with them the breccia of peculiar character noted above.

Because of the structure of these older rocks no idea of their total thickness was obtained. In no exposure was a thickness of more than one hundred feet observed and the stratigraphic relation of rocks of different localities was not ascertained. The age of this series is not known but it is considered to be pre-Puget and probably pre-Tertiary. It is possibly to be correlated with the Peshastin formation of Smith and Calkins, in the Mt. Stuart and Snoqualmie areas.



TYPICAL EXPOSURES OF NEWAUKUM ROCKS.

A. Resistant graywacke here causes a narrows in the stream.
B. Conglomerate phase on Newaukum River.
C. Cinnebar creek here cuts through basalt which is intrusive into the Newaukum breccia.

For the purpose of land classification it was not considered necessary to differentiate this older series, hence on the general reconnaissance map it is grouped with the igneous rocks, thus emphasizing its non-coal character.

PUGET SERIES.

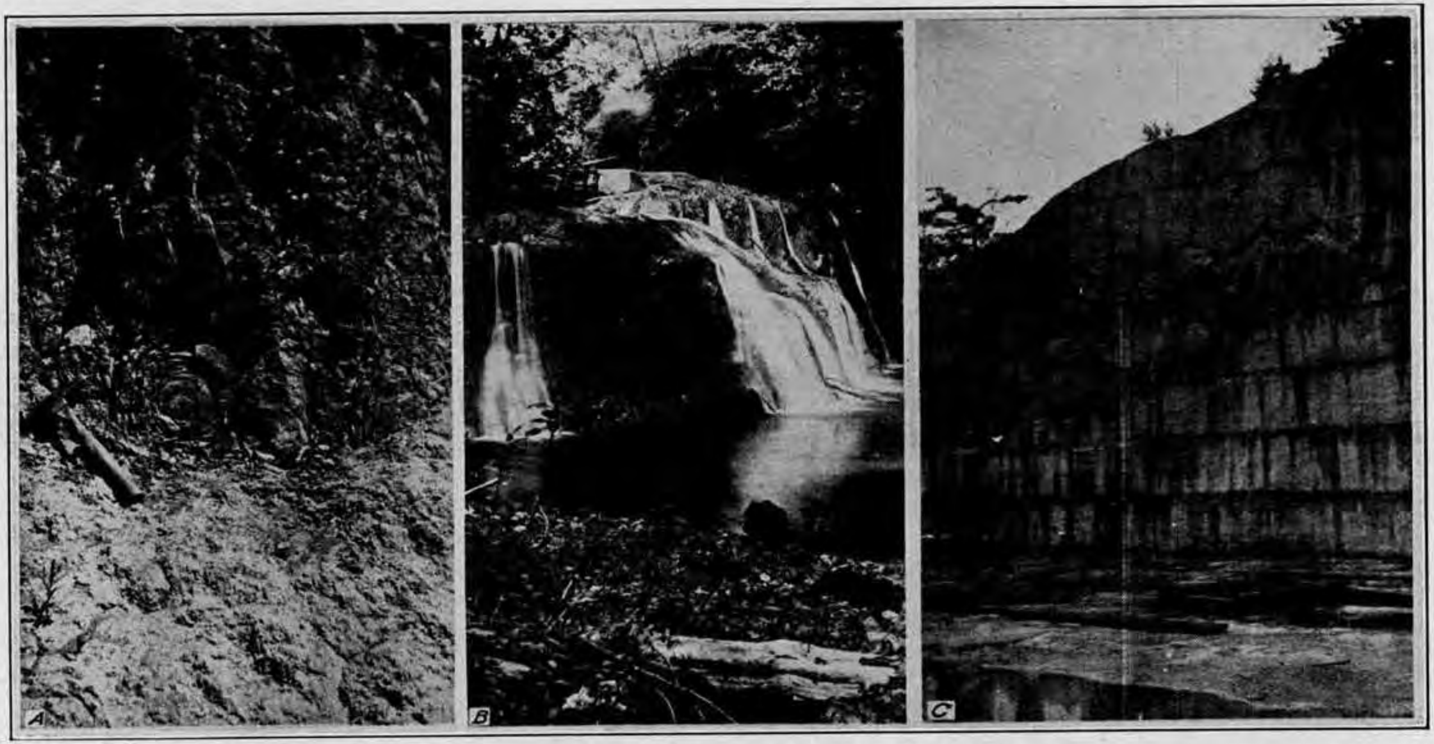
The name Puget was given to the coal-bearing series of western Washington by White*, who placed these rocks in the lower Eocene on the basis of their fossil content.

The rocks of this series have been found in essentially all portions of the field (See Plate I) although wide areas without outcrops are frequently found, more especially in the western part of the field. It is to be noted that the rocks of the Puget series in the western portion are in general less well consolidated and cemented than those in the eastern portion. Hence, while topographic depressions of the Chehalis and lower Cowlitz Valleys may often be fairly interpreted as areas underlain by the weak sediments of the Puget series, in the upper Cowlitz Valley this is not the case, as the igneous rocks frequently outcrop in the depressions.

A great many of the exposures of these sediments are maintained as outcrops by the support of associated igneous rocks. In general, aside from such cases, the exposures of these rocks are in excavations made in the development of roads, mines, etc., while occasionally slightly more resistant strata in the series cause cascades or small waterfalls (See Plate VII). The mineral composition is such that these rocks lend themselves readily to the development of soils, which support considerable vegetation, with the result that only very steep hills show bare ledges.

In a general way these rocks are found in relations suggesting that they represent remnants of originally adjacent or possibly connected estuaries. The wide areas mapped as Pleistocene are thought to be underlain by Puget rocks and probably also by later Tertiary strata. While in the western portion these relations are rather plainly indicated, the areas of Puget rocks in the eastern portion of the field show but slight evidence of connection with those of the west. The general

*White, A. C. On Invertebrate Fossils from the Pacific Coast. Bulletin U. S. Geological Survey No. 51, 1889, pp. 49-63.



TYPICAL EXPOSURES OF PUGET (COAL-BEARING) STRATA.

A. Road cut in massive shales which show well-developed spheroidal structure due to weathering. West of Castle Rock.
B. Falls on Scantigrease Creek caused by a horizontal conglomerate layer overlying less resistant shales.
C. West face of Hercules Quarry No. 2, Tenino. The inclination of the strata is indicated by the uncut bed near the center.

structure of the beds in the Mineral Lake and Ashford areas certainly suggests a closer relation with the Puget series of Pierce County coal fields to the north. The presence of small isolated areas of coal-bearing strata farther east, near the summit of the Cascades, however, suggests that the greater amount of vulcanism and deformation within the mountainous area has caused the lack of apparent connection between the eastern and western portions of the field.

Such wide variations in mineral composition, bedding, fossil content, etc., are shown by the Puget series that the examination of any one outcrop would probably give impressions as to its character which would be quite unreliable for the purposes of comparison with other outcrops. It may be well, nevertheless, to indicate exposures which illustrate certain phases of the series.

For a few miles above its junction with the West Fork of the Tilton River in Sec. 12, T. 13 N., R. 4 E., (See Plate XX) a small stream from the west cuts through the series giving excellent exposures in its bed, best seen at low water. The strata are here lying with rather steep dip, so that some 9,000 feet measured stratigraphically may be observed. In the series are found coarse yellow sandstones, usually thin-bedded; greater thicknesses of micaceous gray sandstone, in part massive, and in part thin-bedded; thin-bedded sandstone with black carbonaceous streaks throughout; and frequent layers, often lenticular, of bony or dirty coal, carbonaceous shale, etc. The shales are mostly black, usually quite resistant so as to appear slaty, but in some places are soft and flaky. Occasional gray shales are seen, quite uniformly thin-bedded. Interspersed with the above mentioned series of beds are numerous masses of igneous rock, mainly a porphyritic basalt, in some places showing mineralization by sulphide waters. These masses are in part sill-like and in part dikes. There is no indication that they are extrusive and the slaty character of the shales which are found in association with these masses may be regarded as a contact effect. The more massive portions of sandstone frequently show well developed pot-holes Fossils are rare, but near the upper portions of the cascades found in the northwest corner of Sec. 10, T. 13 N., R. 4 E., one distinctly fossiliferous gray sandstone was noted. This weathers to a buff from the oxidation of the iron minerals and is rather prominent in the series at this point. Near the center of Sec. 11, in the same township, another thin stratum of fossil-bearing sandstone was noted.

A typical small exposure is that found on Olequa Creek near Vader, just downstream from the Northern Pacific Railroad bridge, near the center of the southeast quarter of Sec. 32, T. 11 N., R. 2 W. Here are found massive to thin-bedded shales at base overlain by coal two feet thick, then followed by shales with gradation to a bony layer in three feet; a peculiar spotted clay above with alternating shaly, bony and coal layers for 6 feet; the coal overlain by a massive sandstone, bluish gray in color and cross-bedded on a large scale. Immediately above these strata are found marine beds of Eocene age mentioned below in connection with the undifferentiated Eocene-Oligocene.

A third and still different phase of this series is shown at Tenino, in Thurston County (See Plate VII C) where the excavations for several stone quarries have exposed a stratigraphic thickness of about 100 feet. This is a massive sandstone phase, almost wholly cross-bedded, of medium fine grain. It is predominantly of well-rounded grains, largely quartz, and shows some muscovite mica, with occasional small pebbles of sub-angular shape, part of which are of tuffaceous material. Gray when freshly fractured, it weathers to a dull buff, with development of sheeting parallel to the surface without relation to the stratification. Some of the quarry exposures show a somewhat more argillaceous phase than others, these usually weathering to a more distinct yellow because of the greater content of iron.

Plant and animal remains are not rare and although in most cases only fragmentary material is found, some excellent specimens of both groups reward careful collecting in a few places. The fossil content of the series as a whole is not large. A few beds are abundantly fossiliferous, some are sparsely so, and probably the greater portion is almost wholly without any organic remains. By far the greater part of the invertebrate fossils found in these beds are classed as estuarine and at present have little value for correlation purposes.

No stratigraphic measurement for this series has been made upon which any reliable estimate of the total thickness can be based. Estimates based upon measurements made on the northwest extension of these rocks in Pierce County gave a total thickness of between 10,000 and 15,000 feet and there is no reason to believe that the total thickness in the Lewis County area, especially in the eastern portion, is less than that. In the western portion, however, it is probable that the deposition in Puget time gave somewhat lesser thicknesses of sediments.

EOCENE-OLIGOCENE (UNDIFFERENTIATED).

Over a rather large area in the western portion of the field are found exposures of sediments which differ from the Puget strata in being of marine origin. While containing insignificant coal seams locally, no workable beds have been found in these rocks. They are probably largely Eocene in age, in part contemporaneous with the Puget series, but in part later. The boundaries in both the Vader and the Independence areas are indefinite as yet and as mapped (See Plate I) include some Oligocene strata. A typical exposure of the marine Eocene rocks of this field is found about two miles north of the Union Station at Centralia, where the Northern Pacific Railroad cuts across the strata for a distance of a quarter of a mile with but slight interruptions. With a nearly uniform dip of 62° this gives a thickness exposed of about 1,100 feet. Examination of this section emphasizes the shallow-water character of these beds; the thin bedding, poor assorting, and interbedding with thin seams of dirty coal are evident. The section is appended:

	Feet.
Very thin-bedded shales	13
Coal, double seam	1
Sandstone	14
Clay, spheroidally weathered	9
Sandstone	6
Sandstone, thin-bedded, fossiliferous, with heavy concretions	7
Sandstone, cross-bedded	5
Shale and yellow sandstone, thin-bedded	17
Coal	1
Shale, sandy	11
Coal	2
Shale, thin-bedded	8
Sands, yellowish, pure, medium thin bedded	70

	Feet.
Concealed	45
Sandstone, shaly and thin-bedded at base	65
Concealed	45
Coal, dirty	1
Shale, thin-bedded	16
Sandstone, clean, thin-bedded	8
Coal	1
Sandstone, yellow, clean, thin-bedded and in part cross-bedded	88
Concealed	50
Shales	6
Coal	3
Shale, fossiliferous	31
Concealed	85
Sandstone, exposed by slump	90
Concealed	176
Shales, highly weathered	62
Coal, burned	5
Thin-bedded shales, baked above	9
Coal, dirty	3
Shales, thin-bedded	18
Coal	3
Shale	22
Coal	1
Sandstone, clean	22
Covered	35
Shales, thin-bedded with interbedded sandy shales	66
Total stratigraphic thickness, in feet	1,120

The total thickness of these strata is only approximately known. Estimates based on measured sections of various portions of the field give a minimum thickness of 5,000 feet. More complete data may show it to be twice or thrice this amount. The intercalated basalt flows which appear in many exposures increase the thickness of the series considerably.

OLIGOCENE.

Bordering the Chehalis River, in the northwestern part of the field, is an area of somewhat later Tertiary rocks which have recently been placed in the Lincoln Horizon of the Oligocene.

No coal has been discovered in this series of beds and their marine origin, of which there is abundant evidence, makes it unlikely that coal in amount to be commercially important is contained in it. A total thickness of about 1,000 feet is exposed in this area. These strata and their fossil content have been described in detail by Weaver* and need not be mentioned further in this connection.

*Weaver, Chas. E., The Tertiary Formations of Western Washington. Bulletin Washington Geological Survey No. 13, 1916, p. 166.

PLEISTOCENE.

Throughout the central portion of the field and northward through Thurston County the older formations are more or less completely obscured by the mantle of overlying sands and gravels of the Pleistocene age. (See Plate VIII). For convenience in mapping, these have been divided into two groups called the Early and Late Quaternary. The former includes sediments of the Satsop formation*; the latter includes deposits of the Vashon glacial epoch, as well as recent alluvium.

No coal of value has been found in these deposits, but there are occasional lenses of lignitic matter. These are perhaps more common in, though not confined to, the Early Quaternary strata.

These two groups differ mainly in the amount of weathering they have undergone, to a lesser extent in the degree of cementation, and somewhat in the character of the materials. Locally the conglomerates of the Early Quaternary are well cemented, comparing very favorably with the coal series sediments in that respect; the sands are yellow, thin-bedded, and well cemented and show abundant muscovite flakes scattered throughout. Except for the apparently perfect gradation upward into the undoubted Pleistocene gravels and their position in an erosion depression in the underlying basaltic rocks below, certain exposures of these deposits might easily be mistaken for strata of the Puget coal-bearing series. Locally coal seams are present in abundance, insignificant in dimensions and of no great purity, but showing that shallow-water conditions permitting local vegetal accumulation obtained at the time of deposition. In general the strata of the Puget formation show better sorting, finer texture, and a higher clay content than the similar appearing strata of Early Pleistocene.

These deposits have been excellently described in detail by Bretz* in several publications and need not be mentioned further in this report.

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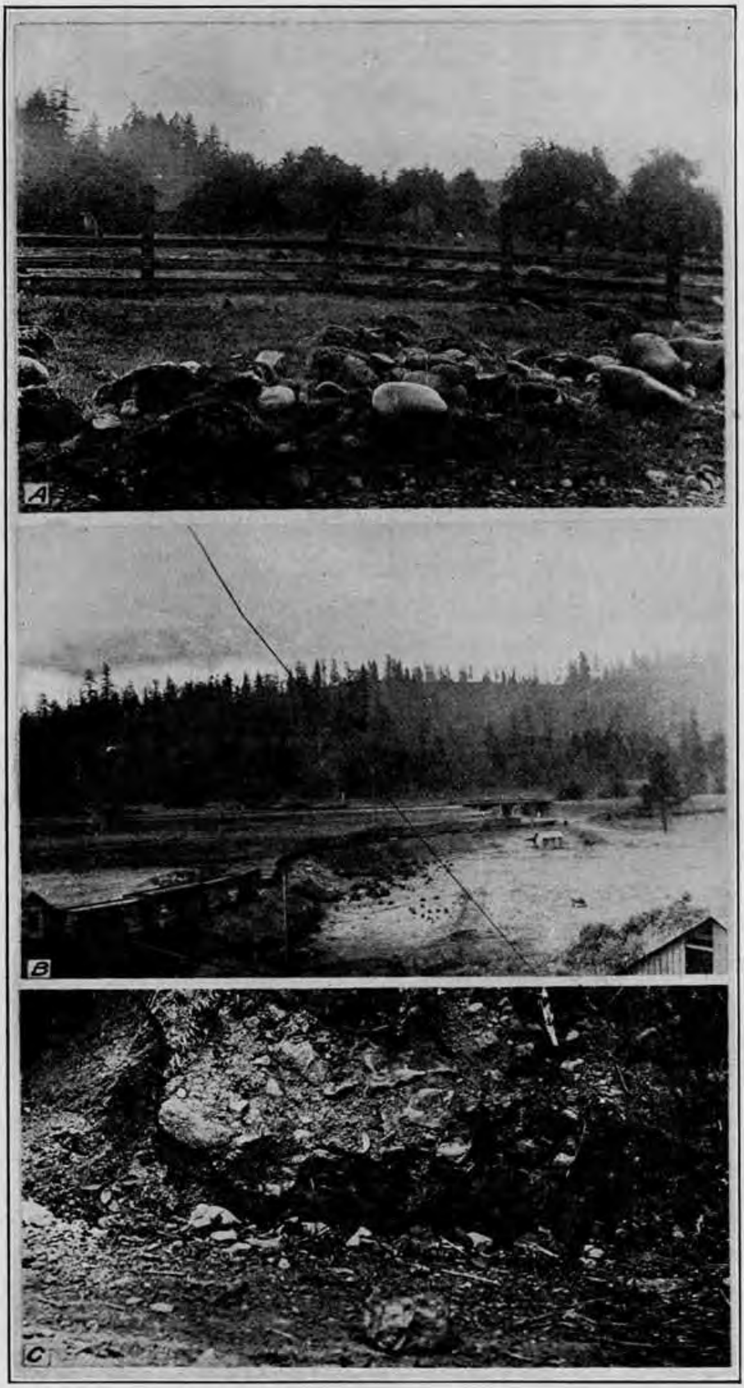
*Bretz, J. H., Glaciation of the Puget Sound Region, Bulletin Washington Geological Survey No. 8, 1913.
Pleistocene of Western Washington, Bulletin Geological Society of America, Vol. 26, 1915, p. 131.
Satsop Formation of Oregon and Washington, Journal of Geology, Vol. 25, No. 5, 1917.



A. Drift covered surface of Tenalquat Prairie.

B. Alluvial flat at Tenino. The lower ridge in the background is underlain by the Puget series and the main elevation is maintained by the basalt of Northcroft Mountain.

C. Contact of the Puget series and Pleistocene gravels, Bear Canyon. This is one of the numerous road cuts which expose the bony coal and carbonaceous shales of the coal series.

GENERAL STRUCTURE.

The field as a whole has not been subjected to severe diastrophism and, although the strata of practically all portions are somewhat deformed, dips of more than 45° or 50° are relatively uncommon and quite local.

In so far as the field is a structural unit it may be considered as comprising sedimentary and intercalated igneous rocks which are thrown into a series of moderate folds with rather uniformly northwest-southeast trend. Cross-folding is apparent in most parts of the field but is relatively insignificant. In the western half these folds are slight, in some portions barely discernible, but to the east as the foothills of the Cascade Mountains are reached, the folding is more pronounced, becoming quite sharp in the extreme eastern townships. The location of the axes of folding required more time than was available and hence they appear on the maps but rarely.

Faulting is quite general throughout the field but is in the main very local. While the areal relations in some localities suggests faulting on a larger scale, the details necessary to a delineation were not obtained. Most of the fractures noted showed displacements of but a few feet. So far as known, then, faulting is not an important phase of the general structure, although the presence or absence of even minor dislocations in the strata of the coal series is of great importance in the coal mining operations. Discussion of this minor faulting will be deferred to a later chapter.

CHAPTER III.

THE COAL BEDS.

DEFINITION OF GRADES OF COAL RECOGNIZED.

In view of the persistent differences in definition it will be of value to precede a discussion of the grades of coal found in this field with a brief statement as to the terminology. In accordance with Campbell's* classification, and the current usage of the U. S. Geological Survey, the following ranks of coal are recognized: Lignite, subbituminous, bituminous, semi-bituminous, semi-anthracite, and anthracite. For the purposes of the present discussion the distinction between the higher ranks is not of concern, but that between the first-named ranks should be made clear. To this end the writer can not do better than quote Smith†, who says: "Subbituminous coal has generally heretofore been called 'black lignite.' The criteria for the distinction of coal of the subbituminous group are, in general, (1) grayish black or black color; (2) almost universal absence of a distinct system of joints; (3) high percentage of moisture, which is given off readily on exposure to the sun or air, this producing the peculiar irregular weathering spoken of as 'slacking' and (4) the tendency of many of these coals to separate on weathering into thin plates parallel to the bedding. Of these features the color and the manner of weathering are the most characteristic. The color distinguishes the group from lignite; the manner of weathering separates it from bituminous coal. Fresh blocks of subbituminous coal, when exposed to the air or to the direct rays of the sun, tend to break up independently of the joint planes into smaller and smaller fragments having irregular faces. The fresh coal has a bright luster and an irregular conchoidal fracture; the resultant fragments are lusterless and the surfaces do not show an even fracture of any kind. Certain subbituminous coals have high heating value and will stand trans-

*Campbell, M. R. Contributions to Economic Geology, 1907. Bulletin U. S. Geological Survey No. 341, 1909, p. 12.

†Smith, E. E. Coals of the State of Washington, Bulletin U. S. Geological Survey No. 474, 1911, pp. 9-10.

portation in closed cars without 'slacking,' but will check slightly when exposed to the direct rays of the sun in open cars. Such coal is evidently near the border line between the bituminous and subbituminous groups.

"Lignite is distinguished from subbituminous coal by its color, texture and amount of moisture. It is brown in color or has a distinctly brownish cast. The texture is usually more or less distinctly woody, although some lignite, notably that of Texas, is amorphous. The amount of moisture is greater than that of subbituminous coal and ranges from 25 to nearly 45 per cent. The lignite of North Dakota is typical of this group."

GRADES FOUND IN THIS FIELD.

Four ranks of coal are to be found within the field under discussion; anthracite, bituminous, subbituminous and lignite. Of these, the first is confined to a small area in the mountainous eastern portion of Lewis County where the strata enclosing the seams have been subjected to severe diastrophic and volcanic action. While considerable sums of money have been expended in the prospecting and development of these seams there has been no coal produced as yet from the area.

Over a somewhat larger area the coal is of bituminous rank. Such coals are bright, show close jointing, and break with cubical fracture. The ash content is rather high, but coal from some of the seams compares favorably with the eastern bituminous coal and the product from a few yields a fair quality of coke. Whether this is of such grade that it can be used for metallurgical purposes remains for determination. At the present time these coals are being mined on only a small scale, but in view of the present demands the development of certain properties is being pushed.

Most of the coal produced in southwestern Washington is of subbituminous rank, although the distinctions between coals of this rank from seams in various parts of the area are obvious. None of the coals mined is typical brown lignite, in fact no coal duplicating the North Dakota lignites in appearance has been found. As to chemical similarity, the lack of analyses of samples from most of the seams makes a definite statement impossible, but so far as data at hand goes, it shows differences in composition equal and corresponding to the differences in physical character.

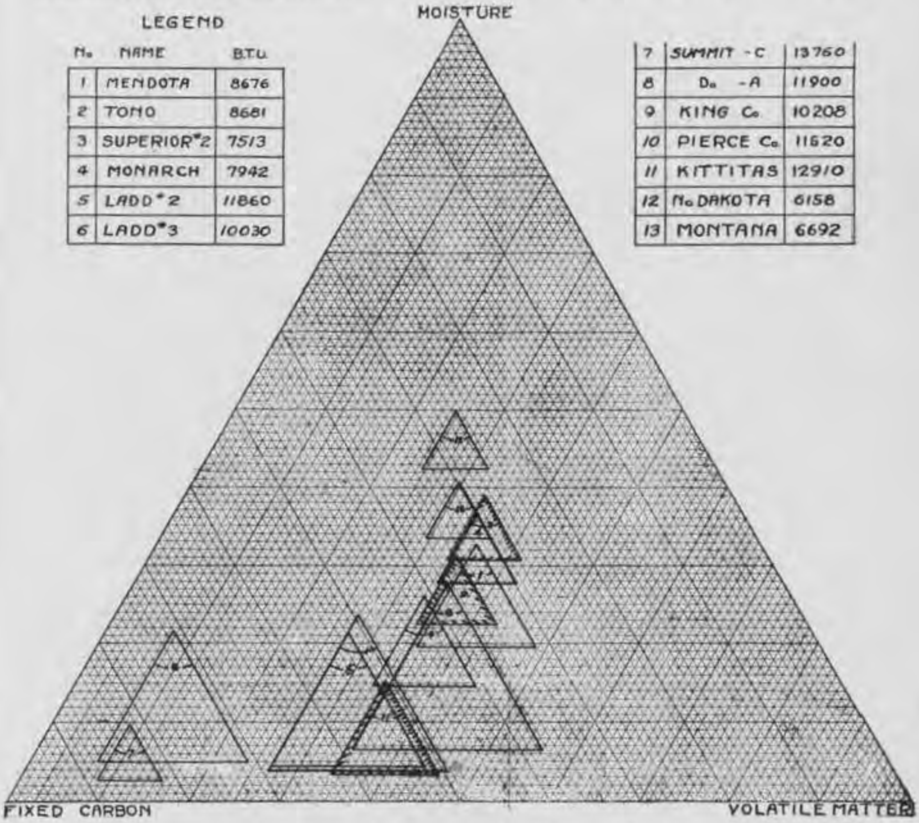
Those coals found in the Vader area and some from the Centralia-Chehalis area and the Kelso-Castle Rock area are the nearest to the true lignites. These are uniformly black in color, with brown streak, but are of distinctly woody texture and have a relatively high moisture content which causes them to air-slack to a considerable degree. They do not stand transportation and must be used locally and within a few months after removal from the mine.

Upon Plate IX have been assembled analyses typical of the coals from various parts of this field, and, for the purpose of comparison, a few from outside fields have been added.

A triangular diagram has been used in which the construction allows the graphic representation of the four important elements in a proximate analysis of coal, viz., fixed carbon, volatile matter, moisture, and ash. Percentages of moisture content are represented by vertical distances in the plot, the fixed carbon and volatile matter content being plotted from right to left and left to right, respectively. In all cases the distances are measured from the base, representing zero per cent, to the apex representing 100 per cent.

It is readily seen that an analysis totaling 100 per cent of fixed carbon would be represented by a single point located at the lower left apex of the triangle, while one showing 50 per cent of fixed carbon and 50 per cent of volatile matter would be represented by a point on the lower line, zero in moisture, midway between the ends. Similarly an analysis showing 50 per cent fixed carbon, 25 per cent volatile matter, and 25 per cent moisture would be represented by a point placed at the intersection of the lines showing these percentages.

An analysis which shows an ash content, on the other hand, would be represented by a triangle instead of a point, since the other three elements would not make a total of 100 per cent. Thus the size of the triangle formed shows the amount of ash present. Any sulphur shown by analysis is plotted with the ash, but in only rare instances is the amount of sulphur great enough to alter perceptibly the graphic expres-



Plot of proximate analyses of coal "as received." For explanation of this method of plotting see Chap. III.

sion of the other elements. One example will serve to make the diagram clear. Analysis No. 12 is as follows:

Moisture	42.2%
Volatile Matter	24.5
Fixed Carbon	26.4
Ash and Sulphur	6.9
	100.0%

For purposes of comparison, then, the higher the content of moisture the higher in the diagram the analysis is shown; the nearer the coal is to graphite the farther toward the lower left apex it appears; the higher the content of volatile matter the nearer the right lower apex; and finally, the greater the ash content the larger the triangle which is formed. Those analyses were chosen for the diagram which would show the gradations in composition between the several ranks. Numbers 1 to 8 are coals from this field, while the rest are introduced for purposes of comparison. No. 9 is from Renton; No. 10 from Carbonado; No. 11 from Beekman; No. 12 from Lehigh; and No. 13 from Glendive. It should be noted that those of the second group are single analyses taken as representing their respective fields rather than "average" or composite analyses. Numbers 1 to 4 are unpublished analyses of samples collected by Joseph Daniels and the writer in 1917; the remainder are taken from Bulletin 22 of the Bureau of Mines. The composition of the coal "as received" has been plotted, thus showing as nearly as possible the constituents as mined.

Of the coals from this field No. 3 is uppermost in the diagram. This analysis is practically duplicated by the others from the Centralia-Chehalis field and so may be taken as fairly typical of the district. While the volatile matter is essentially the same as in No. 9, the higher moisture is accompanied by lower content of fixed carbon. No. 3 is distinctly set off from Numbers 12 and 13, from North Dakota and Montana respectively. These are typical of the true lignites, which analyses show may contain as high as 45 per cent moisture. Numbers 4, 1 and 2, from the Tenino-Mendota field, show, in order, less moisture and more fixed carbon and are thus clearly of subbituminous rank, while No. 3 is on the border line. No.

9, the Renton coal, has much less moisture and correspondingly high content of fixed carbon. This is nearer the boundary between the subbituminous and the bituminous ranks. Numbers 5 and 6, Mineral Lake area, are of bituminous rank and correspond to the Carbonado and Beekman coals, Numbers 10 and 11, respectively. No analyses are available of samples from this field which would occupy an intermediate position between No. 2, the best subbituminous, and No. 6, the lowest bituminous coal. The samples from seams near the summit of the Cascades, while showing essentially the same moisture content as the bituminous coals, are set off from them by the higher content of fixed carbon. These are distinctively anthracitic, No. 7 probably being a true anthracite, while No. 8 is more properly below anthracite grade.

The ash content is seen to be extremely variable, coals of the same group showing no uniformity. The effect of this constituent on the grouping of the coals is best shown by Figure 2, on which have been plotted the same analyses, recalculated to an ash- and sulphur-free basis. Here also the distinction between subbituminous and bituminous ranks is clearer, the former showing more than 14 per cent moisture, the latter less than 9 per cent. The close similarity of the two coals of highest rank is emphasized as is also that of Numbers 5 and 10, from Ladd and Carbonado respectively, both of which are coking coals.

As has been indicated, the coals taken from the whole field represent gradational types between anthracite and high grade lignite. Because of the lack of any system of classification which will place all these coals in their true relation with reference to their commercial value, it is impossible to show graphically the types represented. Between the lower members of the series the intermediate types are well represented and the distinction in luster, fracture, streak, slacking on exposure, and moisture content can be utilized as diagnostics as indicated by Smith.* These do not serve for distinguishing the higher members, however, and the various commonly used bases for classification, such as fuel ratio, split-volatile ratio, etc., have to be utilized.

*Ibid p. 23.

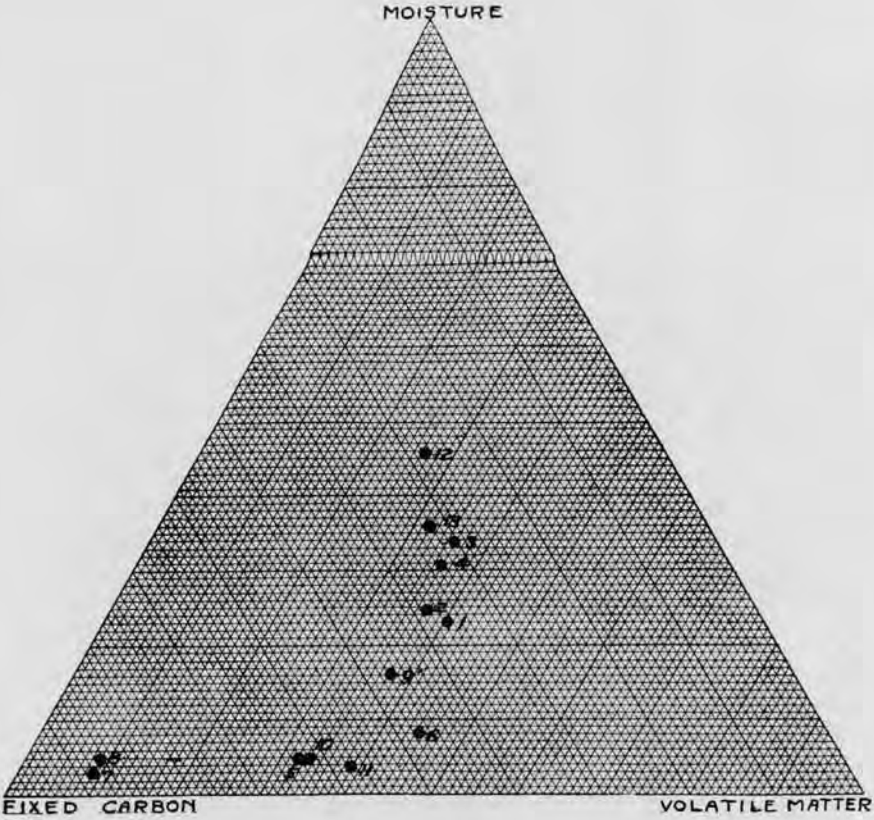


FIG. 2. Plot of the same analyses as those shown on Plate IX, but on an ash-free basis.

The types gradational between the subbituminous and anthracite coals are not so well represented. The reason for this is not far to seek. In the time that has elapsed since the earliest deformation of the coal series a large area presumably once covered by the coal has been swept practically bare by erosive agents. The coal which remains is mainly in the form of down-folded remnants which can be eroded only by the removal of large masses of more resistant rock. Some masses of unknown size have been retained in place through burial by later lava flows. In the main these are inaccessible and so the number of gradational types observed is limited by both factors.

POSSIBLE ORIGIN OF THE DIFFERENT GRADES.

The cause of the differences existing between these coals is a point upon which there has been much discussion. Most of the factors to which the differences noted have been attributed by different students may be grouped under six heads as follows:

a. Length of period elapsing since deposition.
b. Proximity to later igneous masses.
c. Deformation to which the beds have been subjected.
d. Original character of material.
e. Conditions of deposition.
f. Depth of burial.

Of these the first mentioned was uniformly held for some time and it is indeed reasonable to suppose that other factors being equal a great difference in the time during which the coals have been subjected to burial and pressure would result in a corresponding difference in character.

With more careful observation and the widening of the field studied it became evident that the assumption of uniformity of conditions was unwarranted. Subsequently appeal was made to the metamorphosing action of intrusive igneous rocks and later consideration was given to many other factors thought to have an important bearing on the result.

It has been shown that the alteration of vegetal matter to coal comprises two distinct and consecutive processes or sets of processes: one biochemical in character, the other dynamochemical. To quote White,* who has emphasized the im-

* White, David. Bulletin U. S. Bureau of Mines No. 38, 1913, pp. 91-92.

portance of this subdivision: "During the first of these processes the accumulating vegetal matter, under the varying, yet restricted, conditions attending peat formation, becomes more or less disintegrated or decomposed and reduced and many of the organic chemical compounds of the original material are more or less broken down and changed in ways controlled by those conditions. This process was termed 'biochemical,' because the more important transformations take place under the influence of, or in connection with, the vital activities of micro-organisms, the more essential of which are the bacteria. * * * The second or dynamochemical process covers the chemical and physical alterations of the coal-forming matter (peat whether formed under coastal swamp or other conditions) induced and controlled by geodynamic influences. The dynamochemical process follows the 'biochemical,' but it may be conceived as slightly overlapping the latter in most cases."

It is evident that the first process may be terminated with the material at any stage of alteration, from freshly deposited vegetal matter to mature peat, and that even if followed by identical dynamochemical processes the end products will necessarily be different. The introduction of microscopic study of coals has made possible some important inferences as to the conditions under which some coals have been deposited and as to the relation between the character of the original vegetal matter and that of the resulting coal. For a full discussion of this and other phases of the origin of coal the reader is referred to the papers by White, Thiessen and Davis* and by Stevenson†.

None of the coals of this field have been studied in the thin section and as yet it has been possible to give but little thought to this interesting and important line of investigation. It is believed that this field will furnish valuable data as to the dynamochemical processes involved in the coal formation because of the wide range in the degree of deformation to which the strata have been subjected and the equally wide range in the character of the coals formed.

*White, David, Thiessen, Reinhart and Davis, Charles A. Bulletin U. S. Bureau of Mines No. 38, 1913.

†Stevenson, J. J. Proceedings American Philosophical Society. Vol. 50, 1911, pp. 1-116.

The almost complete restriction of the high grade coals to the mountainous areas points to a causal relation between the grade of coal and the degree of deformation, while the local occurrence of coals of high rank adjacent to igneous masses makes plain the relation in such cases. Both factors have operated in this field and the relative part played by each remains for future study to reveal.

In the appendix are listed all the analyses of these coals which are available for comparison. In general the coals of the field show the following variations:

Moisture	4—30%
Volatile	24—35
Fixed Carbon	27—51
Ash	5—21

The character of coals from different parts of the field shows such marked variation, however, that no reliable general statement can be formulated. The reader is referred to the descriptions of local areas and individual mines and prospects in Chapters IV and V, for statements as to the exact character of coal found.

AMOUNT OF COAL UNDETERMINED.

Upon the important question as to the amount of coal in the field and the proportion of this which is recoverable there is but little information. Few seams, if any, are known to have an areal extent of more than five or six hundred acres. In most cases the known area is far less than that although the possible area is much greater. The local character of the deposition of the coal is indicated by that of the enclosing sediments and seems to be more marked in this than in the other fields of the state. On this point, however, serious doubt may be raised as the limited extent of present workings does not warrant generalizations. Because of the frequent interruptions of beds through erosion, intrusion, or faulting, the calculation of tonnage in even the known seams is rendered of small value. The low folding in some parts, the later basalt covering in others, and the widespread "concealed" areas make the presence of many unknown coal beds probable. These factors combined make it unlikely that the coal resources of the field will ever be known in advance of the actual exploratory work.

CHAPTER IV.

DETAILS OF THE VARIOUS AREAS; I, WESTERN PORTION.

KELSO-CASTLE ROCK AREA.

GENERAL GEOLOGY.

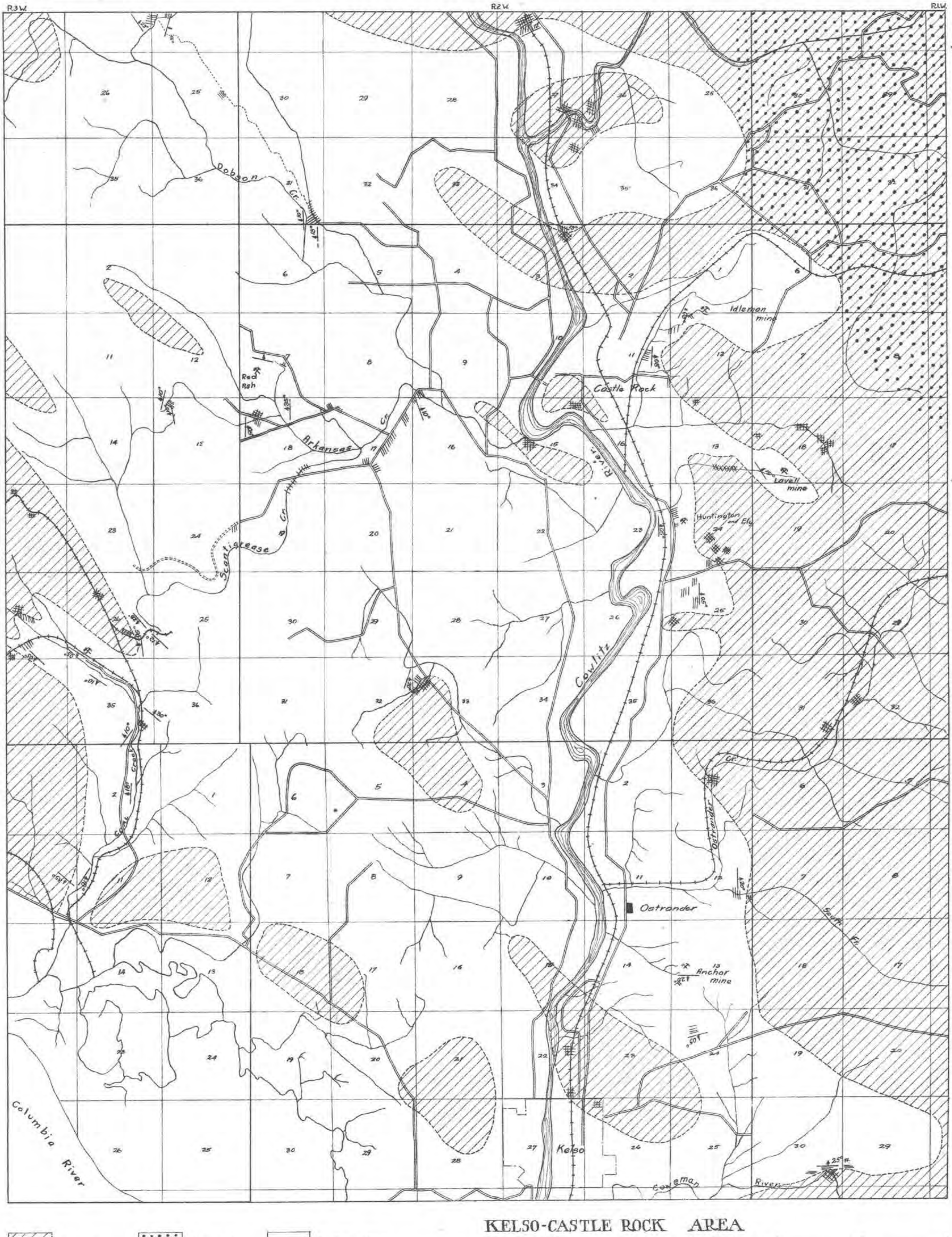
The boundaries for this field include most of T. 8 N., all of T. 9 N., and the south half of T. 10 N., the east half of R. 3 W., all of R. 2 W., and the west half of R. 1 W.

As shown on the detail map, Plate X, igneous rocks occupy the eastern portion of this district, an irregular line separating them from the sedimentary rocks to the west. The two are apparently interbedded throughout the area, the igneous predominating in the east. This relation is clearly indicated at many places along the boundary, the re-entrants being parallel to the strike of the enclosed sediments. Some of the irregularities of the boundary are due, however, to the presence of dikes projected from the major masses.

The extreme northeastern portion is concealed but is thought to be underlain by igneous rocks. Throughout the area mapped as sedimentary, exposures of apparently small masses of igneous rocks are not rare. The close relation existing between lithology and topography in this field was of use in fixing the boundaries of igneous masses as a supplement to the scanty data from the outcrops.

The igneous rocks show great similarity throughout the district in lithology as well as in their relation to the sediments. No slices of these rocks were studied, but the variations in composition are believed to be of minor importance. For practical purposes these rocks may all be classed as basalts. Typical exposures of these rocks are to be seen in the quarries at Kelso and Castle Rock as well as in the cuts along the Northern Pacific Railroad, one of which, showing excellent columnar structure, is illustrated by Plate V B.

The area underlain by sedimentary rocks is one of low relief and outcrops of these beds are found but infrequently, even in the stream channels. Excavations for railways, roads and mines furnish the rest of the exposures.



KELSO-CASTLE ROCK AREA

The sediments are all Eocene so far as known, but it is possible that some of the beds along Dobson Creek in the northwestern portion are Oligocene. In large part these beds are coal-bearing and are for that reason considered to be of estuarine origin. Interbedded marine strata are found, however, as in the Coal Creek area of R. 3 W. Sandstones, occasionally conglomeratic, shales, and coal, with all the intergraduations make up the series wherever exposed. With the exception of the conglomerates and locally at contacts with the igneous rocks, these sediments are loosely compacted and often scarcely cemented. For a typical exposure of about forty feet of these rocks see the section reported below from the mouth of Toutle River. (Page 54).

It is believed that the sediments and interbedded igneous rocks have been upfolded slightly and the tops of the low rolls eroded. The fragmentary character of the data at hand makes an attempt at location of the structural axes of little value, but the general trend of the folds is northwest-southeast. The field, then, is to be considered as comprising repetitions of a sedimentary series of moderate thickness through truncation of several folds rather than a single series of enormous thickness exposed by erosion of a single fold. In view of the structure and the lack of any extensive exposure of section the estimates as to thickness are at best very rough. It seems probable that the series comprises some 4,000 or 5,000 feet of strata.

Coal has been discovered in nearly all portions of this field and has been mined successfully in widely scattered localities. In character it is quite uniform throughout the district, the variations shown in samples from the several mines and prospects being due largely to differences in ash content. The few analyses available place most of these coals with the better grade of lignites, and the physical characters bear this out. Locally, however, the coal is subbituminous or better in rank, but such masses are of very limited extent and probably have resulted from changes induced by the intrusions with which they are always associated. The seams usually show clean coal of slightly dull luster, quite black in color but of brown streak. It is usually more or less woody in texture and sometimes exhibits a slight flexibility. On long exposure to the air it breaks into small fragments.

The seams are usually variable in thickness and more or less lenticular in shape. No seam of great extent has been discovered and examination of sections exposed emphasizes the local character of the deposition of the vegetal matter and of the clastic material composing the coal series as well, so that it is unlikely that seams of wide extent will be found in the area.

The coal series are found over an area of about 85 square miles, but because of the lenticular character of the strata it is impossible to estimate with any accuracy the area underlain by workable coal, or the tonnage of the field.

DESCRIPTION OF MINES AND PROSPECTS.

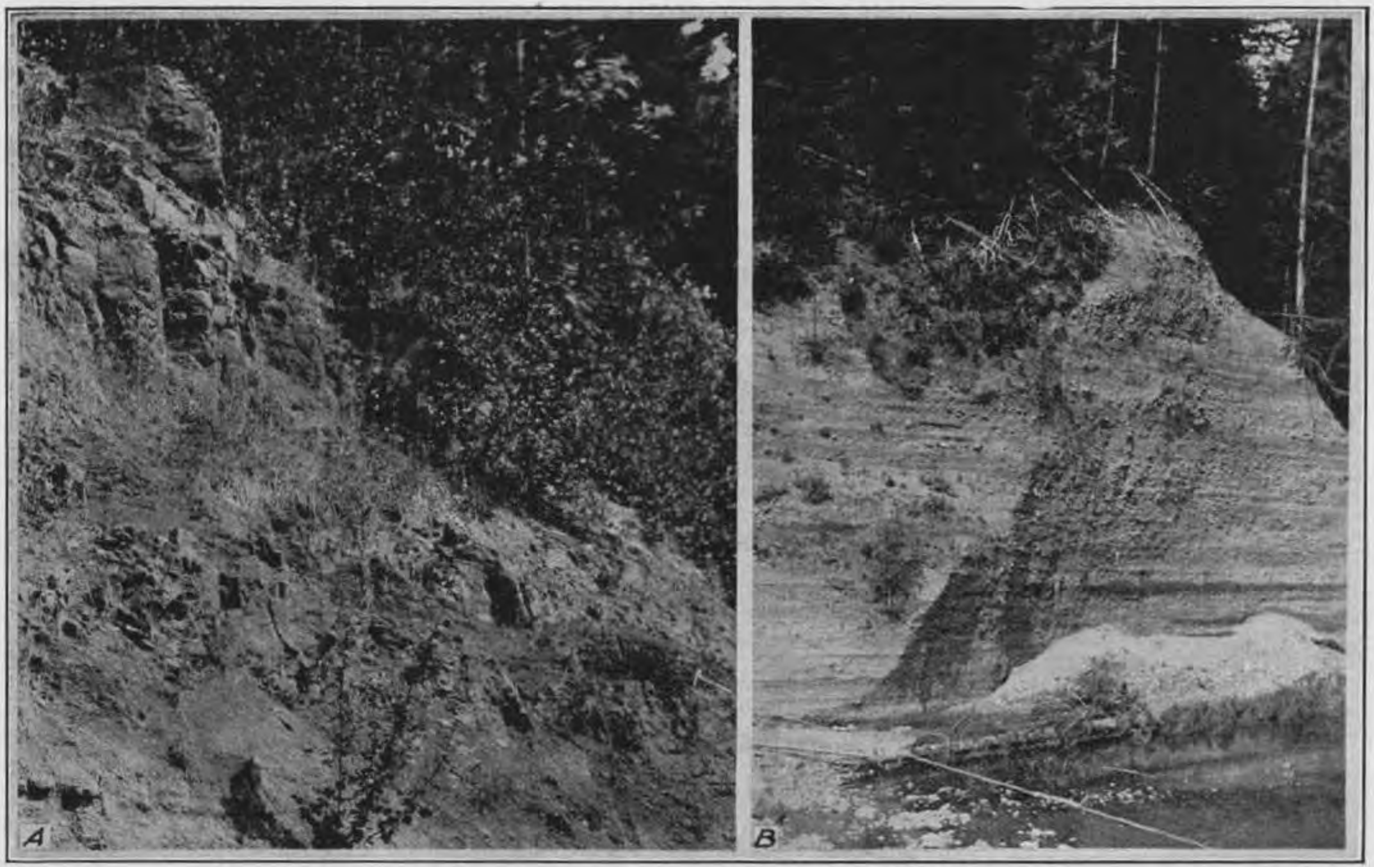
COWEMAN RIVER

Coal is found about three miles due east of Kelso near the south line of Sec. 30, T. 8 N., R. 1 W. A section of about 25 feet is exposed in the north bank of the Coweman River and in a road cut above the bank. An entry was driven at this locality about 1896 but has been abandoned and slides have nearly obscured the entrance. The section comprises several coal layers with shales, sandstones, and some tuffaceous and basalt masses. The basalt is found both above and below the coal, which is in thin bands and of no value. Plate XI A, a photograph of the upper portion of this exposure, shows the interbedded coal and tuffaceous layers with several feet of basalt above. The beds strike N. 90° E. with a 25° dip to the north.

The locality was visited by Collier* and the following section reported from Sec. 31:

	Feet.	Inches.
Sandstone	20	
Coal	1	
Sandstone	3	
Coal	1	
Shale	4	
Coal		6
	29	6

*Collier, A. J., Bulletin U. S. Geological Survey, No. 531, 1913, pp. 324-5.



A. Exposure of coal on Coweman river. The coal series is here overlain by tuffs and basalt. The lignitic layer is indicated by the hammer.

B. Typical exposure of Pleistocene gravels in the "covered" area of the Mineral Lake region. Tilton River west of Morton.

Northeast of Kelso, in the northwest quarter of Sec. 24 (T. 8 N., R. 2 W.) an abandoned shaft is found cutting sandy shales underlain by sandstone. Because of slides, water, etc., but little can be seen. Collier* mentions a "report that considerable coal was found, samples of which air-slacked badly."

ANCHOR MINE.

This mine is located in the west half of Sec. 13 (T. 8 N., R. 2 W.) and two entries have been made. In the west entry a 12-foot bank exposes loose, medium fine, slightly shaly sandstone, gray but weathering to buff. This is quite massive but shows extensive cross-bedding. Within this is about two feet of thin-bedded carbonaceous shale and at the base of the exposure about three feet of bone and dirt with one inch or more of coal. The beds strike east-west and dip south at 15°. In the main entry the section as shown by Figure 3b was measured. Landes† reported on this property as follows: "Two veins were worked, one about four feet and the other five feet in thickness. A narrow gauge railroad three-quarters of a mile long ran from the mine to the Cowlitz River, where the coal was loaded in barges." Reports of the State Coal Mine Inspector show that this mine was opened in 1891 and a total of 4,600 tons mined before 1897, when operations ceased.

OSTRANDER CREEK.

On the south fork of Ostrander Creek, in the southeast quarter of Sec. 12, T. 8 N., R. 2 W., about 15 feet of the coal series is exposed on the west bank. A short drift shows sands and shales associated with the four-foot coal seam. The beds show a strike of 10° east, dipping southeast 20°. Across the stream, and 100 feet above this point, an incline has been run on the coal a short distance. This prospecting was done in the early nineties. The coal is here overlain by a rather coarse grained basalt, probably a part of the same mass which, 50 yards above, causes an interesting cascade in the stream. This cascade is attractive because controlled by well developed vertical columns in the basalt.

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*Ibid. p. 325.
†Landes, Henry. Annual Report Washington Geological Survey, Vol. 1, 1901, pt. IV, p. 64.

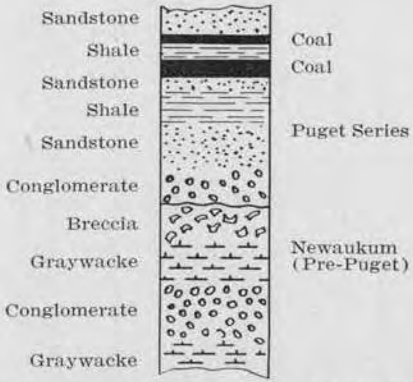


FIG. 3a. Diagrammatic section showing the contact of Puget (coal-bearing) and pre-Puget strata.

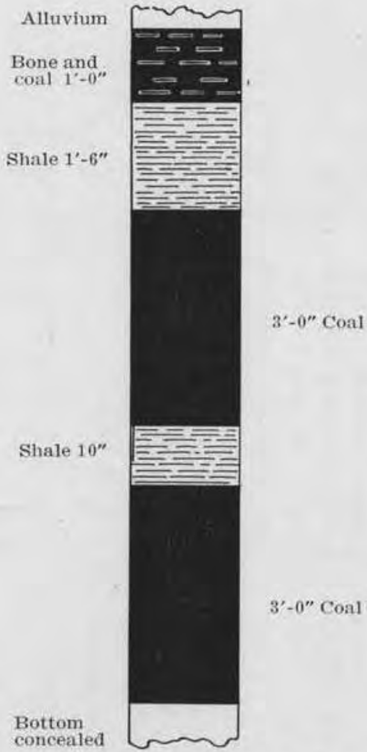


FIG. 3b. Section of coal seam in the main entry of Anchor Mine.

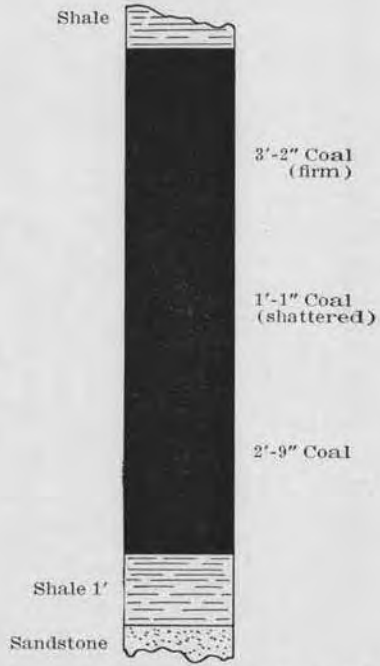


FIG. 3c. Section of coal seam in Sheldon Mine.

COAL CREEK.

The beds of the coal series are found frequently along Coal Creek for four miles above the bridge in Sec. 10, T. 8 N., R. 3 W. Impure coal in seams of from three to six feet in thickness is found in Sec. 11, west half, interbedded with loose, cross-bedded sands with some shales. Below these are several feet of dense basalt underlain by nearly 100 feet of sediments, some very fossiliferous. The structure here is complicated by several minor faults, but the beds have a general southerly dip with strike from northwest to a little south of west.

Throughout Sections 35, 26 and 27, T. 9 N., R. 3 W., the sediments have a northwest strike, dipping to the southwest beneath the basalts at a low angle. The creek here follows along the strike of the beds and hence exposes only a small section comprising sandstones, shales, carbonaceous beds and several coal seams.

On one of these seams outcropping in the southwest quarter of Sec. 26, a slope was run some 400 feet in what was known as the Coal Creek Mine.

Landes* has reported the following section for this mine:

	Feet.
Sandstone	
Coal	3
Shale	2
Coal	4
Sandstone	

In 1904 Diller† collected samples from this mine and reported the coal to have a thickness of about six feet, with two small partings of sand. The upper bench had 12 to 18 inches of bony coal, the middle bench 30 inches of coal of better grade, and the lower bench had 18 inches of coal, in part good. The coal was reported to slack on exposure.

*Landes, Henry. Annual Report Washington Geological Survey, Vol. 1, 1901, Part IV, p. 63, and Vol. 2, 1902, p. 256.

†Diller, J. S. Coal in Washington near Portland, Oregon: Bulletin U. S. Geological Survey, No. 260, 1905, pp. 411-412.

Diller's samples gave the following analyses:

	No. 6760.	No. 6761.
Moisture	15.24	16.26
Volatile matter	36.28	36.33
Fixed carbon	29.54	30.05
Ash	18.94	17.36
Total	100.00	100.00
Sulphur	4.39	4.61

Note—Color of ash, light red-brown; non-coking. This shows a high content of ash and sulphur.

HUNTINGTON AND ELY MINE.

This mine is located in the west half of Sec. 24, T. 9 N., R. 2 W., about 2 miles south and a little east of Castle Rock. The slope was undrained in 1917 and the section could not be measured, but Collier* reported:

	Feet.	Inches.
Coal	2	
Clay, white		2
Coal	2	
	4	2

The strata strike N. 20° E., dipping at less than 5° to the southeast. No analyses are available but the coal is said to have so high a sulphur content as to be undesirable even for domestic uses. This mine was worked more as a prospect than as a producer, so that only a low tonnage was mined before it was abandoned about 1914.

One mile south of this mine, near Tucker, coal has been found in Sec. 25, (T. 9 N., R. 2 W.) in the gullies from the east. Near the center of the section a series comprising some 20 feet of blue sands, thin-bedded and cross-bedded, with some four feet of rather clean coal with interbedded shale is exposed in the stream bed. A prospect on this coal was visited by Collier†, who reported as follows:

	Feet.	Inches.
Coal		6
Sandstone	2	
Coal	2	
Sandstone		6
Coal	4	
	9	

*Collier, A. J. Bulletin U. S. Geological Survey, No. 531, 1913, p. 327. (This was here reported as the Carbondale Mine.)

†ibid. p. 327. (Reported as the Budd prospect.)

LEAVELL MINE.

This mine, formerly called the Carbondale, is located in the southwest quarter of Sec. 18, T. 9 N., R. 1 W., about three miles southeast of Castle Rock. The slope enters at about N. 50° E. on a 27° dip, although the dip of strata nearby is about 15°. Slump within the slope prevented entry, but Collier* reports the following approximate section:

	Feet.	Inches.
Coal	3	6
Clay, white, sandy	1	
Coal	1	3
	5	9

Analyses of this coal, reported to have been made at the State College of Washington in 1908, gave the following results:

	A	B	C
Moisture	15.0	8.0	7.5
Volatile matter	35.4	43.0	44.0
Fixed carbon	43.8	46.0	47.0
Ash	5.6	3.0	1.5
Sulphur	.2	0.0	0.0
	100.0	100.0	100.0

Samples of this coal after exposure of several years still showed a black color, bright luster and but little checking due to air-slacking.

This slope was opened for nearly 250 feet with east and west gangway of about 300 feet. A fault was apparently reached at 212 feet. As shown on Plate X, the coal series here occupies a small area almost wholly surrounded by igneous rocks. These are of coarse texture and hence might be expected to have had considerable metamorphosing effect. It seems probable that the high rank of this coal is to be accounted for in this way.

IDLEMAN MINE.

This mine is in Sec. 1, T. 9 N., R. 2 W., near the south line, hence about one and one-half miles northeast of Castle Rock. The strata strike N. 30° E., dipping S. E. at 15°. Undrained at the time of examination, the slope could not be entered. The seam is reported by miners to flatten out with

*Ibid. p. 328.

depth. The mine opening is at the base of a 100-foot hill capped by basalt, which overlies the coal series in this vicinity. Collier* reported a 4-foot seam of clean coal, of a grade somewhat better than that found near Kelso.

This mine was opened in 1892 and worked intermittently up to 1896 and attempts to reopen it were made several years later. A total production of about 2,000 tons during this time was reported by the State Coal Mine Inspector. Landes† reported three seams "having widths of four feet, six inches; four feet, one inch, and six feet, respectively."

About one-half mile southwest of the mine a prospect drift has been driven, but no ledge rock could be seen at the time of observation. It is reported that a 5-foot seam of clean coal was found dipping at an angle of 8° to the northeast on a strike N. 18° W.

RED ASH MINE.

This mine is located a little southeast of the center of Sec. 7, T. 9 N., R. 2 W., and is thus about four miles due west of Castle Rock. This mine was opened in 1896, but was closed a year or so later. No reliable analyses or measurements of the coal seams are available and the flooded condition of the workings prevents re-examination. The beds in this vicinity strike northwest with a dip of about 30° to the northeast. Examination of material on the dump above shows that the usual impure sands and shales with coal of somewhat woody texture were encountered. Collier‡ says: "The coal bed is said to be about six feet thick, but has near the center a one-foot parting, probably of sandstone."

The area south and southeast of the Red Ash mine shows with few exceptions nearly flat lying strata of the coal series for a radius of five miles or more, while to the north coal has been found in the Shutt prospect, in the northeast quarter of Sec. 32, and in the Whittle prospect in the southeast quarter of the northeast quarter of Sec. 29, both of T. 10 N., R. 2 W. Farther north in the valley of Dobson Creek in the west half

*Ibid. p. 328.

†Landes, Henry. Annual Report Washington Geological Survey, Vol. 2, 1902, p. 256.

‡Collier, A. J. Bulletin U. S. Geological Survey No. 531, 1911, pp. 328-9.

of Sec. 24, T. 10 N., R. 3 W., a coal bed over two feet thick is found in a series of rather fine shales containing much organic matter, with cleaner shales, micaceous sandstones, hard, concretionary, dark blue sandstones and some very fossiliferous shales. These strata, a portion of a rather extensive exposure, strike N. 23° W., dipping 21° to the northeast.

TOUTLE RIVER.

Coal is found along the Toutle River just above its junction with the Cowlitz in T. 10 N., R. 2 W. The section found at this point is as follows:

	Feet.
Pleistocene gravels and sands	8
Shales, micaceous, carbonaceous, with coaly stringers; bone at top	8
Shales, loose, grading below to sandstones	4
Sandstones, loose and coarse	14
Coal, with 2-inch shale parting	2
Shale	2
Conglomerate, fine, well cemented	3
Shale, concretionary, well cemented	3
Basalt, amygdaloidal	2
Total	46

The basalts of the area conform to the bedding of the sediments and because of the common vesicular surfaces are believed to represent lava flows rather than intrusions. Collier* reports an eight-inch coal seam of better grade from a point about one-half mile upstream from the exposure described above. This shows the columnar fracture of bituminous coal and like that from the Leavell Mine may be considered as having been metamorphosed through the introduction of igneous rock into the series either as a flow or as an intrusive sill.

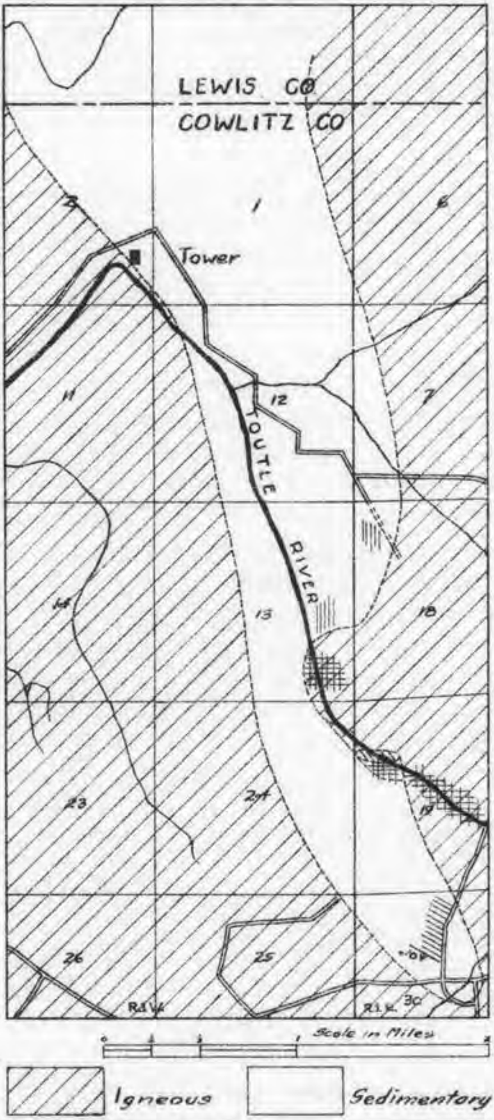
COALBANK RAPIDS AREA.

GENERAL GEOLOGY.

This district is located in T. 10 N., along the Willamette Meridian, with an indefinite boundary to the north in Lewis County. This is a very small area of probably not more than five or six square miles, but because of the occurrence of the coal, as well as its geographic isolation, it should be distinguished from the Kelso field to the west and the Vader field to the northwest.

*ibid. p. 329.

COALBANK RAPIDS AREA



The Toutle River passes at this point from an igneous rock area into one of sediments (See Plate XII), traversing the latter in the strike direction, which is approximately north, before turning to join the Cowlitz some ten miles to the southwest. Igneous rocks are found nearly surrounding the sedimentary series which occupy a strip some six miles long and scarcely a mile wide. Even within this strip, masses of igneous rocks are to be found.

The igneous rocks are for the most part andesitic porphyries and occur in masses much larger than those found to the west at the mouth of the Toutle. The rock usually shows a dense ground mass, gray-black in color, with abundant phenocrysts of feldspars scattered through it. The relation of the various masses is not clear, but there are presumably one or more nearly horizontal sills cut by dikes of smaller size, the texture of the rocks indicating relatively slow cooling without evidence of flow origin.

The sedimentary rocks are very poorly exposed, but show limited outcrops, which appear to be remnants of an originally larger mass so cut by intrusions of the igneous rocks as to leave but small portions at any one place. The beds are essentially horizontal, where reliable structural data could be obtained, but doubtless considerable variation occurs locally.

The best exposure of either igneous or sedimentary rocks is within half a mile of the new bridge across the Toutle River at the rapids in Sec. 19, T. 10 N., R. 1 E. A section at this place shows porphyry, as exposed in the gorge of the Toutle, perhaps one hundred or more feet in thickness, overlain by but separated from a heavy conglomerate or agglomerate containing boulders up to three feet in diameter; the whole showing a high degree of weathering. Above this stratigraphically, but separated by fifty paces, is a series of buff to brown sandstones and shales containing near the base several lignitic seams one foot or more thick.

DESCRIPTION OF MINES AND PROSPECTS.

Coal is found about one-half mile above the County bridge in the northwest quarter of Sec. 19, T. 10 N., R. 1 E. Although reported to outcrop on both sides of the river, at the time of the writer's visit it could be seen on the west bank only and here slump due to undercutting by the stream prevented a satisfactory examination. One or more seams are present associated with a medium conglomerate, fine sandstones, and shales. Large loose fragments of silicified wood were found on the shore. The coal is lignite, of very woody texture and somewhat splintery fracture and has a brown streak. Although frequently reported to the contrary, it is not thought that coal of any value will be found in this vicinity.

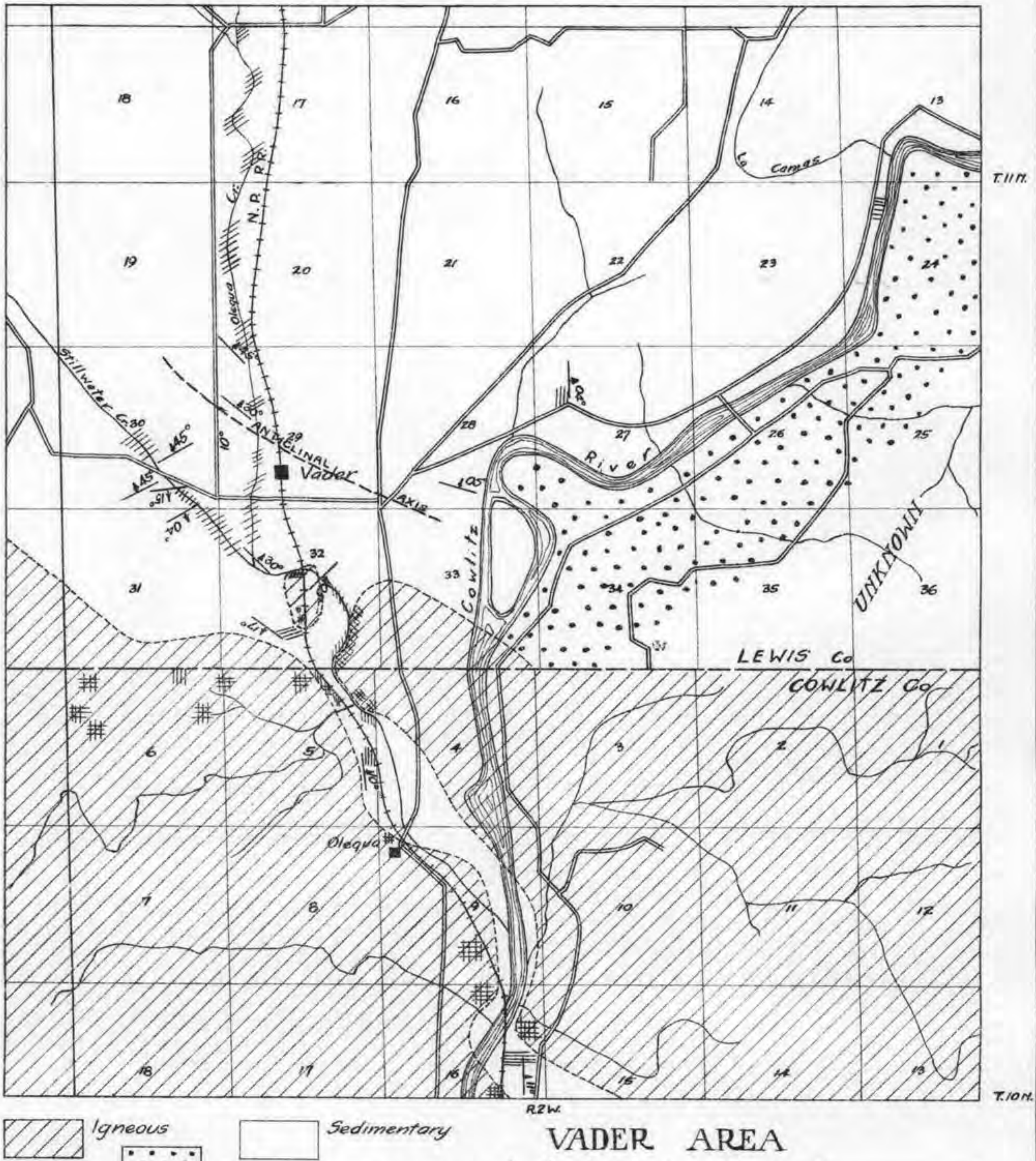
WALKER MINE.

This mine is located in the southeast quarter of Sec. 13, T. 10 N., R. 1 W., on the east bank of the Toutle River. The section exposed in the two open cuts shows a fairly thick seam of lignite without apparent partings. The coal is quite black in color, but is distinctly woody. The bed is nearly flat-lying but has a slight northeast dip.

Coal was found one-half mile to the north on Sec. 18, T. 10 N., R. 1 E., where a drill was sunk in the northeast quarter. Prospects farther east in Sec. 18 encountered only igneous rock.

Coal is reported in the south half of Sec. 35, T. 11 N., R. 1 W., and is thought to belong geographically in this district.

In Sec. 10, T. 10 N., R. 1 W., about two miles southwest of Tower, coal outcrops near the base of the west bank, which is here well over 100 feet high. The river here, in cutting a gorge-like channel through the andesite, has exposed a small mass of the coal series. The relation to the igneous rocks which are found both above and below, and apparently on either side as well, is not clear. The sediments seem to occupy a small pocket within the igneous mass, being entirely cut off from other sediments. The section shows at the top a conglomerate with cobbles up to six inches in diameter, a soft gray clay, thin-bedded, below, and this underlain by at least six feet of woody lignite with the base concealed. No analyses have been made of this seam but in view of the great masses of igneous rock in the immediate vicinity it is unlikely that this seam has sufficient extent to be commercially valuable even though of high grade.


Vader
Olequa
Stillwater Cr.
Olequa Cr.
N.P. R.R.
Cowlitz River
Camas
ANTICLINAL AXIS
UNKNOWN
LEWIS Co
COWLITZ Co
T. 11 N.
T. 10 N.
R 2 W.
Igneous
Sedimentary
Covered
Scale 1" = 1 mile

VADER AREA

VADER AREA.

GENERAL GEOLOGY.

This district lies in R. 2 W., and includes the north half of T. 10 N., and the south two-thirds of T. 11 N.

Except for a narrow strip along Olequa Creek, only igneous rocks are found in the southern half of the field. (See Plate XIII). In most outcrops they are highly weathered, but examination of fresh samples shows them to be mainly basalts of dense texture frequently showing grains and small nodules of olivine. Good exposures are found in cuts along the Northern Pacific Railroad from Vader southward. The igneous rocks are probably with few exceptions sills intruded into the coal series, but because of the nearly horizontal attitude are widespread areally. Little is known of the portion of the field lying east of Olequa and it is possible that it contains sedimentary formations essentially continuous with those to the north along the Cowlitz River. The only relation of the igneous rocks to the coal in this district is the probable effect of their proximity in Sec. 15, mentioned below.

Sedimentary rocks outcrop frequently and indeed almost continuously along Olequa and Stillwater Creeks, less frequently along the Cowlitz River and rarely elsewhere. From the position and structure of the sediments where observed, however, it is clear that they underlie a wide area to the north and west of Vader as well as extending eastward across the Cowlitz River and southward in a narrow strip toward Castle Rock. It is impossible with the present data to fix accurately the limits of the area underlain by the sedimentary formations and the boundaries set are arbitrarily determined.

A typical exposure, that on the west bank of the Cowlitz River, in Sec. 28, T. 11 N., R. 2 W., shows the stream cutting a channel in soft, yellowish-gray shales, sandy in part and locally abundantly fossiliferous. The shales are quite massive, the structure being indicated by the interbedded layers of concretionary shale, which are dense, more resistant, and literally packed with shells, shell fragments and bits of carbonized wood. These beds dip gently to the northeast and are concealed up-stream by Pleistocene gravels.

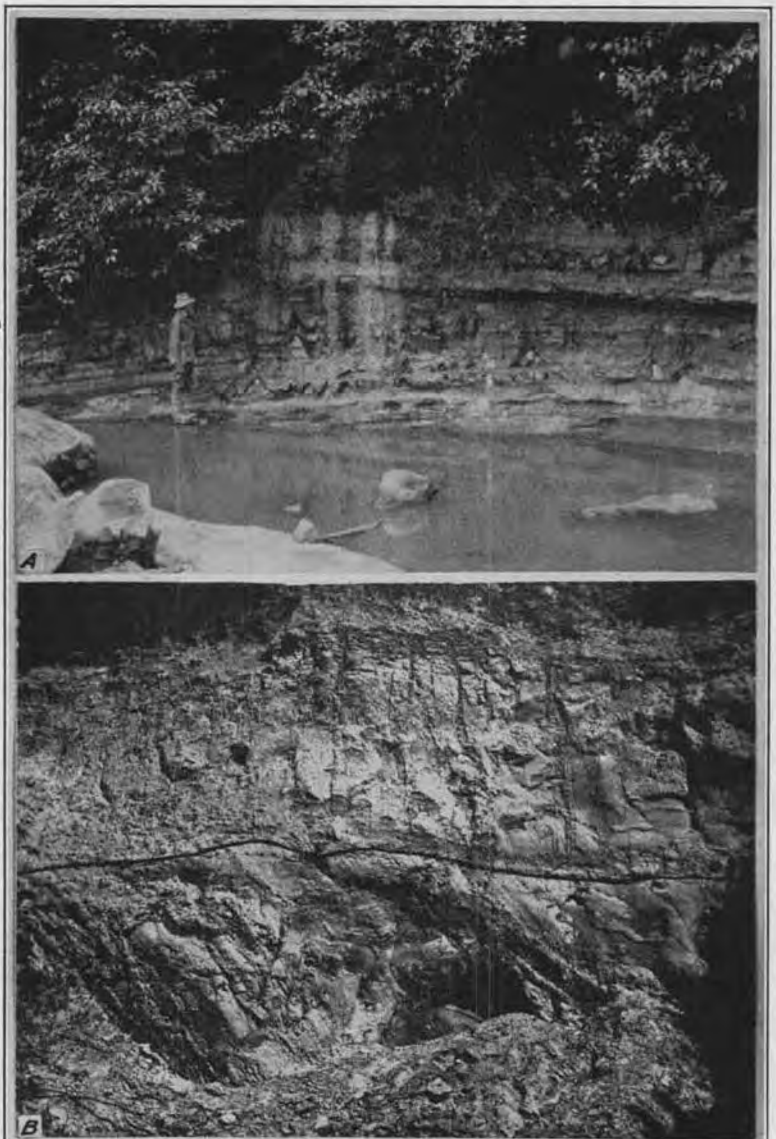
Another exposure, located about one-half mile above Vader on Olequa Creek, shows the following section:

	Feet.
Gravels, with soil above	2
Shale, massive	12
Grit	1
Shale, massive	11
Grit	1
Shale	3
Grit	1
Shale, massive	5
Grit, base concealed	1
Total	37

On Olequa Creek, below Vader and just downstream from the Stillwater Lumber Company's dam, another excellent exposure of shales and sandstones is found. These are considered to be of Eocene age. Two groups of strata are recognized with a slight angular discordance between them. (See Plate XIV A). The lower series is exposed but a few feet and comprises at the base shaly sands, greenish but weathering yellow-brown, overlain by 10 to 15 feet of similar sediments, sparsely fossiliferous and interrupted by about six bands, six to eight inches thick, of harder lenses and nodules in fairly regular beds.

The upper series shows at base two to four feet of sand with one or more nodule layers and some fossils, overlain by a purplish gray quartzitic stratum eight to ten inches thick. This is overlain by a gray sand layer of 15 inches bearing a five-inch fossil layer not definitely delimited. Over this is a three to 12-inch stratum of thin-bedded sand, locally pro fusely fossiliferous, with undulatory surface. Above it comes a series of lenticular sands, in part hardened and in part soft, with thin-bedded sands wrapped about the harder lenses in some cases. Irregular bands of fossils appear in either hard or soft portions. Over this is about 10 feet of massive gray-green shale, no fossils noted. This has above it a tuff, pumiceous at base and conglomeratic at top. Overlying are two feet more of shales with pumice bands, and 15 feet of massive shales, in part thin-bedded, are at the top.

It is seen that there is no marked change in the character of the strata in going from the lower to the upper series to mark the contact of the two series, the lower is simply elim-



A. Exposure of marine Eocene beds near Vader. Note the slight angular discordance between the two series of strata.

B. Pleistocene beds lying on the eroded edges of Eocene shales. The latter dip steeply to the right. Note the apparent stratification produced by weathering discoloration near the center of the picture.

inated along a slightly irregular plane like that of common cross-bedding. The size of the discordance makes that interpretation improbable, while the presence of a wavy contact line points to the inference of local unconformity.

From the variation in the lithology and the fossil content of the sediments of this field, it is evident that more than one formation is present. On the basis of a rather detailed paleontologic study of the rocks along Stillwater and Olequa Creeks Weaver* has shown the probable existence of a series of marine, brackish and fresh water sediments, in part Eocene and in part Oligocene. The differentiation of the coal-bearing strata, which are considered estuarine in origin, from the marine, is not yet complete, but the coal series of this area may fairly be considered to include a considerable thickness of marine strata interbedded with those of brackish and fresh water origin. Weaver's measurements show a thickness of about 1,700 feet for the coal series, including about 400 feet of marine sediments.

At the south end of the field basalts are intercalated with these rocks, which show great variation in both dip and strike, but in the northern half of the field a more uniform structure is exhibited with the major folding in a general northwest-southeast trend. The complications due to cross-folding are locally pronounced as along Stillwater Creek, about one mile due west of Vader. Faulting on a small scale has occurred but it is not an important feature of the structure.

DESCRIPTION OF PROSPECTS.

Coal outcrops in this field at various places and has been rather extensively prospected, but no mines have been opened. Where exposed the coal is a black lignite of woody texture, bright when fresh, but becoming dull on long contact with the air. It is quite uniform throughout the district and although so far as known analysis has been made of none of these coals, they would probably show a low heating power. The lack of structural details except at isolated points makes the estimation of the extent of a given coal bed impossible. It is be-

*Weaver, Charles E. Eocene of the Lower Cowlitz River Valley, Washington. Proceedings California Academy of Sciences, 4th series, Vol. VI, No. 1, 1916.

lieved, however, that the strata of the coal series, and presumably the coal seams, are rather more continuous in this area than in the fields to the north or south. On this assumption the coal series would be found underneath an area of at least 50 square miles. Over a portion of this area they are probably overlain by purely marine beds of later age. Northward, beyond Winlock, the covering of Pleistocene deposits has obliterated all trace of Tertiary rocks but it is fair to assume that at no great depth the coal series will be found, thus extending the Vader field to the southern limits of the Chehalis area.

At the south end of the field, in Sec. 16, T. 10 N., R. 2 W., coal was found in a cut made along the Northern Pacific Railroad on the south bank of the Cowlitz River. The upper portion of the section here exposed includes a mass of olivine basalt showing columnar structure, the three to four-foot columns standing normal to the plane of contact with the sediments below. The latter include about eight feet of clean shales overlying some 15 feet of shales with six interbedded lignite layers, each from one to two feet thick. At the contact with the basalt the shales show blackening and some baking, but no effect was noted on the basalt. One-half mile to the southeast, in Sec. 15, is located the Fuller prospect which, as reported by Collier*, shows the following section:

	Feet.	Inches.
Bone		6
Coal		8
Sandstone	1	6
Coal		6
Total	3	2

The beds dip to the northeast in these sections and their northwest extension beneath the basalt is problematical.

For three miles north of this point outcrops of sediments are found in places along Olequa Creek. Carbonaceous shales are common but no coal beds are exposed. The stream here is following along the strike of a portion of the basalt-sedimentary formation in which the sediments greatly predominate, the basalt remaining as prominent ridges on either side

*Collier, A. J. Bulletin U. S. Geological Survey, No. 531, 1911, p. 329.

with sharp faces to the southeast and gentle slopes to the northeast.

Coal is found in the southeast quarter of Sec. 32, T. 11 N., R. 2 W., in the strata described on page 28. This is a lignite of low grade and the series here is overlain by a thick mass of basalt which renders prospecting impossible.

In many places along Stillwater Creek, as in Sec. 30, T. 11 N., R. 2 W., near the crossing of the county road and in Sec. 24, T. 11 N., R. 3 W., near the mouth of Brim Creek, entering from the north, beds of lignite are frequently found. Similarly, north of Vader, along Olequa Creek, lignite is found outcropping in the stream channel, as in Sections 29, 20, 17 and the northeast quarter of Sec. 8. Again, near the north line of Sec. 24, T. 11 N., R. 2 W., the shales of the coal series containing two or more seams of coal outcrop in the west bank of the Cowlitz River. High water prevented careful examination of this section, but the coal is presumably of about the same grade as that found throughout this area. In the area west and south of Winlock the writer has visited half a score of prospects on lignite seams, one of which has a reported thickness of eight feet. In none of these prospects was the coal series well exposed, so no sections were measured. Lignite, scarcely more than wood in texture, is reported by Collier* as occurring about one mile east of the area shown on Plate XIII, on Cedar Creek, in Sec. 30, T. 10 N., R. 1 W.

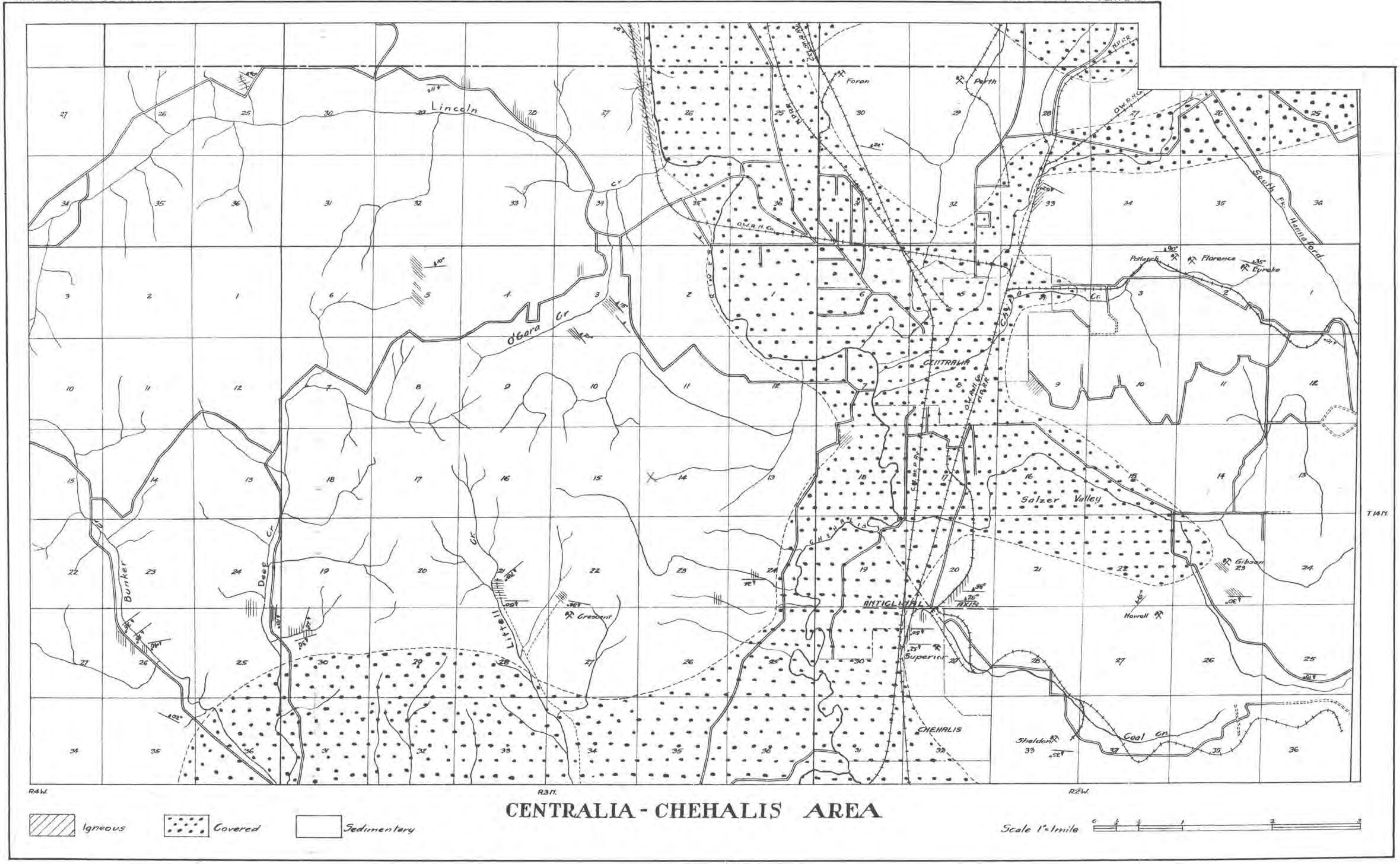
CENTRALIA-CHEHALIS AREA.

GENERAL GEOLOGY.

This field includes T. 14 N., and the southern part of T. 15 N., in R. 2 W., and R. 3 W., and the eastern half of R. 4 W. (See Plate XV). The boundary between this and the Mendota field to the east is drawn arbitrarily for the convenience of discussion, rather than by reason of any geographic or geologic distinction which can be made between them.

This is an area of moderate relief, no hills rising more than 400 or 500 feet above the lowlands. The hilly lands lie in the northwest and southeast parts, while between them lies the level valley of the Chehalis River, in which the thick

*Ibid. p. 330.



CENTRALIA - CHEHALIS AREA

Pleistocene alluvium conceals all the rocks of earlier time. Because of the heavy covering of vegetation, the few natural outcrops of ledge rock must be sought for diligently along the stream courses and the operations of logging, mining and road-building furnish a large part of the data available for this region.

Igneous rocks are found in but two localities in this area, one in a road grade in Sec. 35 (T. 14 N., R. 3 W.), and the other in the bed of Littell Creek, about the middle of Sec. 28 of the same township. In both instances these are relatively small masses of basalt and apparently quite isolated from the flows which are found to the southwest. From the structure of the associated sediments it is probable that these represent a single flow in a series otherwise free from igneous rocks. Indication of the continuity of the mass is found in the development of a red soil along the probable trend.

Two and probably three formations of sedimentary rocks are found within the limits of this field. In the extreme northwestern portion, along the Chehalis River, are found extensive outcrops of marine strata of Eocene age. These are in the main massive, gray, shaly sandstones, locally fossiliferous, but some more resistant concretionary beds are found with the massive strata. On the basis of the fossils contained these beds are classed by Weaver as marine Tejon, and thus they represent the deposits laid down in the sea at the time the coal seams were being formed in adjoining estuaries to the east. West of these outcrops, but with an undetermined boundary separating them, is found an area of somewhat similar sediments which have been placed in the Oligocene. The southern boundary of this formation is not determined, but it must lie near the north line of T. 14 N.

The major portion of this field is thus seen to be underlain by rocks of the coal-bearing formation, of Upper Eocene age. These strata are for the most part thin-bedded sandstones, gray when freshly exposed but showing yellow and brown staining when weathered. They are usually poorly cemented, but occasionally show resistant phases which are frequently fossiliferous. A typical exposure of the coal series is illustrated on Plate XIV B. Here the gravels of Pleistocene age overlie the truncated beds in the south limb of the anticlinal fold mentioned below.

Where details are available the structure of the field is seen to be relatively simple. Folds are encountered, but usually these are neither sharp nor extensive. The area as a whole is dominated by two anticlinal and two corresponding synclinal folds, of roughly parallel trend. The southernmost anticline involves the strata in the vicinity of Chehalis, bringing the beds encountered in the Superior Mine up to a dip of 53° while further to the southeast the dips are less, the beds of the Sheldon Mine showing about 35°. The westward extension of this structural element is problematical, but there is evidence that the trend is maintained to the vicinity of Deep Creek where the fold apparently turns to the southwest before swinging to the northwest north of Meskill.

To the north the axis of the second anticlinal fold is found in the vicinity of Centralia, but the paucity of outcrops makes the exact location in doubt. This is not a sharp fold but is comparable in character with the syncline to the south. The trend is about N. 70° W. at Centralia but swings to the northwest, where it is followed by the Chehalis river as it crosses into Thurston County.

Just north of this anticline the beds are involved in a sharp downfold which gives dips of 62° at Wabash while farther to the east the beds on the axis have vertical dips as shown in the Potlatch, Eureka and Florence mines. The local character of this fold is shown by the shallow dips observed along its extension to the northwest where it involves the beds found in the Ford's Prairie and Perth mines.

What data is available for the northwestern portion of this area shows that low dips are the rule and it is probable that in this portion the cross-folding is nearly as pronounced as the major folding.

The coal from this field is essentially black in color, although showing a faint tinge of brown on most samples. The streak is almost black, the fracture is somewhat conchoidal, giving a slabby appearance to the face of a cut, and the texture is only very slightly woody. Fresh samples of these coals are somewhat satiny in luster, but on short exposure become dull and earthy. In rank they are quite uniform and are placed on the border line between low grade subbituminous and high grade lignite, but are distinctly of better grade than most of the coals previously described from the Kelso and Vader districts.

Nearly a score of mines have been in operation at various times in this field, but the correlation of seams between them has not been possible in most cases. Even for those mines on adjoining sections variations in the thickness and sequence of strata has made correlations doubtful. Obviously the extent of seams where not actually exposed in the mines is uncertain and for this reason the tonnage of this field as a whole can not be estimated. Without doubt the actual tonnage is many times greater than the amount that can be estimated from the workings.

DESCRIPTIONS OF MINES AND PROSPECTS.

SHELDON MINE.

The Sheldon Mine, No. 2 on Figure 1, is located on the southeast quarter of the northeast quarter of Sec. 33, T. 14 N., R. 2 W., about one mile due east of Chehalis. It is reached by a logging road which comes up the valley of Coal Creek from the northwest. This mine is on the south limb of an anticlinal fold, the beds striking nearly due east-west with a southward dip of 35°. The face of the main gangway, where sample 29569 was taken, shows the section illustrated by Figure 3c.

This mine was opened in 1912 and has been a producer on a slowly increasing scale ever since. The average daily production is about 65 tons.

The mine is opened by a slope and levels have been turned to the northwest and southeast. The present method of operation is by chute-and-pillar. Gangways are nine feet wide, and chutes seven feet wide on 36-foot centers have been driven up the full dip of the coal. Pillars are cut by crosscuts, four feet by four feet in size, at variable distances from 35 feet to 50 feet, dividing the lift into a series of blocks of coal. These pillars are removed by angle cuts on the retreat. The coal is screened over two and one-half inch, one and one-eighth inch, and three-eighths inch round screens, producing lump, nut, pea

—3

and slack sizes. This mine was visited by E. E. Smith,* who says: "Sample 8843 was taken 250 feet east of the slope and 40 feet up the rise from the first level. The bed contains near the middle a parting of 10½ inches of carbonaceous shale and coal which can be separated from the remainder of the bed by careful picking and washing, and this portion of the bed was not included in the sample.

"The coal is brownish black and has a reddish brown streak. The structure is massive and banded, and the fracture conchoidal. The high percentage of moisture causes the coal to slack very readily upon exposure to the air. The coal should be classed as low-grade subbituminous."

SUPERIOR MINE NO. 2.

The Superior Mine No. 2 (No. 1 on Figure 1) is located in the northeast quarter of Sec. 30 and the northwest quarter of Sec. 29, T. 14 N., R. 2 W., within the city limits of Chehalis. This mine is on the south limb, but nearer the axis of the same fold that involves the strata of the Sheldon Mine just described. The beds strike essentially due east-west with a 52° dip southward. A section measured at the face of the gangway beyond No. 34 chute, where sample 29568 was taken for analysis, is shown by Figure 4a.

There are several mines in this vicinity on the same or adjacent coal seams and the records as to the early operators on the various properties are not clear. About one-half mile east of Superior No. 2 is Superior No. 1, and about one-quarter mile farther east is the location of Twin City Mine. The first opening of the group, on what was known as the Rosenthal property was probably made as early as 1885, but the report of the Coal Mine Inspector for 1895 shows the Rosenthal Mine to have been opened in that year. About 1901 the property was operated by Miller Brothers and in 1911 the present opening was made. It was known first as the Murphy and Johnson Mine and later as the Superior No. 2. Production has been continuous since that time.

A slope bearing S. 23° W. and having a dip of 52° is the main opening. Two levels have been driven from the slope

*Smith, E. E. Bulletin U. S. Geological Survey, No. 474, 1911, p. 166.

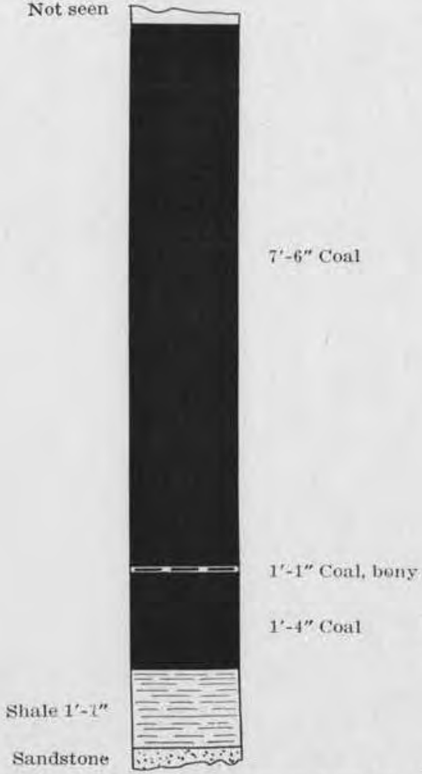


FIG. 4a. Section of coal seam at Superior No. 2 Mine.

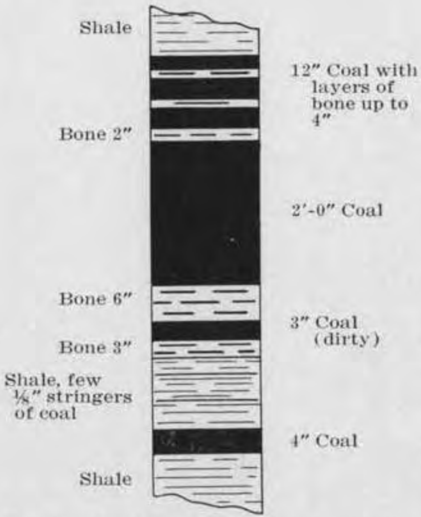


FIG. 4b. Section of coal seam measured near the Littell Mine.

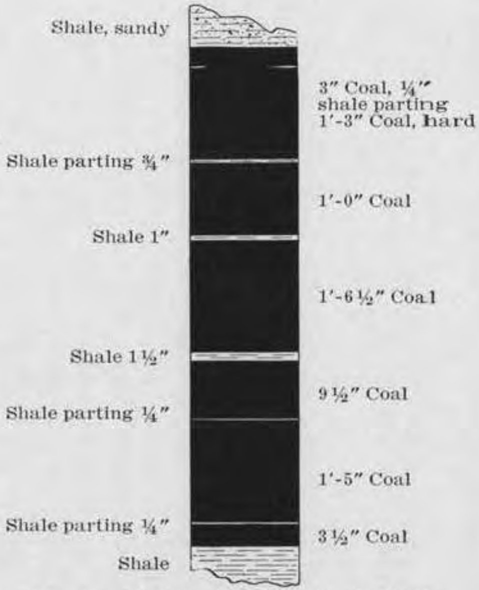


FIG. 4c. Section of coal seam at Ford's Prairie Mine.

towards the southeast, but the lower level is the only one now operated.

The method of working is by chute-and-pillar, a modification of the room-and-pillar method made necessary by the steeper dip of this coal. The gangway is driven nine feet wide and chutes are opened from it across the full dip at an angle, making the dip on the chutes 39°. These chutes are driven seven feet wide on 40-foot centers up to a distance of 45 feet from the gangway and then they are narrowed down to four feet in width. A counter gangway is driven here four feet by four feet in section. Cross-cuts are driven between rooms leaving 35 feet of pillar between successive cross-cuts. This practically divides the pillar coal into blocks 35 feet square. These blocks are removed in slices retreating toward the gangway, using batteries to hold the coal, and timbering the territory over which the pillars have been removed. The coal is drawn from chutes at the gangway.

The method of preparation is by screening. Shaker screens having two and one-half-inch round and two and one-half-inch bar openings followed by one-inch round openings receive the mine coal and separate it with grades sold as lump, egg-nut and pea-slack. The average daily production is about 75 tons.

This mine was visited by E. E. Smith,* who says: "Sample 9941 was obtained in chute 5 about 50 feet above the first level gangway. The bed contains one carbonaceous shale parting near the bottom, which can be separated by picking and was therefore not included in the sample.

"The coal has a brownish-black color, a reddish-brown streak, massive and banded structure, and a conchoidal fracture. It contains a high percentage of moisture, slacks very easily upon exposure to the air, and is a very low-grade subbituminous coal."

Three other mines in this vicinity are reported upon by E. E. Smith†, and the following notes are taken from his report.

*Ibid. p. 164.
†Ibid. pp. 162-165.

SUPERIOR MINE NO. 1.

The Superior No. 1 is a water-level mine one mile northeast of Chehalis, operated by the Superior Coal Company of that town. The "coal bed is about 11 feet in thickness. It strikes N. 70° W. and dips 40° S. W. The entire bed of coal, which is the same bed as that mined in the Twin City Mine of the Twin City Light & Traction Company about one-fourth mile west, is mined, but as the sample from the Twin City Mine was taken from a lower bench very near this mine it was considered that a sample from the upper bench to supplement the Twin City Mine sample was all that was necessary. The following is a section of the upper portion of the bed at this mine and that from which the sample (9942) was taken:

	Feet.	Inches.
Sandstone		
Coal	1	7
Shale, sandy		½
Coal		3
Shale, sandy		½
Coal	2	0
Shale		1
Coal		6
Shale, hard		
Shale		
Total	4	6

"The coal is passed over a one-inch bar screen at the bunker, picked and dumped in the bin. * * * The coal is brownish-black and has a reddish-brown streak. It is massive and banded and breaks with an irregular conchoidal fracture. Owing to its high percentage of moisture, it slacks very readily upon exposure to the air. It is probably on the border line between low-grade subbituminous and high-grade lignite."

TWIN CITY MINE.

The Twin City is a slope mine one mile northeast of Chehalis, operated by the Twin City Light & Traction Company of Chehalis. "The coal bed worked in this mine is a lower part of the bed worked at the Superior No. 1 Mine about one-fourth mile east. It strikes N. 70° W. and dips 40° S. W.

The following section was measured where the sample (9945) was taken:

	Feet.	Inches.
Shale		
Coal, with thin, irregular bands of shale	4	0
Shale		6
Coal	1	7
Shale		3½
Coal	2	6
Shale		1
Coal		7
Shale, thin lens		½
Coal		3½
Shale		½
Coal		9½
Shale		
Total	10	8½

"Sample 9945 was taken on the east end of the first level gangway about 300 feet from the slope. The bed contains several shale partings which can be easily separated by picking and washing and these were, therefore, not included in the sample."

This coal, a subbituminous, is practically identical with that of the Superior No. 1 Mine, according to Smith.

CHEHALIS MINE.

The Chehalis is a drift mine two miles east of Chehalis, operated by the Chehalis Coal Company. "The coal bed strikes N. 30° E., and dips 30° S. W. The following section was measured at the place where the sample (9944) was taken:

	Feet.	Inches.
Shale		
Coal	2	10
Shale, soft "mining"		9½
Coal	2	9½
Shale		
Total	6	5

"Sample 9944 was obtained in the first water-level gangway 250 feet from the entrance of the mine from a stump pillar which had been drawn and which had probably been exposed to the air for some time. A parting of soft shale near the center of the bed is used as 'mining' and is separated from the coal by picking." Smith described the coal here as being similar to that of the Superior Mine.

At least one other mine, known as Leonard's Mine, has been opened in this vicinity. This is located in the north half of the southwest quarter of Sec. 28 (T. 14 N., R. 2 W.). It was operated in 1895 and 1896 by the Chehalis Coal Company, with a production of about 2,500 tons. It was reopened in 1915 and about 2,000 tons mined. No data as to the character of the coal or the structure of the strata are at hand.

CRESCENT MINE.

On Littell Creek, about five miles west of Chehalis, the Crescent Mine was opened in Sec. 22, T. 14 N., R. 3 W. The beds dip about 35° to the south on a N. 80° W. strike. The mine was opened in 1902 on what was reported as a 10-foot seam of good grade lignite and was spasmodically worked, first by the Crescent Coal Company and later, in 1907, by the Coast Range Coal Company. No report from this property appears after 1908 and at the time of the writer's visit slides prevented a detailed examination of the mine, but a section measured in the bank of a creek nearby is shown by Figure 4b.

North of the mine opening an 11-foot seam was reported to outcrop. This would be about 250 feet stratigraphically below the seams mentioned. E. E. Smith* reported upon this as a water-level mine operated by the Union Coal Company, Seattle. He says further: "Several coal beds have been opened at this mine, but a sample could be obtained only from the main bed. This bed strikes N. 85° W. and dips 40° S. A bench of coal one foot six inches thick is left as a roof to support the sand overlying it. Wherever this roof is broken and the rocks are moist the sand flows into the mine in large quantities and makes the conditions of operating very unsafe. This mine was not being operated at the time it was visited. The following section was measured at chute 17, between chutes 18 and 19, and about 800 feet from the entrance to the first water-level gangway.

*Ibid. p. 164.

No. 9940.

	Feet.	Inches.
Sand		
Coal	1	6
Coal		9½
Shale, hard		4
Coal	1	6
Shale		1
Coal		3½
Shale, hard		6
Shale, yellow	1	0
Shale, carbonaceous		9½
Coal	1	5
Shale		½
Coal	1	3½
Shale, carbonaceous		
Total	9	6½

"Sample 9940 was taken where the section given above was measured. The bench of shale two feet three and one-half inches thick near the center and small partings of shale in both the upper and lower benches of the bed should be removed in preparation for the market, and these were not included in the sample. The large amount of foreign material included in the bed, together with that which mixes with the coal from the floor and the roof, will increase the amount of ash in the marketable coal above that shown in the analysis very greatly unless it is very carefully removed.

"The coal is brownish black in color, and has a reddish-brown streak. It is massive and banded, and breaks with a conchoidal fracture. It contains a higher percentage of moisture than any other coal sampled in the state, and slacks very readily on exposure to the air. This coal should be classed as subbituminous."

Near the south line of Sec. 21 along Littell Creek the following section was measured:

	Feet.
Gray sandstone, thin-bedded	20
Black shales	2
Coal	3
Shaly Sandstone, thin-bedded	8
Sandstone tuff, cross-bedded massive-base concealed	30
Total	63

In a tributary stream just west of this location coal was reported from a five-foot seam. In this case possibly the two feet of shale overlying the three feet of coal was included.

Both these occurrences are along the strike of strata in the Crescent Mine and presumably belong at the same horizon in the coal series.

SALZER VALLEY MINES.

Just south of Centralia a broad flat stretches several miles to the east, known as the Salzer Valley. Coal has been found in several places in the low hills along the margin of the flat. In 1904 the Gibson Mine was opened in Sec. 23, T. 14 N., R. 2 W., and was operated for three years and then sold to Jones and Jewell. It was not reported after 1908 and at the present time caving prevents examination of the tunnel which enters the brow of the hill on a S. 80° E. trend. For the production of this mine see appendix B.

MARION HOWELL MINE.

In the northeast quarter of Sec. 27, T. 14 N., R. 2 W., at least two openings have been made on a coal seam about five feet thick. This, the Marion Howell Mine (No. 11 on Figure 1) is located near the crest of a rather sharp anticlinal fold trending southwest. Local flexures introduce considerable variation in both dip and strike. In the present workings the beds are essentially flat but show a monoclinal bend at the east which carries the seam down several feet to the old workings. In other directions the beds show rather sharp upfolds but no fractures of the coal seam have been encountered. At the northwest margin of the workings the bed shows a nearly vertical up-raise and prospect openings in the hill above

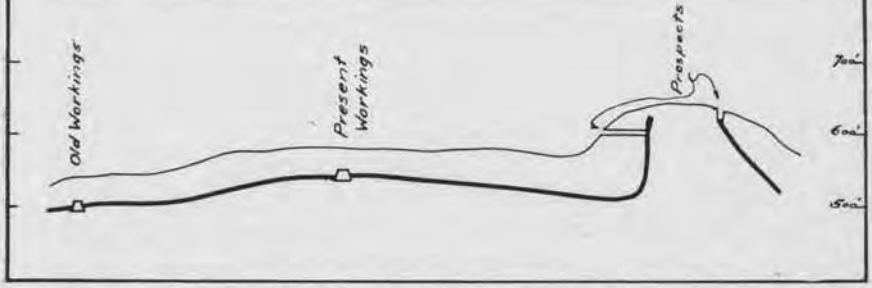


FIG. 5. Diagrammatic section through the property of the Howell Mine. Vertical scale same as the horizontal.

show the seam to be dipping 75° in a southerly direction on the south side and about 45° in a northerly direction on the north side, where drill records are reported to show a six-foot seam of coal. Figure 5 is a diagrammatic structure section through the Howell property on a N. 75° W. line.

This mine was first opened in 1903, running during the winter months only for several seasons. No report was made on it for a decade prior to 1916, since then it has been operated by the Salzer Valley Coal Company, with an average daily production of less than 10 tons. At the time of the writer's visit the mine was not in operation and no sample for analysis was taken.

About four miles west of Centralia coal is found in the northeasterly dipping beds which outcrop on tributaries of O'Gara Creek, in the southwest quarter of Sec. 3, (T. 14 N., R. 3 W.). The following section is exposed:

	Feet.	Inches.
Shale, massive, gray micaceous	2	6
Coal, clean (estimated)	6	0
Shale, as above, concealed	10	0
Sandstone, coarse, yellow and massive	5	0
Carbonaceous shale, loose		2
Coal, clean	2	0
Shale, carbonaceous		6
Shale, thin-bedded, gray, base concealed	3	0
Total	29	2

These beds disappear beneath the later sedimentary beds of marine origin to the northeast. While the coal is apparently a high grade lignite it is not shown in quantity to be commercially important under present conditions.

LINCOLN MINE.

Just west of Galvin, a town on the line of the O-W. R. R. & N. Co., about four miles northeast of Centralia, the Rainier Mine was opened in 1913. This was taken over by the Lincoln Coal Company the following year but only a very small tonnage was extracted before the mine was closed.

Early in 1918 it was reopened and development work is now being pushed. The mine is located on the northeast quarter of Sec. 33 (T. 15 N., R. 3 W.), depending upon a logging company's spur track for connection with the line of the O-W. R. R. & N. Co. The coal-bearing rocks strike about N. 75° W.

dipping northerly at an angle of 35°-38°. The coal seam, as worked, is more than eight feet thick with local lenses of shale up to four inches in thickness. A second seam, called No. 2, is found to lie about 50 feet stratigraphically above the seam worked. This is about 30 inches thick and is not being worked at present. In character these coals are similar to others of this area, having a somewhat woody texture and slacking readily upon exposure to the sun. Analyses are not available, but a rather high ash content is reported. This possibly can be partially eliminated by careful mining.

The old opening was a 40° slope extending somewhat less than 200 feet. From this an entry was run about 300 feet on the level and rooms were turned off, leaving about 40-foot pillars.

The present opening is a tunnel trending due north for 75 feet so as to cut both seams. Along No. 1, 35 feet from the portal, a gangway is run for about 400 feet. An air course parallels this and eight-foot chutes are being put in 30 feet apart.

About two miles to the northwest of the Lincoln Mine in the southwest quarter of Sec. 29, coal has been found in the hillside above one of the southern tributaries to Lincoln Creek. The series exposed here lie nearly horizontal but show a slight dip to the northeast. The following section was measured:

	Feet.	Inches.
Roof, soft, gray sandstone		
Coal	1	1
Shale parting		½
Coal	2	1
Shale parting		1
Coal		10
Shale parting		½
Coal		8
Shale parting		½
Coal (base concealed)	1	6+

Extensions of this seam have been found in the adjacent area and it is probable that operations will be begun soon on the development of this seam.

FORDS PRAIRIE MINE.

About four miles north of Centralia, near the north line of Sec. 30, (T. 15 N., R. 2 W.), the Fords Prairie Mine (No. 3 on Figure 1) is located on the southeast limb of a low cross-fold trending northeast-southwest. The beds dip at an angle of about 12°. A section measured on the main gangway near the last plane where sample 29564 was taken for analysis is shown in Figure 4c.

This coal shows a rather high moisture content and a moderate content of ash. The sulphur is negligible. In composition and physical properties it is fairly comparable with the other coals of the Centralia-Chehalis field.

This mine has been a producer since its opening in 1911, although worked on a small scale. The average daily production amounts to about 65 tons.

A short spur connects the property with the Chicago, Milwaukee & St. Paul and the Northern Pacific railroads. The mine is opened by a 30° rock slope to the main gangway on the coal. An aircourse and traveling way driven in the coal from the surface parallels the main gangway. The development work is very limited. The method of mining is by room and pillar. The gangway is eight feet wide and air-course six feet wide, with a 50-foot pillar between. Planes are driven up the dip, 15° to 17° from the gangway every 400 feet. The rooms are turned off the plane on each side parallel to the general course of the gangway. These rooms are 14 feet wide with a 25-foot to 40-foot pillar between. The coal is mined face-on, leaving top coal two feet high for protection, sheared on both ribs and given a slight undercut, thus breaking the coal without the use of powder. The coal breaks into long slabs.

In the advance mining, the room track is usually placed on the low side. When the pillar is drawn, the track is moved to the high side, a cut is made diagonally across the pillar to cut the fast end, and then a further series of cuts made until the entire pillar is removed. Timbering is used to support the roof during the pillar drawing and sometimes the top coal is left in for additional support.

The cars of mined coal are dropped down the planes to the main gangway and hoisted up the slope to the washery. Here the coal is screened to remove lump coal coarser than three inches. The undersize is sent to a Forester jig for washing and the cleaned coal is then re-screened into domestic and steam sizes. This is one of the few properties in the field which prepare coal by washing.

PERTH MINE.

About a mile east of the Fords Prairie Mine, on the northeast quarter of Sec. 29, is the property on which the Perth Mine was opened in 1909. No report was made from this mine after 1910 and at the present time it cannot be examined. The following statement is taken from the report of E. E. Smith,* who visited the mine when it was in operation: "Although several coal beds are exposed at this mine, the bed now being worked is the only one from which a sample could be obtained. This bed strikes N. 35° W. and dips 20° SW. The section was measured at a point 120 feet north from the foot of the slope and 40 feet up the rise from the first level gangway." It is thus seen that the Perth Mine and the Fords Prairie Mine are on opposite sides of a shallow synclinal fold. The stratigraphic relation of the seams, however, is not certain.

CHINA CREEK MINES.

East and a little north of Centralia in the northeast quarter of Sec. 3 (T. 14 N., R. 2 W.) the Potlatch Mine is located on a series of beds of vertical dip. This mine was operated for the period 1909 to 1912 inclusive. It was opened with a 35° incline in a N. 75° W. direction. The section could not be measured within the mine, but a section exposed in the creek bed 100 yards above the incline was as follows:

	Feet.	Inches.
Sandstone, clean, blue-gray	33	0
Coal	1	6
Shale		6
Coal	1	0
Shale		6
Coal	3	0
Sandstone, as above		
Total coal	5	6

*Ibid. p. 196.

While the stratigraphic relation of this coal to that in the mine has not been determined, from their attitude the exposed strata may be at a higher or lower horizon in the coal series or may be the same as those in the mine, brought up again by close folding.

Less than a half mile to the east, in the northwest quarter of Sec. 2, the Eureka Mine was opened on two seams of coal nine feet apart which had a nearly vertical dip. The relation of these seams to those mentioned above on the Potlatch property is not known, but the location of the mines along the strike of the seams makes it evident that they were stratigraphically adjacent if not identical. The mine was opened by an irregular drift which had a general trend of S. 80° E. The Eureka Coal Company operated this mine from 1892 to 1895, inclusive, but at no time was the production large.

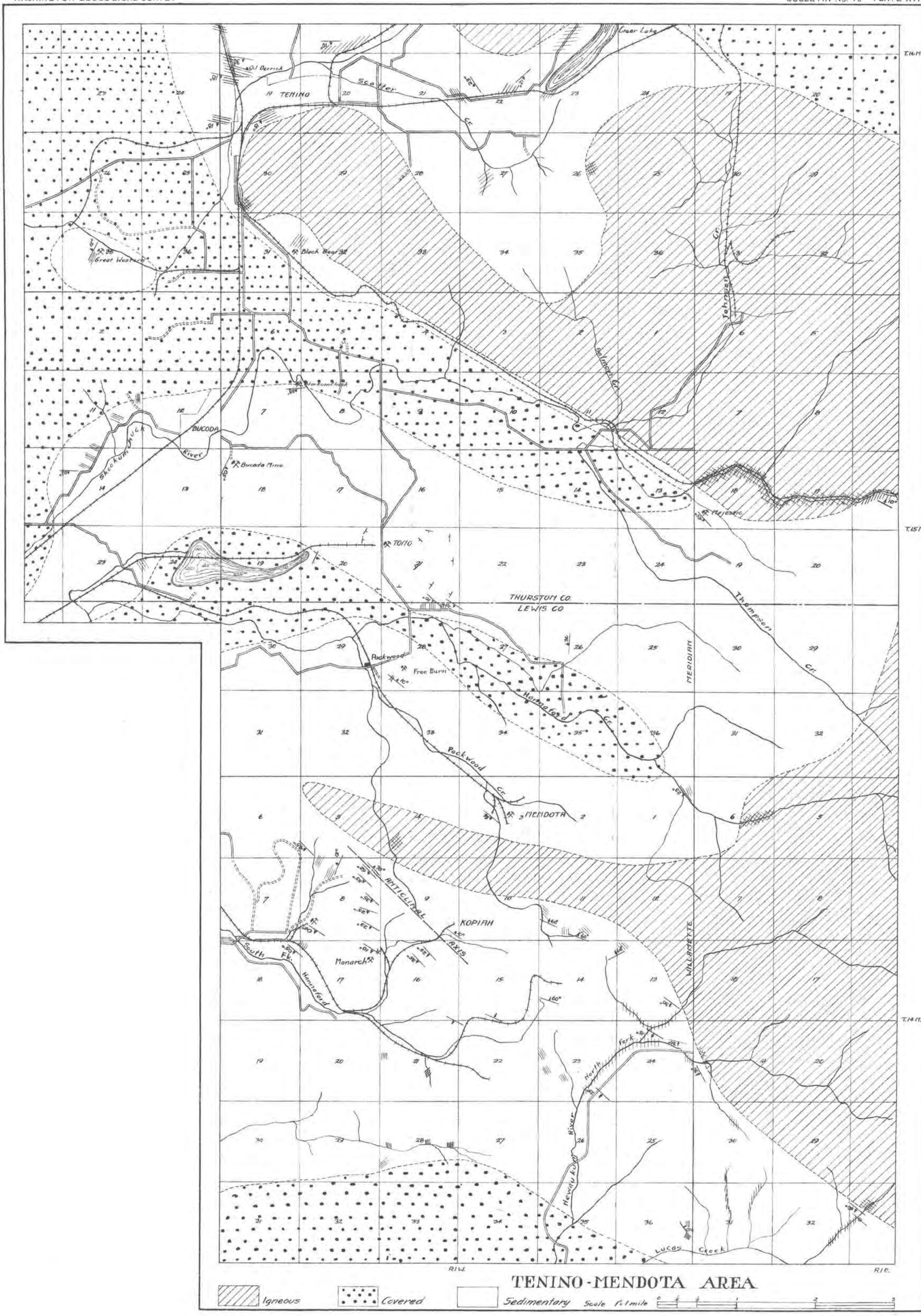
The Florence Mine, on the northeast quarter of Sec. 2, was about one-half mile east of the Eureka and located on practically the same part of the coal series. Very little information as to this mine could be obtained on the property, but the reports of the Coal Mine Inspector show that the first opening, a slope, was made in 1891. A fire in 1893 led to its temporary abandonment. The next year a new drift, called Florence No. 2, was opened and both operated during 1895. No report was made after 1896.

The Richmond Mine is located in the southwest quarter of Sec. 34, (T. 14 N., R. 2 W.) and is seen to be on the north limb of the syncline which involves all the beds of the China Creek region. This property was operated by the Centralia Coal Company in 1907 and E. E. Smith,* who visited the property, reports as follows:

"Only one coal bed is developed at this mine. It strikes N. 40° W. and dips 40° SW. The following section was measured at the face of the north gangway, just beyond chute No. 10, on the first level:

	Feet.	Inches.
Coal	1	0
Shale, hard		6
Coal (used as roof)		8½
Coal	7	8½
Coal and shale, carbonaceous		6
Coal	1+	
Total	11	5+

*ibid. p. 162.



TENINO-MENDOTA AREA

Igneous Covered Sedimentary Scale 1 mile

"The coal is brownish-black in color, and has a reddish-brown streak. It is massive and banded and breaks with an irregular conchoidal fracture. It contains a very high percentage of moisture and weathers very readily on exposure to the air. It should be classed as a very low-grade sub-bituminous coal."

TENINO-MENDOTA AREA.

GENERAL GEOLOGY.

This district lies just east and north of the Centralia-Chehalis area and includes the mines in the vicinity of Kopiah, Mendota, Tono, and Tenino. It comprises the eastern part of R. 2 W., T. 15 N., and T. 16 N., and all of R. 1 W., and the west half of R. 1 E., in T. 14 N., T. 15 N. and T. 16 N. It thus includes about equal portions of Lewis and Thurston counties. (See Plate XVI.)

This is an area of greater relief than the district to the west, showing differences in elevation amounting to more than 1,200 feet. The upland area is divided into three parts by the flat and relatively wide valleys of the Skookumchuck and Hannaford creeks. Bretz* has shown that the former was a temporary gateway for heavily laden waters draining the ice-covered areas to the north and east during the latest period of glaciation and a valley flat was built up which is out of proportion to the small stream now using it. The origin of the Hannaford Flat is doubtless to be connected with that of the Skookumchuck, which it joins a few miles north of Centralia.

The distribution of igneous and sedimentary rocks is rather well indicated by the topography of the area. Thus the steep and rocky hills in the northern part, known as Northcroft Mountain and Holman Mountain, are underlain by basalt to the exclusion, so far as is known, of any of the coal series sediments. Similarly, Meridian Hill, on the Willamette Meridian, is maintained by its core of igneous rock.

The dense forest covering of this area makes the correlation of the scattered outcrops largely a matter of conjecture. For this reason later work may show the westward extension

*Bretz, J. Harlen. Bulletin Washington Geological Survey No. 8, 1913, pp. 43-45.

of the igneous boundary in T. 14 N. to have been unwarranted. It is likely, however, that the igneous rock near the headwaters of Packwood Creek in Sec. 3 and Sec. 4 is connected at no great depth, if not along the present surface, with the mass composing Meridian Hill to the east. Obviously also, the relation of the igneous rocks to the sediments could not be definitely ascertained, but the evidence at hand points to the intrusive character of the masses exposed.

Evidence that these are in part sills, and hence lying approximately parallel to the sediments, is found in the fact that in none of the several workings in close proximity to the igneous rocks have the latter been encountered. No coal has been found within the areas mapped as igneous and hence these masses are of little or no importance in mining operations in this district.

About five-sixths of the Tenino-Mendota area is underlain by sedimentary rocks, including some thirty square miles mapped as covered and presumably having Tertiary sediments beneath the Pleistocene. Two formations older than the Pleistocene are recognized, the Puget coal-bearing strata and the Newaukum pre-Puget rocks briefly described above. (p. 11.) The study of the latter was outside the requirements for this report and time did not permit examination of it far beyond its contact with the younger series. It is made up of conglomerates and finer sediments with possibly some intercalated igneous rocks, all of which are distinctly more dense, resistant, and evidently considerably older than the Puget formation. Only a few square miles of these rocks lie within the Tenino-Mendota area and the known coal areas lie wholly outside these, hence in the delineation of boundaries of the coal fields these are classed with igneous rocks and so mapped. The Puget formation is apparently unconformable with the older rocks wherever they are in contact, although the angular discordance between them is slight even where perceptible.

The rocks of this area have been subjected to greater deformation than those of the districts previously described. This has resulted in sharper folding, with more or less of irregularity in the trend of the axes of folds. This is especially true of the region southeast of Kopiah, where the Newaukum rocks and the coal series as well are involved.

In addition to the anticlinal axis mapped south of Kopiah, the presence of another of similar trend is inferred from the structure of the Newaukum beds in Sec. 19, Sec. 20 and Sec. 28, T. 14 N., R. 1 E. Attempts to locate the coal series, even in isolated patches, on the northern limit of this fold were unsuccessful and it seems probable that if formerly present they have been almost wholly removed by later erosion. The southward extension of the coal series area into the igneous area east of Tenino can be easily explained as resulting from the erosion of the overlying basalt mass on the east of the anticline, which is indicated in data obtained on all outcrops from Clear Lake to Thompson Creek. A slight cross-folding carrying the sediments below the present erosion plane along Salmon Creek and bringing them up again along the Skookumchuck completes the structure in this region.

Faulting is common throughout the area, the coal seams in most mines being displaced somewhat. So far as known these are in all cases high angle faults and are to be related to tensional rather than compressive stresses. Usually the amount of displacement is small in any one fault, but faults of over 30 feet are known, as in the Hannaford No. 1 Mine at Tono.

Taken as a group the coals of this district are of essentially the same rank as the coals of the Centralia-Chehalis field. The difference in deformation to which the two districts have been subjected is not great enough, or at least not localized enough, to cause any marked difference in the quality of the coal. Furthermore the coal that is perhaps the best in the field, that from Tono, has been subjected to as little folding as any. The commercial superiority of this field, which has for years been the biggest producer, probably lies in the greater thicknesses of clean coal between shale partings rather than in a marked superiority of the coals in general. Little can be said as to the available tonnage in this area. Figures as to the extent of the seams now worked are largely conjectural, but that a substantial tonnage can be mined is not doubted. On most properties there are several seams, on the average as good as those mined, which can be utilized in future operations.

DESCRIPTION OF MINES.

GREAT WESTERN MINE.

The Great Western property is located near the center of Sec. 35, T. 16 N., R. 2 W., and hence is about two miles due southwest of Tenino. This mine has not been in operation since 1909 and little could be learned on the property. The following statement is taken from a report made by E. E. Smith:*

"The coal bed lies very nearly horizontal. At the entrance to the main gangway it dips very slightly (1° to 2°) to the east, while at the far end of the gangway the bed has about the same dip in the opposite direction, so that the gangway passes through a syncline near the center of the workings. The bed is thin, and is subjected to considerable pressure, so that a great deal of rock work is necessary in the gangways to keep them open. The following section was measured at the place where the sample (9987) was taken:

	Feet.	Inches.
Sandstone, white		
Shale, hard		2½
Coal		7
Shale, with irregular lenses of coal		3½
Coal		4
Shale		1
Coal	1	6
Shale, brown		1
Coal	1	1
Clay, yellow, soft		4
Shale		
Total	4	6

This mine was opened in 1903 by the Great Western Coal Company. Operations were brisk for two years, then fell off. During 1907 it was worked by the Pacific Coast Coal Company and later by the Keystone Coal Company. After lying idle for a year or more it was operated on a small scale by the King Coal Mining Company for one year, when a receiver was appointed for the company.

BLACK BEAR MINE.

The Black Bear Mine was located on the northeast quarter of Sec. 31, T. 16 N., R. 1 W., about two miles southeast of Tenino. The workings can not be entered at the present time

*Smith, E. E. Bulletin U. S. Geological Survey No. 474, 1911, p. 198.

and only meager data were obtained. A section measured by Smith* was as follows:

	Feet.	Inches.
Shale		
Shale, carbonaceous		3½
Coal	2	1
Shale, spongy, varies from 1 to 2½ inches		1
Coal		8½
Shale, spongy		2
Coal		5
Shale		½
Coal	2	5
Shale		
Total	6	2½

The mine was opened in 1907 by the Tenino Coal & Iron Company and operated for two years. In 1911 it was operated by Graham Brothers, a new slope having been opened.

MAJESTIC MINE.

The property of the Majestic Coal Company lies on the southwest quarter of Sec. 18, T. 15 N., R. 1 E., about nine miles southeast of Tenino on the south side of a small valley tributary to the Skookumchuck. The beds here dip southwest about 20°, although at the mine opening the dip is steeper. A small fault was encountered 65 feet from the entrance, but the coal below was found intact. The mine is opened by a slope trending S. 35° W. The pitch is 45° at the entrance but lessens with depth. At the end of the slope, 440 feet, the dip is less than 20°. A section measured in an exposure near the slope, but believed to overlie the seam mined, is shown by Figure 6a. This mine was opened in 1911 but produced only during that year.

On the low hills just south of Thompson Creek, in Sec. 30, T. 15 N., R. 1 E., coal outcrops in several places and has been found by drilling operations in Sec. 19 of the same township and on Sec. 25, a half mile to the southwest in R. 1 W.

SKOOKUMCHUCK MINE.

The Skookumchuck Mine was located in the northwest quarter of the northwest quarter of Sec. 8, T. 15 N., R. 1 W. The beds here are nearly flat-lying, having a dip of 8° to the

*Ibid. p. 197.

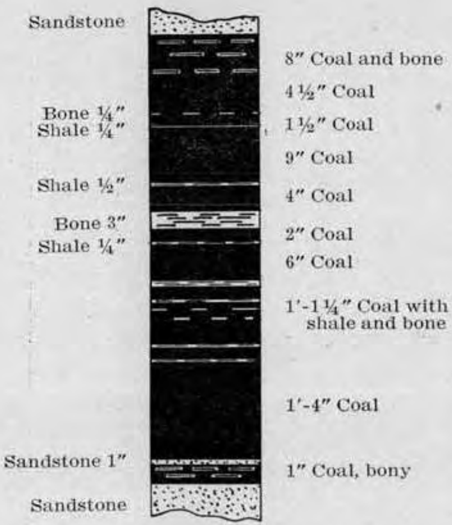


FIG. 6a. Section of coal seam exposed near the Majestic Mine.

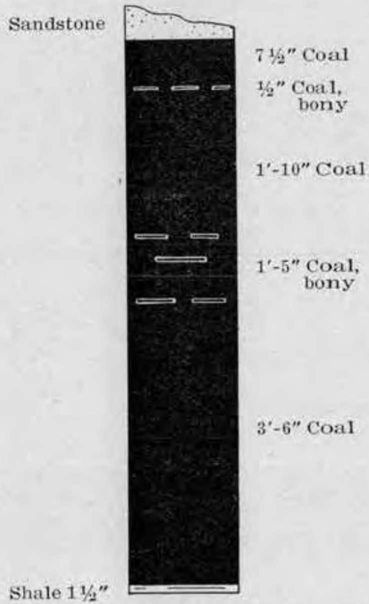


FIG. 6b. Upper portion of section of seam measured in Hannaford No. 1 Mine.

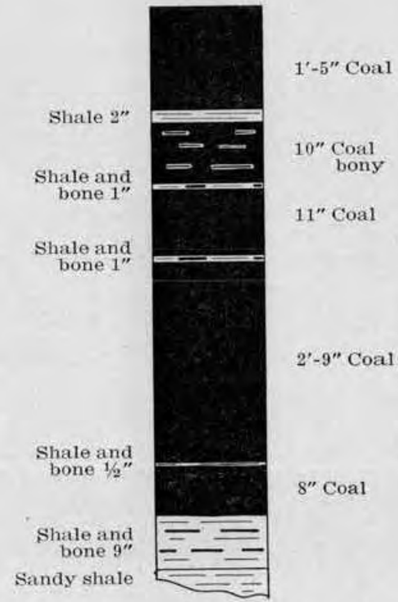


FIG. 6c. Lower portion of section of seam measured in Hannaford No. 1 Mine.

south on a strike N. 80° E. The property could not be entered and no section was measured. The roof is sandy shale, with seven feet of a reported 11-foot seam visible. The mine was opened by an incline which is reported to extend 200 feet. No data as to the history of the property was obtained but the mine has evidently been long abandoned.

BUCODA MINE.

The old Bucoda Mine was located in Sec. 18, T. 15 N., R. 1 W., at about the center of the northwest quarter. The beds here are nearly flat-lying with a dip of only 5° to the east. Several seams of clean coal were reported, one seven feet six inches and another of 12 feet. A fault of nine feet was encountered some distance within the mine. The beds were apparently under strain as it is reported that the floor of this mine raised so that considerable rock work was necessary to keep it open.

This was the first mine opened in this field and has had a long history. First operated by Federal prisoners under contract by Billings, Smith and Shead in the late seventies, it was reopened about 1887 by the Northwest Coal Company and was at that time the only mine operating in the district. The Bucoda Northwest Company took charge about 1892, but the mine was closed after 1895. This same bed was worked in the Sunshine Mine by the Bucoda Coal Company in 1914-1915 and again by the Richmond Brothers still later. No section could be measured at the mine, but Landes* gives the following section:

	Feet.	Inches.
Sandstone roof		
Coal	1	2
Bone		1
Coal	5	6
Bone		¼
Coal	1	3
Sandstone floor		
Total	8	¼

An analysis of the coal reported at that time showed it to have a high percentage of fixed carbon, very low (2.3) per-

*Landes, Henry. Annual Report, Washington Geological Survey, Vol. I, 1901. Plate XXV.

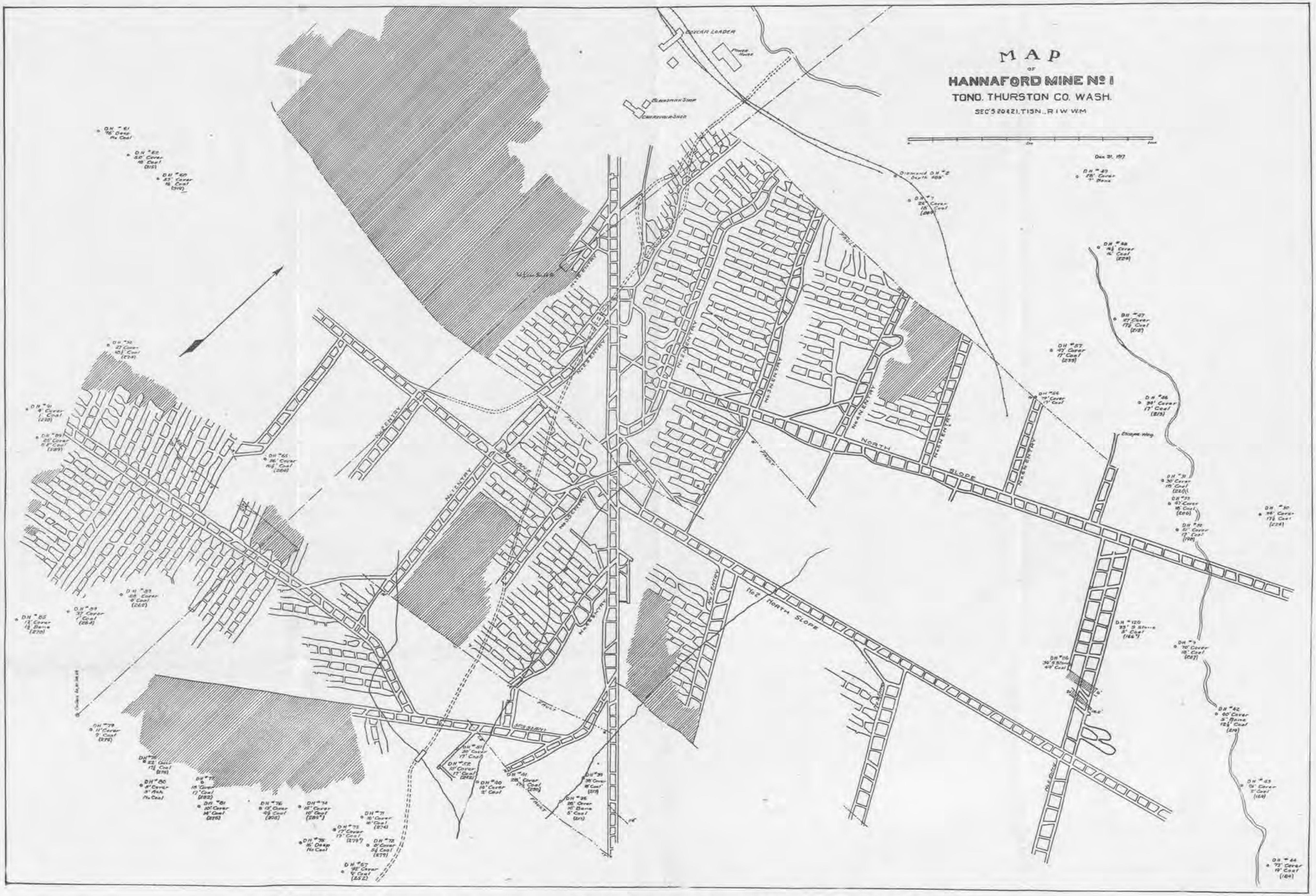
centage of moisture and a moderate ash content. Because this analysis is not known to be comparable with the others for which a standard method of sampling was required, it is not included among the tabulated analyses of Appendix C.

WASHINGTON UNION MINE.

The property of the Washington Union Coal Company (No. 4 on Figure 1) is located at Tono on Sec. 20 and Sec. 21, (T. 15 N., R. 1 W.). The strata dip at low angles toward the mine. A peculiar feature of this region is the extent and character of the faulting to which the strata have been subjected. The displacement in general is greater toward the center of the area from all sides, making a simple structural basin. The depression of the center is further shown by the fact that in the faults at the north side of the basin the north side is upthrown, while in the southernmost displacements the south side is upthrown. (Figure 7a). The fault planes trend in general N. 85° E., no variation greater than 17° from this having been noted. They are steeply inclined with pitch ranging from 50° to nearly 80°. Nearly maximum variation in both trend and pitch may be observed at different places along the same displacement. For example, data taken on the northernmost fault (No. 1, Figure 7a) is as follows: (See the mine map, Plate XVII, in this connection.)

Entryway.	Trend.	Pitch.	Displacement ca.
No. 2 North	N.78°E.	50°S.	10 feet
No. 3 North	N.75°E.	70°S.	
No. 4 North	N.85°E.	60°S.	12 feet
No. 5 North	N.88°E.	60°S.	
No. 6 North	N.88°E.	53°S.	19 feet

Drill records show a probable displacement of less than 10 feet along the eastward extension of this fault. The next fault to the south is possibly less extensive, showing a more uniform trend with a throw of about eight feet. The next (No. 3, Figure 7a) is the biggest fault so far encountered. It shows a throw of 12 feet in the old workings west of No. 1 South Entry and No. 2 South Entry. Seven hundred feet eastward this has increased to 32 feet, which it maintains quite uniformly another 100 feet to the east.



Map of Hannaford No. 1 mine. Tono, Thurston County. Figures showing amount of throw are placed on the down thrown side of fault lines.

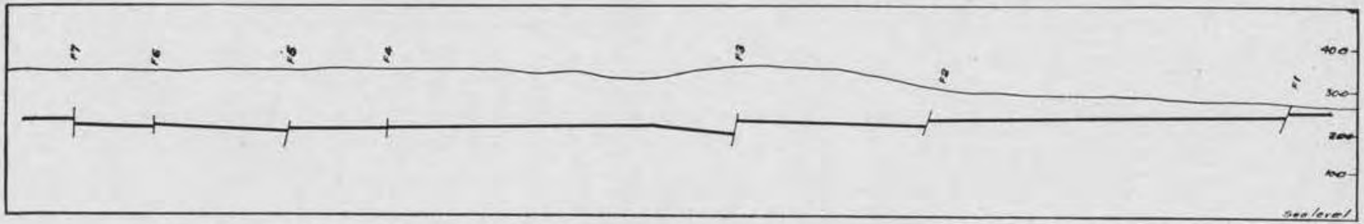


FIG. 7a. Diagrammatic structure section through mine at Tono. Vertical scale same as horizontal. Note the development of a shallow structural basis through the faulting.

FIG. 7b. Diagrammatic structure section through the Mendota Mine. Vertical scale same as horizontal.

One of the greatest variations in throw is found in the southernmost fault. (No. 7, Figure 7a). In the main slope the south side is upthrown 17 feet while 550 feet to the west it is but 10 feet and in the 5th South Slant, 200 feet farther west, the throw is but one and one-half feet.

Until the basin has been more extensively worked the relations between the various displacements as well as their origin cannot be determined. These are probably all tension faults and largely of simple vertical movement. No indication of horizontal displacement was noted, but it should be remembered that the low dip of the beds would make the determination of even considerable horizontal movement difficult. Slickensides and cleavages induced in the gouge alike are essentially uniform in verticality.

The development of a structural basin with greatest displacement in the middle and the uniformity in the trend of the faults point to an origin connected with normal slumps of the beds incident to the conversion of the buried vegetal matter to coal. Obviously the fracturing of the coal now being mined is to be related to coal seams stratigraphically lower in the series. The presence of some such seams is already known from drill records. There remains in doubt, however, the position of the faults in the area, not yet delimited, which was originally covered by this series of beds, and further, the relation of the faults to the variation in the thickness of the coal seams is undetermined.

Whatever the cause of the faulting, it has resulted within the mine in a natural division of the coal into a series of long relatively narrow blocks extending in a nearly east-west direction. Although the data is not complete it seems probable, also, that it has resulted, on the surface, in a series of nearly east-west gullies parallel to, and co-extensive with, the major faults below. The scale of the profile of Figure 7a is not large enough to show these surface depressions.

A section of the seam now worked shows it to comprise two benches called the Upper and Lower, or Mining, benches. In Room 7, 2nd Entry, 2nd Main Slope, where the seam was sampled for analysis, the section, shown by Figure 6b, was measured.

Sample 29566 was taken from the upper bench; No. 29567 was taken from the lower bench. Samples 9089, 9573, 9095, 9094, 9096 and 8752 were taken by E. E. Smith* and the following extract from his report is inserted to explain the variations shown in the analyses:

"Samples 9089 and 9573 were taken from the upper bench, about 150 feet up the slope, in room No. 7 on the second level south. The one-inch shale at the bottom of the bed forms a parting between this bench and the lower bench, which is the one worked in other parts of the mine. Sample 9095 was taken 200 feet from the gangway in room No. 12, on the first level south. The upper parting of this bench, which is the more regular, can be separated by picking, and was not included in the sample. Sample 9094 was collected at the entrance of room No. 12, on the first level north. The coal was slightly moist, owing to seepage from the overlying rocks, and was sealed in the can before it had a chance to dry; the analysis of this sample should therefore show a slightly higher percentage of moisture than the analysis of a sample in a normal condition. The bench at this place contains four partings, of which most of the upper two and part of the lower two can be separated from the coal by careful picking. In order to obtain a representative amount of ash, only the lower two partings were included in the sample. Sample 9096 was taken at the entrance to room No. 8, on the second level north, at which place the bed contains four distinct partings. In order to obtain a representative amount of ash in the sample, the third parting from the top was included. Analysis No. 8752 was made from a mixture of samples of run-of-mine coal from the lower bench of Hannaford No. 1 mine, taken at Pittsburg from two cars which had been on the road from three to five weeks. * * *

"Samples 9089 and 9057 were taken from the same place in the mine, but there is a very notable difference in the heating value and the amount of moisture of the air-dried samples. Sample 9089 was taken * * * when the coal was being mined from the upper bench in this room, and was exposed for a few hours during transportation to the office, but

*Smith, E. E. Bulletin U. S. Geological Survey No. 474, 1911, pp. 195-6.

it was sealed immediately thereafter and was forwarded to the laboratory in an air-tight can. Sample 9573 was taken by removing the surface coal and cutting a fresh channel at the side of the old channel from which No. 9089 was taken. Previous to the time when it was obtained * * * it had been exposed to the mine atmosphere for about nine weeks. A comparison of the amount of moisture in these two samples as received and in samples as received from the other parts of the mine indicates that only a little moisture evaporated from either sample 9089 or sample 9573 during exposure to the atmosphere. The moisture in these two coals, as shown in the samples as received and in the same samples air dried, indicates that, although the total amount of moisture was the same, its relation to the coal had been changed so that it could not be driven off at the ordinary temperature used in the regular method of air drying."

This mine was opened in 1907, only development work having been carried on in that year. Since then the mine has steadily increased its annual production with the single exception of 1910. The average daily production is about 900 tons. It has for years been the largest producer in southwestern Washington and is in many respects the best planned and equipped.

The mine is opened by a slope or entry driven 50° east, across the dip of the coal on a slight grade. From this entry slopes, or planes on the full dip of the coal, have been turned off. These, in turn, have cross-entries opened from them, thus dividing the mine into a series of panels each of which is mined independently.

The cross-entries are driven practically parallel to the main slope, and, like the principal openings, are driven in pairs. The room and pillar method is employed in mining. Rooms are turned from the entries up the dip which is low enough to permit the mine cars to be taken directly to the working face. The entry and the air-course are eight feet wide, separated by a 30-foot pillar. Room necks are 10 feet wide for a distance of 12 feet, where they are widened to 24 feet. Room pillars are 26 feet wide, thus making the rooms 50 feet apart on centers. Cross cuts are driven at 25 feet and

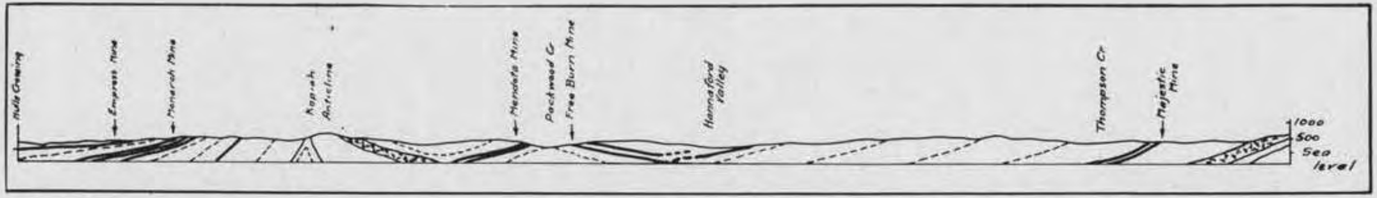


FIG. 8. Diagrammatic structure and profile section from the northeast quarter of Sec. 13, T. 14 N., R. 1 W., to the southwest quarter of Sec. 7, T. 14 N., R. 1 W. The vertical scale is the same as the horizontal. The heavier lines represent coal seams while others show approximate attitude of bedding planes; the patterned beds are basalt masses. It is to be noted that the correlation of the various coal seams has not been made.

50 feet from the entry in alternate rooms, making the stump pillars variable in length. In some parts of the mine, rooms have been turned directly from the slopes or planes parallel to the strike of the coal.

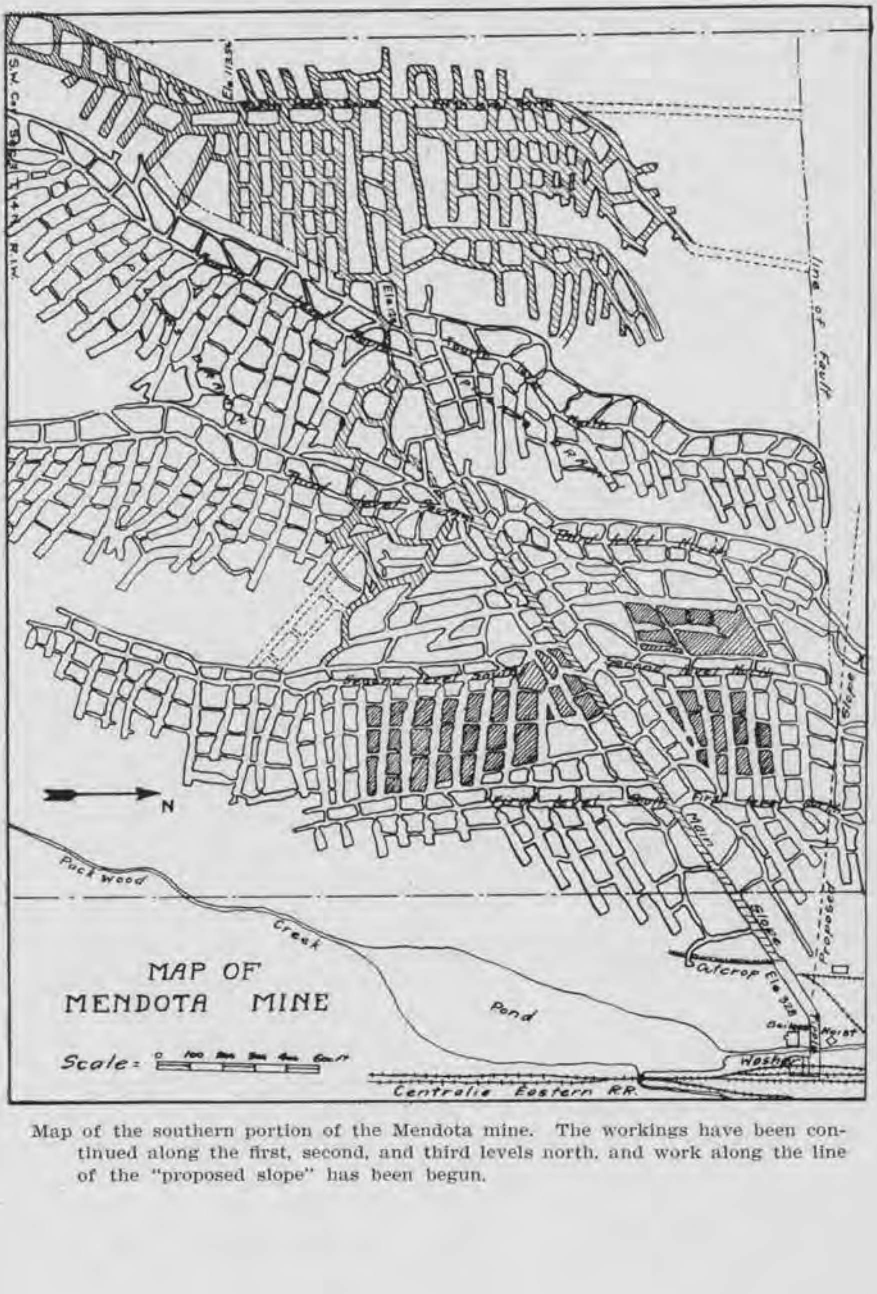
In the advance mining the top coal is left in the rooms to support the roof, but it is entirely removed when the pillars are drawn. The pillar coal is taken out as soon as each section or panel is completed, retreating from the inbye side of the panel towards the slope. The entry pillars are also drawn as soon as practicable.

The coal is hoisted to the tipple and dumped onto six-inch bar screens. The oversize is sold as lump coal to the domestic trade when the coal is not required by the railroad. The undersize is shipped as locomotive coal. The lump coal can be by-passed to a crusher and broken down to small sizes which are shipped as railroad coal in times of great demand for this coal. The mine is on a branch of the O-W. R. R. & N. Co. line from Centralia, and is practically a railroad mine.

FREEBURN MINE.

The Freeburn Mine (No. 6, Figure 1), opened by the Freeburn Coal Company in 1916 and operated by the Olympia Coal Mining Company during 1917, is located in the southwest quarter of Sec. 28, (T. 15 N., R. 1 W.), near Packwood station on the Centralia Eastern Railroad. The strata dip at 10° to the northeast on a N. 50° W. strike, being on the northeast limb of a low anticlinal fold, on the southwest limb of which the Mendota Mine is located, in Sec. 3 to the southeast. (See Figure 8). The workings are on a 12-foot seam which has several partings of shale and bone. No analysis was made of this coal. A section along the slope is shown by Figure 9a and Figure 9b.

A seam of eight or nine feet of clean coal is reported to lie above that which is being worked at present. The general development at the time of examination was a slope bearing N. 40° E. on an initial dip of 13°, but less steep 100 feet in. A few cross-cuts from which a small amount of coal is being shipped have been made from the slope. The average daily production is about 30 tons.



Map of the southern portion of the Mendota mine. The workings have been continued along the first, second, and third levels north, and work along the line of the "proposed slope" has been begun.

About two and one-half miles east of Packwood, along Snyder Creek, coal is exposed in a hillside north of McChesney's ranch, in the southwest quarter of Sec. 26, T. 15 N., R. 1 W. The coal here dips 30° to the east on a nearly north-south strike. This coal has been utilized for domestic purposes by the ranchers nearby for several years. At the face of the open cut the following section was measured:

	Feet.	Inches.
Shales, thin, sandy	1	6
Shales, carbonaceous	1	6
Coal, lignitic, bony in part	6	0
Shale, bituminous		3
Sandstone floor		

MENDOTA MINE.

The Mendota Coal & Coke Company property (No. 5 on Figure 1) lies in the east half of Sec. 3, T. 14 N., R. 1 W., at the town of Mendota on the Centralia Eastern Railroad. The mine is situated on the south limb of a low anticlinal fold, the beds dipping about 14° to the southwest. (See Figure 8). This inclination is considerably lessened with depth, the southernmost portion of the mine being near the trough of a syncline, as shown in Figure 7b, a diagrammatic structure section and a profile compiled from the mine map and topographic sheet. This simple structure is somewhat complicated by a fault trending nearly due east-west, which has been met in the north end of the mine. The north side of the fault shows an apparent movement to the east of over 100 feet in the 3rd Level South, but less than one-fourth that amount in the 1st Level South. (Plate XVIII). With their low dip the strata would show this high net displacement as a result of a comparatively small vertical movement, the north side having been relatively depressed. A glance at Figure 7b makes it evident that a dip fault, i. e., one parallel to the structure section, of small amplitude would produce a relatively high horizontal displacement which would be greatest where the original dip was least. If this was the actual motion a decreased dip farther to the south will show a correspondingly increased horizontal separation of the ends of the fractured coal seam. Extension of the present mine working is necessary to the complete understanding of this fault. Several coal beds are ex-

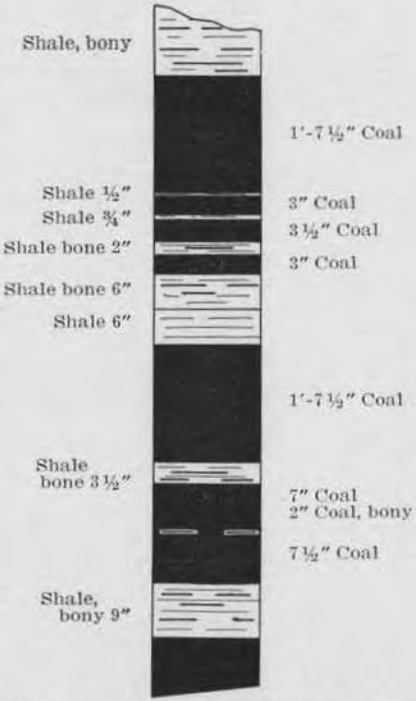


FIG. 9a. Upper portion of section of coal seam worked at Freeburn Mine.

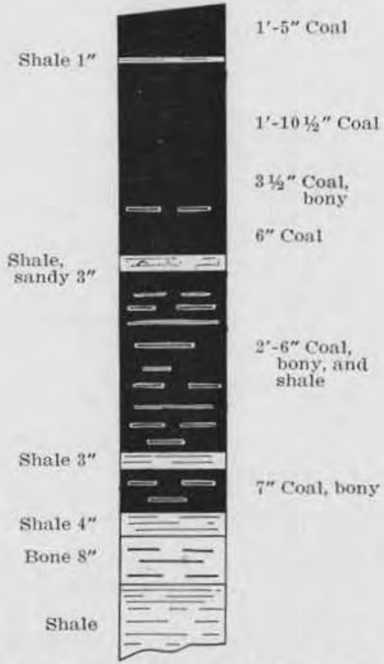


FIG. 9b. Lower portion of section of coal seam worked at Freeburn Mine.

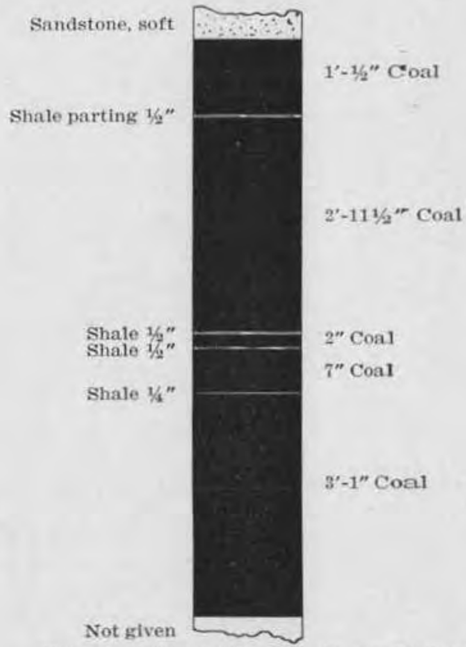


FIG. 9c. Section of coal seam worked at present at Mendota.

posed on the property, but only the one at present being worked was sampled and measured. A section of this seam, 350 feet inside, at the face of No. 5 North gangway, where sample 29565 was taken, is shown by Figure 9c.

E. E. Smith* says of this coal:

"The coal is grayish black and has a reddish-brown streak. It is massive and banded and breaks with a conchoidal fracture. It slacks readily upon exposure to the air, owing to

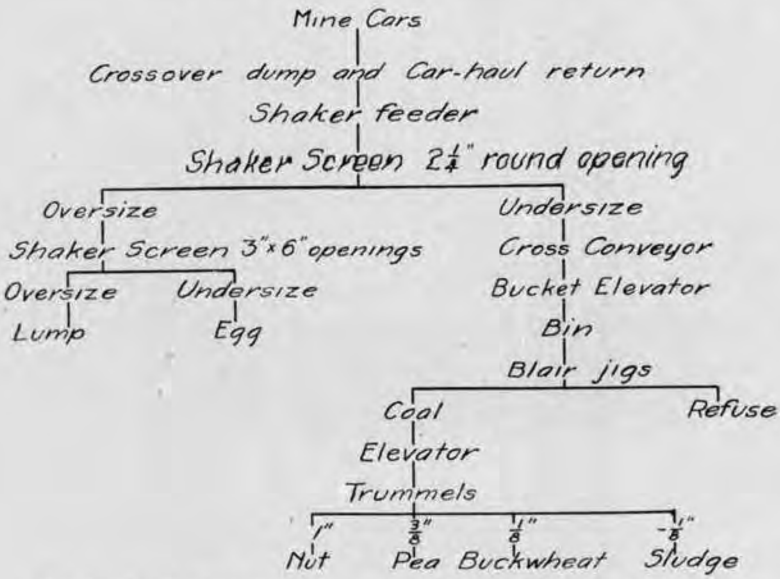


FIG. 10. Flow-sheet showing the screening and washing of the coal at Mendota Mine.

the large amount of moisture it contains—an amount about equal to that of the coal from the Hannaford Mine. It has, however, less fixed carbon than this coal, a greater amount of ash and sulphur, and a lower heating value. It has considerably less moisture than the coal in the vicinity of Chehalis and will probably stand transportation better. It should be classed as low grade subbituminous."

The Mendota Mine is, next to the Tono Mine, the most extensively developed one in this district. It is opened by a

*Ibid. p. 161.

slope in the coal which cuts across the seam in a S. 45° W. direction until the flatter portion of the seam is reached. The direction is then nearly west across the flatter dip of the coal.

The general method of mining is room and pillar. Levels, 10 feet wide, having a north-south direction, have been opened on each side of the slope. Above the gangway a 60-foot pillar is left and an air-course eight feet wide is driven parallel to the gangway. Room necks are opened eight feet wide and the rooms enlarged to 20 feet with 30-foot pillars between. A cross-cut, six feet wide, from the gangway to the aircourse, is driven opposite the center of each pillar. The rooms are driven face-on and the coal is partially mined on one side and then blown down by black powder. A large amount of lump coal is made.

The coal from the mine is prepared by screening and washing. From the tipple the coal passes over a shaker screen with two and one-quarter-inch round openings. The over-size is sent to another shaker screen where lump and egg sizes are made. The under-size of the original screen is sent to Blair jigs for washing, after which the washed product is screened into nut and finer sizes. The flow-sheet of the screenings and washing is shown below. (Figure 10).

This property was opened up in 1908 by the Mendota Coal & Coke Company, who have operated it continuously ever since. The production was at its maximum in 1910-1912, inclusive, but has been increasing again since 1915. The mine has an average daily production of about 300 tons.

KOPIAH AREA.

EMPRESS MINE.

The Empress Mine (No. 9 on Figure 1) is located on the north half of the southwest quarter of Sec. 8, T. 14 N., R. 1 W., on a spur of the Eastern Railway & Lumber Company's line, which runs east from Centralia up the South Fork of Hannaford Creek. This is a mile from the axis of the anticlinal fold between this and the Mendota Mine and the strata have a very low (4°) dip to the southwest. (Figure 8).

At the time of the visit, in 1917, this mine was not being run, consequently the seam was not measured nor sampled, nor the method of mining recorded. The data from a previous visit show that the 12-foot coal seam, which lies under 77 feet of cover, is opened by a 90-foot shaft with gangways extended over 1,000 feet.

This mine, formerly called Bennight's Mine, was opened in 1913 by the Washington Coal & Mining Company. After two years the Empress Coal Company was formed and since 1916 the Centralia Coal Mining Company has operated the property. As yet the average daily production is small, amounting to less than 100 tons.

MONARCH MINE.

The Monarch Mine (No. 8 on Figure 1) is located on the northeast quarter of Sec. 17, T. 14 N., R. 1 W., and is reached by the Kopiah spur of the Eastern Railway & Lumber Company's line. This property is a little nearer the crest of the Kopiah anticline (Figure 8) and the strata show a somewhat greater dip than those of the Empress Mine. They strike N. 47° W., dipping 10° to the southwest. Three seams, the upper seven feet six inches, the middle four feet six inches, and the lower, 14 feet, are reported to outcrop on the property and several more to lie below these. The uppermost is being worked at the present time. At the face of the plane, where sample 29570 was taken for analysis, the section was measured which is shown by Figure 11a.

Above this seam is found six inches of thin-bedded black shale, then four feet eight inches of hard shale, and, finally, a soft sandstone over all. Below the seam is a stratum of grayish blue fire clay, one foot six inches in width; next, one foot two inches of yellow clay, and thin-bedded yellow sandstone below the rest. At the outcrop the coal has been burned back 50 feet or more, the overlying sandstone being fused to a slag while the underlying fire clay was hardened to a bluish flinty mass.

This coal is rather hard, breaking with a conchoidal fracture. It is black, of brownish streak, and has a somewhat dull luster when fresh. It slacks rather slowly in the air, large

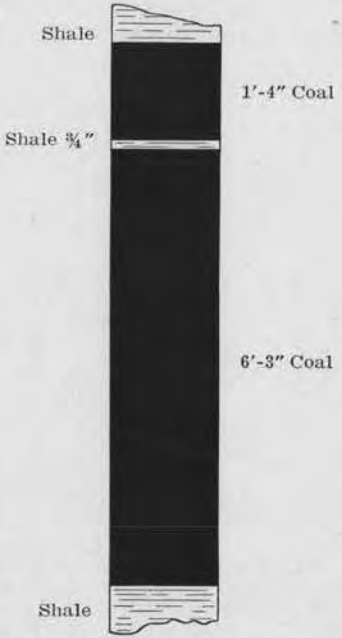


FIG. 11a. Section of coal seam measured at Monarch Mine.

FIG. 11b. Upper portion of a typical section of the coal series on Buckfork creek. (Measurements approximate.)

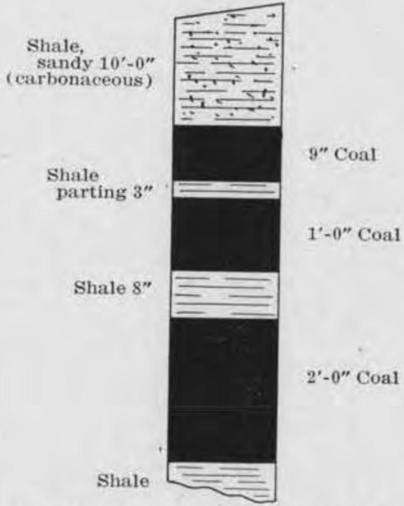


FIG. 11c. Lower portion of a typical section of the coal series on Buckfork creek.

lumps after two months' exposure beginning to show the disintegration into small cubes characteristic of the coal in this region.

The mine is opened by a 10° slope on the full dip of the coal in a S. 45° W. direction. Levels have been formed from the slope and rooms opened from these. The coal is mined at the bottom with a 12-inch cut made by a puncher machine and then is blasted down by powder. At the present time the development is by planes driven from the South Level, bearing S. 25° W. on a 7° dip. From these planes, it is the intention to drive rooms 24 feet wide at 25-foot intervals, hoisting the coal to the main level and then tramming it along the level to the surface, where a new plant is to be erected. The old slope will then be abandoned. The projected development calls for planes at 600-foot intervals, thus giving rooms 300 feet long on each side of the plane.

Preparation at this plant at present is very simple. The coal is screened over three-inch and five-eighths-inch, round opening screens, producing lump, nut and slack coals.

The mine was opened in 1913 by the Monarch Coal Company and, except in 1914, has been producing on a small scale ever since. It was leased by the Agnew Fuel Company in 1917. The average daily output is about 60 tons.

KOPIAH MINE.

The Kopiah Mine is located in the southwest quarter of Sec. 10 and the southeast quarter of Sec. 9 (T. 14 N., R. 1 W.) on a spur of the Eastern Railway & Lumber Company's line. This is on the north limb of the Kopiah anticline, the beds dipping 10° to the north. This mine was opened in 1905 by the Wilson Coal Company, which operated with a fairly steady annual production until 1912, when the Sunshine Coal Company took it over. In 1913 it was run by the Kopiah Coal Company, a co-operative association, succeeded in 1914 by the Lewis County Light & Power Company. No report has been made since that year from this mine and at the time of visit its flooded condition did not permit examination.

Coal outcrops in a score of places along the south limb of the Kopiah anticline and, in a lesser number, on the north limb. On the latter the more resistant basalt overlies the beds, which have low inclination. Many of the prospects in Sections 5, 6, 7 and 8, northwest of Kopiah, were examined, but excavation had not been carried far enough to make the measurement of sections practicable.

Exposures, in Sections 15 and 22, made in logging operations in 1913, showed lignite seams three and four feet thick. These were examined but were found to be decidedly lenticular in form, some beds, several feet thick, pinching out entirely within 30 feet along the dip. It is not known what relation these beds have to those of the mines and prospects to the west, but they may be brackish water and interbedded marine sediments of later time, to be correlated with those found in the vicinity of Winlock and Vader. The intervening area is practically without outcrop. The strata show some fairly fossiliferous bands, but time did not permit collection from them.

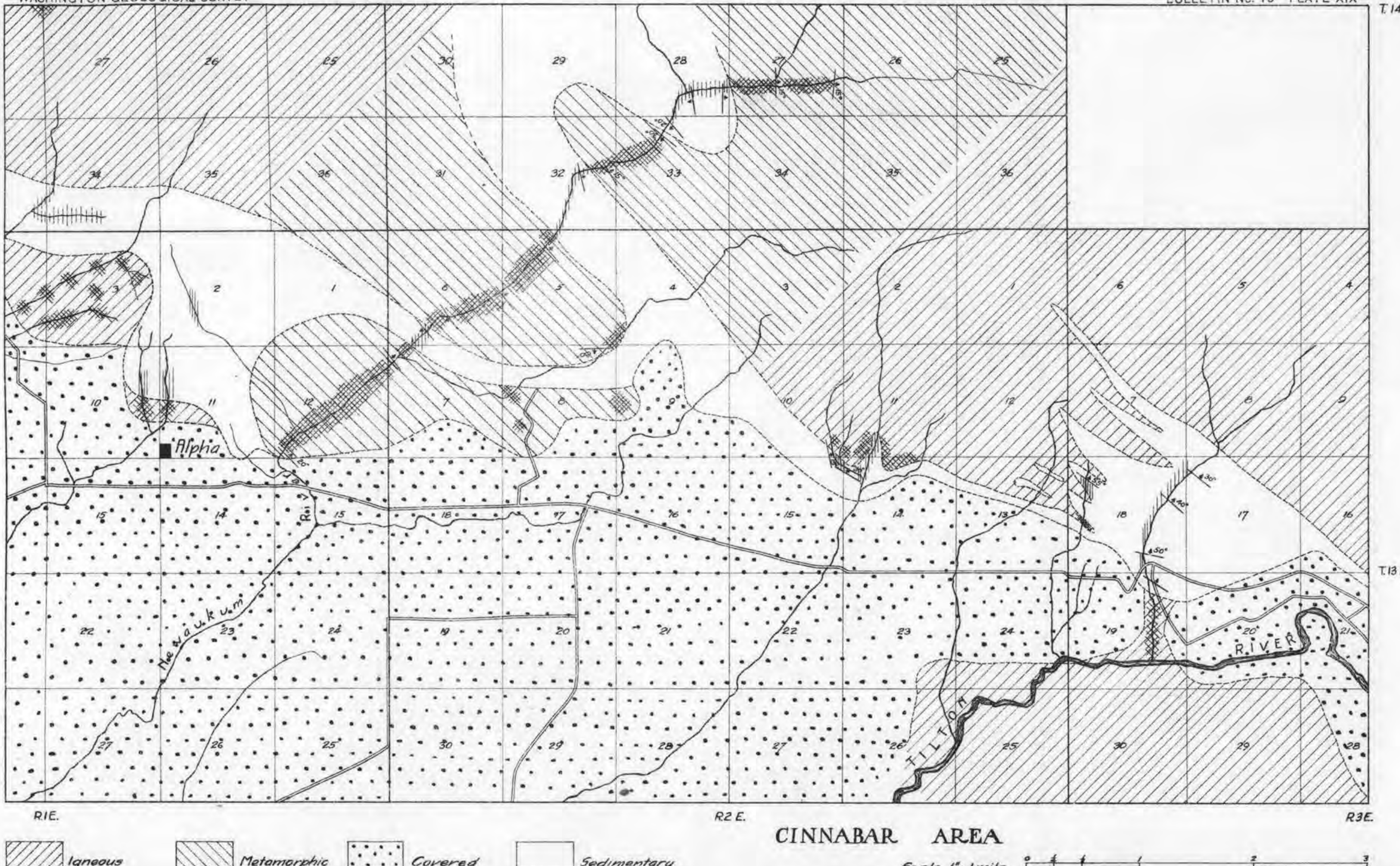
Near the junction of Buckfork Creek and the North Fork of the Newaukum River, in Sec. 13 and Sec. 24 (T. 14 N., R. 1 W.) coal is frequently found in the sandstone-shale series which just overlies the Newaukum formation outcropping to the northeast.

The coal series here has been subjected to considerable folding, which has given the strata a contorted structure. In general the trend of the folds is northwest, the beds dipping southwest, but local strike variations of 70° are met within 250 feet. The coal seams are abundant, most of them being from one to three feet thick. Some are thicker, but the largest seams reported will be found frequently, and perhaps always, to be formed by the doubling of the coal upon itself as a result of the close folding. In these masses the coal shows the fracturing and shearing which such deformation produces. A section typical of this area, taken in the northeast quarter of Sec. 24 (T. 14 N., R. 1 W.), with approximate measurements, is shown by Figure 11b and Figure 11c.

The coal of some seams is apparently of high subbituminous rank, and careful prospecting in the hills north and west, toward Mendota, might reveal coals of better grade than those now being mined. It is probable, however, that these when found may prove to be of too limited extent to warrant their exploitation.

To the southeast the diastrophism has been more severe. The outcrop of the Newaukum formation, in the southeast quarter of Sec. 36 (T. 14 N., R. 1 W.) represents a mass extending some miles southeastward (unmapped on Plate XVI), which is brought to the surface by a sharp fold. The coal-bearing strata to the northeast have been caught between these masses of resistant Newaukum rocks and forced into a close downfold. This has resulted in high and in part vertical dips toward the axis of the fold, the less resistant shale and coal layers showing crumpling and shearing not exhibited by the harder strata. In the scarcely consolidated sandstones there appears to have been more or less of adjustment by a sort of flowage, leaving them as structureless masses occupying their normal position in the sedimentary series. Because of this the outcrops of sandstone are rare except in stream beds and, where found, seldom reveal their attitude. Where not crumpled and sheared the coal of this portion of the area is of good grade and would be placed in the low rank bituminous class.

Typical of these prospects is one near the southern corner of Sec. 30 (T. 14 N., R. 1 E.) where a dump of considerable size was found. No trace of the workings could be found, but probably a drift 100 feet long had been made. The creek showed no ledge rock, although float pieces of good coal were abundant.



CINNABAR AREA

CHAPTER V.

DETAILS OF THE VARIOUS AREAS; II, EASTERN PORTION.

CINNABAR AREA.

GENERAL GEOLOGY.

This area adjoins the Tenino-Mendota area on the west and extends eastward about 12 miles, thus including the area from the middle of R. 1 E. to the middle of R. 3 E, in T. 13 N., and the lower third of T. 14 N. (Plate XIX.)

The relief of this region is pronounced, the uplands in the northern part being nearly 2,500 feet above the lower lands to the southwest. The low-lying portion is confined to the level flats of the Tilton River, Mill Creek, the Newaukum River, and its tributary, Kearney Creek.

Igneous rocks occupy a prominent place in this district and are found in the hilly area south of the Tilton as well as in the higher lands of the north. They are thought to be in large part intrusive into the Newaukum and Puget series, but the paucity of exposures leaves their relations in doubt. It is not known how much of the district is occupied by the Newaukum formation, which here shows some quartzite and carbonate phases not found elsewhere.

After subtracting the concealed area from that remaining it is seen that only a very limited portion of this district is known to be underlain by the Puget formation. This is found to have essentially the same lithologic character as where found farther west in the Tenino-Mendota area, but the strata are, on the whole, better cemented and show greater resistance to erosion. As a result they are found in the uplands to some extent, although they are not known to outcrop at any great elevation in this field.

The whole series has been folded and cross-folded with relatively intricate areal patterns resulting. Intrusions, cutting off some portions of the Puget rocks from the main mass, have increased the complexity of the structure. The northwest-southeast trend of the major folds is maintained, so that most of the exposures show the beds dipping to the northeast or to the southwest. In the north central part cross folding has made the inclination of the beds less steep locally, as along the Newaukum River in T. 14 N. In the southeast portion, along Sherman and Bear creeks, the folding is more pronounced. Some faulting has occurred in this district, but the areal distribution of the formations is almost wholly, if not quite, independent of it, indicating that the existing fractures are of minor importance in the general structure. Locally, however, faults have caused the loss of what would otherwise have been important coal beds.

The rocks are so poorly exposed in this region that correlation between sections in adjoining valleys was found impossible and for larger areas was not attempted. Many seams of coal are known to exist, several of them being six feet or more in thickness, but their extent, either along the strike or down the dip, is problematical, since a given seam may or may not be identical with one exposed a few hundred yards distant along the strike.

DESCRIPTION OF PROSPECTS.

No mines are being worked in this district at present, and in most of the prospects the small amount accomplished, or the time that has elapsed since operations were carried on, has rendered the data available of little value.

Although it has been prospected to a considerable extent, the coal of this area is not well known, because the heavy forest covering practically confines the outcrops to the bed of the streams which are neither powerful nor very numerous. Wherever located, however, the coal is of bituminous rank but has been almost universally subjected to such severe deformations as to make it of little value.

In the extreme northwestern portion the coal beds are identical, in all essentials, with those found to the northwest and described in the section on the Tenino-Mendota area. The only structural difference is in the presence of igneous rock, which probably was intruded into the coal series. To the south, in Sec. 8 and Sec. 9 (T. 13 N., R. 1 E.) the coal has been found by prospecting. It was not of good grade, however, a

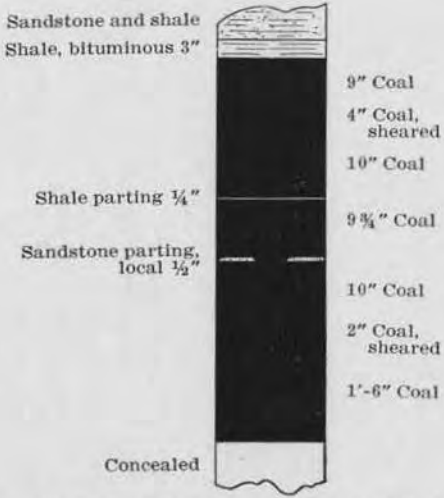


FIG. 12a. Coal seam exposed in Sec. 11 (T. 13 N., R. 1 E.).

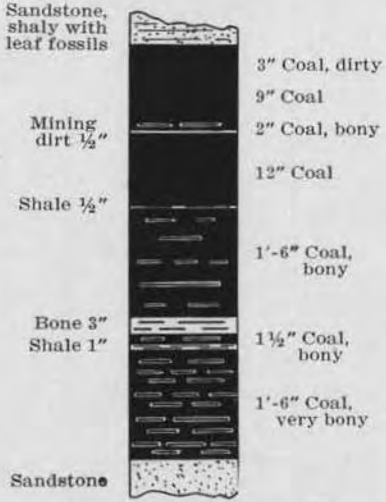


FIG. 12b. Coal seam exposed in Sec. 10 (T. 13 N., R. 1 E.).

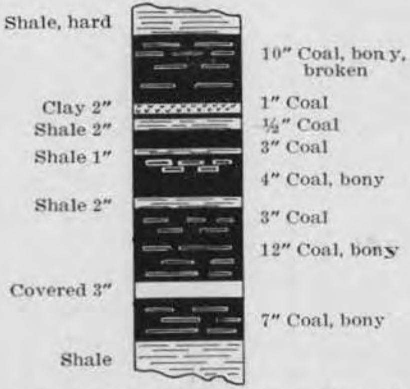


FIG. 12c. Section measured in a prospect on Sec. 14 (T. 13 N., R. 4 E.).

subbituminous rather than bituminous coal, as would be expected from its position outside the area of marked diastrophism. By way of comparison, it is worth while to note that the coal found about two miles to the east, in Sec. 10 and Sec. 11, is of bituminous grade, showing a high degree of resistance to weathering. After several years' exposure large blocks of it remained firm and fairly bright in luster. A section from the southwest quarter of the northwest quarter of Sec. 11, measured in the bed of the creek, is shown by Figure 12a.

A six and one-half-foot seam of impure coal on Sec. 10, one quarter of a mile west of that just mentioned, appears in two small creeks just above their junction in the southeast quarter of the northeast quarter, gave the section shown by Figure 12b.

The coal-bearing strata in the northern part of T. 13 N., R. 2 E., are involved in a synclinal fold and have very limited areal extent, as a consequence of their erosion from the anticlines to the north and south, where the underlying Newaukum series is exposed. While the structure and, necessarily, also, the areal relations, of the rocks of the region are somewhat in doubt, the coal series probably does not extend far east of the line between sections 8 and 9 of this township (T. 13 N., R. 2 E.). North of this point a low anticlinal fold brings the Newaukum strata to the surface for several miles. The Puget series, however, is found outcropping again just north of the boundary of the map, Plate XIX. In the south half of Sec. 22 (T. 14 N., R. 2 E.) a coal seam was worked in the late nineties. Here the strata have a low northerly dip while the Newaukum rocks outcrop a short distance to the south.

The coal series, if not continuous, reappear in sections 10, 11, 14 and 15, two miles to the southeast, and are found, also, in greater or lesser amount, in the valleys of all the creeks flowing south from the rough uplands in the northeastern part of this area. On one of these, Sherman Creek, coal is found in several seams in Sec. 18 (T. 13 N., R. 3 E.) Here the structure is complex, the beds are steeply inclined and, in addition to having been faulted to some extent, have been intruded by andesitic porphyries.

It was not considered practicable to map this portion in detail, and the areal relations shown on Plate XIX are strictly diagrammatic.

Four prospects are found along this creek. In the northernmost, located in the northwest quarter of Sec. 18, about three-quarters of a mile from the County road, an open cut has exposed the seam for a distance of about 15 feet. The coal and associated bone are here intimately comingled. A sill (?) of porphyry overlies the seam, and fragments of coal are found with porphyry adhering to them. The base is not exposed. The bed has been greatly increased in thickness by crumpling, but was originally probably five or six feet thick.

The prospect next downstream is on a coal seam which is probably 100 feet lower in the series. Here a drift enters the hill S. 40° E. along the seam. This could not be entered, but the material on the rather extensive dump indicated that conditions essentially the same as those up the valley were encountered in this prospect. Some small pieces of very good coal were found. Plant fossils are found abundantly in certain strata near this prospect. These fossils are similar to those found near Kendall, Whatcom County, Washington. At the third prospect, a short distance downstream, there is a cross-cut reported to extend about 600 feet in a N. 70° E. trend.

At the fourth prospect, in the southwest quarter of Sec. 18 (T. 13 N., R. 3 E.) a cross-cut, reported to be 1,900 feet long and to cut 10 seams of coal, trends N. 70° E. This coal is also associated with porphyry, and shows the mashing that was a result of folding between the more resistant rocks. It is reported that faults were encountered in this prospect also.

In his report on this field in 1902 Landes* says:

"There are about a dozen veins outcropping on Sherman Creek, and all of them have been prospected more or less by a number of short tunnels which have been driven on the different veins, the longest being 256 feet on vein No. 5. A cross-cut tunnel 1,900 feet long runs at right angles to the strata and brings to view a number of veins, on some of which gang-

*Landes, Henry. Annual Report, Washington Geological Survey, Vol. II, 1902, p. 246.

ways have been driven. Vein No. 5 is about nine feet thick and shows at its mouth clean, hard coal, but further along in the tunnel the coal becomes dirty in places and near the end of the tunnel is involved in a small fault. The coal in all the tunnels makes a little gas, so that safety lamps have to be used to some extent."

The coal series probably extends up the valley of the Tilton River, in a southeasterly direction nearly across R. 3 E., but the coal has not been found far east of Bear Creek Canyon in Sec. 18 (T. 13 N., R. 3 E.)

South of this area the Tilton River for several miles has cut a deep gorge in igneous rocks which are believed to be lower than the sediments stratigraphically. In getting to the Tilton River, Cinnabar Creek has cut a 200-foot gorge through the same rocks (Plate VI C), cascading picturesquely in a series of 25 to 75-foot falls. Three miles to the south the Tilton joins the Cowlitz after traversing an area in which only the heavy filling of Pleistocene gravels appears. These stand in nearly vertical banks along both streams nearly to Mayfield, where the Cowlitz enters a gorge several miles long, cut in basaltic rocks (Plate IV C). The massive walls show a prominent rectangular jointing. In places this is so pronounced a feature that it controls small, tributary streams, which subdivide their waters to flow along parallel joints to the river.

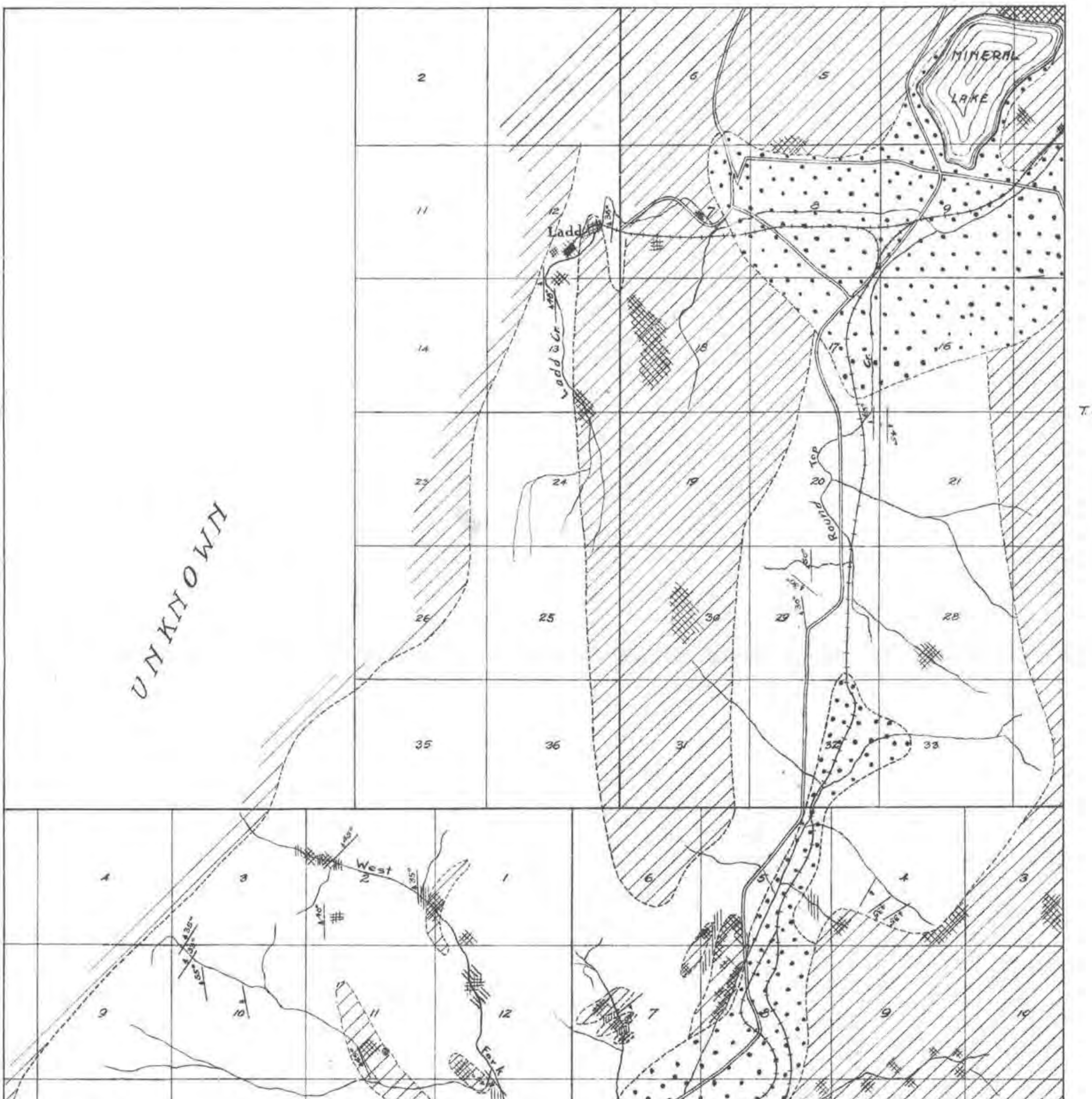
For nearly 20 miles up or down the Cowlitz from Mayfield, as well as an equal distance to the west, exposures of the coal series are practically absent. West of Onalaska, about Sec. 36 (T. 13 N., R. 1 W.) a single outcrop has been noted. The northwest trend and 20° dip to the northeast here indicates that the Puget rocks underlie the Pleistocene deposits throughout the area between the Cowlitz and the Chehalis valleys.

MINERAL LAKE AREA.

GENERAL GEOLOGY.

This district is enclosed within a rectangle about eight by 15 miles in extent, comprising the eastern two-thirds of R. 4 E. and the western two-thirds of R. 5 E., in T. 12 N., T. 13 N. and T. 14 N. (See Plate XX.)

This is an area of somewhat greater relief than that of the Cinnabar district and the hills reach their maximum eleva-



MINERAL LAKE AREA

Igneous Covered Sedimentary Scale 1" = 1 mile tions in shorter distances from the lowlands, which are of very small extent, being confined to the valleys of the Tilton at the south and of Mineral Lake at the north. The Pleistocene conceals the earlier deposits only along the stream channels and, even there, but rarely. Plate XI B shows the usual character of the valley filling. The same older rock formations are recognized in this area as in the Cinnabar district, viz.: Puget, Newaukum and igneous. The latter occupy a place of relatively greater importance, however, to the greater exclusion of the older Newaukum series. These igneous rocks are of post-Puget age as they occur as sills and dikes in the coal series. The baking and blackening at the contact of these intrusive masses was frequently observed.

In a field classification the smaller masses are classed as basalts, while the larger are more andesitic. The difference in degree of crystallization may wholly account for this. The scale of the map of this area (Plate XX) did not permit the placing of all the smaller intrusives encountered within the area of Puget rocks. A score of these may often be found within a single square mile. Those mapped are placed as accurately as possible, but should be taken as indicating the presence of many times their number. The intricacies of the courses of most streams in this district will be found to be controlled by the structure of these resistant masses.

The recognized outcrops of the Newaukum series are restricted to the southeast portion of the area, although their presence beneath the coal series farther north is evidenced by their having been found a few miles east of Mineral Lake. Certain outcrops along the line between R. 4 and R. 5 E., in T. 13 N., are believed to represent this formation, here brought up by folding and exposed by the erosion of the overlying sediments. A conglomerate at the base of the softer strata may be basal for the Puget rocks.

A prominent feature of the Puget rocks in this area is their almost constant association with igneous intrusives which have been involved in the later movements. Not only in most workings on the coal seams but throughout the area the presence of igneous rock nearby is evident. This relation is of prime importance in the coal beds, being at once the cause of lowering the value of coal through more intense shearing and probably of improving the grade of coal through induced devolatilization.

Structurally the rocks of the area are involved in one major anticlinal fold, with minor parallel wrinkles and cross folds which locally are pronounced. The axis of the major fold is curved, trending northwest in the region about Morton, and swinging northeast and then due north in the vicinity of Mineral Lake. This major structure is in evidence in the ridge-like hills of the area. Those south of Morton have a northwest-southeast trend, those to the north have a nearly east-west trend, while those northwest of Morton trend to the north and northeast. In the northern portion the ridges have a prominent north-south alignment. Faulting, while more prominent than in areas previously described, does not, even here, become a factor in the areal distribution of the formation involved.

The coal of this area is of bituminous rank, showing a low moisture content, and high fixed carbon, while it has a lower volatile content than the coals farther west. The ash content is high in most cases, thus bringing down their heating value. These coals are usually bright, show cubical fracture, and do not slack upon exposure. That taken from some seams shows fair coking properties, but this is not usually the case. Certain samples are near anthracite or natural coke in rank, as shown by both physical properties and analyses. Coals of this type are local in distribution, and are found in the immediate vicinity of intrusive igneous rocks.

The original extent of these coal seams was, apparently, not greater than that of those previously described. In no case is a seam known to be continuous for several miles. The folding and subsequent erosion has removed much of the coal, while the frequent interruptions of the seams, by faulting and intrusives, brings down the available tonnage still more. Until much more extensive prospecting has been done no reliable estimate of the amount of coal present can be made.

DESCRIPTION OF MINES AND PROSPECTS.

Coal seams have been found in most of the area mapped as sedimentary (Plate XX), but the plan to locate and examine all of these was found impossible to follow. The heavy growth of vegetation of all types, combined with the lack of accurate locations, made the task of finding any but the most recent prospects all but impossible. The assistance of guides was found indispensable in practically all cases.

In T. 12 N., R. 5 E., several prospects were made a long time ago, but these have been abandoned since, so very little can be learned on the ground. Such workings were found on the southwest quarter of Sec. 8, and the southeast and southwest quarters of Sec. 6. At the latter place an incline was run on the full dip of the seam, trending N. 85° E. and extending about 100 feet. A much weathered exposure at the portal shows the following section:

	Feet.	Inches.
Sandstones, massive, white	20	0
Sandstone, shaley	3	0
Shale, bituminous	1	6
Coal, bony	1	0
Bone, with streaks of coal	2	0
Base concealed		
Total	27	6

Of this prospect Landes* says:

"The vein is from three and one-half to four feet wide and is fairly regular all the way down the slope. Short gangways have been driven in both directions from the slope. * * * An analysis of the coal gave the following percentages: Water, 1.57; volatile matter, 7.87; fixed carbon, 84.42; sulphur, 1.70; ash, 4.04. * * * There are six other veins lying at short intervals from the main vein and a number of short prospect tunnels have been driven upon them."

It is possible, but extremely unlikely, that coal is to be found to the east of these locations within this township, but in T. 13 N., R. 6 E., the coal series, highly metamorphosed, is found in contact with igneous rock, the coal being near-anthracite while the shales have been changed to slate. Of

*Ibid. p. 248.

this occurrence Landes* says: "The coal has a steel-gray appearance and is extremely hard and compact. An analysis of the coal shows the following percentages: Water, 2.67; volatile matter, 4.86; fixed carbon, 88.66; sulphur, 1.22; ash, 2.59."

Of these occurrences that in Sec. 20 dips northeast while that in Sec. 22 dips southwest, indicating a down-warp which has brought a small patch of the coal series below the level of the Newaukum rocks adjacent, and thus temporarily prevented their erosion.

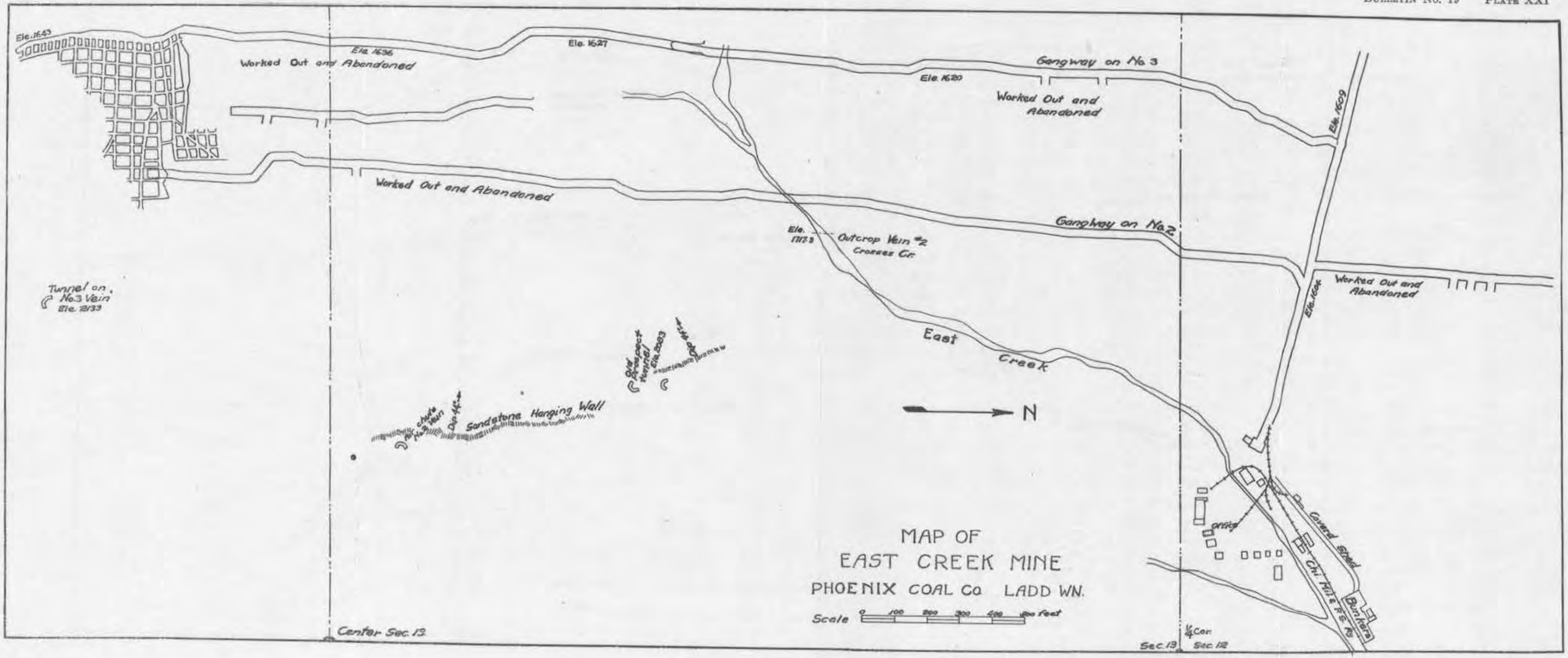
Coal has been prospected in the southwest quarter of Sec. 12 (T. 12 N., R. 4 E.) and the northeast quarter of Sec. 13, of the same township. Here the sandstone series adjoins the basalt to the south, which forms a prominent ridge trending northwest-southeast. A drift on Sec. 12 is reported to have been run on a seam of coal eight feet six inches thick.

In T. 13 N., R. 5 E., coal was prospected on Sec. 30. Landes* gives the following analysis for coal from this section: "Water, 1.80; volatile matter, 34.27; fixed carbon, 58.93; sulphur, 1.34; ash, 3.66." (Sampler and analyst unknown.) The beds here dip to the southwest at a steep angle, 55° being recorded on strata in the East Fork of the Tilton River nearby. To the east the rocks of the Newaukum formations are brought up by a sharp anticlinal fold. At no other point in this township is coal known to outcrop.

To the west (T. 13 N., R. 4 E.) coal has been found in many places along the streams, but prospecting has necessarily been confined to these points of vantage because of the heavy forest growth elsewhere.

Along Connolly Creek several such prospects were examined, as in Sec. 22, southeast quarter of the southeast quarter; northwest quarter of the southeast quarter; and southeast quarter of the northwest quarter. Coal has been found to the west, near the north line of Sec. 21, and to the east, on either side of the north line of Sec. 23. Coal found on Sec. 24 was reported by Landes* to have the following composition: "Water, 3.71; volatile matter, 35.03; fixed carbon, 59.01; sulphur, 1.24; ash, 1.01."

~~*Ibid. p. 250.~~ Annual Rep't vol II p. 250



MAP OF
EAST CREEK MINE
PHOENIX COAL Co LADD WN.

Northwest of this, in Sec. 14, a drift has been driven on a seam four feet thick at the mouth, but less at the face, 55 feet in. The seam dips about 35° to the southwest and shows the section illustrated by Figure 12c. Sample 6496 was taken from this seam, or one nearby, by Umpleby in 1908, and the section measured at that time is quoted by E. E. Smith* as follows:

	Feet.	Inches.
Clay, hanging wall		
Coal	1	1
Parting	1	11
Coal	2	5
Parting	1	0
Coal, bony		2½
Clay		
Shale and coal, bony, footwall		
Total	6	7½

This is classed by Smith as anthracite or natural coke on the basis of analysis. Another seam sampled by Umpleby in 1908 (No. 6488) gave the following section:

	Feet.	Inches.
Hanging wall		
Coal, shaly	1	1
Parting		4½
Coal		11
Parting		2
Coal		5
Parting		1
Coal	1	7
Parting		1½
Coal	1	1
Coal, slaty		9
Clay, plastic		
Footwall		
Total	6	7

This was taken from a 60-foot drift in the southeast quarter of the same section. The analysis shows this to be an impure bituminous coal.

To the north, in Sec. 11 and Sec. 10, seams of nine-foot thickness were noted, but they were apparently rather bony throughout. In the northwest quarter of Sec. 10 Umpleby

*Smith, E. E. Bulletin U. S. Geological Survey, No. 474, 1911, p. 157.

obtained sample 6490 from a seven-foot seam, which measured as follows:

	Feet.	Inches.
Clay, hanging wall		
Coal	1	6
Volcanic ash		1
Coal		8½
Parting		9½
Coal	1	0
Parting		1
Coal		3½
Parting		1
Coal	1	0
Parting		1
Coal	1	6
Shale, footwall		
Total	7	1½

This is about the same quality as that previously described.

Coal is reported on Sec. 2 (T. 13 N., R. 4 E.) and to the north in Sec. 34 (T. 14 N.). At the latter place Umpleby sampled a six and one-half-foot seam in a faulted zone. (No. 6495). The section follows:

	Feet.	Inches.
Clay, hanging wall		
Coal	3	6
Parting		5½
Coal	1	7
Parting		3
Coal		8
Clay, footwall		
Total	6	5½

Northward, in this township, coal is found frequently in Sec. 36, Sec. 25, Sec. 26 and Sec. 24, as well as in the vicinity of the mine at Ladd. In one of these locations, the northeast quarter of Sec. 26 (T. 14 N., R. 4 E.) Umpleby collected sample 6489 from a seam five feet nine inches thick, showing the section below:

	Feet.	Inches.
Hanging wall		
Coal, very bony	1	4
Clay, sandy		5
Coal, very bony		11
Clay		½
Coal and bone in alternating bands		10
Clay		½
Coal, bony, dull layers		4½
Clay		4½
Coal, hard, dull layers		8
Clay		1
Coal, bony		8
Footwall		
Total	5	9

EAST CREEK MINE.

The East Creek Mine, (No. 10 on Figure 1), is located on the south half of Sec. 12 (T. 14 N., R. 4 E.), a spur from the main line of the Tacoma Eastern Railway reaching the property, which joins that of W. M Ladd and J. Bagley, who operated the Ladd Mine from 1906 to 1909. Several seams are found, all of which have been thoroughly prospected; No. 2 being the main commercial bed for a time, although No. 3 afterward became the major producer. No. 2 bed produces a coke of fair quality. It is the only seam known in the district to have this property.

The strata have a strike of about N. 5° E., dipping to the NW. at 45°. The structure is complicated by the presence of sills of igneous rock, one of which was encountered at the portal of the rock tunnel. What is probably the metamorphosed equivalent of the overlying sediments was next encountered, and proved to be nearly as resistant as the igneous rock itself. (See Plate XXI). At about 500 feet in from the portal the tunnel cut No. 2 seam, which was followed with a gangway to the south for several hundred feet, where a fault led to the abandonment of the seam for several years. It is now being reopened and will be worked. At the point in the rock tunnel where No. 3 seam should have been encountered a fault was crossed, and gangways to the north and south failed to show the presence of the coal seam. A bony layer, stratigraphically lower than No. 3, was followed southward to where it pinched out, and the further extension of the gangway along this trend showed the existence of a fault. The fault surface was followed for about 40 feet where No. 3 seam was found in normal attitude. In the later development of this seam the meeting of a fault was preceded by a slight swinging of the seam to the east. An offset in the fault gouge of from 20 to more than 100 feet has to be made for each of the faults. Sections of beds Nos. 2 and 3, as measured by Smith* in 1910, are appended:

*Ibid. p. 159.

No. 9882, Bed No. 2.

	Feet.	Inches.
Sandstone		
Shale	2	0±
Shale, carbonaceous, soft		7
Coal		10
Shale, clayey		1
Coal, "sulphur" in joints	1	9
Shale, carbonaceous		4
Coal, calcite veins		11
Coal bed	3	6±

No. 9880, Lower Bench of Bed No. 3.

	Feet.	Inches.
Coal		
Shale and bony coal		6½
Coal	3	6½
Coal, bony		
Total	4	1

No. 9881, Upper Bench of Bed No. 3.

	Feet.	Inches.
Shale		
Coal	1	8
Shale and bony coal		6½
Total	2	2½

The following sections were measured in this mine by J. B. Umpleby in 1908:

No. 6493, Bed. No. 2.

	Feet.	Inches
Clay		
Coal		9½
Parting		1
Coal	1	11
Parting		1
Coal	1	5
Clay		
Total	4	3½

No. 6494, Bed No. 3.

	Feet.	Inches.
Coal	1	6
Parting		1
Coal		8½
Bone		3½
Coal	4	1
Parting		11
Coal	1	8½
Shale		
Total	9	3½

To make the analyses plain the following notes on the sampling are quoted from Smith's report:

"A sample (No. 9882) of bed No. 2 was taken 60 feet up chute 62 from the first water-level gangway. The two shale partings given in the section can be separated from the bed by careful picking and washing, and were not included in the sample. Two samples were taken at the face of the gangway on bed No. 3, No. 9881 from the upper bench, and No. 9880 from the lower bench. These benches are separated by six and one-half inches of shale and bony coal which is removed from the coal by picking. Sample 9879 was obtained from the face of the gangway on bed No. 4. The bed contains several partings of shale and bony coal. It will probably be somewhat difficult to separate the bony coal from the commercial parts of the bed, but inasmuch as the lower shale parting in the bed was not removed in the sampling it was thought that by removing all the bony coal the resulting amount of ash in the sample would represent that obtained in the ordinary commercial coal from this bed. Sample 6493 was taken from bed No. 2, the two partings of which were not included in the sample. None of the partings were included in sample 6494, taken from bed No. 3. Sample 6492 was taken from the short drift on bed No. 4, where No. 9879 was taken. The parting was not included in the sample. Sample 6491, consisting of two samples of about 300 pounds each of washed coal from bed No. 2, was taken at the bunker as it came from the washer. Each sample was reduced and quartered in the usual manner until 100 pounds were obtained. The two samples were then mixed, ground and quartered until the final sample was about four pounds. It was sealed in the can while still wet."

The mine is opened by a rock tunnel whose portal is in the southwest quarter of Sec. 12, and which extends in a direction north 77° west for a distance of 1,200 feet. A crosscut tunnel, at about 150 feet driven to the southwest, intersects the present worked seam (No. 3). A gangway has been driven on this seam for 4,600 feet and rooms opened above this to the outcrop of the coal. The method is room-and-pillar.

Rooms are 25 feet wide and pillars 30 feet to 35 feet in width. A counter gangway is driven 25 feet from the main gangway and the room pillars are divided into blocks approximately 35 feet square by crosscuts. Some of the rooms are driven through to the surface and used for timber and air chutes. A washing plant is used at this property to prepare coal for market.

This mine was opened in 1907 by the East Creek Coal Company and operated continuously until 1916, when taken over by the Phoenix Coal Company. The present average production is a little less than 100 tons per day.

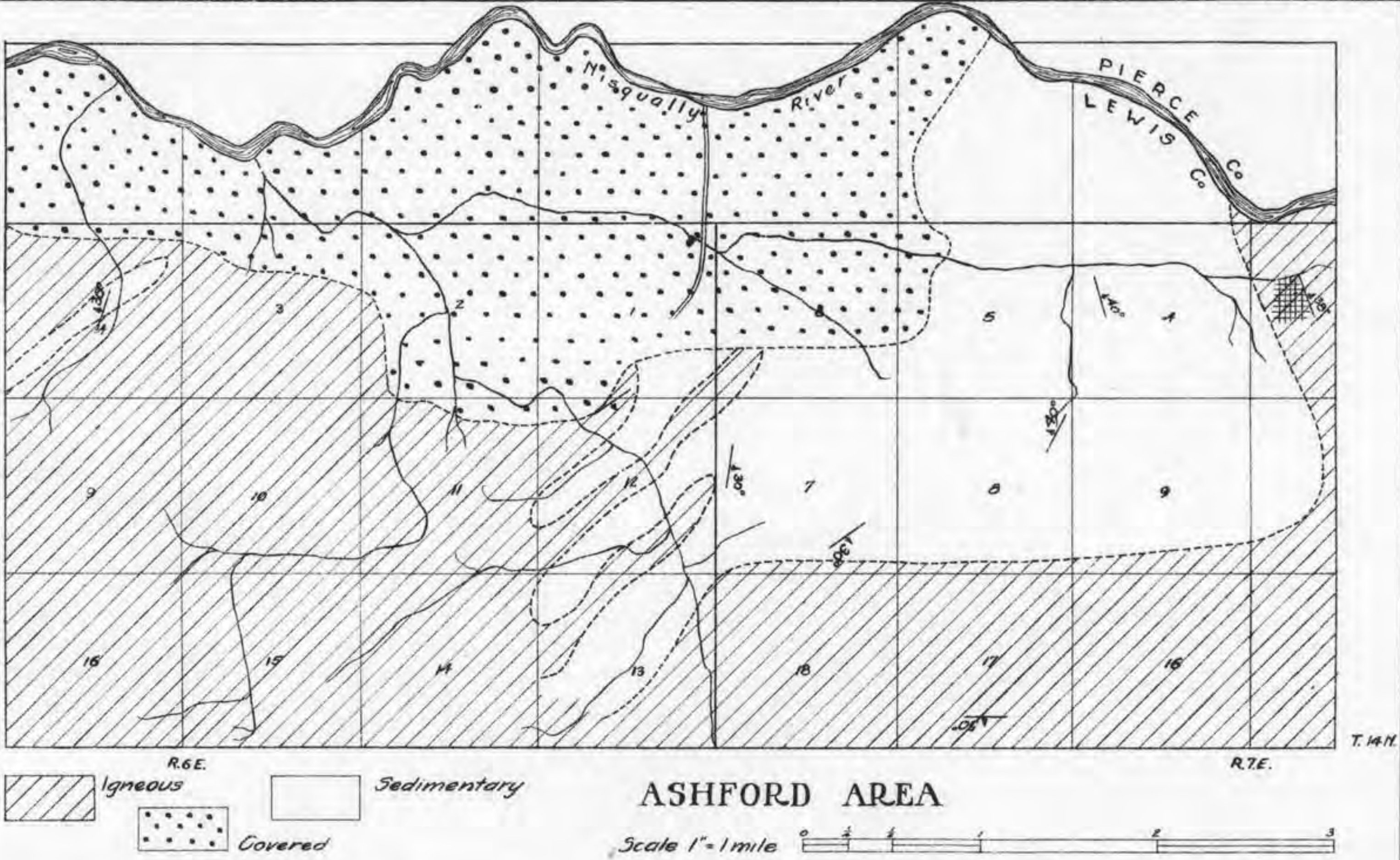
PENNSYLVANIA MINE.

In Sec. 20 and Sec. 21 (T. 14 N., R. 5 E.) are located the old workings of the Pennsylvania Coal Company. The strata here are involved in a sharp anticlinal fold with nearly north-south trend. In the lower workings the coal was opened by a tunnel, the beds dipping westward at 85°. In the upper workings, 1,000 feet up the hill, the coal was reached by a 60-foot incline, which followed a 10-foot seam down the 45° dip to the east. The coal was quite bony throughout and only the upper three feet was mined. This seam was worked in 1912.

To the south, in the west half of Sec. 29, is located the Watkins Mine. The beds here trend northwest, dipping to the southwest at angles of 30° to 50°. After drifting a short distance it was found that the strike swings to the west and beyond this the seam is reported to be interrupted by a 90-foot fault. There is no record of measurement or analysis of this seam.

This mine was opened in 1913 by the Pennsylvania Coal Company and operated up to 1915. At the present time the property is being developed by the Pacific Eastern Coal Company.

Coal prospects are reported from Sec. 33 in this township, but none were located. The coal series are believed to underlie this section and a portion of 34, to the east.



ASHFORD AREA

ASHFORD AREA.

GENERAL GEOLOGY.

The Ashford area is of slight importance commercially but is discussed independently because of its separation from the Mineral Lake area and its close connection with the Pierce County field to the north. The district comprises the northeast part of T. 14 N., R. 6 E., and the northwest quarter of T. 14 N., R. 7 E. This is a mountainous area south of the Nisqually River in the vicinity of Ashford, which town, however, does not appear on the detail map, Plate XXII. The region is, for the most part, inaccessible, and the relations of the formations found are not well worked out. The Puget series occupy the northeastern portion of this area and are presumably continuous beneath the Nisqually flood plain, with the rocks reported by Daniels* in Pierce County.

To the south and east the ill-defined boundary of this formation extends along the east line of Sec. 4, through Sec. 10 and thence westerly to the range line, where it is in complex association with the Newaukum series and also the later intrusives. The areal distribution on Plate XXII is diagrammatic and cannot be interpreted literally. To the south and west, as in Sec. 4 (T. 14 N., R. 6 E.) isolated patches of the Puget formation are found. These are usually adjacent to intrusive masses of igneous rock and whatever coal they contain is greatly changed. Some fragments found resembled impure graphite, while others were more nearly anthracite.

Coal is reported from many points within this area and has been extensively prospected. Because of their apparent high-grade small stringers of coal have been followed, but these have not had sufficient size to merit further development. It is believed that no coal of commercial value is to be found in this district.

PACKWOOD AREA.

GENERAL GEOLOGY.

There is at hand but little data on the geology of the coal-bearing rocks which outcrop in what is known as the Packwood field. This region is in the Upper Cowlitz Valley, north

*Daniels, Joseph. Bulletin Washington Geological Survey No. 10, 1915, p. 29.

of Lake Creek, a tributary entering from the southeast in T. 13 N., R. 9 E. (See Plate XXIII). The area is mountainous and unsurveyed, except for a narrow strip along the Cowlitz River. The following, taken from a report made in 1902 by Landes,* gives the main facts so far as known:

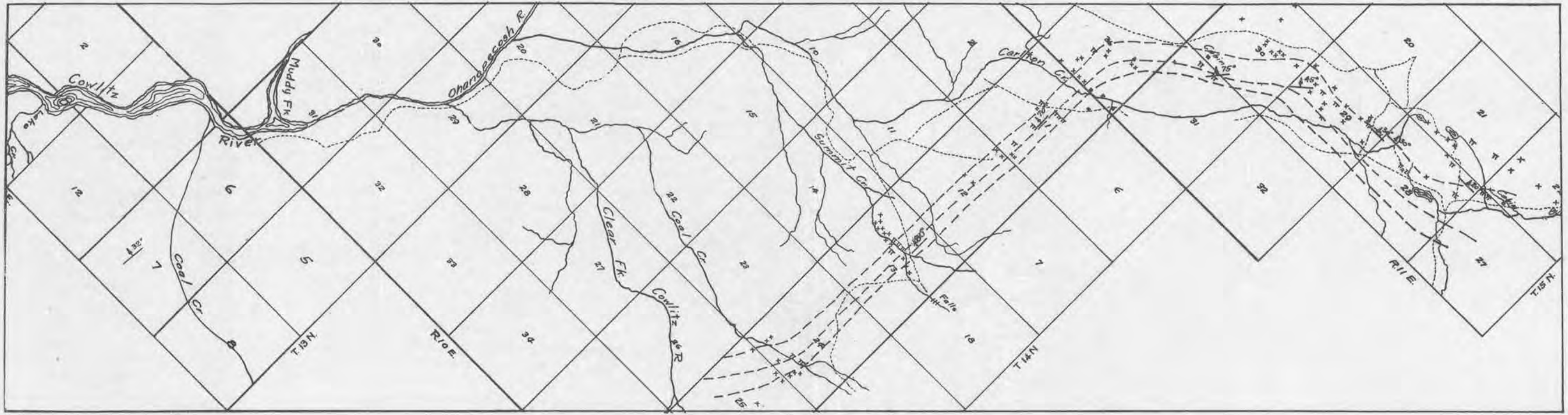
"The coal-bearing shales and sandstones outcrop along the banks of the main river in a few places, but there are more numerous and clearer exposures in the gorges cut by streams entering the valley from each side, and on the intervening ridges. The strata lie mostly within a few degrees of the horizontal. They appear to be free from faults and abrupt folds, but observations made at a number of different points in the region show the direction of dip to vary greatly.

"The chief prospects in the Packwood field are located three miles southeast of the Cowlitz River and two miles north of Lake Creek, at an elevation of 2,600 feet. The workings have a total length of 600 feet. Clean coal lies in thin layers interbedded with shale, which in some cases is highly carbonaceous. The thickness of these layers is most commonly from one to three inches, along with a number of vein-like streaks about one-fourth inch thick, and a few layers from eight to 10 inches thick. Some are continuous for several hundred feet, but the majority are short and taper very gradually at the ends. The beds are overlaid by igneous rock, which at other points nearby show evidence of intrusive origin. At several points in the workings the contact of the igneous mass with the coal shales is plainly shown.

"All of the coal exposed in the tunnels is slacked and crumbles readily, due to its exposure to the atmosphere for several years. Fresh coal, taken a few feet from the face, ignites with difficulty, burns with a short blue flame, gives intense heat, and leaves a small amount of ash. No pyrites of iron is visible in any of the coal.

"Three-eighths of a mile east of the Packwood prospects, just north of the divide between Lake and Coal creeks, two short tunnels have been driven in coal-bearing shales, which seem to belong to the same series as those just described and which may be identical with them, although the connection

*Landes, Henry. Annual Report, Washington Geological Survey, Vol. II, 1902, p. 251-2.



Detail map of the Packwood and Carlton Pass Areas.

cannot be traced accurately. Several feet below the coal a layer of sandy shale contains petrified wood in the form of roots, twigs and stumps. Most of the woody matter has been replaced, but enough carbonaceous material remains to give the specimens a black color, which can be removed by heating.

"Pure coal interbedded with carbonaceous shale and sandstone occurs at a number of places in the beds of Coal and Lake creeks on the high steep ridge between them, and along the smaller creeks to the north and south. The firm hard texture of the coal accounts for the amount of it found as float in all the creeks of the region."

This region was visited in 1909 by E. E. Smith, who took sample 9090 from a surface exposure in the southeast quarter of Sec. 7, T. 13 N., R. 10 E., about two miles east of the Cowlitz River. In regard to this exposure Smith* says: "The coal bed outcropping near the summit of the hill strikes N. 5° E. and dips 32° W. The bed has a total thickness of about 18 feet, only three feet of which was thought to be pure enough to be of commercial value. The remainder of the bed is composed almost entirely of a hard black shale containing thin stringers of coal.

"A drift was run about 20 years ago on a bed outcropping on the opposite side of the hill, about 200 feet below the outcrop described above, and it has always been supposed that the drift and the surface exposure are on the same bed. It was reported that a sample taken from the drift and analyzed at the New Orleans Exposition showed 92 per cent of fixed carbon. It is very clear from the analysis and physical character of the coal from the surface exposures that the drift must be on a different bed.

"Sample 9090 was taken from the three-foot bench of bony coal after removing about six inches of coal from the face of the exposure. The small stringers of coal, which are very hard and jet black, and break with a conchoidal fracture, should probably be considered as anthracite. It would be impossible to separate them from the bony coal in which they are embedded and the marketable coal would have about the same percentage of ash as that obtained in the sample."

*Smith, E. E. Bulletin U. S. Geological Survey No. 474, 1911, p. 156-7.

CARLTON PASS AREA.

GENERAL GEOLOGY.

North and a little east of the Packwood field, and extending beyond the summit of the Cascades, lies the easternmost of the coal areas of Southwestern Washington, known as the Carlton Pass field. This is also called the Cowlitz Pass field.

Topographically this is a region of considerable relief, the general flat, comprising the summit area of the Cascade Mountains, having been sharply incised by the action of ice and the swift mountain streams. The valleys of these latter show elevations of from 1,500 to 2,000 feet below the adjoining peaks. The general character of the topography is shown on the Mount Aix sheet, which includes along its western boundary most of the Carlton Pass field. To the west the field is drained by a series of small streams, of which Carlton, Summit and Coal creeks are the largest. To the east water flows into Bumping River and Deep Creek.

Although this region has been prospected extensively for a number of years not a great deal of information is at hand relative to the general geology of the coal-bearing strata. So far as known the field comprises a narrow strip running north and south through T. 14 N., R. 10 E., but turning rather sharply to the east in T. 15 N., R. 11 E. This belt is from half a mile to a mile and a half wide and some 10 miles in length. (See Plate XXIII).

Several rock types are found within the field, but the relations between them are not clear. Igneous rocks similar in character to those found in the Mineral Lake area to the west outcrop next the Puget rocks. These are probably porphyritic andesites, which have been intruded into the sediments prior to their folding. The latter are usually rather coarse, but show considerable variation in composition. The usual interbedding found in the Puget series of shales, sandstones and carbonaceous layers with the coal is well exhibited in this field. Probably the best single exposure of the series is that on Summit Creek, which runs transverse to the strike of the strata. (See Plate XXIV).

A. A portion of the coal series. Timbering shows where a 20-foot seam has been opened.
B. Falls of Summit Creek. Andesite porphyry here overlies the coal series which is exposed in the foreground.
C. Igneous dike north of the creek. This has been intruded into the coal series and because of the superior resistance forms a prominent ridge.

This place is reported on by Landes* as follows: "A cross-section of the coal measured in the bed of Summit Creek, taken from west to east, but going from above downward in the series, is as follows:

	Feet.	Inches.
Porphyritic andesite		
Sandstone	172	
Carbonaceous shale	1	6
Sandstone	140	
Shale	40	
Micaceous sandstones, thin-bedded with clay inclusions	66	
Porphyritic andesite, intrusive	19	
Sandstone	5	
Shale	20	
Carbonaceous shale	16	
Shale	12	
Coal seam, very impure or bony coal	4	
Shale	4	
Sandstone	8	
Shale	12	
Sandstone	75	
Shale	18	
Coal seam, mostly bone	6	
Sandstone	4	
Coal seam, very little good coal	5	
Carbonaceous shale	20	
Massive sandstone	878	
Coal seam		3
Sandstone	40	
Shale	4	6
Coal seam	1	6
Sandstone	12	
Shale	11	
Coal seam No. 1	21	
Sandstone	70	
Coal seam No. 2, Mammoth vein	39	
Sandstone	2	
Coal seam No. 3	14	
Sandstone	25	
Carbonaceous shales and interbedded sandstones	62	
Coal seam No. 4	10	
Sandstones and shales, interbedded	18	
Carbonaceous shale	6	6
Coal seam	5	
Carbonaceous shale	70	
Basalt, intrusive sheet,	10	
Sandstone, indurated	16	
Micaceous sandstone	7	
Coal seam	12	
Sandstones and shales, interbedded	60	
Carbonaceous shale	4	
Sandstones and shales, interbedded	100	
Coal seam	3	
Sandstones and shales	21	
Coal seam, No. 5	8	8

*Landes, Henry. Unpublished report based on field examination made in 1908.

	Feet.	Inches.
Shale	25	
Coal seam No. 6, Primrose vein	16	
Sandstones and shales	17	
Coal seam	2	6
Sandstone	12	6
Coal seam, mostly bone	4	
Gray sandstone, cross-bedded and hard	75	
Sandstones and shales	14	
Coal seam No. 7, about one-fourth good coal	12	
Sandstone	12	
Coal seam No. 8, about one-half good coal	10	
Blue micaceous sandstone	18	
Coal seam No. 9, nearly all bony coal	10	
Porphyritic andesite, intrusive	3	
Red and white shale	160	
Basalt, intrusive, with inclusions of red and white shale	83	
Indurated shale, with two very small coal seams	147	
Porphyritic andesite, intrusive, thickness unknown		3
Total thickness of section	2,768	11

The structure of the rocks is simple. The beds here are on the western limb of an anticline of nearly north-south trend. At the northern end the trend is almost due east-west, the beds dipping to the north at about 20°. Traced westward the strike swings to the southwest across Sec. 30, (T. 15 N., R. 11 E.) turning due south through sections 1, 12, 13, 24 and 25, T. 14 N., R. 10 E. At this point there is some evidence that the trend is southwest, and the more recently discovered seams on Clear Fork are probably in Sec. 26. No faulting has been observed in this field.

The northern extension of the field is not known, but it would not be surprising if the Puget rocks had been completely eroded from the eastern slope of the Cascades. To the south, however, the westward trend of the coal series points to an original connection with the strata of the same group in the Packwood Lake field about six miles to the southwest. Whether this connection is maintained at present or not remains in doubt.

As would be expected from its position within an area which has been subjected to mountain-forming movements, the coal of this field is of anthracite rank. It is hard, pitch-black, of bright luster and conchoidal fracture. It shows no tendency to slack on exposure; blocks lying on the dump for many years retain their luster and hardness almost perfectly.

From analysis the coal of this field is in part semi-anthracite and in part true anthracite. It is easily the best coal of this region, and with the possible exception of that from Whatcom County, the best in the state. The sections shown below, of the coal seams from this field, show the close interbedding of coal layers with layers of bone and carbonaceous shale. Probably the only difficulty to be overcome in the successful exploitation of this coal is the ready separation of the coal from the associated bone. Because of this close association, the samples of the seams as usually made, that is, in accordance with present mining practice, give the coal an unusually high ash content, whereas careful sampling with due regard to the elimination of these bony layers shows a coal of extraordinarily high rank. Differences in mode of sampling are productive of greater differences in the analytical results with coals of this character than with coals of lower grade.

The relative ease with which the coal-bearing rocks can be traced in this region has led to extensive exploration and prospecting has been carried on in practically every quarter-section in the field. In some places the operations have been prolonged, but in many instances the work has been slight and of little value.

The section quoted above shows the presence of a number of coal seams of remarkable size. Of these, two are more prominent than the rest; they are known as the Mammoth and the Primrose seams and are about 40 and 20 feet in width respectively.

PROSPECT NORTH OF CARLTON CREEK.

The field was visited by Smith* in 1909 and the following is taken from his report on the region:

"Prospect on the north side of valley, about 500 feet vertically above Carlton Creek, in the southeast quarter of the northwest quarter of Sec. 29, T. 15 N., R. 11 E. This coal bed occurs in the lower coal group of the Carlton Pass coal field. An open cut has been made across the face of the bed, exposing a total thickness between hanging and foot walls of about nine feet. The bed is composed almost entirely of black

*Smith, E. E. Bulletin U. S. Geological Survey No. 474, 1911, pp. 152-156.

shale containing very thin stringers of bright coal and several layers of very badly crushed graphite shale. The following is a section of the bed:

No. 9093.

	Feet.	Inches.
Shale, sandy, carbonaceous		
Shale, graphitic	1	6
Shale, hard, black		7
Shale, graphitic		3½
Shale, black, thin stringers of pure coal	2	0
Shale, black, hard		8½
Shale, graphitic	1	7
Shale, carbonaceous, with thin stringers of bright coal	1	11
Sandstone and shale, with thin layers of carbonaceous shale		
Total	8	7

"Sample 9093 was taken from the graphitic shale layer one foot six inches thick near the top of the bed. The material is badly broken and shows considerable movement in the bed. When wet, the slickensided faces are very bright and give the appearance of anthracite coal. This bench was thought by the writer to contain a high percentage of graphite, and has been considered generally by coal prospectors who visited this field to be a high-grade coal. The analysis in the accompanying table shows that the bench is hardly better than carbonaceous shale.

PROSPECT SOUTH OF CARLTON CREEK.

"Prospect on hillside south of Carlton Creek in the southeast quarter of Sec. 1, T. 14 N., R. 10 E., about 1,100 feet above the bed of the creek. A gangway 90 feet in length has been driven on this bed, which strikes north and south and dips 60° W. At the end of the gangway the following section was measured:

No. 9091.

	Feet.	Inches.
Shale		
Shale, black	3	2½
Shale, black	3	2½
Coal, partly graphitic		7
Shale, black, carbonaceous	1	0
Coal (semi-bituminous)	3	6
Coal, impure	1	6
Sandstone		
Total	9	9½

"Sample 9091 was taken from the bed of good coal three feet six inches thick, and its analysis is given in the table. * * * The coal is very hard and bright, but contains a few thin stringers of dull coal. It burns on a forge with a short blue flame and has the appearance of anthracite coal. Analysis shows that it is very high in ash. It is massive and banded, and breaks with a conchoidal fracture.

PROSPECT A, SUMMIT CREEK.

"Prospect on Summit Creek in the southeast quarter of the northwest quarter of Sec. 13, T. 14 N., R. 10 E. This bed, which is known as the Primrose bed, is about 20 feet in thickness between hanging and foot walls. A gangway has been driven about 50 feet in the lower part of the bed, which is slightly overturned, dipping 82° and striking north and south. The following section shows the details of the bed:

	Feet.	Inches.
Shale, hanging wall		
(1) Coal, with thin layers of bone (sample 9101)	2	8½
(2) Coal, bony, with some graphitic shale	2	6
(3) Shale, graphitic (sample 9097)	1	5
(4) Shale, black		8½
(5) Coal and layers of bony coal (sample 9102)	2	1
(6) Coal (sample 9099)	4	11
(7) Coal and graphitic shale in alternating layers	3	11
(8) Shale, black	2	0
Sandstone, footwall		
Total	20	3

"The section was measured and the samples taken from the face of an open cut across the bed at the entrance to the gangway. Bench No. 1, from which sample 9101 was taken, contains a large percentage of hard, bright coal resembling that from bench No. 6, but the numerous thin layers of bony coal scattered through the bed can be separated from pure coal only with extreme difficulty and will increase the percentage of ash in the bed very considerably. No sample of bench No. 2 was taken, but the coal resembles that sampled in bench No. 5. Sample 9097, taken from the graphitic shale of bench No. 3, shows on analysis that this bench is too high in ash to be of economic value. Sample 9102, taken from bench No. 5, contains a large amount of ash, and is too impure to be of commercial value at the present time. Sample 9099 was taken from bench No. 6, and represents the best coal in the bed. Sample 9100 was obtained from a layer of the best coal near the center of bench No. 6, and represents the best picked coal from the bed. * * * The coal from bench No. 6 is pitch black, bright, and very hard. It is massive and breaks with an irregular conchoidal fracture. In the other benches the coal is not so pure, is banded and laminated, and breaks with an irregular, splintery fracture. The coal burns in an open fire with a short blue flame, and, in general, leaves a fairly large amount of ash, though a sample taken from the best layer in the center of bench No. 6 has a fuel ratio of 11 and a relatively small percentage of ash. The analysis (No. 9100) of this sample compares favorably with the analyses of some of the anthracite coals of Pennsylvania. The percentage of volatile matter is somewhat higher than in the average Pennsylvania anthracite, but lower than that of the semi-anthracite coal of Sullivan County, Pa., which is sold in the market as anthracite.

PROSPECT B, SUMMIT CREEK.

"Prospect on Summit Creek, in the southeast quarter of the northwest quarter of Sec. 13, T. 14 N., R. 10 E. The bed is slightly overturned at this place, and has the same dip and strike as that given for the Primrose bed in the preceding description. It is separated from the Primrose by 25 feet of shale. The following section was measured at the face of a drift run along this bed 35 feet:

No. 9098.

	Feet.	Inches.
Shale		
Coal	2	9½
Coal, poor		7
Shale, black	3	0
Coal, bony	2	2½
Shale		
Total	8	7

"Sample 9098 was taken from the best bench of coal in the section noted above. The coal was more or less crushed and mixed with carbonaceous shale. * * * The coal is pitch black, bright, and hard. It is massive and dense, and breaks with a conchoidal fracture. Analysis shows that the

—5

coal contains a very high percentage of ash, and although it is classed as a good grade of semi-anthracite, the percentage of ash in the entire bed is so high that it would be of little value commercially unless the carbonaceous shale could be separated thoroughly by crushing and washing.

PROSPECT C, SUMMIT CREEK.

"Prospect on Summit Creek, in the southeast quarter of the northwest quarter of Sec. 13, T. 14 N., R. 10 E., about 350 feet west of the opening on the Primrose bed previously described. The coal bed which belongs to the same group as the Primrose bed outcrops very near the level of the creek, and only the middle of it was exposed in the prospect. It is slightly overturned, and has a dip and strike practically the same as that of the Primrose. The following section was measured:

No. 9092.

	Feet.
Coal, bony	1+
Coal	1
Coal, bony	1+
Total	3+

"Sample 9092 was taken from the one-foot bench of good coal. * * * The coal, which is very bright, pitch black and hard, is massive and dense, and breaks with a conchoidal fracture. It contains a low percentage of ash and has a high calorific value. The coal is an anthracite and compares favorably with much of the Pennsylvania anthracite."

CHAPTER VI.

THE UTILIZATION OF SOUTHWESTERN WASHINGTON COALS.

The coal from this field is used for domestic trade and steam generation. A larger percentage of the coal produced in these mines is obtained in lump and coarse sizes than from the mines of most of the districts of the state, and this grade of coal goes mainly into the household trade. The remainder, as well as the finer sizes, find use in clay plants for firing kilns, in the logging industry for engines and locomotives, and in general boiler plants. Practically the entire output of the Hannaford Mine at Tono, the largest producer of the field, is used by the O.-W. R. R. & N. Co. on its lines in western Washington.

Among the several factors which determine the market for this coal, three, which show considerable variation over the field, are probably the most important. They are: (1) the grade of coal, (2) the cost of production, and (3) transportation. In regard to the first it is obvious that, other factors being equal, the market for the coals of different rank will not be the same. Coal from the lower grade subbituminous seams of the western part cannot have the same market as the bituminous coals of the eastern portion, but lesser differences in rank are more or less equalized by variations in the other factors. The coking coals, on the other hand, have a market distinct from all others, no matter how the other factors may vary. The cost of production is lower in this field than in others of the state and for this reason the market for the coal is wider than it would otherwise be and overlaps to some extent that of the other fields.

The third factor has two phases: Facilities for transportation and the ability of the coal to stand it. As to the first, the coals of this field are well supplied. Most of the mines are located close to railroad lines. The Mineral Lake area is served by the Tacoma Eastern Railway, and the other producing areas have connection directly, or through one of the shorter branch lines, with the Northern Pacific, the Great Northern, the Oregon-Washington Railroad & Navigation

Company, or the Chicago, Milwaukee & St. Paul lines. Only a few of the smaller mines have had to deliver by wagon.

In regard to the other phase of the transportation factor, the coals of this field are not so fortunate. None of those which slack readily upon exposure to the air stand transportation well, and the two factors combine to limit both the distance to which such coal may be moved and the time that can elapse, after mining, before the coal is burned. This accounts for the limited market open to these coals at the present time and for the more or less spasmodic operation of many properties. With improved methods in handling, or of utilization, they will become exceptionally valuable and their market greatly enlarged. As has been indicated in the preceding pages, however, the coals of the field vary considerably in their air-slacking propensities, some crumbling in a few months, while others show no disintegration even after years of exposure.

Under the existing conditions the market for these coals is mainly western Washington, south of Tacoma, and northwestern Oregon. Occasional shipments have been made to points east of the Cascades, but these constitute an extremely small percentage of the total production. In the direct use of the coal the future expansion of the market will be through improvement in facilities for transportation and storage.

In regard to the future there must be considered a factor which, although minor at present, is increasing in importance and ultimately will determine the development of the coal industry of this field. This is the preparation of the coal (as mined) so as to improve its quality and, also, to make use of what is waste under present modes of utilization. For over a score of years the matter of preparing coal has been studied more or less carefully, and many methods of handling and treating it have been devised. The variation in composition in both domestic and foreign coals, however, made the results obtained with one grade of coal inapplicable to others. Within the last decade the experimental work has emphasized three possible processes, viz., the manufacture of briquets, of producer-gas, and the more direct use of the coal through drying and pulverizing.

Of these the first has been developed to a satisfactory stage for some of the higher grade coals, but the cost of briquetting coal of the lower grades usually has been too high to make the process practicable. It is wholly probable, however, that means will be found to make the simple briquetting of lignites and subbituminous coals commercially possible. The manufacture of producer-gas from those coals that are especially high in volatile constituents has also been developed to a satisfactory state. In fact, there is a large and increasing use of lignite coal in producer-gas plants. What is probably a more efficient method is the combination of these two processes, which results in the manufacture of both producer-gas and briquets. This has been the subject of some valuable experimental work on a moderately large scale done at the College of Mining Engineering and at the mining substation of North Dakota under the direction of E. J. Babcock.

The work was carried out on a scale large enough to approximate closely commercial operations. Using various grades of coal in a specially designed plant and watching every detail of operation, the experimenters obtained a large amount of valuable data on the process. Babcock* summarizes the general results of the experiment as follows:

"The large number of experiments performed during the progress of the work in the laboratory and in the plant just described indicate that one of the methods offering the greatest possibility in the utilization of lignite is that of producing gas in a retort and utilizing the retorted residue and by-products. In carrying out this process, four products are obtained. First, in the use of comparatively dry lignite a large yield of gas is procured, the gas being of a quality adapted for power and for heating and lighting purposes. Second, after the gas has been driven off the lignite is converted into a non-coking residue of good quality, having a high percentage of fixed carbon and excellent heat-producing properties. Third, a tar is obtained, which, with proper distillation or concentration, gives a product promising to be of considerable commercial value. The preliminary experiments thus far carried on would indicate that by special treatment the tar can be

*Babcock, E. J. Bulletin U. S. Bureau of Mines No. 89, 1916, p. 28.

advantageously used in the process of briquetting. It also contains other products of evident worth. Fourth, a product is derived containing a large yield of ammonia which, after being converted into ammonium sulphate, may have considerable market value.

"During the tests of the past two years careful observations were made to determine the temperature required, the amount of gas produced, the amount of coal residue left, and the quantity and character of tar and ammonia by-products. Careful analyses and calorific determinations of the gas were then made. In this manner much valuable information has been procured. The amount and character of the gas obtained from lignite has been rather surprising and very encouraging. Indeed, there seem to be great possibilities in the manufacture of gas from lignite, especially if all of the by-products are carefully utilized."

By thorough carbonization of the lignite the resulting residue, made into briquets, shows a composition quite similar to that of anthracite coal. The following analyses and calorific values are quoted* in this connection for purposes of comparison:

Chemical Analyses and Calorific Values of Anthracite Coal, Lignite and Lignite Briquets.

	Moisture	Volatile Matter	Fixed Carbon	Ash	Heating Value
	%	%	%	%	B. T. U.
Lignite as mined ..	35.01	25.11	34.68	5.21	7,000 to 7,800
Lignite briquets ..	0 to 6	2 to 8	72 to 82	10 to 16	11,500 to 12,000
Anthracite	1 to 5	2 to 6	78 to 92	10 to 15	12,000 to 13,500

Two points are to be noted, (1) the increase of about 70 per cent in the calorific value of the lignite by briquetting; and (2) the increased percentage of ash in the briquet. It is obvious that the ash content of the original coal might be so high as to seriously reduce the heating value of the resulting briquet. For such coals the experiments point to "the desirability of stopping the carbonization before it has been fully completed. By this method the light hydrocarbons are driven off but the heavier hydrocarbons remain behind, increasing the yield of residue considerably and reducing the relative

*Ibid. p. 58.

proportion of ash. The residue gives a briquet that burns with considerable flame, but it has a high heat value and is, withal, an excellent fuel for general use." An average of 25 analysis of semi-carbonized lignite briquets is given for comparison.

Average Analysis of Semi-carbonized Lignite Briquets.

Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	B. T. U.
5.25	15.70	64.51	14.54	11,692

The success of this method of treatment of North Dakota lignites seems to be demonstrated. Equally satisfactory results were obtained with similar coals from Montana, Colorado and Texas. Reference to Plate IX shows that the main difference between the lignites of North Dakota and the subbituminous coals of the Centralia-Chehalis field, for example, is the moisture content. This would mean lower drying cost for the Washington coals. In fact, there appears to be nothing to interfere with the application of the combined producer-gas and briquetting process to the coals of southwestern Washington, and this would furnish an extended market for coals at present used only locally.

The development of the third process, that of pulverizing dried coal, has been brought to a successful stage by experimentation carried on in Seattle under the direction of W. J. Santmyer, advising steam engineer for the Puget Sound Traction, Light & Power Company. Earlier work done in the East made possible the use of powdered coal in cement furnaces and in reverberatory furnace work, but the application to steam boiler practice was not wholly successful even on the small scale operation of the few plants which attempted it.

Without going into the mechanical details of the pulverization plant the essential phases of the process, as developed by Santmyer, may be listed as follows: (1) the preliminary crushing of the raw coal by which it is reduced to about one-inch size; (2) the drying, in which the moisture content is reduced to four per cent or less; (3) the pulverizing, by which the crushed and dried coal is ground to a fineness permitting 95 per cent to pass a 100 mesh screen and 85 per cent to pass a 200 mesh screen; (4) the feeding, by which the pulverized coal is charged into the furnace through a burner which mixes the coal with air in the desired proportions; and (5) the slagging, by which the ash content of the coal, as molten slag, is accumulated and removed from the furnace pit.

Results obtained through pulverization of coals of the sub-bituminous type are of special interest in connection with a study of the coals of southwestern Washington. Such coals, which gave an evaporation of six and one-quarter pounds of water per pound of coal on chain grates gave over eight and one-half pounds of water per pound of powdered fuel. This corresponds to an increase of about 25 per cent in the evaporative efficiency of the raw coal.

After several months of careful experimentation on a moderate scale, utilizing all obtainable grades of coal from high rank bituminous to low grade lignite, it was concluded that all the coals mined in western Washington could be successfully burned in this prepared form. It is to be noted that the increase in efficiency was greater for the lower rank coals than for the coals of bituminous rank.

The physical possibility of the use of the subbituminous coal of this state having been demonstrated, there remains for consideration the factor of cost of operation of the pulverization plant in relation to the increased value of the coal through preparation. While further experimentation is necessary to finally ascertain this factor, it is believed that the cost will lie between 50 cents and one dollar per ton, of prepared coal. In this connection the suggestion to establish the pulverization plant at the mine and transmit by wire the power developed is valuable. This would permit the utilization of a much larger percentage of the coal mined than is at present used, since the "fines" and much of the other waste can apparently be successfully burned after preparation.

The success that has attended the development of this process makes it evident that by this means there is opened a vastly extended market for the coals of this district. The Tono coal, for instance, is reported to give a high efficiency and to "burn like oil." The ease of adjustment of the plant, to meet the demands upon it by the different kinds of coal, make it safe to count upon the availability of practically all the coals of the field. A large percentage of the coal that in present practice is lost or wasted might be utilized in the pulverizing plant and hence the actual recovery from the mines will be increased.

The O.-W. R. R. & N. Co. have begun experiments looking toward the utilization of powdered fuel in locomotives, but the present demand for railroad facilities has necessitated the postponement of this line of investigation. Meanwhile the establishment in Seattle of several boiler plants making use of this process of preparation is an indication that pulverization is economically feasible.

It is evident then, that while some extension of market under present methods of use is possible and, indeed, to be expected for the coals of this district, the further application of one or more of the methods described above for the preparation of the coal will inevitably lead to the marked extension of the use of these coals and a corresponding development of the coal mining industry of southwestern Washington.

APPENDIX A.

COAL PRODUCTION IN WASHINGTON, BY COUNTIES, 1908-1917.

(In Short Tons)

COUNTY	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917
Clallam............	2,979	2,702	696	....	....	....	....	....	....	....
King...............	916,572	1,215,327	1,311,870	1,241,583	1,050,953	1,359,274	1,042,607	844,966	889,275	1,314,366
Kittitas............	1,411,263	1,550,500	1,667,453	1,254,845	1,235,690	1,330,596	1,237,564	879,062	1,316,993	1,741,237
Lewis.............	58,275	101,450	172,219	158,801	127,982	148,592	87,558	78,259	109,121	130,578
Pierce..............	553,406	615,284	784,961	795,768	789,320	832,272	553,841	488,693	533,162	606,049
Skagit............	....	....	....	....	....	....	....	....	....	1,000
Thurston..........	16,032	90,740	29,955	93,849	136,478	153,588	112,189	112,096	165,066	204,688
Whatcom..........	18,963	14,632	12,415	3,476	6,523	7,325	6,602	6,255	5,983	4,841
State Totals..	2,977,490	3,590,639	3,979,569	3,548,322	3,346,946	3,478,013	3,040,361	2,409,331	3,019,600	4,002,759

APPENDIX B.

MINE PRODUCTION IN SOUTHWESTERN WASHINGTON.

(In Short Tons)

MINE	Operating Date	Total Production
KELSO-CASTLE ROCK AREA		
Anchor	1891-1896	4,623
Idleman	1892-1896	2,066
Total		6,689
CENTRALIA-CHEHALIS AREA		
Florence	1891-1895	14,430
Eureka	1892-1895	16,475
Leonards	1895-1896; 1915	4,341
Rosenthal	1895; 1911-1917	49,555
Howell	1903-1914; 1916-1917	4,932
Crescent	1903-1908	4,923
Gibson	1904-1917	5,135
Potlatch	1909-1911	8,796
Perth	1909-1910	2,455
Fords Prairie	1910-1917	40,930
Sheldon	1912-1917	21,633
Rainier	1913-1914	1,721
Total		175,326
TENINO-MENDOTA AREA		
Bucoda	1887-1894; 1914; 1917	70,952
Great Western	1903-1907; 1909	55,755
Kopiah	1906-1914	233,483
Black Bear	1907-1908; 1911	10,340
Richmond	1907	6,112
Hannaford No. 1	1907-1917	1,072,627
Mendota	1908-1917	348,117
Majestic	1911	395
Empress	1913-1917	26,867
Monarch	1913; 1915-1917	19,118
Free Burn	1916-1917	6,067
Total		1,849,833
MINERAL LAKE AREA		
Ladd	1906-1909	31,816
East Creek	1907-1917	248,658
Divide	1912-1915	16,912
Total		297,386
Grand Total		2,329,234

APPENDIX C.

ANALYSES OF COAL SAMPLES FROM COWLITZ, LEWIS AND THURSTON COUNTIES.

COWLITZ COUNTY.

Name of Mine or Form of Exposure	Laboratory No.	LOCATION				Air-drying loss	Form of Analysis	PROXIMATE				ULTIMATE						Heat Value	
		Quarter	Section	Township	Range			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British Thermal Units
Prospect, 12 mi. W. of Kelso (finely ground).	6760	SW.	26	9 N.	3 W.	....	As received.	15.24	36.28	29.54	18.94	4.39	......	......	......	......	......	......
							Dry coal....	......	42.80	34.85	22.35	5.18	......	......	......	......	......	......
							Pure coal...	......	55.12	44.88	....	......	......	......	......	......	......	......
Prospect, 12 mi. W. of Kelso (coarsely ground).	6760	SW.	26	9 N.	3 W.	....	As received.	22.22	33.30	27.11	17.37	4.03	......	......	......	......	......	......
							Dry coal....	......	42.81	34.87	22.33	5.18	......	......	......	......	......	......
							Pure coal...	......	55.12	44.88	....	......	......	......	......	......	......	......
Prospect, 12 mi. W. of Kelso (coarsely ground).	6761	SW.	26	9 N.	3 W.	....	As received.	16.26	36.33	30.05	17.36	4.61	......	......	......	......	......	......
							Dry coal....	......	43.38	35.89	20.73	5.51	......	......	......	......	......	......
							Pure coal...	......	54.72	45.28	....	......	......	......	......	......	......	......

LEWIS COUNTY.

Name of Mine or Form of Exposure	Laboratory No.	Quarter	Section	Township	Range	Air-drying loss	Form of Analysis	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British Thermal Units
Prospect on Carlton Creek...	9093	NW.	29	15 N.	11 E.	7.8	As received.	9.8	6.8	13.6	69.8	0.25	......	......	......	......	1,115	2,000
							Air dried...	2.1	7.4	14.8	75.7	0.27	......	......	......	......	1,205	2,170
							Dry coal....	......	7.6	15.1	77.3	0.28	......	......	......	......	1,235	2,220
							Pure coal...	......	33.4	66.6	....	1.24	......	......	......	......	5,440	9,790
Prospect on Carlton Creek...	9091	SE.	1	14 N.	10 E.	3.5	As received.	4.2	10.5	51.2	34.05	0.48	3.08	53.61	0.87	7.91	4,935	8,880
							Air dried...	0.8	10.8	53.1	35.28	0.50	2.79	55.55	0.90	4.98	5,115	9,200
							Dry coal....	......	10.9	53.5	35.56	0.50	2.73	55.97	0.91	4.33	5,155	9,280
							Pure coal...	......	17.0	83.0	....	0.78	4.24	86.85	1.41	6.72	8,000	14,400

Prospect A. on Summit Creek; Primrose Bed.	9101	NW.	13	14 N.	10 E.	2.8	As received.	3.6	8.4	59.6	28.40	0.66	3.17	60.00	0.99	6.78	5,580	10,050
							Air dried...	0.8	8.6	61.4	29.22	0.68	2.94	61.73	1.02	4.41	5,740	10,340
							Dry coal....	......	8.7	61.8	29.46	0.68	2.87	62.23	1.03	3.73	5,790	10,420
							Pure coal...	......	12.3	87.7	....	0.96	4.07	88.20	1.46	5.31	8,205	14,770
Prospect A. on Summit Creek; Primrose Bed.	9097	NW.	13	14 N.	10 E.	3.7	As received.	5.1	8.6	36.6	49.7	1.00	....	....	....	....	3.325	5,980
							Air dried...	1.5	8.9	38.0	51.6	1.04	....	....	....	....	3,455	6,210
							Dry coal....	......	9.0	38.6	52.4	1.05	....	....	....	....	3,505	6,310
							Pure coal...	......	19.0	81.0	....	2.21	....	....	....	....	7,370	13,260
Prospect A. on Summit Creek; Primrose Bed.	9102	NW.	13	14 N.	10 E.	3.0	As received.	3.9	8.6	52.1	35.4	0.66	....	....	....	....	4,820	8,860
							Air dried...	0.9	8.9	53.7	36.5	0.68	....	....	....	....	4,970	8,950
							Dry coal....	......	8.9	54.2	36.9	0.69	....	....	....	....	5,015	9,030
							Pure coal...	......	14.1	85.9	....	1.09	....	....	....	....	7,945	14,300
Prospect A. on Summit Creek; Primrose Bed.	9099	NW.	13	14 N.	10 E.	3.1	As received.	4.0	7.4	71.1	17.52	0.55	3.35	71.41	1.30	5.86	6,615	11,900
							Air dried...	0.9	7.6	73.4	18.09	0.57	3.11	73.69	1.34	3.20	6,825	12,280
							Dry coal....	......	7.7	74.0	18.25	0.57	3.03	74.33	1.35	2.47	6,885	12,390
							Pure coal...	......	0.94	90.6	....	0.70	3.71	90.92	1.65	3.02	8,420	15,150
Prospect A. on Summit Creek; Primrose Bed.	9100	NW.	13	14 N.	10 E.	2.0	As received.	2.7	7.1	79.5	10.67	0.62	3.48	79.22	1.32	4.69	6,420	13,350
							Air dried...	0.7	7.3	81.1	10.89	0.63	3.33	80.84	1.35	2.96	7,570	13,620
							Dry coal....	......	7.3	81.7	10.96	0.64	3.27	81.39	1.36	2.38	7,620	13,720
							Pure coal...	......	8.2	91.8	....	0.72	3.67	91.41	1.53	2.67	8,560	15,410
Prospect B. on Summit Creek.	9098	NW.	13	14 N.	10 E.	2.9	As received.	3.7	7.3	47.8	41.16	0.70	2.64	47.64	0.87	6.99	4,440	7,990
							Air dried...	0.8	7.6	49.2	42.39	0.72	2.39	49.06	0.91	4.53	4,575	8,230
							Dry coal....	......	7.7	49.6	42.74	0.73	2.31	49.47	0.91	3.84	4,610	8,300
							Pure coal...	......	13.3	86.7	....	1.27	4.03	86.39	1.59	6.72	8,050	14,490
Prospect C. on Summit Creek.	9092	NW.	13	14 N.	10 E.	2.1	As received.	2.9	8.6	81.9	6.6	0.78	....	....	....	....	7,640	13,750
							Air dried...	0.8	8.8	83.6	6.8	0.80	....	....	....	....	7,805	14,050
							Dry coal....	......	8.9	84.3	6.8	0.80	....	....	....	....	7,870	14,170
							Pure coal...	......	9.5	90.5	....	0.86	....	....	....	....	8,440	15,200
Prospect E. on Cowlitz River.	9090	SE.	7	13 N.	10 E.	5.6	As received.	7.4	4.8	52.0	35.8	0.74	....	....	....	....	4,555	8,200
							Air dried...	1.9	5.1	55.1	37.9	0.78	....	....	....	....	4,825	8,690
							Dry coal....	......	5.2	56.2	38.6	0.80	....	....	....	....	4,920	8,850
							Pure coal...	......	8.4	91.6	....	1.30	....	....	....	....	8,010	14,420

ANALYSES OF COAL SAMPLES FROM COWLITZ, LEWIS AND THURSTON COUNTIES—Continued.

LEWIS COUNTY.

Name of Mine or Form of Exposure	Laboratory No.	LOCATION				Air-drying loss	Form of Analysis	PROXIMATE				ULTIMATE					Heat Value	
		Quarter	Section	Township	Range			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British Thermal Units
Prospect, near Ladd..........	6488	SE.	14	13 N.	4 E.	6.0	As received.	8.5	27.3	44.8	19.4	0.27	......	......	......	......	5,830	10,500
							Air dried...	2.7	29.0	47.7	20.6	0.29	......	......	......	......	6,205	11,170
							Dry coal....	......	29.9	49.0	21.1	0.30	......	......	......	......	6,375	11,470
							Pure coal...	......	37.9	62.1	......	0.38	......	......	......	......	8,085	14,550
Prospect, near Ladd..........	6489	NE.	26	14 N.	4 E.	5.1	As received.	9.1	27.8	33.2	29.9	0.63	......	......	......	......	4,475	8,050
							Air dried...	4.2	29.3	35.0	31.5	0.66	......	......	......	......	4,715	8,480
							Dry coal....	......	30.6	36.5	32.9	0.69	......	......	......	......	4,925	8,860
							Pure coal...	......	45.6	54.4	......	1.03	......	......	......	......	7,330	13,200
Prospect, near Ladd..........	6490	NE.	10	13 N.	4 E.	8.7	As received.	13.5	21.7	49.6	15.2	0.35	......	......	......	......	5,335	9,610
							Air dried...	5.3	23.8	54.3	16.6	0.38	......	......	......	......	5,845	10,530
							Dry coal....	......	25.1	57.3	17.6	0.40	......	......	......	......	6,165	11,100
							Pure coal...	......	30.5	69.5	......	0.49	......	......	......	......	7,485	13,470
Prospect, near Ladd..........	6495	SE.	34	14 N.	4 E.	8.5	As received.	11.2	31.3	47.1	10.4	0.56	......	......	......	......	6,195	11,160
							Air dried...	2.9	34.2	51.5	11.4	0.61	......	......	......	......	6,775	12,200
							Dry coal....	......	35.2	53.1	11.7	0.63	......	......	......	......	6,975	12,560
							Pure coal...	......	39.9	60.1	......	0.71	......	......	......	......	7,905	14,230
Prospect, near Ladd..........	6496	NW.	14	13 N.	4 E.	5.8	As received.	8.1	4.6	62.4	24.9	0.30	......	......	......	......	5,455	9,820
							Air dried...	2.5	4.9	66.2	26.4	0.32	......	......	......	......	5,795	10,420
							Dry coal....	......	5.0	67.9	27.1	0.33	......	......	......	......	5,940	10,690
							Pure coal...	......	6.8	93.2	......	0.45	......	......	......	......	8,150	14,670
East Creek-Ladd, at Ladd, No. 2 Bed.	9882	SW.	13	14 N.	4 E.	2.7	As received.	4.1	26.9	51.7	17.31	1.26	4.87	66.51	1.31	8.74	6,590	11,860
							Air dried...	1.4	27.7	53.1	17.79	1.29	5.70	68.36	1.35	6.51	6,770	12,190
							Dry coal....	......	28.1	53.9	18.05	1.31	4.61	69.34	1.37	5.32	6,870	12,360
							Pure coal...	......	34.2	65.8	......	1.60	5.63	84.62	1.67	6.48	8,380	15,090

East Creek-Ladd, at Ladd, No. 3 Bed.	9881	NW.	13	14 N.	4 E.	3.3	As received.	6.3	34.7	37.6	21.4	0.83	......	......	......	......	5,575	10,030
							Air dried...	3.1	35.8	38.9	22.2	0.86	......	......	......	......	5,765	10,370
							Dry coal....	......	37.0	40.1	22.9	0.89	......	......	......	......	5,950	10,710
							Pure coal...	......	47.9	52.1	......	1.15	......	......	......	......	7,710	13,880
East Creek-Ladd, at Ladd, No. 3 Bed.	9880	NW.	13	14 N.	4 E.	4.4	As received.	7.2	34.4	37.8	20.6	0.53	......	......	......	......	5,615	10,110
							Air dried...	3.0	35.9	39.5	21.6	0.55	......	......	......	......	5,875	10,570
							Dry coal....	......	37.0	40.8	22.2	0.57	......	......	......	......	6,050	10,890
							Pure coal...	......	47.6	52.4	......	0.73	......	......	......	......	7,780	14,010
East Creek-Ladd, at Ladd. No. 4 Bed.	9879	NW.	13	14 N.	4 E.	5.2	As received.	8.6	32.5	34.4	24.5	0.85	......	......	......	......	5,135	9,240
							Air dried...	3.6	34.3	36.3	25.8	0.90	......	......	......	......	5,415	9,750
							Dry coal....	......	35.6	37.6	26.8	0.93	......	......	......	......	5,615	10,110
							Pure coal...	......	48.6	51.4	......	1.27	......	......	......	......	7,670	13,800
East Creek-Ladd, at Ladd, No. 2 Bed.	6493	SW.	12	14 N.	4 E.	2.4	As received.	4.4	26.6	51.5	17.5	1.05	......	......	......	......	6,330	11,400
							Air dried...	2.0	27.3	52.8	17.9	1.08	......	......	......	......	6,490	11,680
							Dry coal....	......	27.8	53.9	18.3	1.10	......	......	......	......	6,625	11,920
							Pure coal...	......	34.0	66.0	......	1.35	......	......	......	......	8,110	14,600
East Creek-Ladd, at Ladd, No. 3 Bed.	6494	NW.	13	14 N.	4 E.	2.3	As received.	5.6	33.9	40.4	20.1	0.61	......	......	......	......	5,775	10,390
							Air dried...	3.4	34.7	41.3	20.6	0.62	......	......	......	......	5,910	10,630
							Dry coal....	......	35.9	42.8	21.3	0.65	......	......	......	......	6,115	11,010
							Pure coal...	......	45.7	54.3	......	0.83	......	......	......	......	7,700	13,980
East Creek-Ladd, at Ladd, No. 4 Bed.	6492	NW.	14	14 N.	4 E.	2.9	As received.	6.4	31.2	40.1	22.3	0.88	......	......	......	......	5,470	9,840
							Air dried...	3.6	32.1	41.3	23.0	0.91	......	......	......	......	5,630	10,130
							Dry coal....	......	33.3	42.9	23.8	0.94	......	......	......	......	5,845	10,520
							Pure coal...	......	43.7	56.3	......	1.23	......	......	......	......	7,665	13,800
East Creek-Ladd, at Ladd, washed coal from No. 2 Bed.	6491	SW.	12	14 N.	4 E.	8.9	As received.	10.7	25.9	47.1	16.3	0.84	......	......	......	......	5,865	10,560
							Air dried...	2.0	28.4	51.7	17.9	0.92	......	......	......	......	6,440	11,590
							Dry coal....	......	29.0	52.7	18.3	0.94	......	......	......	......	6,570	11,830
							Pure coal...	......	35.5	64.5	......	1.15	......	......	......	......	8,040	14,480
Mendota, at Mendota........	10324	SW.	3	14 N.	1 W.	11,5	As received.	20.5	33.5	33.7	12.31	1.28	6.24	48.91	0.82	30.44	4,830	8,690
							Air dried...	10.2	37.8	38.1	13.91	1.45	5.61	55.27	0.93	22.83	5,455	9,480
							Dry coal....	......	42.1	42.4	15.49	1.61	4.98	61.56	1.03	15.33	6,075	10,940
							Pure coal...	......	49.8	50.2	......	1.91	5.89	72.84	1.22	18.14	7,190	12,940

ANALYSES OF COAL SAMPLES FROM COWLITZ, LEWIS AND THURSTON COUNTIES—Continued.

LEWIS COUNTY.

Name of Mine or Form of Exposure	Laboratory No.	LOCATION				Air-drying loss	Form of Analysis	PROXIMATE				ULTIMATE					Heat Value	
		Quarter	Section	Township	Range			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British Thermal Units
Mendota, at Mendota........	10323	SW.	3	14 N.	1 W.	9.6	As received.	19.3	33.8	34.3	12.62	1.17	5.99	50.00	0.83	29.39	4,920	8,850
							Air dried...	10.7	37.4	37.9	13.96	1.29	5.44	55.31	0.92	23.08	5,440	9,790
							Dry coal....	......	41.9	42.5	15.63	1.45	4.77	61.92	1.03	15.20	6,000	10,960
							Pure coal...	......	49.7	50.3	....	1.72	5.65	73.37	1.22	18.04	7,220	12,990
Mendota, at Mendota........	29565	SW.	3	14 N.	1 W.	12.0	As received.	19.75	35.16	31.62	13.47	1.17	6.00	48.60	0.92	29.84	5,820	8,676
							Air dried...	8.83	39.95	35.92	15.30	1.33	5.30	55.22	1.05	21.80	5,476	9,857
							Dry coal....	......	43.81	39.41	16.78	1.46	4.75	60.56	1.15	15.30	6,006	10,811
							Pure coal...	......	52.64	47.36	....	1.75	5.71	72.77	1.38	18.39	7,217	12,991
Fords Prairie, 3 mi. N. of Centralia.	29564	NW.	30	15 N.	2 W.	21.5	As received.	29.81	32.88	29.49	7.82	0.61	6.64	43.97	0.75	40.21	4,193	7,547
							Air dried...	10.55	41.90	37.59	9.96	0.78	5.41	56.03	0.95	26.87	5,343	9,617
							Dry coal....	......	46.84	42.02	11.14	0.87	4.74	62.64	1.07	19.54	5,974	10,753
							Pure coal...	......	52.71	47.29	....	0.98	5.33	70.50	1.20	21.99	6,723	12,101
Richmond, 1½ mi. NE. of Centralia.	9177	SW.	34	15 N.	2 W.	14.9	As received.	26.7	32.8	32.1	8.41	1.52	6.60	45.85	0.79	36.83	4,460	8,030
							Air dried...	13.9	38.5	37.7	9.88	1.79	5.80	53.88	0.93	27.72	5,240	9,430
							Dry coal....	......	44.7	43.8	11.47	2.07	4.95	62.56	1.08	17.87	6,085	10,950
							Pure coal...	......	50.5	49.5	....	2.34	5.59	70.68	1.22	20.17	6,870	12,370
Superior, No. 1, 1 mi. N. of Chehalis.	9942	......	.....	14 N.	2 W.	14.3	As received.	27.2	33.8	28.1	10.92	0.33	6.27	43.88	0.80	37.80	4,205	7,570
							Air dried...	15.0	29.5	32.8	12.74	0.38	5.46	51.20	0.93	29.29	4,905	8,830
							Dry coal....	......	46.4	38.6	14.99	0.45	4.46	60.25	1.10	18.75	5,775	10,390
							Pure coal...	......	54.6	45.4	....	0.53	5.25	70.87	1.29	22.06	6,790	12,230
Superior, No. 2, at Chehalis.	9941	NE.	29	14 N.	2 W.	17.1	As received.	30.5	34.9	29.6	4.95	1.25	6.89	45.48	0.75	40.68	4,410	7,930
							Air dried...	16.2	42.1	35.7	5.97	1.51	6.02	54.86	0.90	30.74	5,320	9,580
							Dry coal....	......	50.3	42.6	7.12	1.80	5.04	65.44	1.08	19.52	6,345	11,420
							Pure coal...	......	54.1	54.9	....	1.94	5.43	70.46	1.16	21.01	6,830	12,290

Twin City, 1 mi. NE. of Chehalis.	29568	NW.	29	14 N.	2 W.	25.3	As received.	30.78	33.06	27.73	8.43	0.75	6.81	42.62	0.80	40.59	4,174	7,513
							Air dried...	7.32	44.26	37.13	11.29	1.00	5.36	57.06	1.07	24.22	5,589	10,060
							Dry coal....	......	47.76	40.06	12.18	1.08	4.90	61.57	1.16	19.11	6,030	10,850
							Pure coal...	......	54.38	45.62	....	1.23	5.58	70.11	1.32	21.76	6,866	12,359
Twin City, 1 mi. NE. of Chehalis.	9945	......	.....	14 N.	2 W.	19.3	As received.	30.6	31.8	27.9	9.74	0.27	6.56	41.82	0.73	40.88	4,015	7,230
							Air dried...	14.0	39.4	34.5	12.07	0.34	5.47	51.82	0.90	29.40	4,975	8,960
							Dry coal....	......	45.8	40.2	14.04	0.39	4.55	60.26	1.05	19.71	5,785	10,420
							Pure coal...	......	53.3	46.7	....	0.45	5.29	70.10	1.22	22.94	6,730	12,120
Chehalis, 2 mi. E. of Chehalis.	9944	SE.	28	14 N.	2 W.	15.7	As received.	20.1	34.7	28.5	7.67	1.77	6.69	45.28	0.74	37.85	4,415	7,940
							Air dried...	16.0	41.1	33.8	9.10	2.10	5.87	53.71	0.88	28.34	5,235	9,420
							Dry coal....	......	48.9	40.3	10.83	2.50	4.87	83.91	1.04	16.85	6,230	11,210
							Pure coal...	......	54.9	45.1	....	2.80	5.46	71.68	1.17	18.89	6,985	12,580
Sheldon, 3 mi. E. of Chehalis.	9943	......	.....	14 N.	2 W.	15.2	As received.	29.9	34.0	30.4	5.75	0.58	6.98	45.50	0.85	40.34	4,405	7,930
							Air dried...	17.3	40.0	35.9	6.78	0.68	6.24	53.65	1.00	31.65	5,195	9,350
							Dry coal....	......	48.4	43.4	8.19	0.83	5.22	64.89	1.21	19.66	6,285	11,310
							Pure coal...	......	52.7	47.3	....	0.90	5.69	70.68	1.32	21.41	6,845	12,320
Sheldon, 3 mi. E. of Chehalis.	29569	NE.	33	14 N.	2 W.	22.3	As received.	31.00	32.65	30.55	5.80	0.46	6.96	44.76	0.76	41.26	4,286	7,715
							Air dried...	11.18	42.08	39.33	7.47	0.59	5.77	57.62	0.98	27.57	5,517	9,931
							Dry coal....	......	47.32	44.27	8.41	0.67	5.10	64.87	1.10	19.85	6,212	11,182
							Pure coal...	......	51.66	48.34	....	0.73	5.57	70.83	1.20	21.67	6,782	12,208
Crescent, 4 mi. NW. of Littell	9940	......	22	14 N.	3 W.	19.1	As received.	32.1	31.9	27.3	8.7	2.97	....	....	....	....	3,970	7,140
							Air dried...	16.1	39.4	33.8	10.7	3.66	....	....	....	....	4,905	8,830
							Dry coal....	......	47.0	40.2	12.8	4.36	....	....	....	....	5,850	10,530
							Pure coal...	......	53.9	46.1	....	5.00	....	....	....	....	6,705	12,070
Monarch, at Kopiah..........	29570	NW.	12	14 N.	1 W.	22.5	As received.	27.82	33.66	29.74	8.78	0.99	6.68	45.34	0.87	37.33	4,412	7,942
							Air dried...	6.84	43.44	38.39	11.33	1.28	5.40	58.53	1.12	22.34	5,694	10,249
							Dry coal....	......	46.63	41.21	12.16	1.37	4.97	62.83	1.21	17.46	6,112	11,002
							Pure coal...	......	53.08	46.92	....	1.56	5.66	71.53	1.38	19.87	6,958	12,524
Perth, 3 mi. N. of Centralia.	9178	NE.	29	15 N.	2 W.	12.4	As received.	25.1	32.3	34.0	8.65	0.82	6.37	47.26	0.91	25.91	4,540	8,170
							Air dried...	14.5	36.8	38.8	9.88	0.94	5.70	53.95	1.04	28.49	5,180	9,330
							Dry coal....	......	43.1	45.4	11.55	1.09	4.77	63.08	1.21	18.30	6,060	10,910
							Pure coal...	......	48.7	51.3	....	1.23	5.39	71.32	1.37	20.69	6,840	12,320

ANALYSES OF COAL SAMPLES FROM COWLITZ, LEWIS AND THURSTON COUNTIES—Concluded.

THURSTON COUNTY.

Name of Mine or Form of Exposure	Laboratory No.	LOCATION				Air-drying loss	Form of Analysis	PROXIMATE				ULTIMATE					Heat Value	
		Quarter	Section	Township	Range			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Calories	British Thermal Units
Hannaford, No. 1, at Tono.	9089	SE.	20	15 N.	1 W.	16.0	As received.	21.0	33.1	36.7	9.2	0.42	......	......	......	......	4,950	8,910
							Air dried...	5.9	39.5	43.7	10.9	0.50	......	......	......	......	5,890	10,610
							Dry coal....	......	42.0	46.4	11.6	0.53	......	......	......	......	6,265	11,270
							Pure coal...	......	47.5	52.5	......	0.60	......	......	......	......	7,085	12,760
Hannaford, No. 1, at Tono.	9573	SE.	20	15 N.	1 W.	7.2	As received.	21.5	31.8	40.7	6.04	0.43	6.34	52.61	1.11	33.47	5,095	9,170
							Air dried...	15.4	34.3	43.8	6.51	0.46	5.97	56.69	1.20	29.17	5,490	9,880
							Dry coal....	......	40.5	51.8	7.69	0.55	5.03	66.99	1.41	18.33	6,485	11,670
							Pure coal...	......	43.9	56.1	......	0.60	5.45	72.57	1.53	19.85	7,025	12,640
Hannaford, No. 1, at Tono.	9095	NE.	20	15 N.	1 W.	17.4	As received.	23.6	31.0	37.3	8.13	0.36	6.19	50.36	1.02	33.94	4,750	8,550
							Air dried...	7.4	37.6	45.2	9.84	0.44	5.16	60.97	1.23	22.36	5,750	10,350
							Dry coal....	......	40.6	48.8	10.63	0.47	4.68	65.85	1.33	17.04	6,210	11,180
							Pure coal...	......	45.3	54.7	......	0.53	5.24	73.68	1.49	19.06	6,950	12,510
Hannaford, No. 1, at Tono.	9094	SW.	21	15 N.	1 W.	16.8	As received.	22.2	31.7	37.0	9.1	0.35	......	......	......	......	4,755	8,560
							Air dried...	6.5	38.2	44.4	10.9	0.42	......	......	......	......	5,720	10,290
							Dry coal....	......	40.8	47.5	11.7	0.45	......	......	......	......	6,115	11,000
							Pure coal...	......	46.2	53.8	......	0.51	......	......	......	......	6,925	12,460
Hannaford, No. 1, at Tono.	9096	SW.	21	15 N.	1 W.	16.7	As received.	22.7	31.0	38.3	8.02	0.37	6.19	49.56	1.08	34.78	4,795	8,630
							Air dried...	7.2	37.3	45.9	9.63	0.44	5.20	59.50	1.30	23.93	5,755	10,360
							Dry coal....	......	40.1	49.5	10.37	0.48	4.75	64.08	1.40	18.92	6,200	11,160
							Pure coal...	......	44.8	55.2	......	0.54	5.30	71.49	1.56	21.11	6,915	12,340
Hannaford, No. 1, at Tono, car sample, run-of mine coal.	8752	......	......	......	......	6.7	As received.	20.2	31.5	39.9	8.44	0.52	5.93	52.52	1.06	31.53	5,150	9,280
							Air dried...	14.5	33.5	42.9	9.05	0.56	5.56	56.29	1.14	27.40	5,520	9,940
							Dry coal....	......	39.5	49.9	10.58	0.65	4.61	65.83	1.33	17.00	6,460	11,630
							Pure coal...	......	44.0	56.0	......	0.73	5.16	73.62	1.49	19.00	7,230	13,000

THURSTON COUNTY.

Hannaford, No. 1, at Tono, upper bench.	29566	NW.	21	15 N.	1 W.	16.3	As received.	21.60	34.77	33.29	10.25	1.24	6.29	48.91	0.93	32.38	4,831	8,696
							Air dried...	6.44	41.54	39.77	12.25	1.48	5.35	58.43	1.11	21.38	5,772	10,390
							Dry coal....	......	44.40	42.51	13.09	1.58	4.95	62.46	1.19	16.73	6,169	11,104
							Pure coal...	......	51.09	48.91	....	1.82	5.70	71.87	1.37	19.24	7,098	12,776
Hannaford, No. 1, at Tono, mining bench.	29567	NW.	21	15 N.	1 W.	15.1	As received.	22.51	33.91	34.69	8.89	0.61	6.30	49.87	1.04	33.29	4,823	8,681
							Air dried...	8.69	39.96	40.88	10.47	0.72	5.44	58.76	1.22	23.39	5,683	10,229
							Dry coal....	......	43.76	44.77	11.47	0.79	4.90	64.36	1.34	17.14	6,224	11,203
							Pure coal...	......	49.43	50.57	....	0.89	5.54	72.70	1.51	19.36	7,031	12,656
Black Bear, 2 mi. SE. of Tenino.	9939	SW.	31	16 N.	1 W.	6.3	As received.	16.0	31.9	28.9	23.19	1.50	5.04	43.44	0.73	26.10	4,335	7,800
							Air dried...	10.4	34.0	30.9	24.75	1.60	4.63	46.36	0.78	21.88	4,625	8,330
							Dry coal....	......	37.9	34.5	26.61	1.79	3.88	51.72	0.87	14.12	5,160	9,290
							Pure coal...	......	52.4	47.6	....	2.47	5.36	71.46	1.20	19.51	7,130	12,830
King, 3mi. SW. of Tenino....	9987	SW.	35	16 N.	2 W.	9.5	As received.	22.4	33.6	33.0	10.95	2.40	6.04	48.99	0.72	31.01	4,875	8,770
							Air dried...	14.3	37.2	36.4	12.10	2.65	5.50	54.01	0.80	24.94	5,385	9,690
							Dry coal....	......	43.4	42.5	14.12	3.09	4.58	63.02	0.93	14.26	6,285	11,310
							Pure coal...	......	50.5	49.5	....	3.60	5.33	73.38	1.08	16.61	7,315	13,170

APPENDIX D.

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Bulletin 3.—The Coal Fields of King County, by Geo. W. Evans. Bound in cloth; price, 75 cents.

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