Geology and Coal Resources of the Centralia-Chehalis District Washington

GEOLOGICAL SURVEY BULLETIN 1053

Geology and Coal Resources of the Centralia-Chehalis District Washington

By PARKE D. SNAVELY, Jr., R. D. BROWN, Jr., ALBERT E. ROBERTS, *and* W. W. RAU

With a section on

MICROSCOPICAL CHARACTER OF CENTRALIA-CHEHALIS COAL

By J. M. SCHOPF

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GEOLOGY AND COAL RESOURCES OF THE CENTRALIA-CHEHALIS DISTRICT, WASHINGTON

By Parke D. Snavely, Jr., R. D. Brown, Jr., Albert E. Roberts, and W. W. Rau

ABSTRACT

The Centralia-Chehalis coal district includes about 570 square miles in southwestern Thurston County and northwestern Lewis County, Wash., midway between Seattle, Wash., and Portland, Oreg., and forms a part of the subbituminous and lignite coal fields of southwestern Washington. It adjoins the Morton coal field on the east and the Toledo coal field on the south. It includes a part of the extreme western foothills of the Cascade Range and a part of the eastern border of the Coast Ranges.

The consolidated stratified rocks exposed at the surface are: a sequence of poorly consolidated nonmarine sedimentary rocks of Pliocene(?) and Miocene age; the Columbia River(?) basalt and Astoria(?) formation of Miocene age; the Lincoln formation of Oligocene age; the coal-bearing Skookumchuck and the Northcraft formations of late Eocene age; and the McIntosh formation of late and middle Eocene age. This sequence of Tertiary rocks consists of interbedded siltstone, sandstone, and conglomerate; some coal beds; and associated volcanic rocks with basalt and gabbro intrusive rocks. The total thickness of these rock units in the district is more than 12,000 feet. Unconformities are present, locally at the base of the Skookumchuck formation, at the base of the Astoria(?) formation, and at the base of the Columbia River(?) basalt. The contacts between the other rock units are probably conformable. Overlying the Tertiary rocks in parts of the district are poorly consolidated gravel, sand, silt, and clay of the Logan Hill formation of early Pleistocene age and Vashon drift of late Pleistocene age. Other unconsolidated deposits include sand and gravel of stream terraces, landslide debris, and alluvium.

The dip of the beds in the Centralia-Chehalis district ranges from 0° to 90°. Most of the major structural elements have a northwesterly trend but a few faults trend westward. A large structurally complex anticlinal fold, known as the Lincoln Creek uplift, is in the western part of the area. This fold is bounded on the north by the northwestward-trending Centralia syncline and on the south by the Chehalis River syncline. Except for the Tenino and Crawford Mountain anticlines and the shallow Tono basin, the folds in the eastern half of the area are narrow and asymmetric, and faults are present along the former axes of some of the anticlines.

The principal faults in the area are the westward-trending Doty, Salzer Creek, and Chehalis faults, and the northwestward-trending Scammon Creek, Kopiah, China Creek, Newaukum, and Coal Creek faults. Except for the Chehalis, Salzer Creek, and Scammon Creek normal faults, all are high-angle reverse(?) faults downthrown to the south or southwest.

At least 13 different coal beds have been mined in the district. The coal beds range in thickness from a few inches to 40 feet and have an average thickness of 6 to 8 feet. Most of the minable coal is subbituminous C in rank, has a moisture content ranging from 14 to 35 percent, and an ash content ranging from about 5 to 25 percent. Its heating value varies from 6,700 to 9,880 B. t. u. The coal slacks readily when exposed to the air because of its high moisture content. According to estimates made by the authors, the district contains more than 3½ billion tons of coal, of which about 40 percent is considered recoverable with present mining methods. Nearly 15,000 feet of drilling was done from 1949 to 1951 to obtain information on the extent, thickness, physical characteristics, and reserves of coal. During 1951 four mines were operating in the area and produced a total of 52,500 tons of coal.

Fourteen test holes for oil and gas have been drilled within the area from January 1901 to July 1952, but the results of this drilling have not been encouraging, and only small shows of gas have been reported. The McIntosh formation, which includes a thick sequence of marine siltstone with interbedded sandstone, is considered the most favorable formation to test for oil and gas.

INTRODUCTION

SCOPE OF INVESTIGATION

Geologic investigations in the Centralia-Chehalis district were made in the summer months of 1948, 1949, 1950, and 1951. These studies were supplemented by core-drilling programs for which contracts were made in 1949, 1950, and 1951. The area is of economic importance because of the existence of large reserves of subbituminous coal and the presence of marine sedimentary rocks, and structures in the surface rocks that may be favorable for the accumulation of oil and gas. It is hoped that the information obtained will provide basic data useful in the development and utilization of the coal, the natural resource which furnishes one of the bases for the potential industrial growth of this region. Test drilling for oil and gas, until July 1, 1952, has been unsuccessful; however, the geologic information contained in this report may be helpful in delimiting new areas for exploration within the Centralia-Chehalis district and in other parts of western Washington.

LOCATION OF THE DISTRICT

The Centralia-Chehalis coal district is in the northwestern part of Lewis County and the southern part of Thurston County in southwestern Washington and is bounded by meridians 122° 37′ and 123° 22′ W., and parallels 46° 34′ and 46° 53′ N. It includes a rectangular-shaped area of about 570 square miles lying south of Puget Sound, west of the Morton coal field, and north of the Toledo-Castle Rock coal field. The district is the largest of the subbituminous and lignite fields of southwestern Washington. It is named after the two largest cities, Centralia and Chehalis, within the limits of the mapped area.

Figure 1 shows the location of the district, and outlines the coal-bearing areas in western Washington mapped and described in publications of the U. S. Geological Survey.

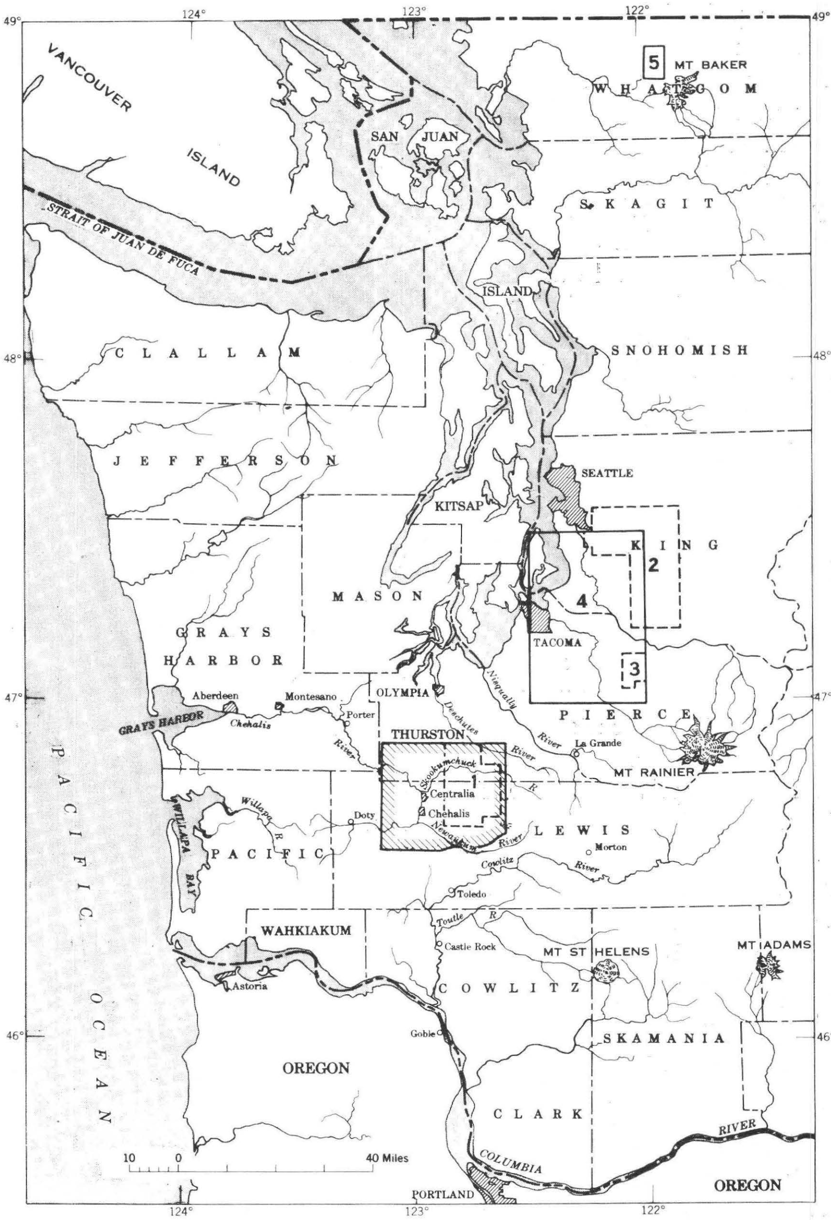

FIGURE 1.—Index map showing the location of Centralia-Chehalis coal district, Washington. Other areas in western Washington for which U. S. Geological Survey reports are available are: 1, Eastern part of Centralia-Chehalis district, Map C–8; 2, King County preliminary map, 1945; 3, Wilkeson-Carbonado, 18th Annual Report, part 3; 4, Tacoma, Wash., Geologic Atlas folio 54; 5, Glacier coal field, Bulletin 541 (i).

PREVIOUS INVESTIGATIONS

The general stratigraphy and structure of a part of this area have been known for many years; none of the published reports, however, give a detailed description of the geology and the coal deposits. The existing published reports are largely reconnaissance studies and reports on coal mines.

Although coal was known from the Centralia-Chehalis district as early as 1855, no report of a geologic nature was published until Lawson (1894) gave a brief description of sedimentary rocks and fossils found during the construction of a water tunnel near the north city limits of Chehalis. Landes and Ruddy (1903) gave the first detailed description of a few of the coal beds in this area. Smith (1911) described and sampled the coal beds in mines in the district and furnished information about mining operations. The Pleistocene history of the northern part of the described area was discussed by Bretz (1913). Culver (1919) described the general geologic features of the coal fields in southwestern Washington and included a reconnaissance geologic map. A part of his report is devoted to the Centralia-Chehalis district and includes several maps that show the areas of outcrop of the various rock sequences and the locations of many of the mines. The stratigraphic and paleontologic studies made by Weaver (1912, 1916, 1937, and 1942) contain descriptions of some of the better known localities where fossils were collected in the western part of the Centralia-Chehalis district. Weaver (1937) discussed the stratigraphic relations of the rock sequences in western Washington and northwestern Oregon and included geologic maps for many of the areas where fossil collections were made. The western part of the Centralia-Chehalis district was mapped by Weaver (1937, pl. 6*c*) but no descriptive text accompanies the map. In a later paper, Weaver (1942) presented a detailed study of Tertiary marine fossils found in Oregon and Washington and described several localities in the Centralia-Chehalis district.

A report on the Oligocene paleontology of the Chehalis Valley by Van Winkle (1918) includes a discussion of fossils found within the mapped area and a review of the Oligocene stratigraphy of western Washington.

Etherington (1931) published a study of the Astoria formation of southwestern Washington that is accompanied by a geologic map of parts of Grays Harbor, Lewis, and Thurston Counties. This paper describes the fauna of the Astoria formation and discusses the Miocene stratigraphy of the Pacific Northwest. Most of Etherington's work was done west of the Centralia-Chehalis district; however, his map includes the extreme northwestern part of the area mapped in the present report.

Cushman and Frizzell (1940, 1943) described Foraminifera found in the Lincoln formation near the town of Galvin and discussed briefly the lithology and stratigraphic correlatives of the Lincoln formation.

Snavely, Rau, Hoover, and Roberts (1951) named and described the Eocene McIntosh formation from exposures in the northeastern part of the Centralia-Chehalis coal district and presented a brief summary of the stratigraphic relationship of the McIntosh formation to the other rock sequences in the eastern part of the Centralia-Chehalis district.

A report on the geology and coal resources of the eastern part of the Centralia-Chehalis area was made by Snavely, Roberts, Hoover, and Pease (1951) and the area mapped in the eastern part of the district is included in the present report.

Two preliminary total-intensity aeromagnetic maps of parts of Grays Harbor, Pacific, Thurston, and Lewis Counties were released on open file by the Geological Survey in September 1952. These maps include that part of the Centralia-Chehalis area lying between the latitudes of 46° 38′ and 46° 51′ N. and show the changes in total magnetic intensity by means of contours.

FIELD WORK AND ACKNOWLEDGMENTS

During the summer months of 1948 and 1949, the eastern part of the Centralia-Chehalis coal district was mapped by Parke D. Snavely, Jr., assisted by W. D. Pitt, W. C. Gere, J. D. Hill, and R. E. Wolf in 1948; and by Albert E. Roberts, Linn Hoover, and M. H. Pease, Jr., in 1949. Geologic studies were extended into the western part of the district during the summer months of 1950 by the senior author, assisted by Albert E. Roberts, Linn Hoover, M. H. Pease, Jr., W. W. Rau, and R. D. Brown, Jr. The mapping of the western part of the district was completed during the summer of 1951 by R. D. Brown, Jr., and W. W. Rau, under the supervision of Parke D. Snavely, Jr.; A. L. Parmer and C. I. McCormack were field assistants for a part of the summer.

The micropaleontologic identifications were made by W. W. Rau; Albert E. Roberts made the petrographic studies. Linn Hoover and M. H. Pease, Jr., assisted in preparing this report. The writers wish to thank H. E. Vokes and Roland W. Brown for the paleontologic determinations, and J. M. Schopf for the petrographic studies of coal samples. The cooperation of Sheldon L. Glover, supervisor, Division of Mines and Geology, Washington State Department of Conservation and Development, is gratefully acknowledged. The authors thank Dr. H. E. Culver for the use of his original field notes, which yielded valuable information, particularly on abandoned mines and

prospects. The friendly assistance rendered by the mine operators and residents of the area is deeply appreciated.

The positions of geologic boundaries, outcrops of coal beds, coal mines and prospects, and attitudes of the strata were largely plotted on aerial photographs. These observations were later transferred from the photographs to the base map with a vertical projector. The base map was compiled from the Chehalis quadrangle, scale 1:125,000, and Tenino and Yelm quadrangles, scale 1:62,500, U. S. Geological Survey and the Gate and Meskill quadrangles, scale 1:62,500, Corps of Engineers. Additions were made to the road net and drainage with the use of aerial photographs. Altitudes plotted on the base map are based on bench marks established by the United States Coast and Geodetic Survey, Geological Survey, and the Corps of Engineers. The position of land lines in the southeastern part of the mapped area is in part based upon observation of section corners in the field and upon data obtained from maps prepared by engineers of the Weyerhaeuser Timber Co.

Three exploratory drilling projects totaling 14,916 feet of core and solid-bit drilling were undertaken in 1949, 1950, and 1951. This test drilling was undertaken to supplement surface stratigraphic information, to obtain information regarding the physical character of the coal beds, and to obtain samples of coal for chemical analyses. Most of the drilling was done in the coal-bearing upper Eocene rock sequence. The correlations between coal beds penetrated in the various test holes are shown on plate 3.

During the first drilling project cores from coal beds with thickness of 30 inches or more were sent to the U. S. Bureau of Mines Experiment Station in Pittsburgh, Pa. for ultimate analyses. The coal cores obtained from the other two drilling projects were shipped to the coal geology laboratory of the U. S. Geological Survey, Columbus, Ohio, to be sampled for petrographic studies; the remainder of the cores were then forwarded to the Bureau of Mines for chemical analyses.

Shallow auger drilling during the summer of 1951 with a jeep-mounted auger furnished samples of unweathered rock for micropaleontologic studies.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Centralia-Chehalis coal district lies in the downwarp between the Cascade Range and the Coast Ranges, and includes a part of the extreme western foothills of the Cascade Range and a part of the eastern border of the Coast Ranges. The surface configuration of the district is largely the result of streams eroding rocks with varying degrees of resistance to erosion. In some areas, the topography has been modified by ice action or by Quaternary glaciofluvial deposits.

The maximum relief in the area is about 2,600 feet. The most northwesterly point along the Chehalis River lies at an altitude of less than 75 feet above sea level. The highest point is near the eastern margin of the area in sec. 1, T. 14 N., R. 1 E., Willamette meridian, and has an altitude of more than 2,680 feet above sea level.

The area can be divided into three distinct types of topograpy, all dependent on the underlying rock types. In most places the line of demarcation between these topographic units is well defined.

In the eastern and northeastern parts of the area, which are underlain chiefly by various types of volcanic rocks, the topography is characterized by sharp, generally northwestward-trending ridges and valleys. The altitudes of these ridges range from 1,250 to 1,700 feet above sea level. The altitude decreases rapidly but rather unifomly, in many places at the rate of almost 1,000 feet per mile, away from the volcanic highlands, until the more rounded topographic surface of the less indurated sedimentary rocks is reached.

The central and western parts of the Centralia-Chehalis district consist of low rounded hills, whose altitudes range from 500 to 750 feet above sea level in the area east of the Chehalis River and from 600 to 900 feet above sea level west of the Chehalis River. In many areas, as on Logan Hill, glaciofluvial deposits form tablelike surfaces that increase in altitude from about 500 to 600 feet above sea level in the western and central parts of the area to more than 900 feet above sea level near the eastern margin of the area.

The northern part of the mapped area is covered by thick deposits of till and outwash; the outwash forms low, mounded prairie topography. The altitude of these prairies ranges from about 500 feet in the northeastern corner of the area mapped to 100 feet along the valley of the Chehalis River.

The mapped area is almost entirely within the drainage basin of the Chehalis River. The river enters the area from the southwest near Meskill and flows eastward to the vicinity of Chehalis. Downstream from Chehalis the river flows generally northward and northwestward toward Helsing Junction, which is located near the west edge of the area. Beyond Helsing Junction the river follows a northwesterly course for 40 miles to its mouth at Grays Harbor.

The principal tributaries of the Chehalis River in the eastern part of the area are the Skookumchuck and Newaukum Rivers, both draining the extreme western foothills of the Cascade Range along the east margin of the area. These rivers flow westward through narrow, steep-walled canyons in the volcanic rocks and emerge onto the broad, flat valleys underlain by sedimentary rocks. Both rivers join the Chehalis River near the geographic center of the area. The runoff in the western part of the area is carried largely by Bunker, Deep, and Lincoln Creeks, and their tributaries; the South Fork of the Chehalis River drains the southwestern part. A small area in the extreme northeast corner of the mapped area is drained by streams that flow northward into the Deschutes River which, in turn, empties into Puget Sound near Olympia, Wash.

In the northern part of the mapped area the drainage is largely controlled by the distribution of till and outwash deposits. Marshes and ponds are common in areas underlain by till, whereas most streams flowing on outwash deposits are intermittent and have poorly developed drainage patterns.

The larger streams flow on broad, level flood plains and are bordered in many places by low-level terrace deposits that range in altitude from 5 to 20 feet above river level. These terraces are usually poorly developed and in most places are discontinuous. A prominent terrace, which lies about 35 to 40 feet above river level, was mapped along the valley of the Newaukum River and its South Fork; however, in places dissection by erosion makes it difficult to recognize this terrace. Small remnants of terraces locally lie at higher altitudes along the major streams, but generally they are obscured by landslide and vegetation and have not been mapped.

The rivers in the Chehalis River drainage system have a wide seasonal variation in flow, which is due primarily to the amount of rainfall. Figure 2 shows the intimate relation between precipitation and surface runoff.

CLIMATE AND VEGETATION

The Centralia-Chehalis area, like most of the Pacific Northwest coastal region, has a moist temperate climate. Mean rainfall at Centralia for the 10-year period 1938–47 was 38.43 inches (fig. 2), and mean annual temperature for the same period was 52.75° F. Seasonal temperature variations are relatively small; winters are usually mild, and summer temperatures rarely exceed 95° F. Rainfall is concentrated in the late fall, winter, and early spring. During the period of heavy rainfall (November through March) the ground is almost continually saturated with water and this condition has formed a thick mantle of soil above the deeply weathered bedrock. In some rock outcrops, the chemical weathering action of ground water has extended to a depth of as much as 50 feet.

The heavy rainfall plays an important part in the mechanical weathering cycle, and the mass wasting of saturated bedrock by landslide, slump, and mudflow is common during the wet months.

Native vegetation in the Centralia-Chehalis area is characteristic of that found along the coastal areas of Oregon and Washington. The large amount of rainfall, combined with the cool, temperate climate,

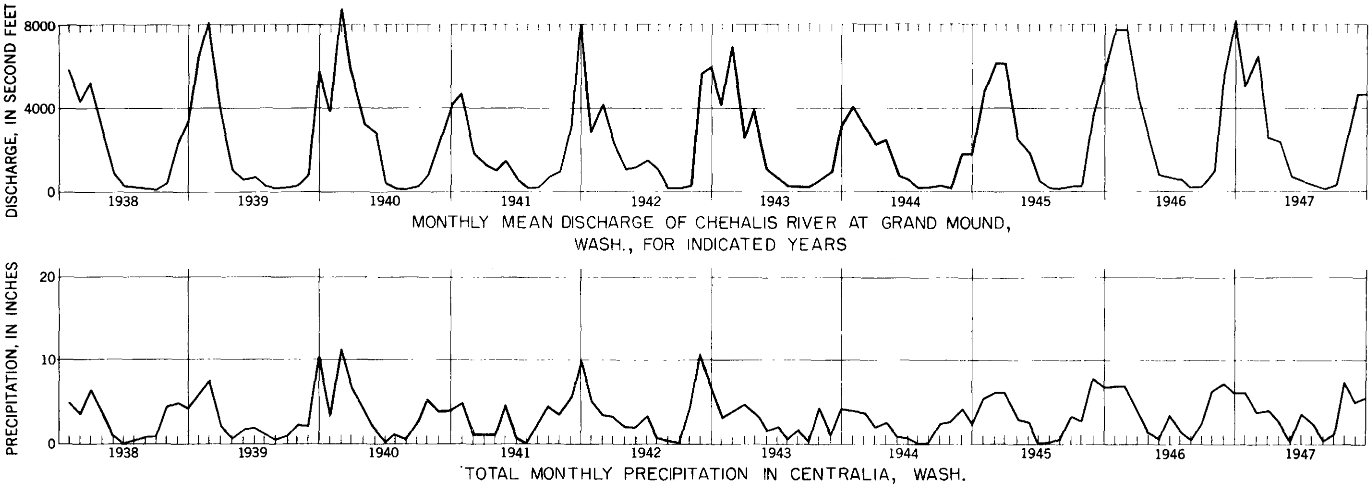

FIGURE 2.—Chart showing relation between precipitation and runoff for the years 1938 through 1947 in the Centralia-Chehalis district, Washington. Data compiled from U. S. Geological Survey Water-Supply Papers and U. S. Weather Bureau annual summaries, "Climatological data for the United States."

has produced an environment well suited to the growth of extensive coniferous forests.

Douglas fir is the most valuable and most common timber tree in the Centralia-Chehalis district. The Douglas fir forests of the area also contain large numbers of grand fir, western redcedar and western hemlock. Mature Douglas fir forests are relatively clear of large underbrush but contain an abundant low growth of western swordfern, blueberry, salal, and Oregon grape.

Valley bottoms and ravines contain few large trees; these moist alluviated areas are better suited to the growth of deciduous trees and the thorny plants and bushes. Red alder is the most common large tree growing in valley bottoms and is usually associated with vine maple, bigleaf maple, western black willow, and rarely by silky willow, and Oregon ash. These trees grow out of a dense mat of lower plants that usually covers the entire valley floor. The lower plants include such forms as American devilsclub, blackberry, salmonberry, western serviceberry, redberry elder, blueberry elder, and several species of ferns.

Most of the Centralia-Chehalis region has been logged at least once, and the logging operations have had a profound effect upon the vegetation. Fern, salal, and Oregon grape are abundant in cutover areas as they represent the original forest undergrowth. Red alder is the first large tree to appear in abundance after logging and is extremely common on cutover land. Alder, willow, maple, and ash are the most common trees in areas undergoing natural reforestation but are accompanied by many other forms. Among these are redberry and blueberry elder, cascara buckthorn, dogwood, serviceberry and bitter cherry. Except for devilsclub and one or two species of ferns, undergrowth on the hills is composed of the same plants that are common to valley bottoms.

Oregon white oak and black cottonwood comprise a very small percentage of the total forest growth and are found on the glaciated areas in the northern part of the mapped area.

Throughout the area field work was greatly hindered by this dense vegetation which reduces visibility to less than 100 feet and causes considerable difficulty in moving over the ground.

POPULATION AND INDUSTRY

Centralia and Chehalis, the two largest cities in the mapped area, are only 2 miles apart and have a combined population of about 15,000. Chehalis is the county seat of Lewis County. These two cities are the economic centers of the area; they are supported by lumbering, farming and dairying, stock raising, and by the trade they receive as railroad centers. The coal-mining industry has made important economic contributions to the growth of Centralia and Chehalis and to the growth of the smaller towns; however, in 1951 only 55 persons were employed in the mining industry.

Most of the smaller towns and farms in the area are restricted to the alluviated or terraced parts of the valleys of Chehalis, Newaukum, and Skookumchuck Rivers and to their tributary valleys. Many of the smaller farms are on the terraced upland surfaces but, in general, the upland areas have not been utilized because of the lack of water. A small part of the cutover land has been cleared for cultivation or grazing, but most of the logged areas are covered with thick underbrush and second-growth timber.

Logging is the principal industry in the area and, although most of the virgin timber has been removed, many stands of second growth are now being cut. Virgin timber from outside the area also is cut or finished at the large sawmills in Centralia and Chehalis.

ACCESSIBILITY

The Centralia-Chehalis area is crossed by four major rail lines; the Union Pacific; Northern Pacific; Chicago, Milwaukee, St. Paul, and Pacific; and Great Northern railroads all maintain north-south service through the area. The Northern Pacific and Milwaukee roads also provide branch-line service to Aberdeen on the Pacific Coast; both lines follow the lower Chehalis River through the Coast Ranges. Branch lines of the same two railroads connect with the coastal town of Raymond by way of the upper valley of Chehalis River. A number of small branch lines and logging railroads connect with these major systems.

The Pacific Highway (U. S. Highway 99) passes through both Centralia and Chehalis, and is a good, all-weather highway to Portland and Seattle. State Routes 9 and 12 provide surfaced roads between Highway 99 and the Pacific Coast. State Route 5H provides a paved road from Tenino to Tacoma. Another hard-surfaced highway, State Route 5K, extends from the southern part of the Centralia-Chehalis area to Morton and thence across the Cascade Range to Yakima and other eastern Washington points. Graveled or dirt secondary roads provide access to most parts of the Centralia-Chehalis area and, where these are lacking, logging roads are usually found. The most remote parts of the area mapped are not more than 2 to 3 miles from the nearest road.

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STRATIGRAPHY

GENERAL FEATURES

The rocks exposed in the Centralia-Chehalis district range in age from early Tertiary (Eocene) to Quarternary. The total thickness of these rocks is more than 12,000 feet, and they consist of marine, brackish-water, and nonmarine sedimentary rocks with interbedded volcanic rocks. They are folded and faulted and, in most places, are now buried by poorly consolidated till and outwash from Pleistocene glaciers and by Recent alluvium. The Eocene and Oligocene rocks are intruded by dikes and sills of basalt and gabbro.

Most of the Tertiary strata were laid down near the marine shorelines. They therefore show an alternation of marine nearshore and offshore facies; and near the ancient coastlines lagoonal, estuarine, and terrestrial deposits were laid down. These types of deposition give rise both to facies of different lithology but of the same age, and to facies of similar lithology but of different age. Generally, the offshore marine deposits are thickest in the western part of the area, whereas the nearshore and nonmarine rocks are found chiefly in the eastern part of the area.

A summarized description of the rock units exposed in the Centralia-Chehalis district is given in chart 1.

TERTIARY SYSTEM

EOCENE SERIES

McINTOSH FORMATION

GENERAL FEATURES

The McIntosh formation was named and described by Snavely, Rau, Hoover, and Roberts (1951) from beds that are well exposed in road cuts along State Route 5H on the south side of McIntosh Lake. The type area of outcrop for the McIntosh formation was designated as the axial parts of the Crawford Mountain anticline in the south-central part of T. 16 N., R. 1 W. The formation is also found in small discontinuous outcrops in the drift-covered northern part of the district, and in weathered outcrops in the vicinity of Gate. In the extreme southeastern part of the area the upper part of the formation is exposed along the axial parts of a small fold in secs. 24 and 25, T. 14 N., R. 1 E. The base of the McIntosh formation is not exposed within the mapped area; however, about 7 miles west of the area it rests upon pillow lavas considered to be equivalent in age to the Crescent formation of Arnold (1906) and the Siletz River volcanic series of Snavely and Baldwin (1948), both of Eocene age. Basalt flows of middle Eocene age are believed to have been penetrated below the McIntosh formation in a test hole drilled by the Ohio Oil Co. in sec. 10, T. 16 N., R. 1 W., immediately adjacent to the northern boundary of the area mapped.

A part of the strata mapped as the McIntosh formation was previously included with the younger coal-bearing rocks of the Puget group of Eocene age or, in some areas, mapped as undifferentiated Eocene and Oligocene (Culver, 1919). The McIntosh formation and the overlaying coal-bearing rocks were shown on the geologic map of Washington (Weaver, 1937) as the Cowlitz formation of late Eocene age.

Several deep test holes within, or adjacent to, the mapped area were drilled through rocks assigned to the McIntosh formation. The thickest sequence of these rocks was found in the Mottman test hole 1 in sec. 12, T. 16 N., R. 2 W., where more than 4,000 feet of siltstone, sandstone, and volcanic (?) rocks was penetrated. The driller's log for this test hole showed, below the depth of 2,815 feet, "Black lime and hard black rock", which is interpreted by the authors as flows and pyroclastic rocks interbedded with the McIntosh sedimentary rocks. Sandstone and siltstone of the upper part of the McIntosh formation were logged in the Oregon-Washington and Scheel test holes, in the vicinity of Tenino. About 2,600 feet of marine siltstone, with minor amounts of sandstone and pyroclastic rocks in the upper part were drilled in the Union Oil Co., of California Bannse well 1, located in the NW¼ sec. 22, T. 15 N., R. 2 W. In the west-central part of the area, in the Chehalis test hole 1, in sec. 17, T. 14 N., R. 3 W., more than 1,450 feet of siltstone and sandstone that the authors correlate with the McIntosh formation were penetrated in lower part of the hole.

The McIntosh formation within the mapped area consists chiefly of offshore marine siltstone, with near-shore sequences of arkosic and basaltic sandstone in the lower and upper parts. Beds equivalent in age to the McIntosh formation crop out east of the mapped area; they are chiefly siltstone interbedded with massive arkosic sandstone and coal beds.

A rock sequence, predominantly of volcanic rocks, is known only from outcrops in the Black Hills in the extreme northwestern part of the mapped area. This sequence consists of porphyritic basalt flows and pyroclastic rocks, with minor amounts of interbedded sedimentary rocks. Good exposures of this sequence occur immediately to the west of the area, along the Northern Pacific Railway between Oakville and Gate and along the Union Pacific Railroad, about 1½ miles west of Independence. Approximately 1½ miles southwest of Independence, also outside of the mapped area, typical siltstone of the McIntosh formation overlies basalt flows that are believed to be equivalent in age to part of the flows that crop out in the vicinity of Gate. Data from test holes indicate that the volcanic rocks may be interbedded with the McIntosh formation throughout the western part of the mapped area.

LITHOLOGIC COMPOSITION

The McIntosh formation consists chiefly of dark-gray well-indurated tuffaceous siltstone and claystone with thin interbeds of tuff (fig. 3). Some beds are massive, although at times stratification is made apparent by tuffaceous zones or by interbedded sandstone. Irregularly located calcareous nodules and lenses are common. The siltstone and claystone are often fissile and are commonly finely micaceous. Carbonaceous material and pyrite are present in most places. Most beds are laminated, consisting of fine layers of siltstone and fine tuff or fine-grained sandstone. These sedimentary rocks

FIGURE 3.—Tuffaceous siltstone of the McIntosh formation in road cut along State Route 5H, 3½ miles east of Tenino. Stratification is made apparent by light-gray tuff beds.

weather to iron-stained platy fragments and crumbly soil, which are mottled light gray or light yellowish orange.

The upper part of the McIntosh formation consists of 250 feet of massive arkosic sandstone, which has been quarried for building stone near Tenino (fig. 4). Dark-gray basaltic sandstone and light-gray arkosic sandstone are commonly interbedded in the lower part of the formation, in the northeastern part of the area. Sandy strata with interbedded carbonaceous layers are commonly found in the formation immediately east of the Centralia-Chehalis coal district, indicating that the shoreline of the basin of deposition of the McIntosh formation was east of the mapped area.

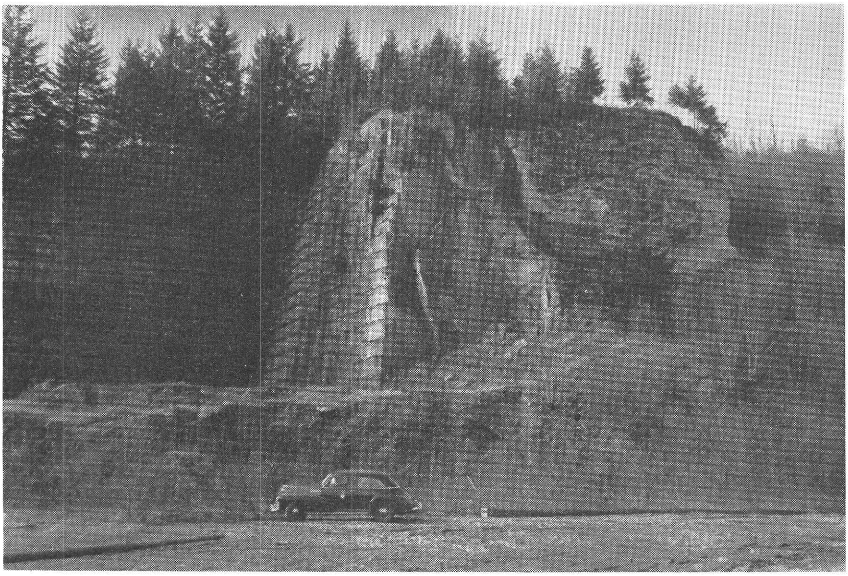

FIGURE 4.—Massive arkosic sandstone in the upper part of the McIntosh formation, Western quarry, Tenino, Wash.

Microscopic examination of thin sections indicates that the arkosic sandstone is composed of 75 to 90 percent clastic grains and 10 to 25 percent calcite, clay minerals, chlorite, and glass, which form the matrix (fig. 5). Plagioclase (andesine) makes up 25 to 40 percent

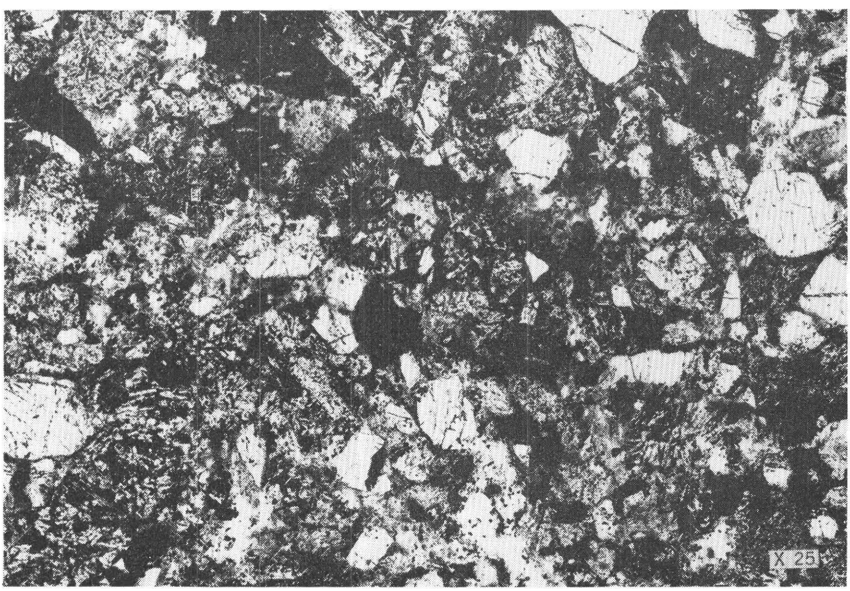

FIGURE 5.—Thin section of sandstone from the McIntosh formation. Light grains are chiefly plagioclase. Remainder of section is composed of volcanic rock fragments and alteration products. Ordinary light, $\times$ 25.

of the rock and in places is in euhedral form with pronounced zoning. Subrounded grains of quartz, commonly strained, make up 15 to 30 percent of the rock; they contain inclusions of biotite or muscovite. Biotite and muscovite make up 10 to 15 percent of the rock. Basalt fragments average less than 10 percent of the sandstone. Glass is in some of the rocks and is commonly altered to chalcedony. Other minerals identified are magnetite, augite, zircon, apatite, and hornblende.

Pyroclastic material interbedded in the McIntosh formation ranges from fine tuff to lapilli tuff. The tuffs consist of basalt fragments, and crystals of plagioclase, augite, and magnetite. Many of these tuffs are cemented by chalcedony, calcite, zeolitic minerals, and altered glass. Tuffs, observed in several outcrops, are so firmly welded that on cursory examination they might be mistaken for basalt flows.

The volcanic rocks interbedded with the McIntosh formation are composed predominantly of massive porphyritic and vesicular basalt flows, with a minor amount of pyroclastic and marine sedimentary rocks. The basalt generally has a porphyritic texture with an intersertal groundmass, but in places has a trachytic texture (fig. 6).

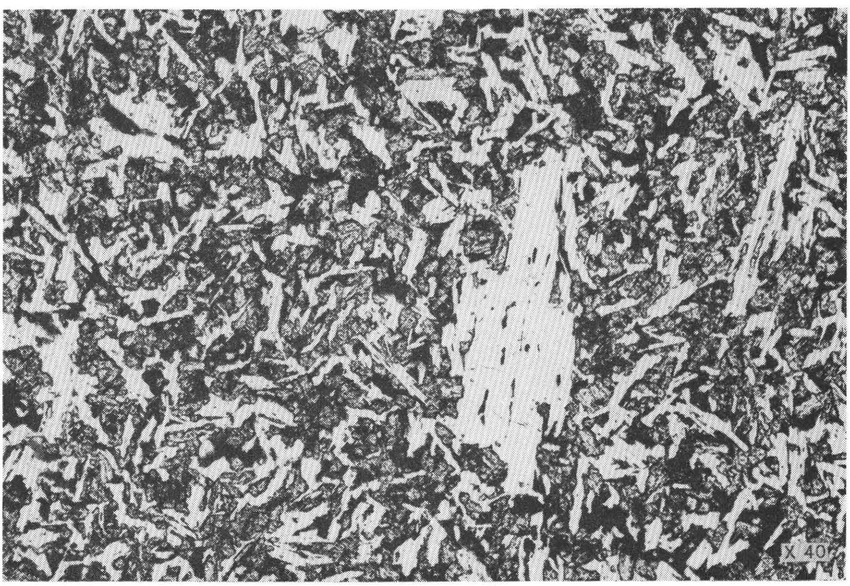

FIGURE 6.—Porphyritic basalt flow in volcanic member of McIntosh formation, in NW¼ sec. 9, T. 15 N., R. 4 W., showing large corroded phenocrysts of labradorite with a granular groundmass of augite and labradorite. Ordinary light, ×40.

Phenocrysts of plagioclase feldspar are most common; phenocrysts of augite and hypersthene occur in smaller amounts. The plagioclase phenocrysts are labradorite with zoned borders; the laths in the groundmass are alkalic labradorite. Plagioclase feldspar comprises about 55 percent of the rock. Pyroxene, occurring as phenocrysts and granules in the groundmass, forms 15 to 25 percent of the basalt. Euhedral to subhedral crystals of magnetite and ilmenite occur in the groundmass and form 3 to 15 percent of the rock. Minute acicular crystals of apatite and volcanic glass are found in the groundmass in most thin sections.

Secondary alteration by hydrothermal solutions has formed a considerable amount of chlorite minerals, biotite, kaolinite, magnetite, and zeolites. The plagioclase feldspars alter to zeolites and kaolinite. Secondary solutions have replaced part of the zeolites with calcite.

FOSSILS AND CORRELATION

Foraminifera occur abundantly in the offshore facies of the McIntosh formation. Invertebrate megafossils are rarely found in the formation and are either too small or too poorly preserved for detailed study. Fossil plants are found in the near-shore facies of the formation east of the mapped area. Studies of the fossils indicate that the McIntosh formation is of Eocene age and is to be correlated with the upper part of the Domengine stage and lower part of the Tejon stage of California.

Four foraminiferal zones are tentatively recognized in the McIntosh formation in the Centralia-Chehalis area. No attempt is made in this report to give a detailed discussion of the species associations within zones, and the reader is referred to the faunal lists on the following table for this information. A detailed discussion of the foraminiferal zonation of the Tertiary rocks in the Centralia-Chehalis area and a description of the many new species found are to be included in later publications.

The foraminiferal zones proposed in this report are recognizable within the area mapped, but as detailed mapping has not been done adjacent to the Centralia-Chehalis area the continuity of these zones is not known outside the mapped area. The zones in the McIntosh formation are referred to from older to younger as follows:

Vaginulinopsis vacavillensis zone
Amphimorphina californica zone
Bulimina cf. *jacksonensis* zone
Gyroidina—Uvigerina zone

Foraminifera from the McIntosh formation in the Centralia-Chehalis district, Washington

[Species arranged to show the highest observed occurrence in the formation, indicated as follows: V, very abundant; A, abundant; C, common; F, few; R, rare. Localities arranged in stratigraphic sequence with youngest on the left]

Species	Frequency of occurrence for indicated zone and locality number																						
	Gyroidina-Uvigerina zone										*Bulimina* cf. *jacksonensis* zone						*Amphimorphina californica* zone		*Vaginulinopsis vacavillensis* zone		Localities not used in zonation		
	f11097	f11079	f11080	f11081	f11082	f11083	f11084	f11085	f11086	f11087	f11088	f11089	f11090	f11091	f11092	f11093	f11094	f11098	f11147	f11148	f11096	f11149	f11095
Globigerina sp.	R		R						R				R										
Cibicides haydoni (Cushman and Schenck)	V	C	R		F												C						
Dentalina colei Cushman and Dusenbury	R	R		R		R					F	R						F			R	R	
Bulimina pupoides d'Orbigny	R	F	F	F	F						C	F						F	C		R	F	
Gyroidina soldanii octocamerata Cushman and G. D. Hanna	R											R							R				
Eponides yeguaensis Weinzierl and Applin	F	C			C				F								C	F		F	C		
Nodosaria latejugata Gümbel	F																F	C	F	F			
Robulus holcombensis Rau	C	C	C	F	C	C	C	C	A	F	F	F		F			V	C	C	C	F		
Plectofrondicularia packardi Cushman and Schenck		C	F	F	F	F	F	C	V		R											R	
Uvigerina cf. *yazooensis* Cushman		C	A		C							F											
Cyclammina sp. A		R					F	F	R		F	F	R	R	F	R		F				C	C
Cassidulina globosa Hantken			F					F													F	R	R
Marginulina subbullata Hantken			F								F	R			C	F						R	
Robulus welchi Church			R							R	C			C	C	C						C	
Discorbis cf. *samanicus* (W. Berry)					R	R				C	C	F										A	
Dentalina cf. *consobrina* d'Orbigny					F				R		R				R	R	F	F	R	R			
Gyroidina sp. A						A	C	C	F														
Quinqueloculina cf. *minuta* Beck						R	C	R	R									R					
Clavulinoides sp.						F											R	F					
Bulimina corrugata Cushman and Siegfus								R	A	C					V			F				A	C
Cassidulinoides cf. *howei* Cushman									C														
Valvulineria pygmea (Hantken)										A	R												
Robulus sp. B											F												
Allomorphina macrostoma Karrer											R												
Marginulina sp. A											R										R		
Dentalina cf. *adolphina* d'Orbigny											F	F				R							
Bulimina cf. *jacksonensis* Cushman											A	C	F	C	F	V	C	R				C	
Robulus sp. A											C	C	F	C	C	C	F					A	R

Cibicides warreni Cushman and R. E. and K. C. Stewart											F	A				C	F	A			C	C	
Vulvulina sp											C	C					F		C				
Chilostomella oolina Schwager											R								F				R
Epistomina eocenica Cushman and M. A. Hanna											R								C		F		
Triloculina cf. *gilboei* Beck											R						R			R	F		
Amphimorphina californica Cushman and McMasters												F			F	C	F	V				F	
Alabamina sp												R					F	F		F			
Dentalina jacksonensis (Cushman and Applin)													C	C			C	F				R	
Marginulina cf. *truncana* (Gümbel)																F							
Eponides cf. *guayabalensis* Cole																C						C	
Robulus sp. C																	C	F					
Lenticulina cf. *washingtonensis* Beck																	R			R			
Pseudoglandulina nallpeensis Rau																	C	F	R				
Anomalina cf. *A. garzaensis* Cushman and Siegfus																	F		C				
Baggina teninoensis Rau																	F	F		R		R	
Cibicides lobatus (d'Orbigny)																	F						
Vaginulinopsis vacavillensis (G. D. Hanna)																			A				
Siphonina cf. *claibornensis* Cushman																			F				
Rotorbinella colliculus Bandy																			R				
Amphistegina californica Cushman and M. A. Hanna																				C			
Cibicides mcmastersi Beck																				R			

Explanation of samples arranged according to locality numbers follows:

Locality No.	*Map reference*	*Depth in well (ft)*
f11097	F–4	
f11079	Union Oil Co., Bannse well 1	2, 110
f11080	do	2, 115
f11081	do	2, 205
f11082	do	2, 342
f11083	do	2, 548
f11084	do	2, 572
f11085	do	2, 791
f11086	do	2, 923
f11087	do	3, 149
f11088	do	3, 364
f11089	do	3, 374

Locality No.	*Map reference*	*Depth in well (ft)*
f11090	Union Oil Co., Bannse well 1	3, 582
f11091	do	3, 810
f11092	do	3, 822
f11093	do	3, 826
f11094	F–1	
f11098	F–5	
f11147	NW¼ sec. 34, T. 16 N., R. 4 W.	
f11148	SE¼ sec. 27, T. 16 N., R. 4 W.	
f11096	F–3	
f11149	SE¼ sec. 15, T. 15 N., R. 4 W.	
f11095	F–2	

The lowest zone recognized in the McIntosh formation contains abundant well-coiled *Vaginulinopsis vacavillensis* (G. D. Hanna) in association with *Amphistegina californica* Cushman and M. A. Hanna. These species, in combination with others shown on the faunal list, characterize the *V. vacavillensis* zone.

Amphimorphina californica Cushman and McMasters occurs abundantly within the zone of that name but by itself does not entirely characterize the zone. It has not been found below this zone within the formation but does occur in small numbers in the overlying zone. The association of *Bulimina corrugata* Cushman and Siegfus, *Baggina teninoensis* Rau, *Alabamina* sp., *Anomalina* cf. *garzaensis* Cushman and Siegfus, and *Cibicides warreni* Cushman, R. E. Stewart, and K. C. Stewart is an important characteristic of the *A. californica* zone.

The *Bulimina* cf. *jacksonensis* zone is best represented from the lower part of the Bannse test hole 1. The common occurrence of *B.* cf. *jacksonensis*, in association with *Vulvulina* sp., *Robulus welchi* Church, *Marginulina subbullata* Hantken, *Amphimorphina californica* Cushman and McMasters, *Discorbis* cf. *D. samanicus* (W. Berry), and *Valvulineria pygmea* (Hantken) characterizes the faunal assemblage of the *B.* cf. *jacksonensis* zone.

The uppermost zone of the McIntosh formation is referred to as the *Gyroidina-Uvigerina* zone because of the common occurrence of a punctate *Gyroidina* and a small costate *Uvigerina* within that part of the formation. *Robulus welchi* Church, *Plectofrondicularia packardi* Cushman and Schenck, *Bulimina corrugata* Cushman and Siegfus, *Discorbis* cf. *D. samanicus* (W. Berry), *Valvulineria pygmea* (Hantken) and *Cassidulinoides* cf. *C. howei* Cushman are additional significant species occurring in this zone. In the Bannse test hole 1, the punctate *Gyroidina* is restricted to the lower part of the zone whereas the costate *Uvigerina* occurs largely in the upper part; therefore, it may be possible to establish two zones instead of one zone in this part of the McIntosh formation. However, until more material is available to verify this possibility the upper part of the McIntosh formation is referred to as one zone, the *Gyroidina-Uvigerina* zone.

In the original description of the McIntosh formation, Snavely (Snavely, Rau, Hoover, and Roberts, 1951) suggested that the foraminiferal assemblages from the lower part of the formation were similar to the fauna described by Cushman and McMasters (1936) from the middle Eocene Llajas formation of California. Further studies substantiate this age assignment as the lower two, and possibly three, zones of the McIntosh formation contain many species that are identical or closely related to those listed by Cushman and McMasters from the Llajas formation.

Laiming (1940, p. 546–547) has designated most of the assemblage of Cushman and McMasters as typical of his *B–1A* zone. The occurrence of well-coiled *Vaginulinopsis vacavillensis* in the oldest known assemblages of the McIntosh formation suggests an age older than *B–1A* for the lowest part of the formation. The lower two zones of the formation are therefore tentatively considered equivalent in age to Laiming's *B–1* and *B–1A* zones of the Eocene of California.

The upper two zones of the McIntosh formation contain many species that are especially common in upper Eocene formations of the West Coast. The following forms, generally found in beds of late Eocene age, occur in the McIntosh formation:

Robulus welchi Church
Plectofrondicularia packardi Cushman and Schenck
Discorbis cf. *D. samanicus* (W. Berry)
Valvulineria pygmea (Hantken)
Eponides yeguaensis Weinzierl and Applin
Cibicides haydoni (Cushman and Schenck)
Cibicides warreni Cushman, R. E. and K. C. Stewart

Plectofrondicularia packardi has not been previously known to occur below the upper Eocene. *Discorbis* cf. *D. samanicus* and *Valvulineria pygmea* have been previously recorded in the Northwest only in the Moody shale member of the Toledo formation of Oregon (Cushman, Stewart, and Stewart, 1949, p. 134) at Toledo, Oreg. *Cibicides warreni* was originally described from beds exposed at Helmick Hill, Polk County, Oreg. (Cushman, Stewart, and Stewart, 1947, p. 104). It is also known from the Toledo formation at Toledo. Both of these units have been assigned to the Eocene, and it is generally believed that they represent a late Eocene age.

The Yamhill formation (Baldwin, Brown, Gair, and Pease, 1955) that crops out in the Sheridan quadrangle, Oregon, contains many foraminiferal species which occur in the McIntosh formation. Furthermore, variations in the fauna of the Yamhill formation are generally similar to those of the McIntosh formation. Therefore, the Yamhill formation is considered a probable correlative of the McIntosh formation of the Centralia-Chehalis area. Foraminifera from the sedimentary rocks exposed at Sacchi Beach south of the mouth of Five Mile Creek, near the south border of the Empire quadrangle, Oregon, are generally similar to the upper three zones of the McIntosh formation. Therefore, a part of the McIntosh formation is tentatively correlated with the Sacchi Beach strata of Oregon. A few small assemblages have been obtained from beds referred to the Tyee formation exposed in the Albany quadrangle of Oregon (Vokes, Myers, and Hoover, 1954). These Foraminifera have a general similarity to those in the lower part of the McIntosh formation.

Immediately adjacent to the eastern part of the Centralia-Chehalis district the McIntosh formation crops out along the Skookumchuck River 1 mile east of Camp Five of the Weyerhaeuser Timber Co., sec. 2, T. 14 N., R. 2 E. The strata in this area are partly of shallow-water origin and contain coarse-grained clastic deposits with thin coal beds and well-preserved leaf prints. The following species were identified by Roland W. Brown:

Allantodiopsis erosa (*Lesquereux*) Knowlton and Maxon
Quercus nevadensis Lesquereux
Platanus sp.
Cercidiphyllum elongatum Brown
Plantanophyllum angustilobum MacGinitie
Davilla intermedia Potbury
Tetracera castaneaefolia MacGinitie
Cinnamomum dilleri Knowlton
Persea sp.
Musophyllum sp.
Mallotus riparius MacGinitie
Other fragments of dicotyledons

Brown made the following comment regarding the age of the flora:

> The species comprising this flora are found in other middle and late Eocene floras of the Pacific Coast region. In particular, *Allantodiopsis erosa, Cercidiphyllum elongatum, Cinnamomum dilleri,* and *Platanophyllum angustilobum* are present in the Comstock, Clarno, and Cowlitz floras, indicating a broad general agreement in the time relationship of these floras * * *.

Dark-gray siltstone and shale with interbedded massive arkosic sandstone and coal beds crop out in the Morton coal field in the eastern part of Lewis County. Although no diagnostic marine fauna has been found in these beds, they contain leaf imprints similar to those found in the McIntosh formation. The writers suggest that these rocks may be equivalent in age to the McIntosh formation of the Centralia-Chehalis coal district.

NORTHCRAFT FORMATION

GENERAL FEATURES

The Northcraft formation was named by Snavely, Roberts, Hoover, and Pease (1951) from typical exposures in the northeastern part of the area in the vicinity of Northcraft Mountain. This sequence of volcanic and sedimentary rocks overlies the McIntosh formation with apparent conformity throughout most of the area.

Culver (1919, p. 21–25) described a sequence of rocks consisting of conglomerate, breccia, graywacke, and black siliceous shale which crops out along the Newaukum River. He named these beds the Newaukum series and considered them to be pre-Puget and probably pre-Tertiary in age. The dark shale and arkosic sandstone described by Culver are mapped as the McIntosh formation in this report. The conglomerate, graywacke, and breccia in Culver's Newaukum series are probably equivalent to a part of the Northcraft formation.

The Northcraft formation extends both south and east beyond the limits of the mapped area. These rocks have been mapped along the valleys of the Tilton and Cowlitz Rivers by Erdmann (1951, p. 41–44). He described a sequence of andesite and basalt flows, flow agglomerate, tuffs, and associated sedimentary rocks between Mayfield and Mossyrock, and estimated their thickness to be between 1,200 and 1,400 feet. Farther south, volcanic rocks of the Northcraft formation are known to crop out in the eastern part of the Toutle quadrangle, Washington. The authors also have traced these volcanic rocks eastward to the vicinity of Morton where they overlie the coal-bearing strata of Eocene age.

The Northcraft formation crops out chiefly in the northern and eastern parts of the area; in several drill holes, however, the formation was penetrated elsewhere in the mapped area (pl. 4). In the vicinity of Northcraft Mountain the formation has a thickness of approximately 1,000 feet; to the southwest it thins to 680 feet in the Bannse test hole 1. It is not known to be present west of the Chehalis River, but the Northcraft formation may be equivalent in age to the tuffaceous sedimentary rocks that are found in the lower part of the Skookumchuck formation in the extreme western part of the mapped area. The predominance of fine-grained pyroclastic rocks in the central and western parts of the area, in contrast to the predominance of lava flows and breccia in the eastern part, suggests that the source of volcanism probably was east of the mapped area.

LITHOLOGIC COMPOSITION

The Northcraft formation consists chiefly of ferromagnesian lavas, flow breccia, and pyroclastic rocks in the upper part and basaltic conglomerate, sandstone, and pyroclastic material in the lower part.

The lava flows are largely calcic andesite but some are basalt. In hand samples the textures are vesicular, trachytic, porphyritic, and aphanitic. The flows are platy (fig. 7) in many places. The platy structure generally is concordant with the cooling surfaces. In fresh exposures the andesite is a dark olive gray but weathers to reddish brown. Vesicular flows with amygdules composed of calcite, zeolites, and chalcedony are common. Flow breccia is present in some flows and contains massive and platy blocks of andesite and basalt as large as 6 feet in diameter. In both the flows and breccia secondary quartz, calcite, and zeolite minerals fill in irregular joints and voids.

Petrographic studies of the Northcraft volcanic rocks indicate that they usually are hemicrystalline and are porphyritic, trachytic, and vesicular in texture (fig. 8.) Many of the rocks show well-developed flow cleavage due to the trachytic texture of the groundmass. Pheno-

FIGURE 7.—Platy andesite flows of the Northcraft formation from a point on the Skookumchuck River, in southeast corner of sec. 12, T. 15 N., R. 1 E.

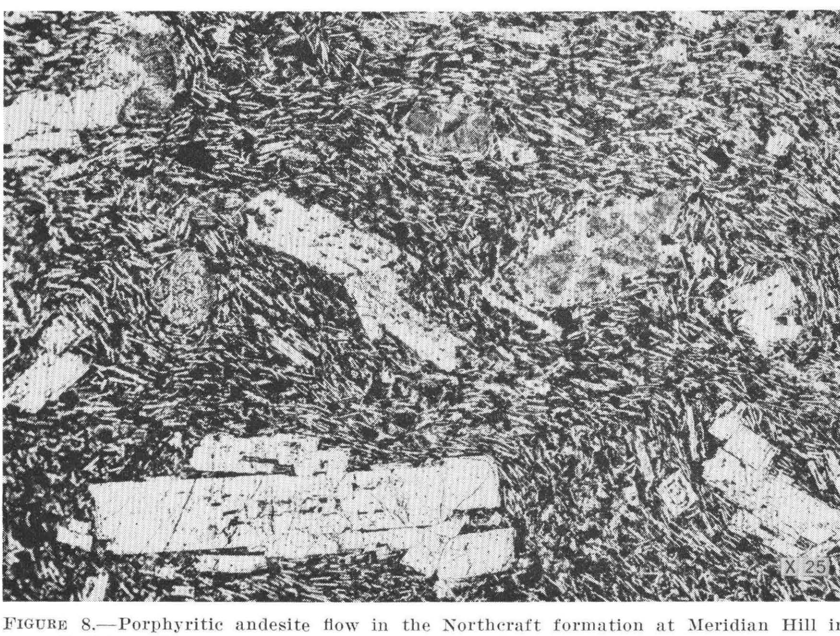

FIGURE 8.—Porphyritic andesite flow in the Northcraft formation at Meridian Hill in the NE¼ sec. 13 T. 14 N., R 1 W., showing trachytic texture of the plagioclase laths in the groundmass surrounding phenocrysts of andesine. Ordinary light, ×25.

crysts of plagioclase, An_{40} (andesine) to An_{60} (labradorite) and augite are set in a groundmass of plagioclase laths, granules of augite and magnetite, and volcanic glass. The phenocrysts of plagioclase usually are zoned and some are fractured by postcrystallization movement. Augite phenocrysts and granules are in all the thin sections studied and form 5 to 25 percent of the basalt and calcic andesite. Magnetite, composing 3 to 12 percent of the sections, is an important constituent of the groundmass. Volcanic glass in the groundmass usually is devitrified to a brown palagonitic material. Alteration is common in most of the flows studied; secondary minerals make up 10 to 20 percent of the thin sections. Secondary minerals identified are chlorite, biotite, calcite, zeolites, kaolinite, hematite, chalcedony, quartz, and ilmenite, in order of decreasing abundance.

The lower part of the Northcraft formation within the area of this report consists chiefly of sedimentary rocks derived from basaltic material and includes some pyroclastic material and mudflows. The sedimentary rocks range from basaltic sandstone to coarse basaltic conglomerate. The conglomerate is widely distributed throughout much of the eastern part of the area. The boulders and cobbles of basalt, many of them well-rounded, range from several inches to 4 feet in diameter and are set in a matrix of tuffaceous basaltic sandstone. Most of the boulders and cobbles of basalt are coated with a waxy palagonitic(?) or chloritic material, which gives outcrops of the rock an olive-green color. The pyroclastic rocks range from fine tuff to volcanic breccia. The most common type is a water-laid lapilli tuff and tuff-breccia composed of a heterogeneous mixture of varicolored basalt fragments and crystals of plagioclase. Fine tuff and tuffaceous siltstone are common; they are vivid shades of red and purple at many places. The pyroclastic rocks are often chloritized to a waxy olive-green material. Mudflow breccia containing subangular blocks of basalt or andesite as large as 4 feet in diameter in a muddy tuffaceous matrix are interbedded with the volcanic rocks. Welded tuff was recognized at several outcrops and consists of basalt fragments, glass shards, plagioclase crystals, and magnetite grains. This rock originally was porous but the voids are now filled with zeolites, chalcedony, or chlorite.

FOSSILS AND CORRELATION

Inasmuch as the Northcraft formation consists chiefly of volcanic and nonmarine sedimentary rocks, fossil material is rare. A few fossil plants have been collected from strata of the formation, but they are not well enough preserved to permit identification. Along the axial part of the Lincoln Creek uplift, near the western border of the mapped area, tuffaceous siltstone beds included in the lower part of the Skookumchuck formation may be equivalent in age to the Northcraft formation. These beds contain a foraminiferal assemblage which correlates best with assemblages of early late Eocene age. This correlation together with the stratigraphic position of the Northcraft formation indicates it is of late Eocene age.

Wilkinson, Lowry, and Baldwin (1946, p. 4–15) mapped a sequence of volcanic flows and associated pyroclastic rocks in the St. Helens quadrangle, along the Columbia River in the vicinity of Goble, Oreg. These rocks, referred to as the Goble volcanic series, were assigned a late Eocene to early Oligocene age. On the basis of lithologic similarities and general stratigraphic position a correlation is suggested between the Northcraft formation and the lower part of the Goble volcanic series.

SKOOKUMCHUCK FORMATION

GENERAL FEATURES

The Skookumchuck formation, consisting of marine, nonmarine, and brackish-water sedimentary rocks and intercalated coal beds, overlies the Northcraft formation with an apparent local angular unconformity. The Skookumchuck formation has a maximum thickness of about 3,500 feet and crops out in a broad irregular belt that extends across the mapped area from southeast to northwest. Snavely, Roberts, Hoover, and Pease (1951) named and described the Skookumchuck formation from exposures along the Skookumchuck River west of the Willamette meridian. Strata referred to this formation previously were included in the Puget series of Eocene age (Culver, 1919, pl. 1). The Skookumchuck formation of this report is equivalent to a part of the Cowlitz formation of Weaver (1937, pl. 6).

The Skookumchuck formation consists generally of a lower sandstone unit which is separated from an upper sandstone unit by a westward-thickening wedge that is predominantly siltstone. Vertical and lateral variations in lithology within a short distance are common in this formation. Throughout most of the Centralia-Chehalis district the Skookumchuck formation is typified by an alternation of marine and continental facies in which deposition occurred within or near the littoral zone. Tongues of offshore, marine, fine-grained sedimentary rocks that are generally restricted to the middle part of the Skookumchuck locally interfinger with near-shore coarser clastic rocks. Beds that were deposited under shallow-water conditions consist chiefly of massive, crossbedded, and thin-bedded sandstone and thin-bedded siltstone or shale. All gradations between sandstone and siltstone are found, but sandstone beds predominate. A marine tuffaceous fissile siltstone unit crops out in the western part of the mapped area, between Bunker and Deep Creeks. This siltstone unit is tentatively considered in part to be an offshore marine equivalent of the coarser clastic rocks of the Skookumchuck formation farther to the east. This correlation cannot be made with certainty, because of the lack of continuous outcrops; therefore, the possibility exists that this siltstone unit is older than the type Skookumchuck formation.

A local angular unconformity is present between the Skookumchuck formation and the underlying Northcraft formation in the eastern part of the district. This unconformity is made apparent by the on-lapping of the coal-bearing strata on the Northcraft formation; however, a part of this angular discordance is probably due to the initial dip of the volcanic flows. In the vicinity of Thompson Creek, 100 to 200 feet of conglomerate derived from the Northcraft formation is present at the base of the Skookumchuck formation. Immediately west of the mapped area, surface mapping indicates an apparent gradation from the older siltstone of the McIntosh formation upward into the overlying siltstone of the Skookumchuck formation. Therefore, the authors believe that the unconformity at the base of the Skookumchuck formation may be local in extent, and that away from areas of pre-Skookumchuck structural relief the Skookumchuck formation may be essentially conformable with the underlying rocks.

Section of the upper part of the Skookumchuck formation along railroad cut about 1 mile north of Centralia, in sec. 33, T. 15 N., R. 2 W., Centralia-Chehalis district, Washington

	Thickness Ft	In
Sandstone, massive to thin-bedded, mottled-gray and brownish-orange, fine-grained, micaceous; contains intercalated brown carbonaceous siltstone	15	6
Siltstone, brown, tuffaceous, shaly; imprints of plant material	5	
Sandstone, massive, mottled-gray and brownish-orange, fine-grained	10	
Sandstone, poorly exposed	87	
Covered	33	
Sandstone, medium-gray, silty, fine-grained	13	
Siltstone, brown, micaceous and carbonaceous; with thin coal and bone streaks	3	
Sandstone, silty, micaceous, fine-grained	6	
Siltstone, massive, dark-gray, carbonaceous; somewhat shaly	9	
Sandstone, iron-stained, fine-grained, silty, micaceous	13	
Sandstone, fine-grained, with sporadic poorly preserved gastropods and pelecypods; contains thin zones of abundant brackish-water pelecypods	5	
Siltstone and sandstone, thin-bedded, crossbedded, ripple-marked, carbonaceous; contains a few coaly streaks	18	
Sandstone, dark-gray, massive, carbonaceous and micaceous	12	

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Section of the upper part of the Skookumchuck formation along railroad cut about 1 mile north of Centralia, in sec. 33, T. 15 N., R. 2 W., Centralia-Chehalis district, Washington—Continued

	Thickness Ft	In
Shale, carbonaceous; with intercalated thin, bony coal partings and micaceous siltstone layers	1	6
Sandstone and siltstone, fine-grained, carbonaceous and micaceous; contains a half-inch hard ferruginous zone	7	
Sandstone, medium-gray, fine-grained, silty, somewhat micaceous	10	
Siltstone, carbonaceous, micaceous; with thin bone and bony coal layers	6	6
Siltstone, brown; with interbedded fine-grained, iron-stained sandstone	5	
Sandstone, mottled-orange and light-gray, friable, massive to crossbedded. micaceous	26	
Covered	75	
Sandstone, massive to crossbedded, medium-grained	6	
Siltstone, gray and brown, carbonaceous; with interbedded 7-in. bone and coal bed	9	
Sandstone, gray, iron-stained, fine-grained, silty	10	
Sandstone, fine-grained; with interbedded dark-gray, ripple-marked siltstone	6	
Sandstone, gray, fine- to medium-grained, friable micaceous	17	
Siltstone, dark-brown, shaly, carbonaceous; with interbedded fine-grained sandstone, and coal streaks	8	
Coal, bright; with rectangular cleavage		6
Siltstone, carbonaceous; with a few bony and shaly partings	6	
Covered	12	
Sandstone, medium-gray, fine-grained, massive, micaceous, silty	21	
Siltstone and sandstone, brown, carbonaceous; with coal and bone partings	3	6
Sandstone, massive to crossbedded, micaceous; with limy concretions up to 10 ft in diameter	73	
Sandstone, silty; with interbedded siltstone and iron oxide layers	12	
Sandstone, fossiliferous; with iron-stained calcareous pebbles	1	
Sandstone, fine-grained, silty, micaceous; with sporadic gastropods and pelecypods	8	
Siltstone, sandy; with brown limonitic concretions and sporadic gastropods and pelecypods	15	
Siltstone, sandy, clayey, fossiliferous	8	
Sandstone and siltstone, dark-gray, carbonaceous; with thin bone and coal layers	1	6
Siltstone, medium-gray, clayey	2	
Sandstone, thin-bedded, silty; with irregular siltstone layers and coalified log 20 in. in diameter	8	
Siltstone, gray, sandy, fossiliferous; few lenses of bone as much as 1 in. thick	33	
Coal, bony; with carbonaceous and tuffaceous partings	2	6
Siltstone, sandy, carbonaceous, somewhat shaly	1	6
Sandstone, crossbedded, medium- to fine-grained, micaceous	15	
Covered	83	
Sandstone, medium-gray, fine-grained, silty	11	
Claystone, dark-brown, fissile	6	
Sandstone, medium-grained, arkosic	10	

Section of the upper part of the Skookumchuck formation along railroad cut about 1 mile north of Centralia, in sec. 33, T. 15 N., R. 2 W., Centralia-Chehalis district, Washington—Continued

	Thickness Ft	In
Coal ash, brick-red; with thin baked sandstone partings	3	6
Siltstone, dark-gray, thin-bedded, sandy	8	
Sandstone, massive, fine-grained	23	
Covered	76	
Siltstone, platy, micaceous; with interbedded fine-grained sandstone	64	
Sandstone, baked; with thin pebble zones and sporadic gastropods and pelecypods	10	
Coal ash, light-reddish-orange to brick-red; contains thin porcellanite partings	9	
Siltstone, baked, reddish-brown; with coal ash	5	
Siltstone, dark-gray, partly baked, carbonaceous	2	
Siltstone, thin-bedded, dark-brown, micaceous, carbonaceous, somewhat shaly	13	
Siltstone, dark-gray, carbonaceous, tuffaceous; contains white ash fragments	1	
Coal, bony streaks; with tuffaceous, sandy siltstone partings	3	6
Bone, with thin bright coal streaks	1	6
Siltstone, brown, shaly, carbonaceous	2	
Coal, with thin siltstone and bone partings		6
Coal, bony; contains thin carbonaceous siltstone and sandstone partings	1	
Sandstone, light-gray, massive to thin-bedded, iron-stained	15	
Sandstone, partly covered	46	
Sandstone brownish-gray, thin-bedded, carbonaceous, micaceous, fine-grained; with interbedded siltstone laminae	72	
Sandstone, mottled light-orange to yellowish-brown, crossbedded, friable, micaceous, fine-grained; contains irregular iron-stained joints	72+	
	1, 178+	

LITHOLOGIC COMPOSITION

The sandstone of the Skookumchuck formation is fine to medium grained, micaceous and carbonaceous, basaltic and arkosic, and locally contains fine tuff. It is generally friable but may be cemented with calcium carbonate, iron oxide, and perhaps with silica derived from divitrified volcanic glass. Calcium carbonate makes up as much as 40 percent of some sandstone beds. These beds are generally lenticular, but they may sometimes be traced for several miles. The sandstone is well to poorly sorted, usually better sorted in the more massive beds.

Porosity and permeability measurements were made on cores of sandstone from several of the shallow drill holes (pl. 3). The porosity of the sandstone ranges from 5.3 to 35.2 percent and the permeability from 1.42 to 3,506.0 millidarcies, depending upon the amount of fine clastic material in the sandstone. In outcrops the sandstone appears to have a low porosity owing to the filling of a part of the pore space of the rock by clay minerals, derived chiefly from the alteration of feldspar grains.

Sandstone in thick beds generally is massive and shows little evidence of bedding except by the orientation of mica flakes, carbonaceous material, thin siltstone or clay partings, or intraformational breccia. Crossbedding on a large scale, possibly of an offshore bar type, is common.

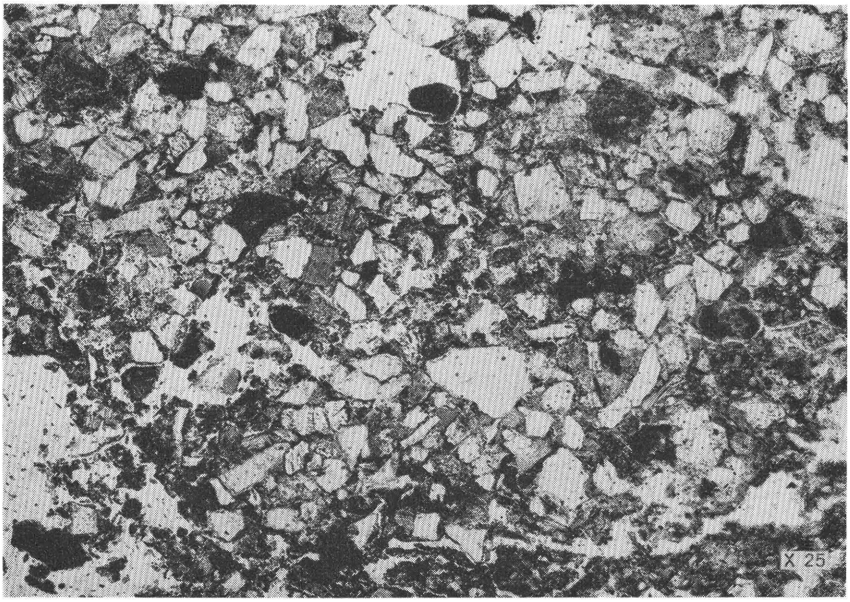

FIGURE 9.—Thin section of sandstone from the Skookumchuck formation. Light grains are feldspar and quartz. Dark areas consist of fragments of volcanic glass and iron stain. Ordinary light, × 25.

The principal clastic constituents of the sandstone are feldspar, quartz, muscovite, biotite, and fragments of tuff, basalt, and andesite (fig. 9). The sandstone is composed of 50 to 80 percent clastic fragments and 20 to 50 percent calcite, clay minerals, chloritic material, and altered glass, which form the matrix. Angular to subangular grains of plagioclase (andesine) usually make up 10 to 40 percent of the rock; however, the plagioclase content in some beds is as much as 80 percent. Subrounded to rounded grains of quartz, some of which are strained, make up 5 to 40 percent of the sandstone; muscovite and biotite may amount to as much as 10 percent, and subrounded lithic fragments of basalt and andesite form 5 to 80 percent. In general, the average values given above are true for the entire Skookumchuck formation, but feldspar is a more important detrital constituent in the upper part of the formation than in the lower part, and tuffaceous and volcanic material is generally more common toward the base of the formation.

The plagioclase crystals are generally fresh and display zoning and twinning. The angularity of some of the grains of plagioclase suggests that they are of pyroclastic origin. Some grains of plagioclase contain inclusions of apatite. Oligoclase, anorthoclase, and microcline were identified in a few samples. Mica is characteristic of the sandstone and in many places is concentrated in zones. Minor constituents of the sandstone are magnetite, hornblende, augite, chlorite, chalcedony, glass, garnet, and pyrite.

When fresh the sandstone is medium bluish gray and weathers to mottled-light-gray, light-yellowish-orange, and brown, iron-stained sand. The ferromagnesian minerals and the fragments of basalt and andesite show the greatest amount of alteration, but the grains of plagioclase and quartz are usually fresh with little staining.

The siltstone of the Skookumchuck formation ranges from dark brown to medium greenish gray and is finely micaceous, carbonaceous, tuffaceous, and often fissile. It is frequently interbedded with fine-grained sandstone, forming laminae that have a poker-chip appearance. A shallow-water type of deposition of the finer clastic rocks is evidenced by ripple and swirl marks, flow-casts, scour-and-fill channels, and intraformational breccia. Mollusk borings occur in some of the siltstone beds, and well-preserved leaf imprints are occasionally found in tuffaceous claystone and mudstone. In the Lincoln Creek uplift in the western part of the area, a part of the formation consists predominantly of tuffaceous and fissile siltstone which commonly contains small white spherical objects (radiolaria ?) that can be seen seen without the aid of a lens.

Conglomerate is not common in the Skookumchuck formation but is locally near the base of the formation in the eastern part of the area, and a few lenses of conglomerate are found near the upper contact of the formation in the western part of the area. The basal part of the formation in the eastern part of the area consists of 20 to 200 feet of olive-gray to greenish-gray spheroidally weathering basaltic and andesitic sandstone and conglomerate. These sedimentary rocks were largely derived from the underlying Northcraft formation but include some andesite tuff. Pebbles in the basal conglomerate average between 2 and 3 inches in diameter and are well rounded. The matrix consists of clay or fine sand and secondary minerals. Carbonaceous balls, pumice pebbles, and pyrite are common. The sandstone consists of coarse grains and granules that are poorly sorted and usually stained with iron oxide. Crossbedding and scour-and-fill channels are in the coarse clastic rocks in many places.

Beds of carbonaceous shale and siltstone, bone, bony coal, and coal are interbedded with other sedimentary rocks and range from a few inches to more than 15 feet in thickness. Beds rich in carbonaceous material are generally found in association with the upper and lower coal groups of the formation and are particularly common in the eastern part of the mapped area. Carbonaceous beds frequently grade

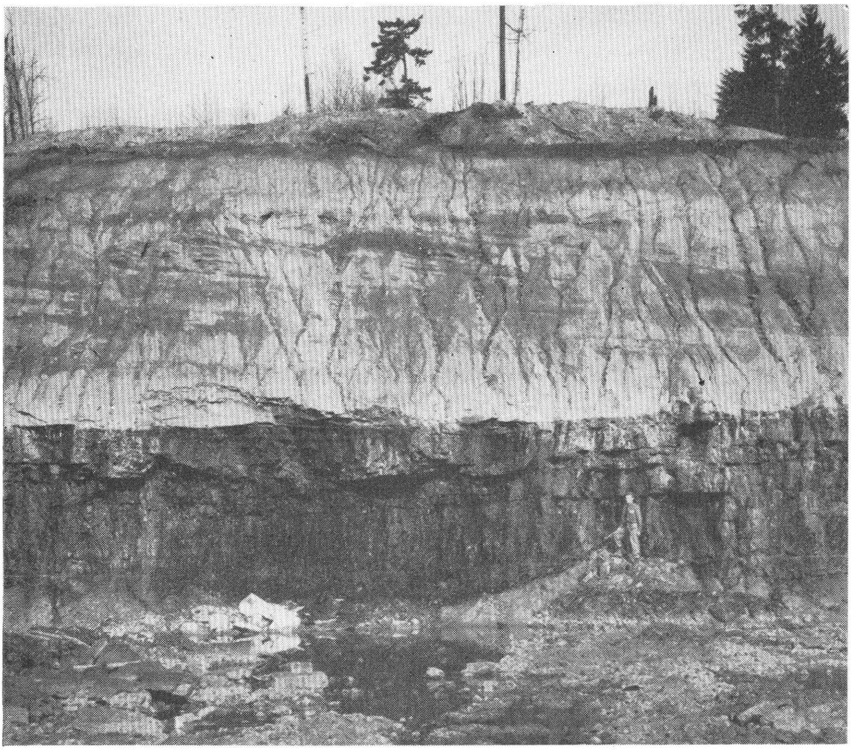

FIGURE 10.—The Tono No. 1 coal bed in the Skookumchuck formation, Tono strip pit, Tono, Wash. The Tono No. 1 coal bed in this area is about 18 feet thick and is overlain by crossbedded brackish-water sandstone. Man standing near center of coal bed, in the lower right-hand corner of picture, indicates scale.

laterally and vertically into coal beds and are separated from the other sedimentary rocks by sharp or gradational contacts. The coal beds usually have sharp contacts with the overlying and underlying sedimentary rocks (fig. 10) and in places the upper parts of some of the coal beds are cut by scour-and-fill channels. The bone consists of a mixture of inorganic and coaly material, varies from black to dark brown, and has a dull luster and a platy parting, but it lacks the cleavage and brittleness of coal. In the eastern part of the area silicified bone is fairly common and often contains small pumice fragments and imprints of plants and leaves. Fragmental carbonaceous material locally is in beds of fine- and medium-grained sandstone, but the amount of carbonaceous material in the sandstone is rarely as great as that in the siltstone beds. Near the western margin of the area, however, siltstone and claystone beds of offshore marine origin are mainly noncarbonaceous.

FOSSILS AND CORRELATION

Foraminifera have not been found in abundance in the Skookumchuck formation, because where best exposed it consists predominantly of sandstone and brackish-water fine-grained clastic rocks. A fauna of generally large mollusks, however, is common in the near-shore marine facies of the formation. Fossil plants occasionally are found in the carbonaceous strata of the Skookumchuck formation but are too poorly preserved or fragmentary to permit identification. Paleontologic data indicate that the Skookumchuck formation is of late Eocene age and is a correlative of the type Cowlitz formation (Weaver, 1937, p. 90–93) of southwestern Washington.

The Foraminifera identified from the Skookumchuck formation are listed in table 1. No attempt has been made to establish foraminiferal zones in this formation because the faunal variations usually reflect changes in facies. A detailed study of the faunas obtained from a stratigraphic sequence of more than 1,700 feet of rock, core drilled by the Geological Survey in holes *K*, *I*, and *J*, indicates that the foraminiferal species occuring in drill hole *K* largely reoccur at a lower stratigraphic horizon in Geological Survey hole *J* (pl. 3).

A study of Foraminifera shows that faunas of the Skookumchuck formation are best correlated with those in the upper Eocene Cowlitz formation exposed about 15 miles south of the Centralia-Chehalis coal district, along the Cowlitz River. Most of the Foraminifera known from the Skookumchuck formation have been recorded by Beck (1943) who described the foraminiferal assemblage from a zone 200 feet thick in the Cowlitz formation. The species in the Skookumchuck formation are largely indicative of a shallow-water, near-shore marine environment; however, a few deeper water marine forms are found in the finer grained clastic rocks of the Skookumchuck formation which crop out in the west-central part of the area. Most of these deeper water forms also occur in the Cowlitz formation.

The foraminiferal faunas from the type section of the Cowlitz formation are generally correlated with those of the upper part of the Tejon formation of California and referred to the upper part of the Eocene (Beck, 1943, p. 591). Beck also suggests a correlation between the type Cowlitz foraminiferal assemblage and assemblages from the middle part of the Coaledo formation of western Oregon and the Poway conglomerate of California.

Diagnostic foraminiferal assemblages have not been obtained from the weathered outcrops of the tuffaceous siltstone strata included in the Skookumchuck formation which crops out in the western part of the Lincoln Creek uplift. However, since field investigations were completed the tuffaceous siltstone strata that contained microfossils was found in two drill holes, Siefert No. 1, in the NW¼SE¼SW¼ sec. 4, T. 14 N., R. 3 W., and Lohman-Standard, State No. 1, in the NE¼SW¼ sec. 14, T. 14 N., R. 3 W., both of which were drilled on the northern part of the Lincoln Creek uplift. These Foraminifera differ only slightly from those found in the *Gyroidina-Uvigerina* zone of the McIntosh formation. Since the faunal assemblages found in the tuffaceous siltstone strata of the Skookumchuck formation and in the upper part of the McIntosh formation had similar environments, the slight difference in these assemblages is attributed to a difference in age. *Plectofrondicularia* cf. *jenkinsi* Church is usually present in the tuffaceous siltstone strata of the Skookumchuck formation but is not known in the underlying *Gyroidina-Uvigerina* zone of the McIntosh formation. *Uvigerina* cf. *yazooensis* is absent and *Gyroidina* sp. A and *Valvulineria pygmea* are not common in the tuffaceous siltstone strata, but all three species are common in the *Gyroidina-Uvigerina* zone of the McIntosh formation. The faunas of the tuffaceous siltstone are generally comparable to those found in the middle part of the Coaledo formation of Coos Bay, Oreg. (Detling, 1946), and the Moody shale member of the Toledo formation exposed at Toledo, Oreg. (Cushman, Stewart, and Stewart, 1949).

Immediately adjacent to the southwestern part of the mapped area, along the Chehalis River between the towns of Pe Ell and Doty, foraminiferal faunas have been collected from siltstone beds that occur both above and below sandstone beds lithologically similar to the coal-bearing sandstone beds of the Skookumchuck formation. As the faunas in these siltstone beds are essentially the same as the faunas present in the tuffaceous siltstone strata of the Skookumchuck formation in the Lincoln Creek uplift, it suggests that the tuffaceous siltstone strata are offshore facies of the coal-bearing sandstone beds of the Skookumchuck formation.

Invertebrate megafossils have been collected from the Skookumchuck formation throughout the area and are commonly found in the near-shore marine facies, often in calcareous sandstone beds. Species identified and listed on the following table indicate a correlation between the Skookumhuck formation and the Cowlitz formation of late Eocene age in Cowlitz County, Wash. In many places, such as the rock tunnel of the Stoker mine, thin richly fossiliferous beds are found immediately adjacent to the coal beds. The fine-grained noncarbonaceous clastic rocks in the eastern part of the mapped area in a few places contain a meager assemblage of small megafossils, but they are rarely found in the offshore marine beds in the western part of the area.

OLIGOCENE SERIES

LINCOLN FORMATION (OF WEAVER)

GENERAL FEATURES

Weaver (1912, p. 10–22) applied the name Lincoln formation to the strata exposed along the west bank of the Chehalis River near the mouth of Lincoln Creek about half a mile north of Galvin. He estimated a thickness of 1,000 feet for this formation and stated that it grades upward into "Porter shales," which he correlated with the lower part of his Blakeley formation. Later, Weaver (1937, p. 110-111) regarded the Lincoln formation as equivalent to the entire middle Oligocene of Washington. In a discussion of the stratigraphy of Grays Harbor County, Weaver (Weaver and others, 1944, p. 592) redefined the type section of the Lincoln formation to include the composite of many sections exposed in the banks of the Chehalis River between Centralia and Porter, Wash. He further stated that these sections consist predominantly of shaly medium-grained tuffaceous sandstone, with basal grits and conglomerate.

As recognized by the authors the Lincoln formation in the Centralia-Chehalis area consists of approximately 2,000 feet of tuffaceous and basaltic marine sandstone and siltstone with associated continental deposits composed predominantly of sediments derived from volcanic rocks and pyroclastic material. The Lincoln formation of Weaver crops out chiefly in the western part of the mapped area and is generally restricted to broad westward- and northwestward-trending synclines. The formation rests conformably on the Skookumchuck formation and, in a few places, beds of the Skookumchuck formation grade upward into the lowermost part of the Lincoln formation. The contact between the two formations is usually marked by a distinct lithologic break or by what appears to be a buried soil zone.

The Lincoln formation in the eastern part of the Centralia-Chehalis district consists predominantly of deltaic, near-shore, and continental deposits of basaltic sandstone with interbeds of pyroclastic rocks. These strata are herein referred to the basaltic sandstone member of the Lincoln formation. Sedimentary rocks of the Lincoln formation which crop out west of the Chehalis River are indicative of a shallow-water offshore marine environment. These beds are composed of tuffaceous silty sandstone and siltstone and are referred to in this report as the tuffaceous siltstone member of the Lincoln formation.

Megafossils from the Skookumchuck formation in the Centralia-Chehalis district, Washington

[Identifications by H. E. Vokes]

Species	Locality number (Map reference number in parentheses)																
	17399 (M-8)	17392 (M-9)	18483 (M-10)	17404 (M-11)	17396 (M-3)	17397 (M-15)	17408 (M-14)	17390 (M-2)	17410 (M-4)	17403 (M-1)	17964 (M-6)	17960 (M-16)	17962 (M-17)	17965 (M-12)	17391 (M-5)	18482 (M-7)	18484 (M-13)
Acila (*Truncacila*) *decisa* (Conrad)					×			×				×					×
Nuculana cowlitzensis (Weaver and Palmer)												cf.					cf.
Glycymeris eocenica (Weaver)	×		×														
sp. indet																×	
Barbatia (*Barbatia*) *cowlitensis* (Weaver and Palmer)											×				×		
(*Obliquarcea*) *suzzaloi* (Weaver and Palmer)															×		
landesi (Weaver and Palmer)										×							
Trigonodesma hornii (Gabb)										×							
Pteria clarki Weaver and Palmer			×							×	×			×	×	×	
Ostrea idriaensis Gabb	×		×		×	×	×		×		×		×	×	×	×	
idriaensis fettkei Weaver and Palmer			×				×								×		
Chlamys n. sp										×							
Mytilus stillwaterensis Weaver and Palmer										cf.							
Brachidontes cowlitzensis (Weaver and Palmer)		×	×							×		×					×
Thracia dilleri Dall	×						×										
Crassatella uvasana (Conrad)	×	×	×											aff.		aff.	
dalli (Weaver)	cf.	×															
washingtonensis (Weaver)												×					
Corbicula cowlitzensis Weaver				×													
sp. indet																×	
Venericardia hornii clarki (Weaver and Palmer)	×	×	×				×			×			×	×	×		
"*Lucinia*" n. sp							×		×								
Loxocardium olequahensis (Weaver)											×	×					
Plagiocardium (*Schedocardia*) *brewerii* (Gabb)	×	×	×				×				×			×	×		
Macrocallista (*Costacallista*) *conradiana* (Gabb)	×	×	×						×					cf.			
williamsoni Weaver and Palmer	?									×	?			×			
Tivelina vaderensis (Dickerson)											×						
Pitar californiana (Conrad)		×	?				?										
quadrata (Gabb)							×			×			?	?			
(*Lamelliconcha*) *eocenica* (Weaver and Palmer)	?	×								?							
Pelecyora n. sp						×									×		
Tellina cowlitzensis Weaver	×														×	×	
Gari olequahensis (Weaver and Palmer)	×		×				cf.										
"*Sanguinolaria*" *howardi* (Dickerson)	×	×	×														

Solen parallelus Gabb												?			cf.		
Solena (Eosolen) columbiana (Weaver and Palmer)	×																
Spisula bisculpturata (Anderson and Hanna)	×						cf.										
Anatina sp. indet																	×
Corbula dickersoni Weaver and Palmer		×															
Homalopoma n. sp			×				×										
Polinices (Polinices) hornii (Gabb)							×		?	×							
(Neverita) secta (Gabb)	×										×						
(Euspira) nusciformis (Gabb)	×	×					×										
"*Amaurellina (Euspirocromium)*" *clarki* Stewart										×							
Calyptraea diegoana (Conrad)	×		×	×						×			×	×	×	×	
Crepidula pileum (Gabb)	×	×	×								×			cf.	×		
Turritella uvasana stewarti Merriam	×	×	×		×	?	×	×	×	×	×	×	aff.	×		×	
Cerithiopsis washingtoniana (Dickerson)							?					×					
Ficopsis cowlitzensis (Weaver)														×	×		
Cantharus perrini Dickerson	×		?														
Siphonalia sopenahensis (Weaver)	×		×									?					
Siphonalia? sp																×	×
Perse washingtonensis (Weaver)					×				×								
Dentalium stramineum Gabb	×			×					×			×					
sp	×	×							×								
Barnacle	×																
Terebratula sp				×													

BASALTIC SANDSTONE MEMBER

The basaltic sandstone member of the Lincoln formation is thickest in that part of the Centralia-Chehalis district which lies east of the Chehalis River. Typical exposures of this member occur about 1 mile east of Centralia, in road cuts along the north side of the valley of Salzer Creek and in cuts along logging grades in the area between Salzer and South Hanaford Creeks. Strata of the basaltic sandstone member, totaling more than 1,500 feet in thickness, crop out in the bed of the North Fork of the Newaukum River, in the SE¼ sec. 26 and in the NW¼ sec. 35, T. 14 N., R. 1 W. West of the Chehalis River the basaltic sandstone member is thin or absent and is confined to the basal part of the Lincoln formation. Throughout most of the western part of the Centralia-Chehalis district the formation consists largely of tuffaceous siltstone and sandstone.

The base of the basaltic sandstone member of the Lincoln formation is commonly marked by granule sandstone or pebble conglomerate beds, but in some areas the contact with the underlying Skookumchuck formation is gradational. The basal beds of the basaltic sandstone member are fossiliferous in many places and contain borings of marine organisms and an occasional shark tooth. The borings extend below the contact between the basaltic sandstone member and the Skookumchuck formation, carrying basaltic sandstone into the underlying arkosic sandstone.

The conglomerate and granule sandstone at the base of the basaltic sandstone member are rich in pyroclastic debris and contain abundant pebbles of basalt and andesite, and red scoria fragments. Basal strata are rarely bedded; however, in places bedding may be made apparent by lenticular interbeds of pyroclastic material. Pebbles of volcanic rock in the basal conglomerate lenses are usually less than 2 inches in diameter, subangular to subrounded, and poorly sorted. Tuffaceous material forms a matrix in the conglomerate beds in some places and angular pumice fragments as much as 1 inch in diameter are an important constituent of the rock.

The basaltic sandstone member is composed chiefly of fairly well indurated massive fine-grained basaltic sandstone and siltstone. The strata range in color from light greenish gray to medium olive brown, but most of the beds in the member are medium olive gray. Calcareous concretions and nodules occur locally in the member and the fine-grained sandstone beds are commonly cemented by calcium carbonate. The sandstone is composed of volcanic material with lesser amounts of feldspar, quartz, and mica, and represents a distinct change in lithology from the underlying Skookumchuck formation. Some of the detrital material in the beds was derived from the older Skookumchuck formation. The volcanic material includes rounded fragments of basalt and andesite, which were probably derived from the Northcraft formation; and pumice and glass shards of pyroclastic origin.

The basaltic sandstone member is relatively resistant to erosion and forms a more rugged topography than the underlying Skookumchuck formation. Beds of this member typically weather to spheroidal, iron-stained, light- to medium-greenish-gray masses (fig. 11). The calcareous concretions usually break down to a grayish-brown soft and powdery material.

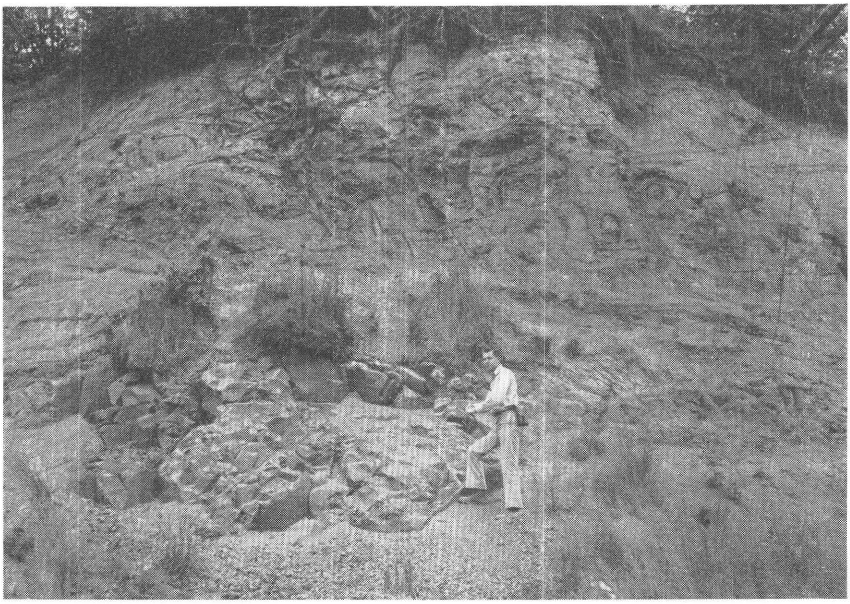

FIGURE 11.—Basaltic sandstone member of the Lincoln formation in railroad cut, about half a mile north of Centralia, Wash. Man is standing on unweathered massive basaltic sandstone which weathers typically to spheroidal masses as shown in upper part of cut.

Microscopic examination of several samples of the basaltic sandstone member indicates that the clastic grains are composed of 40 to 60 percent basalt or andesite, 5 to 25 percent plagioclase (andesine and labradorite), and as much as 10 percent magnetite; the remainder consists of quartz, hornblende, augite, biotite, and red scoriaceous fragments. The fragments of basalt are generally subrounded to rounded, whereas the grains of plagioclase and quartz are subangular to angular. The matrix consists of altered volcanic glass, chlorite, zeolite minerals, and clay.

Waterlaid pumiceous lapilli tuff beds, which range from a few inches to several feet thick, occur at several different stratigraphic horizons in the basaltic sandstone member. The most persistent of these beds is 50 to 100 feet stratigraphically above the base of the basaltic sandstone member. This lapilli tuff bed crops out at several localities in T. 14 N., R. 2 W., and probably throughout most of the township. It may correlate with a lithologically similar lapilli tuff bed that crops out in the northern part of T. 13 N., R. 1 E.; and therefore may occur throughout the southeastern part of the mapped area.

Examination of thin sections of the lapilli tuff shows it to be composed of 90 percent volcanic glass and pumice fragments, with minor amounts of feldspar, augite, hypersthene, magnetite, and fragments of andesite and basalt (fig. 12). The feldspar crystals are fresh and

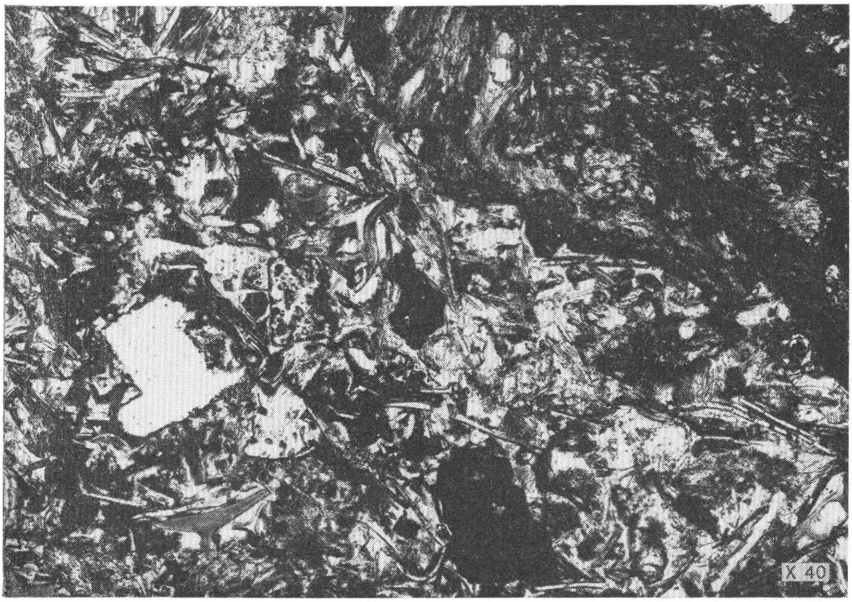

FIGURE 12.—Tuff from basal part of Lincoln formation, in sec. 29, T. 15 N., R. 3 W. Note the large pumice fragment in the upper right corner and the glass shards. Ordinary light, × 40.

vary in shape from sharply angular to somewhat rounded, suggesting that they are, in part, of pyroclastic origin.

TUFFACEOUS SILTSTONE MEMBER

The tuffaceous siltstone member of the Lincoln formation is best exposed in cliffs along the Chehalis River between Galvin and Helsing Junction (fig. 13). Most of the area north of Lincoln Creek and south of the Chehalis River is underlain by beds of the tuffaceous siltstone member.

The tuffaceous siltstone member consists predominantly of fine-grained to very fine grained tuffaceous sandstone and tuffaceous siltstone. The lower part of the tuffaceous siltstone member of the Lincoln formation is not well exposed in the Centralia-Chehalis area. However, a study of these beds was made from cores and cuttings obtained from Geological Survey drill hole *CH*–1, located in the NE¼ sec. 5, T. 15 N., R. 3 W. (pl. 3). The cores and cuttings show that the lower 400 feet of the tuffaceous siltstone member is composed predom-

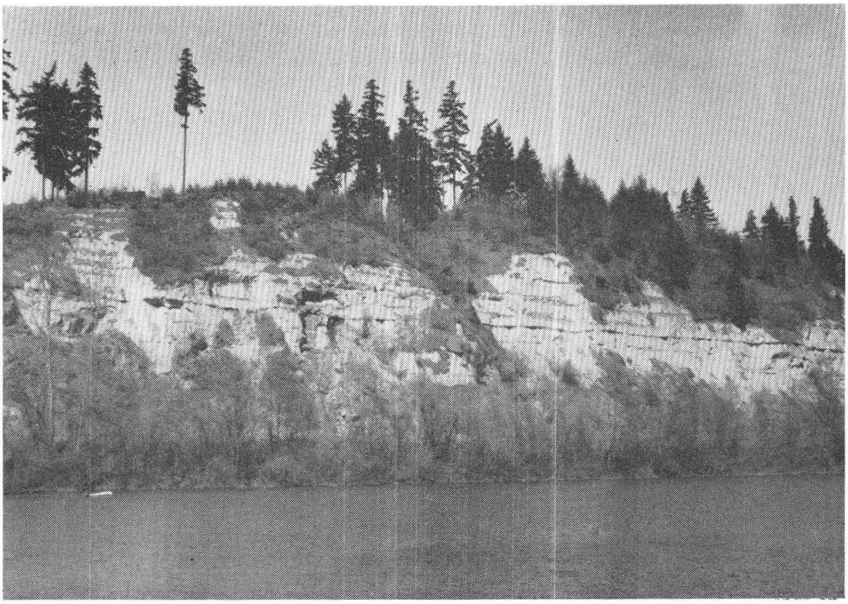

FIGURE 13.—Tuffaceous siltstone member of the Lincoln formation from a point half a mile north of Galvin, Wash. The persistent ledge-forming beds are calcareous siltstone and sandstone. Height of cliff is approximately 125 feet.

inantly of brownish-gray tuffaceous siltstone and sandy siltstone. The strata are generally massive but in places contain thin interbeds of basaltic sandstone which are similar lithologically to beds of the basaltic sandstone member. The siltstone and sandy siltstone strata penetrated in this test hole are fossiliferous.

Microscopic examination of thin sections of the tuffaceous siltstone member of the Lincoln formation has yielded the following average values for detrital constituents: volcanic glass, 34 percent; lithic fragments of basalt and andesite, 26 percent; plagioclase (oligoclase), 25 percent; chloritic material, 6 percent; hornblende, 5 percent; and magnetite, 4 percent. Chemical analyses of two samples from this member are as follows:

Chemical analyses of tuffaceous siltstone from the upper part of the Lincoln formation in the northwestern part of the Centralia-Chehalis district

[Robert N. Eccher, analyst, U. S. Geological Survey]

	1	2		1	2
SiO_2	58.08	59.45	H_2O-	2.84	2.51
Al_2O_3	15.48	15.49	H_2O+	3.78	5.02
Fe_2O_3	5.05	4.29	TiO_2	1.04	.83
FeO	2.52	2.12	CO_2	.07	.10
MgO	2.21	1.83	P_2O_5	.17	.14
CaO	4.09	2.83	MnO	.08	.07
Na_2O	2.33	2.09	C	.40	.92
K_2O	1.67	1.89			
				99.81	99.58

1. Sample from 1500′ E. 500′ S., NW corner sec. 35, T. 14 N., R. 3 W.
2. Sample from 200′ E. 1100′ S., NW corner sec. 7, T. 15 N., R. 3 W.

The tuffaceous siltstone member is relatively resistant to weathering and forms moderately steep slopes or cliffs. When weathered the rock has a mottled light-gray to pale-olive color with irregular iron-stained areas. The calcium carbonate content of the siltstone is leached from the rock in many places to an average depth of 25 feet, even though the rock appears to be impervious.

Composite section of the tuffaceous siltstone member of the Lincoln formation exposed in the cliffs along the Chehalis River from a point half a mile north of Galvin, Wash., to the Prather Road, in secs. 23, 26, and 35, T. 15 N., R. 3 W.

	Thickness	
	Ft	*In*
Sandstone, tuffaceous and basaltic, greenish-gray, fine-grained, massive; upper 10 feet weathered to brownish gray	30	
Siltstone, calcareous and highly tuffaceous, greenish-gray, indurated; forms ledge that persists throughout exposure		8
Siltstone, sandy, tuffaceous and basaltic, greenish-gray, massive; more silty in lower part	38	
Siltstone, calcareous, greenish-gray to olive-gray, indurated		3
Siltstone, sandy, tuffaceous and basaltic, greenish-gray to light-olive-gray, massive	14	
Sandstone, very tuffaceous, silty, light-olive-gray		5
Siltstone, sandy, tuffaceous and basaltic, greenish-gray to light-olive-gray, massive	14	
Siltstone, very calcareous, greenish-gray; forms most pronounced ledge of exposure		10
Sandstone, silty, tuffaceous and basaltic, light-olive-gray, fine-grained, massive	6	
Siltstone, calcareous, light-olive-gray		6
Sandstone, silty, tuffaceous and basaltic, light-olive-gray, fine-grained, massive	8	
Siltstone, calcareous, light-olive-gray to greenish-gray, concretionary		3
Sandstone, silty, tuffaceous and basaltic, light-olive-gray, fine-grained, massive	4	
Tuff, fine-grained, yellowish-gray to light-olive-gray; bed can be traced throughout exposure		2
Sandstone, silty, tuffaceous and basaltic, light-olive-gray, fine-grained, massive	4	6
Siltstone, calcareous, light-olive-gray; forms small ledge		5
Sandstone, silty, tuffaceous, basaltic, light-olive-gray, fine-grained, massive	12	
Siltstone, calcareous, light-olive-gray, concretionary; not a persistent bed		6
Siltstone, sandy, tuffaceous, light-olive-gray, massive	14	
Siltstone, calcareous, light-olive-gray, concretionary		4
Sandstone, tuffaceous, silty, fine-grained, pale-olive, massive	20	
Siltstone, calcareous, light-olive-gray, concretionary		5
Sandstone, tuffaceous, silty, fine-grained, pale-olive, massive	10	

Composite section of the tuffaceous siltstone member of the Lincoln formation exposed in the cliffs along the Chehalis River from a poinnt half a mile north of Galvin, Wash., to the Prather Road, in secs, 23, 26, and 35, T. 15 N., R. 3 W.—Continued

	Thickness Ft	In
Tuff, fine-grained, yellowish-gray		8
Sandstone, tuffaceous, silty, pale-olive, fine-grained, massive	6	
Siltstone, tuffaceous, moderate-brown (iron-oxide stained)		2
Sandstone, tuffaceous, silty, pale-olive, fine-grained, massive	3	6
Tuff, fine-grained, yellowish-gray		2
Sandstone, tuffaceous, silty, pale-olive, fine-grained, massive	4	
Sandstone, calcareous, pale-olive; forms prominent ledge in exposure	1	
Sandstone, tuffaceous, silty, pale-olive, fine-grained, massive	33	
	227	9

FOSSILS AND CORRELATION

Parts of the Lincoln formation contain abundant Foraminifera and larger invertebrate fossils. Studies of the Foraminifera indicate that four tentative faunal zones can be recognized: three are in the tuffaceous siltstone member and one is in the basaltic sandstone member. The tuffaceous siltstone member and the basaltic sandstone member also contain a generally well preserved molluscan fauna. Fossil plants and carbonaceous material are uncommon in the Lincoln formation. Faunal studies indicate that the Lincoln formation ranges in age from latest Eocene to late Oligocene.

Small faunal variations are found vertically within the Lincoln formation; however, lateral variations are particularly pronounced in the lower part of the formation. The basaltic sandstone member of the Lincoln formation contains Foraminifera typical of a sandy near-shore environment. This member is contemporaneous in part with the tuffaceous siltstone member of the Lincoln formation that contains Foraminifera characteristic of a shallow-water off-shore environment.

Foraminiferal zones recognized are listed below from older to younger and a faunal list showing the associated species in each zone is given in the following tables.

Offshore facies	*Nearshore facies*
Sigmomorphina schencki zone	*Cibicides hodgei* zone
Eponides kleinpelli zone	— — — — — ? — — — — —
E. mansfieldi oregonensis zone	

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Foraminifera from the Cibicides hodgei *zone in the basaltic sandstone member of the Lincoln formation (of Weaver) in the Centralia-Chehalis district, Washington*

[Species arranged taxonomically, with frequency of occurrence indicated as follows: V, very abundant; A, abundant; C, common; F, few; R, rare]

Species	Locality number																				
	f11042	f11043	f11044	f11045	f11046	f11047	f11048	f11049	f11050	f11052	f11053	f11054	f11055	f11127	f11125	f11136	f11134	f11132	f11133	f11131	f11135
Ammodiscus sp.			C							F											
Cyclammina pacifica Beck		F	R							C											
Karreriella contorta Beck											C		R								
Quinqueloculina imperalis Hanna and Hanna	C		C	F	C	C	C	F		F	F			F	F	R			R		
Pyrgo sp												R					R				
Cornuspira byramensis Cushman					R	C	R														
Robulus holcombensis Rau	A	C	C	R	F	C	C	C	C	C	C	F	C		C	V				A	V
texanus (Cushman and Applin)				A	C	F	R														
cf. *kincaidi* Beck										R											
sp. D									A						R	R					
Lenticulina washingtonensis Beck	F					R															R
Vaginulinopsis saundersi (Hanna and Hanna)		C	R	R		C	C	C	F	C		R				C	R				F
Dentalina dusenburyi Beck	R		F	F	R	R	C	R	R							R					F
communis (d'Orbigny)			F			R			F							R					F
Pseudoglandulina cf. *conica* (Neugeboren)	R			R	R					R					F	R	F	R			F
Lagena sp. A				R						R					F						R
Guttulina irregularis (d'Orbigny)		C		C			C			F		R							R	R	C
frankei Cushman and Ozawa		R			R		R	R								R				R	
Globulina cf. *landesi* (Hanna and Hanna)			F	R		F	R	F								R					F
Sigmomorphina sp. A	C	C	F	F	R	F	R	F		C	R		R		R	C				R	C
Nonion cf. *applini* Howe and Wallace	F	C										R									
halkyardi Cushman	R							R						C	R		C		C		
Plectofrondicularia packardi Cushman and Schenck				F	F	R										C					F
garzaensis Cushman and Siegfus																					C
Globobulimina cf. *pacific* Cushman	F	C		R						R	R	R	R	C			R			F	F
Valvulineria willapaensis Rau											R										
Eponides yeguaensis Weinzierl and Applin	F	C						R		F				C	A		F			R	
Pseudoparrella sp	C	F		A	C	R	C	R								R			R	C	A
Ceratobulimina washburni Cushman and Schenck		F		R				R	F	C				C	C			R		C	
Cassidulina cf. *globosa* Hantken	C	C	F	R		R	C		C	F				F			R				V
Pullenia salisburyi R. E. and K. C. Stewart									R						F		R				
Globigerina sp				R											R						
Cibicides elmaensis Rau	F	F	F							R				R	R		R		R		
hodgei Cushman and Schenck	C			C	C	C	C	F	F			R		F		C				F	C
haydoni (Cushman and Schenck)				V	A	A	F	C	F		A	R	F	C	C	F	F		F	R	R
lobatulus (Walker and Jacob)		F									R							F			F

Explanation of samples arranged according to locality numbers follows:

Locality No.	*Map reference*	*Depth in well (ft.)*
f11042	Geological Survey drill hole S	51–56
f11043	do	81–86
f11044	do	111–116
f11045	do	141–143
f11046	do	150–156
f11047	do	181–186
f11048	do	211–216
f11049	do	241–246
f11050	do	271–276
f11052	Geological Survey drill hole V	75– 80
f11053	do	116
f11054	Geological Survey drill hole V	125
f11055	do	135
f11127	F–34	
f11125	F–32	
f11136	F–42	
f11134	F–40	
f11132	F–38	
f11133	F–39	
f11131	F–37	
f11135	F–41	

Foraminifera from the tuffaceous siltstone member of the Lincoln formation (of Weaver) in the Centralia-Chehalis district, Washington

[Species arranged to show the highest observed occurrence in the formation, indicated as follows: V, very abundant; A, abundant; C, common; F, few; R, rare. Localities arranged in stratigraphic sequence with youngest on the left]

Species	Frequency of occurrence for indicated zone and locality																																		
	Eponides mansfeldi oregonensis zone				*Eponides kleinpelli* zone										*Sigmomorphina schencki* zone												Localities not used in zonation									
	Locality number																																		
	f11106	f11104	f11105	f11107	f11120	f11119	f11110	f11118	f11117	f11115	f11112	f11116	f11113	f11111	f11062	f11063	f11064	f11065	f11066	f11067	f11068	f11069	f11070	f11071	f11072	f11073	f11123	f11114	f11109	f11121	f11108	f11122	f11130	f11129	f11124	f11128
Robulus sp. G	C	C	F																													F	F			
Eponides mansfeldi oregonensis Cushman, Stewart and Stewart	R			C																										R		R	F			
Bolivina marginata adelaidana Cushman and Kleinpell	C	F	C																													F	F			
Buliminella cf. *bassendorfensis* Cushman and Parker	R																																			
Marginulina sp. B	F																																R			
Nodogenerina? sp	C	C	R																														R			
Marginulina sp. C	F	F	F																																	
Nonion cf. *halkyardi* Cushman	F		R																																	
Cibicides elmaensis var. A Rau	C	C	C	C																																
Cassidulina crassipunctata Cushman and Hobson	C	C		C																																
Gyroidina orbicularis planata Cushman	C	V	A		R				R	F		A	C	C		C		F	C	F	C	V	C	V	V	C	C		C	A	F		A	F	F	A
Robulus cf. *weaveri* Beck	C	F	C		F	F						C				C	A	A	A	F		A	C	C	C	C	R	R			R	C		F	C	C
sp. H		R	R																																	
Pseudoglandulina inflata (Bornemann)		C	R												R							F	R	R			F							F		F
Dentalina adolphina d'Orbigny		R				R																F	F	F	R			R								
Lagina sp. B		R						R															F								R					
sp. C		R																																		
Nonion cf. *applini* Howe and Wallace		R																				R								F						
planatum Cushman and Thomas		F	R	R																														R		
Bulimina sp		R																																		
Quinqueloculina sp		F			F																									R						
Dentalina sp. A		R	F													F			R	R		F	F											R		F
Guttulina irregularis (d'Orbigny)		R							R				R									R	F	F	R	F										

Textularia sp.		R																																		
Nodosaria cf. *longiscata* d'Orbigny		R	R	R																																
Virgulina sp.		R																															R			
Plectofrondicularia sp.			R																																	
Sigmoilina tenuis (Czjzek)					F																															
Epistomina eocenica (Cushman and Hanna)					F	F		A				F			R	A	F		V			A	C	V	F	F	F				F					C
Cassidulina galvinensis Cushman and Frizzell								R	R	F		F	F	C		R		C	A	F	F	R	C	C	C	C			F	C	F	C	F	F	F	
Quinqueloculina imperalis Hanna and Hanna					F	F		F				C	R	C								A	A	A					R							
Cibicides elmaensis Rau					A	C		R	R	F		C	C	F	R	A	C	V	C		F	V	C	V	A	A	F	A	A	C	C	C		R	C	A
Sigmomorphina undulata Rau							R				R	R	R						F	C		R	R													
Cyclammina pacifica Beck							F																F	R	F	F										R
Robulus cf. *texanus* (Cushman and Applin)								F																												
cf. *limbosus hockleyensis* (Cushman and Applin)								F							R	F																R				
Ceratobulimina washburni Cushman and Schenck											R	F	R					F	V	F	F	R	F	C	C	F			R		R					
Eponides kleinpelli Cushman and Frizzell										C	V	V	C	V															R						C	
Guttulina cf. *pacifica* (Cushman and Ozawa)										R	F			R					R																	
Nonion halkyardi Cushman										C			F	C																						
Pyrgo cf. *lupheri* Rau												R										F		R										R		
Valvulineria willapaensis Rau													C	R															F							
Robulus chehalisensis Rau													R			R																				
Anomalina californiensis Cushman and Hobson														F								F	F	F	F											
Lagina sp. D														R											R											
Guttulina problema d'Orbigny														F					R	R			F	F	R											
Pseudopolymorphina? sp.														R																						
Gaudryina alazanensis Cushman																R						V	A	F	R						R				R	R
Dentalina communis d'Orbigny																R							R													
Sigmomorphina schencki Cushman and Ozawa																		F	C	C	R	V	V	C		F					A				R	R
Dentalina cf. *dusenburyi* Beck																		F						C	R	F					F					
Guttulina hantkeni Cushman and Ozawa																		F	R	F		F	F		R	F										
Plectofrondicularia packardi Cushman and Schenck																		R			R	F		F	C	R										F
Bulimina cf. *pyrula* d'Orbigny																		R				R								F		F	R			
Guttulina frankei Cushman and Ozawa																			R						F						R					F
sp.																					R	R	F	F	F	F										
Eponides cf. *duprei* Cushman and Schenck																				R	C	C	C	F	R	R										F
Quinqueloculina weaveri Rau																						R		F											R	R
cf. *ovata* Romer																						R														
Karreriella washingtonensis Rau																						F	C													R
Clavulina? sp.																						F	C	F												
Buliminella sp.																						F														
Bulimina pupoides d'Orbigny																						F														F
Spiroloculina texana Cushman and Ellisor																						R	R	R												
Cornuspira byramensis Cushman																						R	R													F
Bolivina sp.																						R	R													
Allomorphina sp.																						R	F		R											
Robulus cf. *holcombensis* Rau																							R													
texanus (Cushman and Applin)																							R													
Dentalina sp. B																							F	R												

Foraminifera from the tuffaceous siltstone member of the Lincoln formation (of Weaver) in the Centralia-Chehalis district, Washington—Continued

Species	Frequency of occurrence for indicated zone and locality: *Eponides mansfeldi oregonensis* zone				*Eponides kleinpelli* zone										*Sigmomorphina schencki* zone												Localities not used in zonation									
Locality number	f11106	f11104	f11105	f11107	f11120	f11119	f11110	f11118	f11117	f11115	f11112	f11116	f11113	f11111	f11062	f11063	f11064	f11065	f11066	f11067	f11068	f11069	f11070	f11071	f11072	f11073	f11123	f11114	f11109	f11121	f11108	f11122	f11130	f11129	f11124	f11128
Marginulina sp. D	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	R	--	--	--	--	--	--	--	--	--	--	--	--	--
Vaginulinopsis saundersi (Hanna and Hanna)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	F	--	--	--	--	--	--	--	--	--	--	--	--	--
Uvigerina cocoaensis Cushman	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	R	--	--	--	--	--	--	--	--	--	--	--	--	--
Pullenia salisburyi R. E. and K. C. Stewart	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	F	--	--	--	--	--	--	--	--	--	--	--
Gyroidina sp. B	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	R	--	--	--	--	--	C	--	--	--	--	--

Explanation of samples arranged according to locality numbers follows:

Locality No.	*Map reference*	*Depth in well (ft)*
f11106	F-13	
f11104	F-11	
f11105	F-12	
f11107	F-14	
f11120	F-27	
f11119	F-26	
f11110	F-17	
f11118	F-25	
f11117	F-24	
f11115	F-22	
f11112	F-19	
f11116	F-23	
f11113	F-20	
f11111	F-18	
f11062	Geological Survey drill hole Ch-1	63–73
f11063	do	84–89
f11064	do	114–119
f11065	do	145–150
f11066	Geological Survey drill hole Ch-1—continued	218–223
f11067	do	249–254
f11068	do	281–286
f11069	do	323–328
f11070	do	354–359
f11071	do	383–388
f11072	do	415–420
f11073	do	420–436
f11123	F-30	
f11114	F-21	
f11109	F-16	
f11121	F-28	
f11108	F-15	
f11122	F-29	
f11130	F-36	
f11129	F-35	
f11124	F-31	
f11128	F-34A	

The *Cibicides hodgei* zone contains the nearshore assemblages found in the basaltic sandstone member of the Lincoln formation. The following combination of species typify this zone:

Vaginulinopsis saundersi (Hanna and Hanna)
Sigmomorphina sp. A
Valvulineria willapaensis Rau
Cibicides hodgei Cushman and Schenck
C. elmaensis Rau

Cibicides hodgei and *Vaginulinopsis saundersi*, although present in the Skookumchuck formation, are common in this zone. A few species such as *C. elmaensis* and *V. willapaensis* first occur in this zone. *Sigmomorphina* sp. A has not been found in any of the other zones. A few species common in underlying zones, such as *Quinqueloculina goodspeedi* and *Karreriella contorta*, last appear in this zone.

The *Sigmomorphina schencki* zone occupies the lower part of the offshore tuffaceous siltstone member of the Lincoln formation and is in part contemporaneous with the *Cibicides hodgei* zone; but it may not extend as high stratigraphically as does the *C. hodgei* zone. The more significant species occurring in the *Sigmomorphina schencki* zone are as follows:

Gaudryina alazanensis Cushman
Karreriella washingtonensis Rau
Spiroloculina texana Cushman and Ellisor
Cornuspira lewisensis Beck
Vaginulinopsis saundersi (Hanna and Hanna)
Guttulina hantkeni Cushman and Ozawa
Sigmomorphina schencki Cushman and Ozawa
Plectofrondicularia packardi Cushman and Schenck
Uvigerina cocoaensis Cushman
Eponides cf. *duprei* Cushman and Schenck
Ceratobulimina washburni Cushman and Schenck
Cassidulina galvinensis Cushman and Frizzell
Cibicides elmaensis Rau

Sigmomorphina schencki is common throughout most of this zone and is not known to occur above or below it. Both *Cibicides elmaensis* and *Cassidulina galvinensis* first occur in this zone. *Plectofrondicularia packardi* is not recorded above this zone. The first occurrence of *C. elmaensis* and the last occurrence of *Vaginulinopsis saundersi* in both the *S. schencki* and *C. hodgei* zones suggest that these zones are in part contemporaneous.

The *Eponides kleinpelli* zone generally occupies the middle part of the tuffaceous siltstone member of the Lincoln formation. The Foraminifera of this zone are not particularly distinct from those in the overlying and underlying zones, except that *E. kleinpelli* is usually found in substantially greater numbers than in the other zones.

The following species typify the assemblage of the *E. kleinpelli* zone:

Nonion halkyardi Cushman
Gyroidina orbicularis planata Cushman
Eponides kleinpelli Cushman and Frizzell
Cassidulina galvinensis Cushman and Frizzell
Cibicides elmaensis Rau

The *Eponides mansfieldi oregonensis* zone contains a combination of Foraminifera noticeably distinct from that of other parts of the Lincoln formation. The assemblage is characterized by the presence of a few species known from beds of Miocene age in association with species commonly present in beds of Oligocene age. The combination of the following species is particularly characteristic of the *E. mansfieldi oregonensis* zone:

Robulus sp. G
Marginulina sp. C
Buliminella cf. *bassendorfensis* Cushman and Parker
Bolivina marginata adelaidana Cushman and Kleinpell
Cassidulina crassipunctata Cushman and Hobson
Cibicides elmaensis var. A Rau

The Foraminifera of the Lincoln formation correlate with faunas that range in age from latest Eocene to late Oligocene. The foraminiferal assemblages of the *Sigmomorphina schencki* zone and the *Cibicides hodgei* zone of the lower part of the Lincoln formation contain many species identical to those present in the upper Eocene Cowlitz formation (Beck, 1943) and in the Keasey formation and Bastendorf shale of Oregon (Cushman and Schenck, 1928; Detling, 1946). The Keasey formation and the Bastendorf shale are considered to be either latest Eocene or earliest Oligocene in age. Foraminifera collected from siltstone beds in the Willapa River in the NE¼ sec. 36, T. 13 N., R. 8 W. and assigned an age equivalent to the Keasey formation (Rau, 1951, p. 423) also display a characteristic combination of upper Eocene and Oligocene Foraminifera. Foraminifera from the *C. hodgei* zone of the near shore facies also compare with a fauna collected from a drill hole near the Gries Ranch megafossil locality in the SW¼SE¼ sec. 24, T. 11 N., R. 2 W. Weaver (1937, p. 109) and Effinger (1938) correlated the Gries Ranch strata with the lowermost Oligocene. Inasmuch as the foraminiferal assemblages from the lower part of the Lincoln formation of Weaver compare most closely with faunas of the Keasey formation, and as many species are also found in the Cowlitz formation, the assemblage in the lower part of the Lincoln formation is considered to be latest Eocene or earliest Oligocene in age.

A foraminiferal assemblage comparable to that of the *Eponides kleinpelli* zone of the middle part of the tuffaceous siltstone member of the Lincoln formation is found in exposures along State Route 9 in the immediate vicinity of Porter, about 10 miles northwest of the mapped area, and in beds referred to as the "Lincoln equivalent" (Rau, 1951, p. 425) from the valley of Willapa River.

The occurrence of Oligocene forms together with a few forms known from Miocene rocks of other areas indicates that the *Eponides mansfieldi oregonensis* zone is of late Oligocene age. Tuffaceous siltstone and sandstone exposed in road cuts immediately south of Malone along State Route 9, approximately 11 miles northwest of the mapped area, contain a foraminiferal assemblage that is a correlative of the *E. mansfieldi oregonensis* zone. Beds referred to as the "Blakeley (?) equivalent" in the valley of Willapa River by Rau (1951, p. 426) also contains both Oligocene and Miocene species.

Well-preserved invertebrate megafossils are commonly present in the tuffaceous siltstone member of the Lincoln formation. The basaltic sandstone member also contains megafossils but most of them are poorly preserved. Fossils are uncommon in the upper part of the basaltic sandstone member south of the North Fork of the Newaukum River, which suggests that the strata there may be largely of nonmarine origin.

The molluscan fauna collected from the lower part of the basaltic sandstone member was identified by H. E. Vokes, who divided the fauna into two faunal units; a lower one that is closely related to the fauna of the Cowlitz formation, and an upper one that is very similar to the lower faunal zone of the Keasey formation of Oregon (Warren and Norbisrath, 1946, p. 227; Moore and Vokes, 1953, p. 118–120).

Vokes assigned a late (or latest) Eocene age to the molluscan fauna collected from the lower part of the basaltic sandstone member of the Lincoln formation. He further stated that the close relationship of the lower fauna of the basaltic sandstone member to the fauna of the Cowlitz formation seems clearly to indicate that there was no very significant time interval between the close of Skookumchuck (Cowlitz) deposition and the beginning of deposition of the basaltic sandstone here assigned to the Lincoln formation.

The stratigraphic position of the localities containing megafossils in the basaltic sandstone member suggests that the two faunal units established by Vokes do not have stratigraphic significance but reflect differences in ecology rather than time. Megafossils collected at locality M–26 (tables page 52) and assigned to the upper faunal unit by Vokes are from a siltstone interbed in the basaltic sandstone member that rests about 10 to 15 feet stratigraphically above the contact with the underlying Skookumchuck formation. It therefore appears that the megafossils in the fine clastic interbeds of the basaltic sandstone member more closely correlate with faunas of the lower

Megafossils from the basaltic sandstone member of the Lincoln formation (of Weaver) in the Centralia-Chehalis district, Washington

[Identifications by H. E. Vokes]

Species	Lower zone					Upper zone				Species present in lower zone of Keasy formation at type locality
	Locality No. (map reference in parentheses)									
	17405 (M-20)	17398 (M-21)	17963 (M-24)	17961 (M-25)	18485 (M-19)	17394 (M-18)	17401 (M-22)	17395 (M-26)	17411, 17412 (M-23)	
Acila (Truncacila) decisa (Conrad)	×	×								
(Truncacila) nehalemensis (G. D. Hanna)								×		×
"Nuculana" washingtonensis (Weaver) n. subsp.[1]	×	×	?	×		×	×	×		×
Nuculana?					×					
Ostrea sp. indet			×							
Volsella eugenensis (Clark)									aff.	
sp								×		
Thracia dilleri Dall	×	×								
n. sp.[1]						×	×		×	×
Thyasira n. sp. (aff. *T. disjuncta*) [1]						×				×
"Lucina" washingtonensis Turner			×							
Taras sp				×				×		
Pitar clarki (Dickerson)				cf.					×	×
(Lamelliconcha) eocenica (Weaver and Palmer)	×	?								
s. sp		×	×		×			×		
Tellina n. sp									×	×
Spisula sp. indet			×	×						
Solen parallelus (Gabb)		×								
Dentalium stramineum Gabb			×						aff.	
Solariella n. sp			×	×		×		×		×
Homalopoma n. sp		×								
Polinices (Neverita) secta (Gabb)		×								
Sinum obliquum (Gabb)								×		×
Rimella (Ectinochilus) washingtonensis (Clark and Palmer)			×							
Ficopsis cowlitzensis (Weaver) ? n. subsp	×	×		×						
Siphonalia sopenahensis (Weaver)		?								
Bruclarkia n. sp. [1]							×	×		×
Perse washingtoniana (Weaver) ? n. subsp	×	×	?			×		×		
sp					×					
Priscofusus n. sp								×		
Exilia dickersoni (Weaver)								×		
lincolnensis Weaver						×		×		×
Spirotropis sp								×		
"Gemmula" bentsonae Durham						×			×	×
Hemipleurotoma pulchra (Dickerson)	aff.	aff.								
Turricula cowlitzensis (Weaver)	×									
columbiana Dall							×	×	×	×
Scaphander stewarti Durham						×		×	×	×
(Mirascapha) costatus (Gabb)	×	×								
Ringicula? sp								×		
Cylichnina tantilla Anderson and Hanna	×	×								

[1] Moore, R. C., and Vokes, H. E., 1952, U. S. Geol. Survey Prof. Paper 233-E.

faunal zone of the Keasey formation, whereas the megafossils collected from the sandstone beds of the member are more closely related to the near-shore faunas of the Skookumchuck and Cowlitz formations.

Within the mapped area megafossils have not been obtained from the lowermost part of the tuffaceous siltstone member of the Lincoln formation. West of the area, however, strata equivalent to the tuffaceous siltstone member immediately overlying basalt flows of middle Eocene age are exposed in a quarry in the SW¼ sec. 34, T. 17 N., R. 5 W. These strata have yielded well-preserved fossils which have been tentatively correlated by Vokes with the upper part of the Keasey formation of Oregon and with the beds exposed at Gries Ranch fossil locality in southwestern Washington.

Megafossils from the middle part of the tuffaceous siltstone member of the Lincoln formation have been illustrated and described by Weaver (1937), who assigned a middle Oligocene age for the containing rocks. Collections of fossils from this part of the member were made by the authors and were identified by H. E. Vokes (see tables following), who assigned a middle Oligocene age to the fauna.

A molluscan fauna collected from the uppermost exposed part of the tuffaceous siltstone member, in cliffs immediately southeast of Helsing Junction, is referred to as late Oligocene in age by Vokes, who correlates it with the fauna of the type Blakeley formation of Weaver.

Megafossils from the tuffaceous siltstone member of the Lincoln formation (of Weaver) in the Centralia-Chehalis district, Washington

[Identifications by H. E. Vokes]

Species	Locality No. (Map reference in parentheses)							
	18488 (M-32)	17389 (M-30)	17400 (M-34)	17402 (M-27)	18487 (M-31)	18489 (M-33)	18490 (M-35)	18486 (M-29)
Acila (Truncacila) shumardi (Dall)							×	
(Acila) gettysburgensis Reagan								×
Volsella restorationensis (Van Winkle)								×
Nuculana washingtonensis (Weaver)	×	×	×	×			×	
Yoldia chehalisensis (Arnold)	×				×		×	
n. sp. aff. *newcombei* Anderson and Martin							×	
Minormalletia (?) n. sp							×	
Pseudamussium sp							×	
Delectopecten sp							×	
Anadara sp								×
Crenella porterensis Weaver	×	×	×	×		×	×	
washingtonensis Weaver	×							
Crassatella lincolnensis (Weaver)	×							
Venericardia sp. indet			×					
"*Lucina*" *acutilineata* Conrad	×							
Loxocardium lincolnensis (Weaver)	×	×					×	
Nemocardium lorenzanum (Arnold)	×	×			×		×	
Macrocallista pittsburgensis (Dall)	×							
Pitar dalli (Weaver)	×	×	×	×			×	
Tellina lincolnensis Weaver	×	×			×		cf.	
Solen lincolnensis Weaver	×					×		
Solena eugenensis (Clark)	×							
Dentalium porterensis Weaver	×	×						
Natica (Tectonatica) weaveri Tegland	×			aff.				
Polinices (Polinices) washingtonensis (Weaver)	×					×		
(Polinices) washingtonensis lincolnensis (Weaver)	×						×	
Turritella porterensis (Weaver)	×	×•		×				
cf. *blakeleyensis* Weaver								×
Echinophoria fax (Tegland)	×							
Olequahia lincolnensis (Weaver)	×							
Siphonalia washingtonensis (Weaver)	×						×	
Molopophorus lincolnensis Weaver	×							
Perse lincolnensis (Van Winkle)	×			×	×		×	
Priscofusus chehalisensis (Weaver)	×	×	×	×			×	
stewarti (Tegland)								×
Exilia lincolnensis Weaver	×	×					×	
sp								×
"*Suavodrillia*" *thurstonensis* (Weaver)	×							
Spirotropis kincaidi (Weaver)	×			×	aff.		×	
Turricula aff. *washingtonensis* Weaver							×	
worcesteri (Van Winkle)	×							
Scaphander washingtonensis Weaver							×	

MIOCENE SERIES

ASTORIA(?) FORMATION

GENERAL FEATURES

A sequence of continental and marine beds of conglomerate, sandstone, and siltstone unconformably overlies the Lincoln formation in three widely separated areas in the Centralia-Chehalis district. These sedimentary rocks are tentatively correlated with the Astoria formation of Oregon on the basis of their contained fauna, their stratigraphic position, and their lithologic characteristics.

Condon (Cope, 1880) originally applied the name "Astoria shales" to the beds of Oligocene and Miocene age that are exposed in and near the town of Astoria, Oreg. It has been the practice among most recent workers to restrict the Astoria formation to those beds of middle Miocene age that occur below or interfinger with the Columbia River basalt. In accordance with this usage, Etherington (1931) mapped and described the Astoria formation in Grays Harbor, Lewis, and Thurston Counties, Wash.; and Weaver (1937) mapped beds west of Chehalis that he assigned to the Astoria formation. Parts of the areas mapped by these two workers are included in this report. The Astoria formation, as described and mapped by Etherington and Weaver, is accepted with reservation by the authors, as beds of middle Miocene age in the Centralia-Chehalis area cannot be traced, without interruption, into the type section of the Astoria formation of Oregon. The Astoria(?) formation of this report, therefore, may not occupy a stratigraphic position identical to that of the Astoria formation of Oregon.

The two largest areas of outcrop of the Astoria(?) formation occur along the Centralia syncline in the northwestern part of the mapped area, and along the Chehalis syncline in the southwestern part. The Astoria(?) formation is also exposed in small isolated outcrops along the North Fork of the Newaukum River in sec. 35, T. 14 N., R. 1 W. The beds exposed in the North Fork of the Newaukum River were described by Snavely, Roberts, Hoover, and Pease (1951) as "basaltic conglomerate" of Miocene(?) age. These beds consist largely of material derived from the Northcraft formation and were probably laid down in the same narrow basin of deposition as were the sandstone beds of the Astoria(?) formation in the Chehalis syncline to the west.

Folding and faulting probably preceded deposition of the Astoria(?) formation throughout the Centralia-Chehalis district, as along the margins of its basins of deposition, the Astoria(?) formation in places nearly overlaps the Lincoln formation. However, away from structurally positive areas, as in the Centralia syncline, the Astoria(?) formation disconformably overlies the Lincoln formation.

LITHOLOGIC COMPOSITION

The Astoria(?) formation is typically exposed in cliffs south of the Chehalis River from Independence to a point about half a mile to the east and consists of a lower unit of friable medium-grained tuffaceous fossiliferous sandstone with a few siltstone lenses, and an upper unit of fine-grained arkosic sandstone with numerous fragments of siltstone and pebbles of mottled quartzite. Megafossils and plant fragments are commonly found in both units. When fresh, the rock is bluish gray but weathers to olive-buff. Microscopic studies of several sand samples from the Astoria(?) formation in the Centralia syncline show that the sand is composed of lithic fragments, plagioclase, and quartz, with lesser amounts of hornblende, glass, chlorite, biotite, muscovite, magnetite, augite, garnet, topaz, and apatite. Heavy minerals are much more abundant in the sandstone of the Astoria(?) formation than in the older rocks. The lithic fragments are volcanic rock debris with some altered volcanic glass. These volcanic constituents probably represent material derived from the underlying Lincoln formation. The mineral grains are generally angular to subangular and the lithic fragments are usually subrounded.

The formation where exposed in the Chehalis syncline is composed predominantly of massive or crossbedded friable medium-grained sandstone. Angular to subangular grains of feldspar and quartz, and subrounded lithic fragments of volcanic origin are the most important detrital components. The beds in the Chehalis syncline are mineralogically very similar to those exposed in the Centralia syncline to the north. Crossbedded sandstone in the Chehalis syncline contains thin irregular zones of intraformational breccia in some places, scour-and-fill channels, and other shallow-water depositional features. Zones of granule sand, and sporadic pebbles, which are commonly quartzite, are found throughout much of the sandy part of the formation. Typical exposures of sandstone of the Astoria(?) formation are present in road cuts north of Ceres, in sec. 14, T. 13 N., R. 4 W., along the Military Road north of Claquato, in W½ sec. 25, T. 14 N., R. 3 W., and in the Bunker quarry on the Chehalis-Raymond highway in sec. 7, T. 13 N., R. 3 W.

The conglomeratic parts of the Astoria(?) formation are composed predominantly of volcanic material in the east and of metamorphic rock types in the west. Although thin conglomerate zones occur in the sandstone of the Astoria(?) formation in the western part of the mapped area, the maximum known thickness is along the North Fork of the Newaukum River in sec. 35, T. 14 N., R. 1 W. In this area about 500 feet of pebble and cobble conglomerate is interbedded with coarse- to medium-grained basaltic and arkosic sandstone. The pebbles and cobbles are composed chiefly of black porphyritic basalt with a few cobbles of agate and vein quartz. Petrographic studies of a few of the cobbles from the conglomerate indicate that a part of the material was derived from the Northcraft formation, which is exposed to the east.

Fossil wood and plants are commonly found throughout the Astoria(?) formation but occur in greatest abundance in the basaltic conglomerate and sandstone beds exposed along the North Fork of the Newaukum River, in the southeastern part of the mapped area. Here, limbs of trees as much as 10 feet in length and stumps as large as 3 feet in diameter are interbedded with sedimentary rocks (fig. 14).

FIGURE 14.—Fossil wood interbedded with conglomerate and sandstone of the Astoria(?) formation, in stream bed of the North Fork of the Newaukum River, NW¼ sec. 35, T. 14 N., R. 1 W. Pick is resting on limb that lies parallel to strike of beds. Large dark-colored stump, near center of picture, is inclined parallel to dip.

The larger fragments of wood are not carbonized and, although distorted, retain most of their primary wood structure. At the Bunker quarry, in the SE¼ sec. 7, T. 13 N., R. 3 W., wood imbedded in the Astoria(?) formation at the contact with overlying basalt flows has been burned. The finely divided plant material and small fragments of wood that are commonly found in the fine-grained clastic rocks of the formation are generally carbonized.

FOSSILS AND CORRELATION

Identifiable invertebrate fossils were found in the Astoria(?) formation only in the Centralia syncline and suggest a correlation with the fauna of the middle Miocene Astoria formation of Oregon. Fossil plant material from the Astoria (?) formation also indicates a middle Miocene age for these beds.

Two collections of megafossils from the Astoria (?) formation were made in the western part of the Centralia syncline. The following mollusks were identified and assigned a Miocene Astoria age by H. E. Vokes:

Fossil locality: *M*–36 (pl. 1):
- *Acila (Truncacila) conradi* (Meek)
- *Nuculana chehalisensis* (Weaver)
- *Mytilus watersi* Etherington
- ? *Pitar oregonensis* (Conrad)
- "*Marcia*" *angustifrons* (Conrad)

Fossil locality: *M*–37 (pl. 1):
- *Acila (Truncacila) conradi* (Meek)
- "*Marcia*" ? sp. indet.
- *Crepidula praerupta* Conrad
- *Calyptraea inornata* (Gabb)

Fossils were collected from the Astoria (?) formation east of Independence (pl. 1, *M*-36) by Etherington (1931, p. 54–56), who assigned a middle Miocene age to the containing rocks and considered them to be equivalent in age to the type section of the Astoria formation at Astoria, Oreg.; the Miocene strata exposed at Yaquina Bay, Oreg.; and the Temblor formation of California.

In the southeastern part of the mapped area, along the stream bed of the North Fork of the Newaukum River, in the NW¼ sec. 35, T. 14 N., R. 1 W. (pl. 1, fossil locality *P*–3), abundant well-preserved limbs and trunks of fossil trees are interbedded in the sandstone and conglomerate of the Astoria (?) formation. A species of *Abies* (fir) from this locality was identified by Roland W. Brown who comments:

> Foliage, cone scale, and seeds of firs are common in Oligocene and Miocene deposits of the Northwestern States. In this instance, considering the degree of preservation of the wood and accompanying circumstances, I consider a Miocene age quite probable.

Abundant well-preserved fossil logs as much as 40 feet in length have been uncovered at the base of the basalt flows in the Bunker quarry, SE¼ sec. 7, T. 13 N., R. 3 W. (fossil locality *P*–2). Brown identified *Sequoia affinis* Lesquereux and a species of *Thuja* from this locality. Concerning the *Thuja* species, he states:

> This wood appears to be a species of *Thuja* (western red cedar). Foliage called *Thuites* sp. has been identified from correlative strata near Spokane, Wash., thus confirming the presence of a red cedar in the flora of Washington during the middle Miocene time.

COLUMBIA RIVER(?) BASALT

GENERAL FEATURES

In the southwestern part of the Centralia-Chehalis area, a dark-gray aphanitic basalt flow rests unconformably upon sedimentary rocks of the Astoria(?) and Lincoln formations and is overlain by beds ranging in age from late Miocene to Recent. A few erosional remnants of this flow are present south of Independence, in the northwestern part of the area.

The name "Columbia River lava" was proposed by I. C. Russell (1893, p. 20–22) for extensive basalt lava flows that cover parts of Washington, Oregon, Idaho, and northern California. The basalts of Russell included several geologic ages, and later workers have restricted the name Columbia River basalt to include only that basalt which is of Miocene age.

In northwestern Oregon and southwestern Washington, along the lower gorge of the Columbia River, basalt assigned to or correlated with the Columbia River basalt has been mapped by Weaver (1937), Treasher (1942), Warren and Norbisrath (1946), and Wilkinson, Lowry, and Baldwin (1946). Reconnaissance studies south of the Centralia-Chehalis area to the Columbia River indicate that the basalt flow that overlies the Astoria(?) formation in the mapped area is a correlative of, and may have been continuous with, the flows mapped as Columbia River basalt along the lower gorge of the Columbia River.

The Columbia River(?) basalt in the Centralia-Chehalis area has a rather uniform thickness of between 70 and 80 feet throughout most of its outcrop area and a maximum thickness of about 100 feet. The basalt, however, thins rapidly toward areas that were topographically high in pre-Miocene time.

The Columbia River(?) basalt, one of the most resistant rock types in the area, when unweathered forms cliffs and steep slopes. Most of the area underlain by the basalt is characterized by a reddish-brown lateritic soil. The leaching of the ferromagnesian minerals produces a light-gray porous rind, ¼ to ½ inch thick on weathered surfaces. In this rind the relict textures of the basalt are visible with the aid of a lens.

The Columbia River(?) basalt is known to crop out only in the western part of the Centralia-Chehalis area, where it is exposed along the Chehalis syncline and near the axis of the Centralia syncline. Most of the area in the vicinity of Crego Hill is underlain by the Columbia River(?) basalt, which dips northward and eastward into the Chehalis syncline. The basalt is much more extensive south of the Chehalis syncline than north of it. The most easterly known extent of the basalt is in a water well in the NW¼ sec. 21, T. 13 N.,

R. 2 W. Fifty-four feet of basalt was found in this well at a depth of 522 feet. As the Columbia River(?) basalt maintains a fairly uniform thickness throughout most of the southwestern part of the Centralia-Chehalis district, it probably extended at least as far east as the central part of the Napavine syncline. The greater areal extent of basalt in the extreme southern part of the mapped area is probably due to the fact that the source of the flows was to the south. Two small erosional outliers of Columbia River(?) basalt are found in the northwestern part of the Centralia syncline, in sec. 24, T. 15 N., R. 4 W., and in sec. 19, T. 15 N., R. 3 W. The Columbia River(?) basalt probably was not continuous across the Lincoln Creek uplift

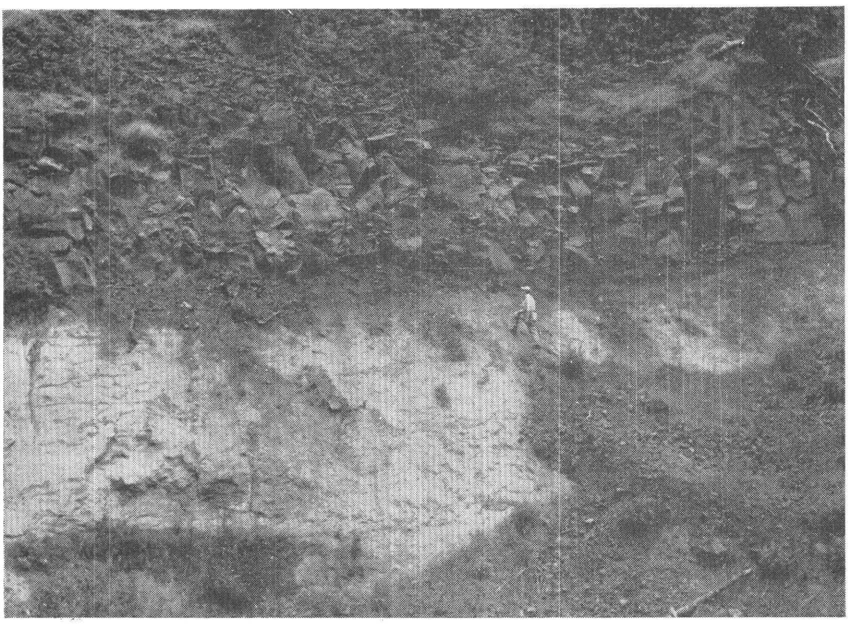

FIGURE 15.—Columnar-jointed Columbia River(?) basalt overlying sandstone of the Astoria(?) formation at the Bunker quarry, in the SE¼ sec. 7, T. 13 N., R. 3 W.

which separates the two known areas of outcrop. However, the basalt that crops out in the Chehalis syncline and in the Centralia syncline may have been continuous west of the mapped area and part of the same flow.

The Columbia River(?) basalt usually has well-developed short prismatic, rosette, and columnar types of jointing. Along Stearns Creek, in sec. 24, T. 13 N., R. 3 W., and in the Bunker quarry, SE¼ sec. 7, T. 13 N., R. 3 W., vertical columnar joint blocks frequently are 10 to 15 feet in length and 1 to 2 feet in diameter (fig. 15). Vesicular zones occur at both upper and lower flow contacts of the basalt, and vesicles are common throughout the entire flow. Occasionally the larger vesicles are lined with a thin coating of white material and rarely contain a liquid. Vesicularity is generally pronounced at the upper part of the basalt, but in most areas erosion has removed this part of the flow. No evidence of more than one flow of Columbia River(?) basalt has been found within the area mapped.

LITHOLOGIC COMPOSITION

In hand samples the Columbia River(?) basalt is usually dark gray and aphanitic, and breaks with a conchoidal fracture. In some specimens a very fine-grained porphyritic texture may be seen with

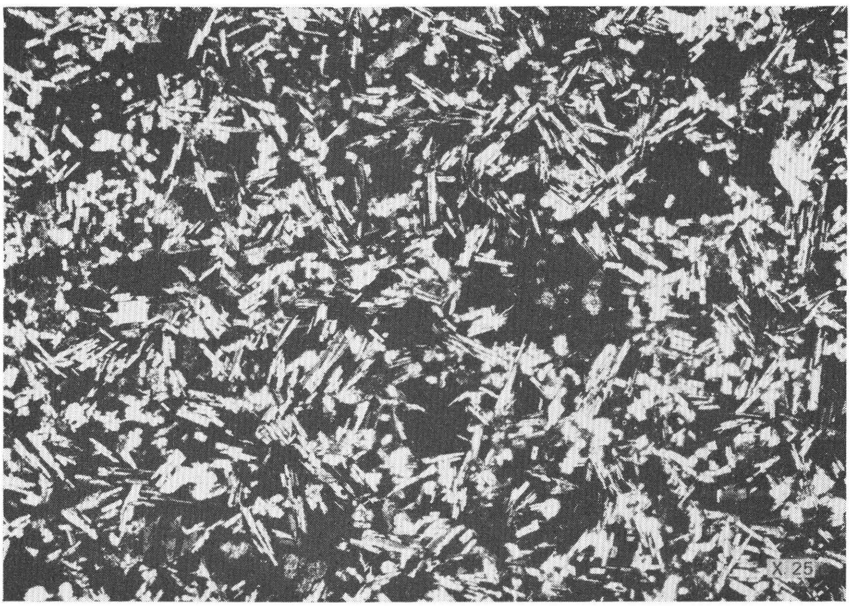

FIGURE 16.—Columbia River(?) basalt from Bunker quarry, in the SE¼ sec. 7, T. 13 N., R. 3 W. Light-colored rectangular phenocrysts are labradorite and large dark areas are glass with disseminated dust of magnetite. Ordinary light, × 25.

the aid of a hand lens. Petrographic studies of the basalt show it is hemicrystalline, with intersertal, vesicular, and, less commonly, porphyritic textures. The basalt is composed of plagioclase feldspar, augite, magnetite, volcanic glass, and chloritic minerals (fig. 16). Plagioclase comprises approximately 55 percent of the rock and is alkalic labradorite, which is usually unaltered. The feldspar crystals, which are seldom longer than 1 millimeter, generally are euhedral and show well-developed albite twinning. The augite crystals constitute 15 to 25 percent of the basalt and range from euhedral to subhedral and are very uniform in size and distribution.

The groundmass is composed of magnetite, volcanic glass, chlorite minerals and palagonite. Magnetite occurs as dust or as a late magmatic crystallization product, forming branching aggregates of minute octahedrons in the interstitial glass. The volcanic glass comprises 15 to 30 percent of the samples studied and is in places altered to palagonitic material. Crystallites and perlitic cracks are in some unaltered samples. The ferromagnesian minerals show a small amount of alteration to chloritic minerals.

MIOCENE AND PLIOCENE(?) SERIES

GENERAL FEATURES

An unnamed sequence of fluvial, lacustrine, and brackish-water deposits consisting of as much as 1,000 feet of semiconsolidated siltstone, sandstone, conglomerate, and tuff overlies the Columbia River(?) basalt and older formations in the southern part of the Centralia-Chehalis area. This rock sequence is usually covered by Quaternary deposits, and exposures are rarely found. Previous workers, therefore, did not differentitate the nonmarine sedimentary rocks from other Tertiary formations. The nonmarine sedimentary rocks are better exposed in the vicinity of Toledo, about 8 miles south of the mapped area, and they will be named and described from these exposures in a later report. Stratigraphic position and paleobotanic evidence indicate that these sedimentary rocks range in age from middle to late Miocene, and possibly to Pliocene.

The nonmarine sedimentary rocks are restricted chiefly to the broad synclines in the southern part of the mapped area. The basin of deposition of these rocks was shallow, and downwarping probably kept pace with sedimentation, permitting the accumulation of a thick sequence of rocks. In some places the nonmarine sedimentary rocks overlap the Astoria(?) formation and the Columbia River(?) basalt to rest with angular unconformity upon beds of the Lincoln formation.

In the southwestern part of the mapped area, the nonmarine sedimentary rocks form a relatively restricted belt that extends along the valley of the Chehalis River from the west edge of the area eastward to the vicinity of Littell. They underlie most of the south-central part of the mapped area, extending from Stearns Creek eastward almost to the head of the valley of the North Fork of the Newaukum River; and from the south side of Salzer Creek in the NE$\frac{1}{4}$ sec. 35, T. 14 N., R. 2 W. to and beyond the south edge of the described area. Nonmarine sedimentary rocks are probably present along the base of many of the low hills which border the valley of the Newaukum River, but most of these areas are masked by colluvium from the overlying Logan Hill formation and cannot be mapped.

LITHOLOGIC COMPOSITION

The nonmarine sedimentary rocks consist of massive semiconsolidated siltstone and sandstone with intercalated beds of conglomerate and waterlaid tuff. Beds of partly carbonized wood, as much as 4 feet thick, occur within this unit. Blue-gray and blue-green silty sandstone and siltstone comprise most of the nonmarine sedimentary rocks that are exposed in the valleys of the Newaukum River and its North Fork in the south-central part of the mapped area. However, subsurface data in the Newaukum River valley indicate conglomerate and sandstone beds are present at depth in the nonmarine unit. In the southwestern part of the area, along the Chehalis River and in the hills west of Bunker Creek the nonmarine sedimentary rocks consist chiefly of massive conglomerate beds and thin-bedded sandstone, with only minor amounts of interbedded siltstone and tuff.

Unctuous medium-bluish-gray and medium-blue-green semiconsolidated siltstone, claystone, and silty sandstone are the predominant rocks in the nonmarine unit. When weathered the rocks are an iron-stained mottled yellowish-orange to reddish-orange color. Thin irregular zones rich in iron oxide are commonly found along the base of the siltstone and claystone beds. Siltstone beds are usually sandy and contain mica and tuffaceous and carbonaceous material. These finer clastic rocks are massive, but bedding occasionally is made apparent by thin sandstone beds or by the concentration of fossil plant fragments (fig. 17). Limbs, twigs, and fragments of partly carbon-

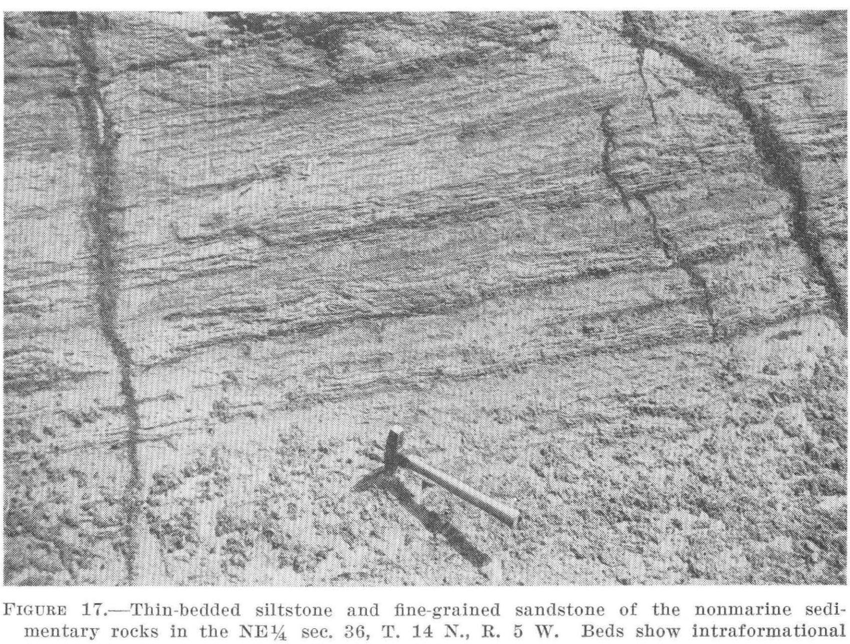

FIGURE 17.—Thin-bedded siltstone and fine-grained sandstone of the nonmarine sedimentary rocks in the NE¼ sec. 36, T. 14 N., R. 5 W. Beds show intraformational deformation due to slumping prior to consolidation.

ized wood are often found in the finer clastic rocks. Olive-green tuffaceous siltstone and claystone with interbedded basaltic and tuffaceous sandstone crop out along the stream bed of the North Fork of the Newaukum River. The green color of these rocks probably results from the alteration of volcanic debris.

Beds 6 inches to 25 feet thick of fine- to coarse-grained arkosic and basaltic tuffaceous sandstone and waterlaid tuff are interbedded with the finer clastic rocks. Beds of medium-grained tuffaceous sandstone are well exposed along a logging road west of Bunker Creek, in sec. 35, T. 14 N., R. 4 W. Poorly sorted pebbly sandstone interbeds contain wood fragments in many places. The pebbles consist of rounded to subangular volcanic rocks with chalcedony and other lithic fragments. Bluish-gray thin-bedded micaceous, feldspathic sandstone, commonly interbedded with dark-brown carbonaceous siltstone, is poorly exposed along the valley of the Chehalis River, west of Bunker quarry. These beds closely resemble those of similar facies in the Skookumchuck formation and are well exposed immediately west of the mapped area in the bed of the Chehalis River between Doty and Rainbow Falls.

Microscopic examination of samples obtained from outcrops and from water wells drilled in the valley of the Newaukum River indicates that the nonmarine sedimentary rocks are composed chiefly of subangular to subrounded lithic fragments (basalt or volcanic glass), feldspar, quartz, and mica. Lithic fragments and feldspar are most abundant but the ratio between these constituents is variable. Heavy minerals make up 5 to 10 percent of the rock and consist of green and brown hornblende, magnetite, hypersthene, and augite. Biotite, garnet, and chlorite are less common constituents.

Conglomerate beds of the nonmarine sedimentary rocks consist chiefly of subrounded to subangular pebbles and cobbles of porphyritic basalt and andesite, with lesser amounts of other rock fragments. The material in the conglomerate strata ranges from ¼ inch to 8 inches in diameter, but most of the fragments are less than 4 inches in diameter. The conglomerate is usually poorly sorted and has a matrix of medium-grained friable basaltic sand. Bedding is usually absent or poorly developed in the conglomerate strata but in a few places is shown by the presence of sandstone lenses. In the western part of the area mapped, along Bunker Creek in sec. 26, T. 14 N., R. 4 W., the nonmarine sedimentary rocks contain basal conglomerate composed of material reworked from the underlying Lincoln formation. This basal conglomerate is composed of subangular to angular fragments of siltstone and sandstone in a matrix of sandy siltstone. Conglomerate strata are exposed along a logging road west of Bunker Creek, in sec. 35, T. 14 N., R. 4 W. At this locality, which is several hundred feet stratigraphically above the basal conglomerate zone, the predominant rock types in the conglomerate are porphyritic basalt and andesite; acid volcanic rock types compose about 5 percent of the pebbles, and subangular blocks (as much as 3 feet in diameter) of sedimentary rocks occur in places in the conglomerate. A thin basaltic conglomerate was observed overlying the Columbia River(?) basalt immediately west of the area. This conglomerate is composed principally of pebbles and cobbles of scoriaceous basalt in a matrix of coarse-grained basaltic sandstone.

Section of the nonmarine sedimentary rocks exposed along logging road in NE¼, NE¼, sec. 35, T. 14 N., R. 4 W., Centralia-Chehalis district

	Thickness	
	Ft	*In*
Top of unit not exposed.		
Sandstone and siltstone, light-yellowish-gray, thin-bedded	6	
Sandstone and siltstone, mottled, light-gray and medium-gray, massive; abundant mica flakes and macerated plant material along bedding planes	3	
Sandstone, light- to medium-gray, thin-bedded, fine-grained; somewhat silty and carbonaceous	1	6
Sandstone, medium-gray, well-compacted, massive, carbonaceous	0	6
Siltstone and sandstone, medium-brownish-gray, micaceous, carbonaceous	1	
Siltstone, dark-brownish-gray, finely micaceous, carbonaceous; with 4 in. bed of compressed lignitized wood and lignite at top	4	
Siltstone, dark-brownish-gray, highly carbonaceous; thickness variable	0	2
Claystone, medium-dark-gray, semiconsolidated, silty; with partly altered lithic fragments	1	8
Tuff, light-gray, fine-grained, waterlaid, somewhat bentonitic(?)	3	
Siltstone and mudstone, dark-yellowish-orange, iron-stained, tuffaceous; contains imprints of fossil plants	14	
Tuff, coarse, light-gray to light-bluish-gray, massive to crossbedded, waterlaid; becomes finer grained toward top; iron stained at base	6	
Sandstone, medium-grained, poorly sorted, tuffaceous; tuff lenses up to 6 in. thick	20	
Covered	72	
Sandstone, moderate-yellowish-brown, poorly sorted, medium-grained, slightly micaceous	3	
Siltstone, light-olive-gray, tuffaceous, clayey, sandy	4	6
Sandstone, light-gray, silty, iron-stained; contains thin siltstone interbeds; poorly exposed in upper part; abundant imprints of fossil plants 1 ft. above base	10	
Sandstone, moderate-yellowish-brown, semiconsolidated, fine- to medium-grained, crossbedded; contains thin pebble conglomerate lenses	22	
Conglomerate, pebble to cobble, porphyritic basalt rock types with few acid volcanic rock types and quartzite; contains angular blocks of siltstone up to 7 in. in diameter	10	
Sandstone, light-yellowish-gray, moderately indurated, pebbly, medium- to coarse-grained, iron-stained; contains lenticular zones of pebbles and thin clay partings	7	

Section of the nonmarine sedimentary rocks exposed along logging road in NE¼, NE¼, sec. 35, T. 14 N., R. 4 W., Centralia-Chehalis district—Continued

	Thickness Ft	In
Conglomerate, pebble and cobble, chiefly porphyritic basalt rock types with a few acid volcanic rock types and quartzite, semiconsolidated, poorly sorted; medium-grained friable sandstone matrix; contains subangular blocks, as much as 3 ft in diameter, of medium-gray, medium-grained tuffaceous sandstone in upper part	28	
	217	4

FOSSILS AND CORRELATION

Fossil plants occur abundantly in the nonmarine sedimentary rocks, but in most cases the material is unidentifiable because of carbonization or prolonged rotting. However, fossil wood from sandstone and conglomerate in the west bank of Bunker Creek, in the NE¼ sec. 35, T. 14 N., R. 4 W. (pl. 1, fossil locality *P*–1), was identified by Roland W. Brown as *Taxodium* sp. (bald cypress), and he assigned a middle to late Miocene age to the containing strata. Mr. Brown stated that the wood is very similar to the wood of the widespread Miocene species, *T. dubium* (Sternberg) Heer, which occurs abundantly in the Mascall and Latah formations of Oregon and Washington. Imprints of fossil leaves occurring in strata of silty tuffaceous sandstone were collected from a locality in the NE¼ sec. 35, T. 14 N., R. 4 W. (fossil locality *P*–1*a*) and were examined by Mr. Brown, who identified the following species:

Alnus relatus (Knowlton) Brown
Betula fairi Knowlton
Acer bendirei Lesquereux

Concerning the age of this material Mr. Brown stated:

> From the small number of species I can identify, this collection seems to represent a Latah flora and, therefore, to be middle to late Miocene in age. * * *

Approximately 4 miles west of the mapped area, in the NE¼ sec. 36, T. 14 N., R. 5 W., a small collection of fossil plant material was taken from carbonaceous sandstone that is a part of the nonmarine sedimentary rocks of this report. Mr. Brown assigned a probable middle to late Miocene age to this material and made the following identifications:

Metasequoia occidentalis (Newberry) Chaney
Sequoia affinis Lesquereux
Salix sp.
Fragments of other dicotyledonous leaves

On the basis of stratigraphic position and paleobotanic evidence, the lower part of the nonmarine sedimentary rocks is assigned a late middle or late Miocene age. Fossil material from the upper part of the sequence consists of unidentifiable wood and horsetail tubers that are not diagnostic of age. As a thick section of strata, without an apparent erosional break, is present above the beds from which plants of late Miocene age were obtained, a Pliocene age is suggested for the upper part of the nonmarine rock sequence.

Strata which are equivalent to the nonmarine sedimentary rocks crop out south of the mapped area and are well exposed along the Cowlitz River east of Toledo, Wash. These rocks, which contain well-preserved fossil plants that have been assigned a Miocene age by Roland Brown, will be named and described in a forthcoming geologic report on the Toutle and Olequa quadrangles by A. E. Roberts.

West of the mapped area, in the vicinity of Grays Harbor, Weaver (1937, p. 187–191) described several thousand feet of rocks consisting predominantly of sandstone with interbedded sandy carbonaceous shale and conglomerate beds. These rocks, which overlie the Astoria formation, were named the Montesano formation by Weaver, who assigned to them a late Miocene to middle Pliocene age on the basis of their contained marine invertebrate fauna and fossil plants. LaMotte (1936, p. 348) identified 14 species of fossil plants collected from the Montesano formation of Weaver in the vicinity of Aberdeen, Wash.; he stated that these species have close affinities to the flora of the Mascall formation of eastern Oregon. Therefore, a correlation based upon stratigraphic position and paleobotanic evidence is suggested between the nonmarine sedimentary rocks and a part of the Montesano formation.

About 12 miles east of the mapped area a sequence of nonmarine tuffaceous claystone, siltstone, sandstone, conglomerate, tuff, and beds of partly carbonized wood is well exposed along the valley of the Nisqually River from La Grande (sec. 32, T. 16 N., R. 4 E.) downstream to sec. 1, T. 16 N., R. 2 E. J. E. Sceva, who called this section to the writer's attention, collected fossil plants from siltstone strata in the upper part of the sequence. These plants were identified by Roland W. Brown, who assigned an early Pliocene age to them. Strata exposed along the Nisqually River have a marked lithologic resemblance to the nonmarine sedimentary rocks in the Centralia-Chehalis area and are correlated with them. Strata correlative to the nonmarine sedimentary rocks in the mapped area, therefore, probably occur beneath the Pleistocene deposits in many places in the southern Puget Sound basin.

In the vicinity of Portland, Oreg., semiconsolidated sedimentary rocks, which are lithologically similar to the nonmarine sedimentary rocks, overlie the Columbia River basalt and have been considered a part of the Troutdale formation by Piper (1942, p. 23), Treasher (1942, map), and Wilkinson, Lowry, and Baldwin (1946, p. 28). The log of the Ladd well (Piper, 1942, p. 132) in the Portland area shows that approximately 895 feet of poorly consolidated fine-grained sedimentary rocks with interbedded conglomerate beds and fossil plants are present above what is presumed to be Columbia River basalt. Similar strata overlying the Columbia River basalt have been penetrated in drill holes west of Portland in the eastern part of the Tualatin Valley (Donald A. Hart, oral communication). On the basis of lithologic similarity and stratigraphic position, the nonmarine sedimentary rocks of the Centralia-Chehalis district are correlated with strata assigned to the Troutdale formation in the vicinity of Portland, Oreg.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

The western slopes of the Cascade Range and the Puget Sound trough underwent extensive and repeated glaciation during the Pleistocene epoch. Russell first called attention to two till sheets and interglacial sediments in the Puget Sound region, but his work was never published. Later, Willis (1898) described the glacial history of Puget Sound and named two glacial stages, Admiralty and Vashon, and the Puyallup interglacial stage. Bretz (1913) described the glacial deposits in the Puget Sound region and made many valuable observations relative to the origin of these deposits.

Geologic mapping in the Centralia-Chehalis area has revealed the presence of till, outwash, and glaciofluvial material deposited by both continental and alpine glaciers. Generally, the glacial deposits from these two distinct sources can be easily recognized by their rock types, depth of weathering and oxidation, and their general altitude and topographic expression.

LOGAN HILL FORMATION

GENERAL FEATURES

The name Logan Hill formation was proposed by Snavely, Roberts, Hoover, and Pease (1951) for partly consolidated, weathered, and iron-stained gravel and sand which form flat-topped upland surfaces throughout much of the Centralia-Chehalis district. These gravel deposits at one time probably covered all but the structurally high areas within the area mapped.

Snavely, Roberts, Hoover, and Pease (1951) referred to the gravel of the Logan Hill formation as fluvial deposits of early Pleistocene age. The glaciofluvial origin of these deposits could not be demonstrated until the Logan Hill formation was mapped south of the Middle Fork of the Newaukum River, where deposits that are believed to be till are interbedded with the Logan Hill formation. The presence of till in deposits equivalent to the Logan Hill formation in areas immediately east of the mapped area has been studied by Erdmann (1951) and Mundorff (1952) and supports a glaciofluvial origin for the Logan Hill formation.

The initial surface of the Logan Hill formation has an altitude of about 1,000 feet in the eastern part of the area and decreases uniformly westward to an altitude of about 400 feet between Stearns Creek and the Newaukum River, and to an altitude of about 350 feet in the northwestern part of the area, on Michigan Hill. The gravel is found at altitudes as high as 700 feet along the east side of Crego Hill and as high as 600 feet along the southern flank of the Lincoln Creek uplift. As the source for most of the Logan Hill gravel was to the east, the apparent rise of the initial surface of these deposits in the southwestern part of the area may be the result of post-depositional deformation. However, there is a possibility that the gravel at a higher elevation in the vicinity of Crego Hill may have been derived from the highland areas west of the mapped area.

Benches, ranging in altitude from 20 to 320 feet above the valley, are found throughout the area underlain by the Logan Hill formation. The lower benches are erosional terraces cut by the present streams, along which the upper weathered part of the formation has been removed. As the gravel on the higher benches is deeply weathered, these benches may be the result of terracing by lateral planation of the streams that deposited the gravel of Logan Hill formation. In places, the Logan Hill formation has been entirely removed by erosion and the cut surface at the base of the formation has been exhumed. The low tablelike area just southeast of Rochester represents such a a surface.

The authors believe that the gravel of the Logan Hill formation represents outwash debris from alpine glaciers in the highland areas immediately east of the mapped area and in the western Cascade Range. The outwash carried by the melt waters of these glaciers formed extensive piedmont alluvial fans throughout much of the Centralia-Chehalis district. The presence of local glaciers in the Puget Sound basin during the early Pleistocene has been pointed out by Newcomb (1952, p. 15) in his ground water studies of Snohomish County, Wash. In referring to the origin of the till deposits of Admiralty age, he states:

> * * * a local-ice theory of glaciation would fit more reasonably the conditions under which the considerable thicknesses of clay and silt that marked Admiralty time were deposited.

The Logan Hill formation was deposited on an old land surface of mature relief, drowning or beveling the preexisting topography. Truncation of the underlying bedrock is apparent from exposures along the south bank of the Chehalis River between Grand Mound and Helsing Junction. The average thickness of the formation is 75 to 100 feet; however, in areas where old channels have been filled, the thickness may exceed 200 feet. Typical exposures of this formation are found in road cuts and canyons on Logan Hill, which is the type area. Particularly good exposures of these deposits are found along an old logging road that runs northeast from Onalaska, in secs. 20 and 21, T. 13 N., R. 1 E. A new road cut just south of Chehalis in the NW¼ sec. 8, T. 13 N., R. 2 W., affords an excellent opportunity to study about 100 feet of this formation.

LITHOLOGIC COMPOSITION

The Logan Hill formation is composed largely of reddish- to yellowish-brown, iron-stained gravel and minor amounts of interbedded sand and silty clay. The gravel consists chiefly of pebbles and cobbles of porphyritic volcanic rocks in a silty clay matrix. Most of the volcanic rocks are derived from the Northcraft formation. Pebbles and cobbles of metamorphic and igneous rocks, agate, chalcedony, and petrified wood are present locally. The metamorphic rocks are generally found near the base of the formation, which suggests that they represent material reworked from conglomerates of Miocene age. The gravel is usually massive or crossbedded and constituents are well-rounded and well-sorted. Many of the pebbles are flattened and a few are faceted and grooved, suggesting abrasion by ice. There is a general decrease in the size of the gravel westward from the eastern part of the mapped area. In the western part of the area, as on Michigan Hill, the Logan Hill formation contains a higher percentage of sand and silt than is found in the eastern part of the area.

The sand of the Logan Hill formation contains a high percentage of material eroded from the underlying Tertiary formations. In several areas, as in the vicinity of Tono, it is difficult to differentiate the sand of this formation from the underlying sandstone of the Skookumchuck formation. The sand of the Logan Hill formation is usually poorly sorted, massive to crossbedded, medium to coarse grained, and in places it interfingers with gravel deposits. Scour-and-fill channels are numerous. The grains are iron stained and consist of rock fragments, quartz, feldspar, biotite, mafic minerals, magnetite, and muscovite, in order of decreasing abundance. Many of the rock fragments and mafic minerals are chloritized and the feldspar is kaolinized. The quartz and feldspar grains are angular to subangular, whereas the rock fragments are generally more rounded.

The clay is usually silty and bentonitic (?) and contains fragmental plant material and irregular zones rich in iron oxide. The clay commonly is slickensided, which may be the result of a postdepositional increase in volume resulting from the alteration of the original volcanic ash to bentonitic(?) clay. The contacts between the clay and the coarser grained sediments are usually sharp, but at places clay grades laterally into silty sand.

The upper part of the Logan Hill formation has been weathered to a depth of 25 to 50 feet. The surface outcrops of gravel are decomposed to the degree that the gravel can be cut with a knife (fig. 18). A thin film of manganese oxide covers the surface of many of the pebbles in the weathered zone; the film outlines the shape of the

FIGURE 18.—Decomposed gravel in the upper part of the Logan Hill formation, in the NW¼ sec. 8, T. 13 N., R. 2 W. The cobbles consist predominantly of porphyritic volcanic rocks which are decomposed to a degree that they can be cut with a knife.

pebbles in freshly cut sections. Many of the volcanic rocks are entirely leached to light-gray kaolinitic(?) material. The feldspar phenocrysts in these rocks are also altered to kaolin, and the ferromagnesian minerals are oxidized to reddish-brown ferruginous products. Below the initial surface the pebbles are less weathered, usually having a weathered iron-stained soft porous rind that becomes thinner with depth. The gravel is relatively fresh 50 to 75 feet below the initial surface; however, oxidation often stains the gravel to this depth. Some of the gravel in the lower part of the formation is used for road rock. The weathered upper part of the formation in places forms moderately steep slopes as it contains sufficient clay derived from weathering of the volcanic rocks to partly consolidate the gravel.

Along stream courses there are many landslides in the Logan Hill formation.

Deposits of till are interbedded with the Logan Hill formation in the south-central part of the area. Approximately 75 feet of till and weathered gravel is exposed along a road cut just south of the Middle Fork of the Newaukum River, in sec. 28, T. 13 N., R. 1 W. The till is a light- to medium-gray massive compact mixture of boulders, cobbles, and pebbles that are composed chiefly of subangular to subrounded porphyritic volcanic rocks and set in an iron-stained sandy clay matrix. A few cobbles of vein quartz, metamorphic rocks, and sedimentary rocks were found. Rinds of light-gray kaolinitic(?) material are on some of the boulders and cobbles; other boulders and cobbles are unaltered. They range in size from less than 1 inch to 16 inches, averaging about 4 to 6 inches in diameter. A few of the cobbles are highly polished, have 2 to 4 facets, and are striated and grooved. The till grades laterally into gritty sand and massive compact iron-stained fairly nonplastic silty clay that shows slickensides.

AGE AND CORRELATION

Correlations between the Logan Hill formation and other lower Pleistocene deposits of similar origin can be only tentative. However, as the valley glaciers of the western Cascade Range probably reached their maximum extent at about the same time, it seems justifiable to correlate the outwash deposits from these glaciers.

The Logan Hill formation is widespread in areas adjacent to the Centralia-Chehalis district. This formation has been mapped about 10 miles south of the type area, in parts of the Olequa and Toutle quadrangles by Roberts. The gravel is composed chiefly of porphyritic volcanic rocks similar to those found in the Centralia-Chehalis area. Lowry and Baldwin (1952, p. 17) suggest that the gravel immediately south of the mapped area is similar to the Troutdale formation of Oregon, which was assigned an early Pliocene age by Chaney (1944). They assign a Pliocene(?) age to the gravel that crops out in sec. 1, T. 12 N., R. 3 W. and to similar gravel exposed immediately to the east of this locality. These gravel deposits can be traced northward into the lower Pleistocene Logan Hill formation of this report. Therefore, the authors believe that the Troutdale formation includes a sequence of rocks that range in age from at least early Pliocene to early Pleistocene and that the Logan Hill formation is equivalent to the upper part (early Pleistocene) of the Troutdale formation as mapped by Lowry and Baldwin.

Erdmann and Bateman (1951, p. 48–52) described deposits of weathered and iron-stained gravel between the Cowlitz River below the mouth of the Tilton River and U. S. Highway 99 and referred to these deposits as "Ancient drift(?)." Erdman tentatively considered the "Ancient drift(?)" to be outwash gravel and till related to an early Pleistocene ice advance, possibly Nebraskan or Kansan. A reconnaissance map, which includes a part of the Centralia-Chehalis district, accompanies his report and shows the known outcrops of "Ancient drift(?)." These outcrops in the Centralia-Chehalis district are a part of the Logan Hill formation in this report.

Gravel deposits that are believed to be equivalent in age to the Logan Hill formation are discontinuously exposed in cuts along the valley of the Chehalis River westward from the mapped area to Satsop, Wash. The red gravel in the vicinity of Satsop and westward to Grays Harbor were named Satsop formation and described by Bretz (1913, p. 39–43), who states:

> The conclusion seems probable that these red gravels [Satsop] are Pleistocene stream deposits in the Pliocene or early Pleistocene Chehalis Valley, and on a Pliocene or early Pleistocene wave-cut coastal shelf.

He concluded:

> Their decay and staining are somewhat greater than that of known Admiralty gravels in the Puget Sound basin, and with one exception no granite or other rock has been found in them by which they could be identified with Puget Sound glaciation.

As the Satsop gravel deposits contain rock types similar to those found in the Logan Hill formation, as well as rock types probably derived from the Olympic Mountains, it is possible that the gravel deposits along the Chehalis River between Satsop and Grays Harbor represent a mixture of glaciofluvial material from both the Olympic Mountains and the western Cascade Range, and that the Satsop and the Logan Hill formations are contemporaneous.

Immediately north and east of the Centralia-Chehalis area, in the Ohop Valley quadrangle, Mundorff, Weigle and Holmberg (1955) mapped decomposed gravels of the Logan Hill formation as far east as the valley of the Nisqually River and on the upland surface north of Alder, Wash. Mundorff states that north of Alder the gravels appear to be interbedded with glacial till.

TERRACE DEPOSITS

GENERAL FEATURES

Unconsolidated gravel and sand of glaciofluvial origin form an extensive terrace along the Newaukum River and its South Fork from the vicinity of Chehalis to the eastern margin of the area. The terrace has been modified by erosion and in places is so highly dissected that it cannot be mapped separately from the alluvium. The surface of the terrace rises from an altitude of about 200 feet in the vicinity of Chehalis to more than 700 feet near the eastern edge of the mapped area, along the South Fork of the Newaukum River. In general, the dip of the deposits is parallel to the present gradient of the Newaukum River and its South Fork. North of Chehalis the only expression of the Newaukum River terrace is about 1 mile west of Centralia, on the west side of the Chehalis River. Here the altitude of the surface of the terrace is about 180 feet. The terrace deposits have a maximum exposed thickness of 30 to 35 feet, but well logs indicate that the deposits are more than 50 feet thick.

The large volume of glaciofluvial material deposited along the valley of the Newaukum River raised the base level of the smaller tributary streams, causing them to deposit fluvial debris near their mouths and to alluviate their valleys. The largest tributary, the North Fork of the Newaukum River, has removed most of the glaciofluvial material deposited near its mouth, but the smaller tributaries, such as Dillenbaugh and Berwick Creeks, still have a thin veneer of iron-stained silt, sand, and gravel on their flat valley floors.

LITHOLOGIC COMPOSITION

The pebbles and cobbles in the terrace deposits are usually hard and have a very thin weathered or iron-stained rind. The few cobbles that are partially or completely decayed were probably derived from the Logan Hill formation. The terrace gravel near Onalaska and along the South Fork of the Newaukum River appears to consist chiefly of outwash deposits and contains poorly stratified rounded to subrounded pebbles and cobbles in a sand matrix. The gravel is closely packed and the cobbles and boulders usually are coated with a thin film of rock flour. Rounded boulders as much as 2 feet in diameter are found sporadically in the cobble gravel. The rock types consist largely of prophyritic andesite and basalt derived from the Northcraft formation, but a few cobbles are of middle Eocene sedimentary rocks, Cascade andesite(?), and weathered volcanic rocks reworked from the Logan Hill formation.

Down river from Onalaska the terrace is composed of a higher percentage of locally derived material of fluvial origin. Sandy silt and weathered gravel derived from the Logan Hill formation and debris from Tertiary sedimentary rocks form a large percentage of the deposits.

AGE AND CORRELATION

The Newaukum terrace is believed to have a glaciofluvial origin and to represent a mixture of alpine outwash and locally derived fluvial material. The large volume of glaciofluvial material that once partially filled the entire valley of the Newaukum River was probably transported by melt waters from alpine graciers down either the Cowlitz River or its tributary, the Tilton River.

No till was found in the terrace deposits, although immediately east and south of the area mapped, Erdmann (1951, p. 63) described small masses of till interbedded with outwash gravel equivalent to those in the Newaukum River terrace. As the outwash gravel deposits are slightly more weathered than the latest drift in the Puget Sound area, Erdmann tentatively considered them to be of earliest Wisconsin or Iowan age.

The terrace deposits along the Newaukum River are assigned a late Pleistocene age; however, the dissected character of the surface of the terrace suggests that glaciofluvial deposits may be somewhat older than the Vashon drift.

VASHON DRIFT

GENERAL FEATURES

The Puget Sound lobe of the late Pleistocene continental Vashon glacier extended southward into the northern part of the Centralia-Chehalis district. Till and outwash derived from this ice sheet are widespread throughout the northern part of the mapped area, reaching as far south as Centralia. At the time of maximum glaciation, the southern margin of the ice sheet extended from the Black Hills eastward across Rochester, Mound, and Rock Prairies, thence north to Tenino. The southernmost exposure of till is found just south of Violet Prairie, in the SE$\frac{1}{4}$ sec. 34, T. 16 N., R. 2 W. The glacier rode up to a maximum altitude of about 1,100 feet along the volcanic highland area that extends from Tenino to the eastern margin of the mapped area. Ice tongues of the Vashon glacier probably extended down Johnson Creek and the lower canyon of the Skookumchuck River.

Large volumes of melt water from the wasting Puget Sound lobe of the Vashon glacier flowed generally southward and westward across the northern part of the mapped area, reaching the Pacific Ocean by way of the lower Chehalis River. The melt waters followed three main drainage routes which roughly correspond with the present courses of the Skookumchuck River, Scatter Creek, and the Black River. The Skookumchuck River drainage channel received the discharge of Mulqueen Gap and Johnson Creek which were the southern outlets for the melt water in the present Deschutes River area. The large quantities of outwash gravel deposited along the length of the drainage channels dammed the mouths of the tributary valleys. Lakes and swamps formed behind the gravel dams, and paludal and lacustrine deposits were laid down in these impounded areas. Hanaford and Zenkner valleys are good examples of tributaries that were blocked by outwash debris, and excellent exposures of outwash material in the dams are found in gravel pits at the mouths of these valleys. The largest of these outwash-impounded areas existed south of Centralia and is referred to as "Glacial Lake Chehalis" by Bretz (1913, p. 120–121).

Drainage diversions, due to blocking by glacial ice and damming by outwash debris, have affected the development of the present topography; many examples of each were found during the course of the field work.

However, it is beyond the scope of this report to give a comprehensive discussion of the physiographic history of the area. The reader is referred to Bretz (1913) for a detailed discussion of the late Pleistocene history of the area.

DEPOSITS OF TILL

Vashon till is restricted to the northern part of the mapped area where it was deposited as a sheet at the base of the ice. It is best exposed in road cuts in the low hills west and north of Tenino and north of Vale, where it mantles the bedrock. Generally the till is not very thick, probably less than 50 feet; however, a greater thickness is found where the till was deposited in topographic depressions.

The till consists of a light-bluish-gray compacted mixture of material that ranges in size from clay to boulders 8 to 10 feet in diameter. The matrix predominates and is composed of well-compacted and tough clay and silt, and poorly sorted silty sand. The boulders and cobbles are subangular to subrounded and are usually composed of metamorphic and igneous rock types foreign to the area, and of various types of volcanic rock. Till consisting predominantly of subangular boulders of light-brownish-gray gabbro porphyry with a maximum diameter of 6 feet and subrounded cobbles of basalt and andesite are found in morainal deposits along the Skookumchuck River east of Stony Point School, in the S½ sec. 12 and the NE¼ sec. 13, T. 15 N., R. 1 W., and in an isolated exposure in the canyon of the Skookumchuck River one-half mile west of Fall Creek, in the NW¼ sec. 16, T. 15 N., R. 1 E. Studies of thin sections of several of the gabbro porphyry boulders indicate that the boulders are identical mineralogically to the gabbro porphyry in a sill exposed along the Skookumchuck River in the northern part of sec. 14, T. 15 N., R. 1 E. The cobbles of volcanic rocks are similar to the basalt and andesite of the Northcraft formation.

The accumulation, near Stony Point School, of till containing local rock types may also be explained by the presence of alpine glaciation in the foothills of the Cascade Range during late Pleistocene time. If a Pleistocene valley glacier extended as far west as the lower gorge of the Skookumchuck River; the till in the vicinity of Stony Point School may represent a terminal moraine of this glacier. The writers believe that small ice fields were present in the hills immediately adjacent to the eastern border of the mapped area during late Pleistocene time, but sufficient field work has not been done to establish the existence of large valley glaciers.

DEPOSITS OF OUTWASH

Outwash sand and gravel of Vashon valley trains form the broad prairies in the northern part of the mapped area. Terraces of outwash gravel, modified in recent erosion, are present along the margins of Johnson Creek and in the valleys of Skookumchuck and Chehalis Rivers. The surface of the outwash prairies is close to that of the initial surface of deposition, and commonly several well-defined terrace levels descend in steps to the altitude of the youngest outwash

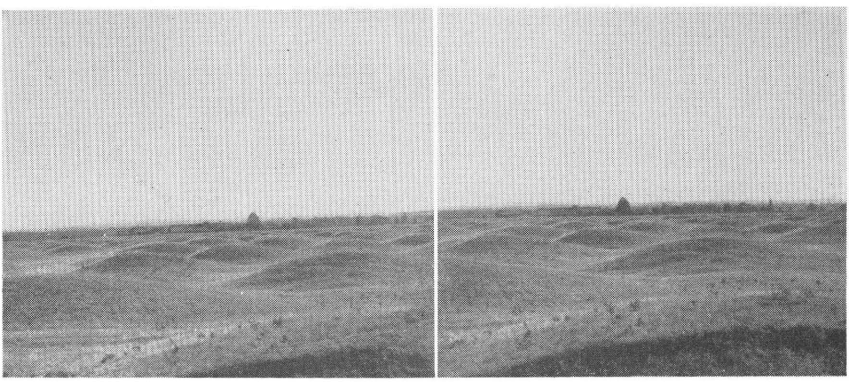

FIGURE 19.—Stereoscopic pair showing typical mounded prairies on the Vashon drift from a point about 1 mile north of Mima, Wash. Height of individual mounds ranges from about 3 to 4 feet.

channels. Kettle topography is local and many of the outwash prairies in the northwestern part of the area are mounded (fig. 19). A thin veneer of black pebbly silty soil, 1 to 3 feet thick, overlies the outwash material. Newcomb (1952) ascribes the formation of the mounds to a glacial or periglacial origin, and to the result of combined water and ice-wedging action in permafrost. In most places the surface of the outwash deposits is crossed by many small intermittent streams that follow the course of former outwash channels. Present drainage systems on the outwash prairies are poorly developed because the high porosity and permeability of the gravels permit internal drainage.

In general, the outwash gravels are composed of various types of igneous and metamorphic rocks foreign to the area. These deposits show little evidence of weathering. The outwash material ranges in size from fine sand to boulders several feet in diameter; cobbles and pebbles are the most common. The deposits are massive to well-bedded, and cross bedding and foreset bedding are found in many places. The sand varies from poorly sorted to well-sorted and usually contains pebbles. The gravel deposits form steep slopes, although little cementation is apparent (fig. 20).

Deposits of Vashon outwash gravels that contain large quantities of material derived from the Northcraft formation are found in terraces around the bases of Blumaer Hill and Crawford Mountain and along the north and west margins of the hills south of Mound Prairie. These terrace deposits are 50 to 150 feet above the adjacent outwash

FIGURE 20.—Outwash gravel and sand of the Vashon drift exposed in a pit along the railroad, in NW¼ sec. 7, T. 16 N., R. 1 E.

prairies and may represent deposition by streams that flowed along the margins of the ice sheet where it rested against the bedrock hills. The material deposited by these marginal drainages was derived from nearby volcanic highlands and from outwash of the Vashon glacier. Other deposits of outwash composed of a high percentage of locally derived material occur in the valley of the Skookumchuck River east of Frost Prairie. This material was transported by the melt waters of the ice tongue that occupied the gorge of the Skookumchuck River. The outwash gravels that contain locally derived material, although contemporaneous with the Vashon outwash deposits, are more weathered as they contain a higher percentage of volcanic rocks.

PLEISTOCENE AND RECENT DEPOSITS

LANDSLIDE DEBRIS

Landslides and other forms of mass wasting that have occurred in Recent and possibly late Pleistocene time are found throughout the Centralia-Chehalis area but are most common in areas underlain by fine-grained sedimentary rocks and along the principal stream courses. High seasonal rainfall combined with rapid runoff results in accelerated erosion of the generally poorly consolidated Tertiary and Quaternary rocks, frequently producing oversteepened and undercut slopes. Subsequent failures along these slopes by landsliding and soil creep modifies the topography and contributes large volumes of debris to the drainage systems. Landslides commonly cover the valley areas with debris and mask and distort the true structure of the bedrock. The landslide basins vary in shape from elliptical or arcuate to irregular. Recent landslide areas are characterized by hummocky topography, irregular drainage systems and ponds; in many places they are bordered on the upslope contact with bedrock by a distinct, and nearly continuous, break-away scarp. With increasing age, such basins tend to develop a concave shape and have a dendritic drainage pattern.

Landslides are particularly common along the axial parts of the Lincoln Creek uplift, where siltstone of the Skookumchuck formation is the predominant rock type. In this area most of the valleys are filled with landslide debris and undisturbed rock is found only along the ridge tops and along those creeks that have cut below the landslide material.

The most extensive area of landslides is south of Chehalis, along the margins of the valley of the Newaukum River and its tributary valleys. In this part of the mapped area semiconsolidated siltstone and mudstone of the nonmarine sedimentary rocks are overlain by gravel of the Logan Hill formation. Physical conditions are particularly favorable for the development of landslides along the contact between these formations. Ground water moving along the contact saturates the fine-grained clastics, causing them to become semifluid. This contact, lubricated by the unctuous material, acts as a gliding surface along which the overlying Logan Hill formation moves valleyward by sliding.

Landslide materials, debris from Tertiary and Quaternary rocks, range in size from small particles to blocks that are expressed topographically and cover several acres. Most of the landslide debris consists of a matrix of unctuous yellow to brown clay with scattered blocks of locally derived rock types. Frequently, the landslide debris is so completely altered by weathering that the parent rock cannot be determined.

Landslides within the mapped area are largely of Recent age; however, Vashon outwash deposits apparently overlie landslide debris along the Skookumchuck River, about 1 mile west of Bucoda. The large volume of melt water from Pleistocene glaciers cut new channels in the Tertiary rocks and deepened and undercut the preexisting drainage. These steep-sided valleys were later modified by landslides during both Pleistocene and Recent times.

ALLUVIUM

Alluvial deposits of Recent and Pleistocene(?) ages occur along the stream courses and on the flood plains of the larger streams and rivers of the Centralia-Chehalis area. The deposits are composed chiefly of silt and sand, with some gravel, and are unconsolidated to partly consolidated. The alluvial deposits mapped in the Centralia-Chehalis area include several stages of valley filling and contain material deposited under changing environmental conditions. Most of the alluvium consists of fluvial clastic material deposited along river courses and flood plains; however, in some areas, paludal and lacustrine deposits are included. In the northern part of the mapped area it is often difficult to delineate the contact between Vashon glacial outwash and the reworked outwash gravel and sand along the stream courses.

Alluvium along the present course of the Chehalis River includes, in addition to flood-plain deposits, several stages of terrace deposits. Most of these terraces, however, are 5 to 10 feet above the present river level and are so closely related to the present river gradient that no attempt has been made to map them separately. Similar low-level terraces have been noted in the valleys of the Skookumchuck River and the Middle and North Forks of the Newaukum River, where they have also been mapped with alluvium.

The composition of the alluvium is not the same for all places as it is dependent in part upon the local source rocks from which it was derived. The alluvium along the Skookumchuck and Chehalis Rivers contains quantities of gravel derived from Vashon drift, whereas the gravels along the North and South Forks of the Newaukum River consist of basaltic rocks derived from the Northcraft formation.

In the northern part of the area the larger tributary valleys of the Skookumchuck and Chehalis Rivers contain paludal and lacustrine deposits consisting of silt, clay, and thin peat beds. These deposits which range in age from late Pleistocene to Recent, were laid down in shallow lakes and swamps formed during the late Pleistocene.

INTRUSIVE ROCKS

Intrusive igneous rocks are not common in the Centralia-Chehalis area, but dikes and sills have been mapped in several places. The intrusive rocks consist of gabbro porphyry and porphyritic basalt which intrude sedimentary and volcanic rocks of Eocene and Oligocene age. Feeder dikes and sills within the volcanic flows have not been differentiated on the map. The largest and most continuous igneous bodies are sills, which have a maximum thickness of about 500 feet. Intrusive activity was apparently more pronounced in the eastern part of the area mapped, as good exposures of igneous rocks are found near the top of Miller Hill, in sec. 10, T. 15 N., R. 1 E.; at the Columbia quarry, in sec. 11, T. 15 N., R. 1 E.; along the canyon of Bear Creek, in the SW¼ sec. 25, T. 14 N., R. 1 W.; and in cuts along logging roads north of Alpha Prairie, in sec. 11, T. 13 N., R. 1 E.

Thick intrusive bodies have been penetrated in two deep test holes; the Bannse 1, in the NW¼ sec. 22, T. 15 N., R. 2 W.; and the Wulz 1, in the NE¼ sec. 29, T. 13 N., R. 1 W. (pl. 4).

PORPHYRITIC BASALT

Sills and dikes of porphyritic basalt crop out between the North and South Forks of the Newaukum River, in T. 13 N., Rs. 1 W., and 1 E. Intrusive bodies of this rock type are best exposed in the vicinity of Bear Creek and in the hills northeast of Alpha Prairie (secs. 2 and 11) where they form a large sill, generally less than 50 feet thick. This sill has intruded, probably at shallow depth, strata of the Skookumchuck and Lincoln formations.

In several places the sill might be mistaken for a flow because of the texture of the basalt and the almost conformable relationship with sedimentary beds. However, along the canyon of Bear Creek exposures of the upper part of the sill show that the sandstone near the upper contact has been hydrothermally altered and intruded by small apophyses. Farther south, however, in sec. 11, T. 13 N., R. 1 E., the contact of the basalt with the sedimentary rocks is not exposed and the possibility exists that a part of the basalt in that area may be of extrusive origin.

In hand samples the basalt is dark greenish gray, with a porphyritic and vesicular texture. Many of the vesicles are filled with zeolites and chlorite. Rectangular phenocrysts of plagioclase and rounded phenocrysts of augite are visible megascopically. The rock usually weathers spheroïdally to moderate-reddish-brown masses. In places near the upper contact of the sill, the rock is intensely weathered and the ferromagnesian minerals break down to form light-bluish-gray patches set in a light-gray groundmass of kaolinized feldspar.

Microscopic studies show that this rock is holocrystalline, with porphyritic, diabasic, vesicular and, less commonly, trachytic textures. The feldspar ranges in composition from andesine (An_{64}) to labradorite (An_{54}). Plagioclase phenocrysts and laths in the groundmass form 60 to 65 percent of the rock. The phenocrysts of labradorite are faintly zoned. Augite, which is present in all the thin sections studied as phenocrysts and granules in the groundmass, forms 5 to 20 percent of the rock; it is commonly altered to chlorite, biotite, and magnetite. Olivine phenocrysts are present in a few of the rock sections, forming as much as 10 percent of the rock; they are commonly altered to chlorite and serpentine. Magnetite is a constituent of the groundmass, forming an average of 5 percent of the rock; hypersthene and ilmenite are also present. Hydrothermal alteration has developed abundant secondary minerals which form as much as 20 percent of some samples; biotite, chlorite, zeolites, calcite, and hematite are the most common.

Porphyritic basalt similar to that described above was found at 2,270 feet in the Wulz test hole 1 of the Selburn-Washington Oil Co. The basalt body in the Wulz drill hole is about 600 feet thick and occurs in the upper part of the Skookumchuck formation (pl. 4). The basalt in this drill hole is mineralogically similar to the intrusive rocks in the vicinity of Alpha Prairie and Bear Creek but contains as much as 35 percent glass.

GABBRO PORPHYRY

Intrusive bodies of gabbro porphyry are chiefly found in the northeastern part of the mapped area. These rocks occur as sills or sill-like bodies and are more coarsely crystalline than the porphyritic basalt. The gabbro porphyry bodies have a maximum thickness of about 500 feet and they intrude rocks of the McIntosh, Northcraft, and Skookumchuck formations. Gabbro porphyry intrusives can best be studied and sampled at the Columbia quarry and along the gorge of the Skookumchuck River in the SW¼ sec. 11, T. 15 N., R. 1 E. (fig. 21). A gabbro porphyry mineralogically similar to that exposed in the Columbia quarry was found at a depth of about 4,200 feet in the Union Oil Co. Bannse test hole 1, in the NW¼ sec. 22, T. 15 N., R. 2 W.

In fresh exposures the gabbro porphyry is massively jointed, medium gray, medium grained, and has granular and porphyritic textures. Phenocrysts of feldspar and augite are visible without the aid of a lens. In several outcrops veinlets of aplite cut the rock. The rock commonly weathers to spheroidal masses and the ferromagnesian minerals break down to reddish-brown masses set in a groundmass of light-gray altered feldspar.

Studies of thin sections indicate that the rock is holocrystalline with porphyritic and less commonly diabasic and trachytic textures (fig. 22). Plagioclase An_{50} to An_{60} (labradorite) occurs as pheno-

FIGURE 21.—Jointed gabbro porphyry sill exposed in the west end of the Columbia quarry, in SW¼ sec. 11, T. 15 N., R. 1 E. View southwest down a part of the valley of the Skookumchuck River.

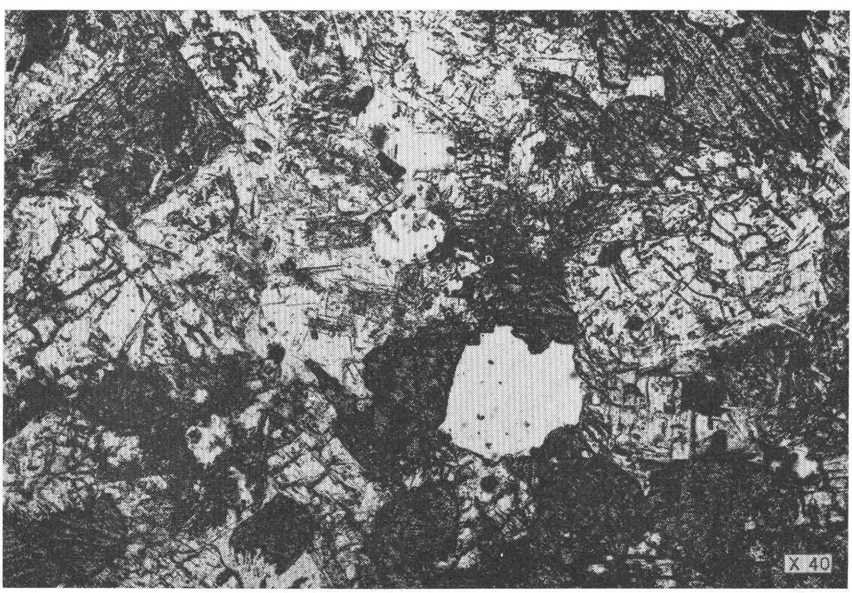

FIGURE 22.—Gabbro porphyry from Columbia quarry in the SW¼ sec. 11, T. 15 N., R. 1 E., showing large fractured phenocrysts of labradorite with inclusions of apatite and magnetite slightly altered to kaolinite. The dark subhedral grains are augite. Clear area in lower right corner is balsam. Ordinary light, × 40.

crysts and in the groundmass and forms about 60 percent of the rock. Augite occurs as phenocrysts and granules in the groundmass and makes up from 10 to 25 percent of the rock; it is generally altered to chlorite minerals and biotite. Other constituents present in minor amounts are hypersthene, magnetite, ilmenite, and apatite. Late hydrothermal and perhaps deuteric alteration has produced abundant secondary minerals; those identified are biotite, chlorite, zeolite, sericite, kaolinite, and calcite.

The rock sections studied from the upper part of the sill at the Columbia quarry contain an unusually high concentration of feldspar, ranging from 60 to 80 percent. This high feldspar content may be due to magmatic differentiation in the sill, as the samples were taken from the upper 80 feet of the sill, which has a total thickness of about 500 feet.

A spectrographic analysis of the gabbro porphyry at the Columbia quarry was made by the State of Washington, Division of Mines and Geology. This analysis is given below and is compared with a chemical analysis of granophyric gabbro from the Coast Ranges of Oregon at Mount Hebo.

Spectrographic analysis of gabbro porphyry from the Columbia quarry, Washington

[Grant Valentine, analyst, Washington Division of Mines and Geology]

	Percent		*Percent*
SiO	56.6	CaO	10.8
Al_2O_3	19.7	Na_2O	3.5
Fe_2O_3	1.7	TiO_2	1.5
FeO	3.9		
MgO	3.7	Total	101.2

Chemical analysis of granophyric gabbro from Mount Hebo, Oreg.

[Unpublished records of U. S. Geological Survey]

	Percent		*Percent*
SiO_2	53.92	TiO_2	1.60
Al_2O_3	14.37	K_2O	1.28
Fe_2O_3	3.79	MnO	0.19
FeO	9.84	P_2O_5	0.36
MgO	4.00	H_2O+	0.32
CaO	7.28	H_2O	0.42
Na_2O	3.26	Total	100.63

AGE OF INTRUSIVE ROCKS

The porphyritic basalt and the gabbro porphyry probably belong to the same period of igneous activity. The gabbro porphyry occurs only within strata of Eocene age but the porphyritic basalt intrudes beds of the lower part of the Lincoln formation. As intrusive rocks are not known to occur in the mapped area within strata younger than Oligocene age, a late Oligocene age is tentatively assigned to these intrusives. Similar intrusive bodies of gabbro in the Coast Ranges of Oregon were discussed and assigned a late Oligocene age by Snavely, Baldwin, Roberts, and Isotoff (1950, p. 1503).

STRUCTURE

GENERAL FEATURES

The rock strata of the district are folded and faulted, and their angles of inclination are as much as 90°. Paucity of outcrops throughout the area makes it difficult to delineate structural features with accuracy and precludes mapping of key beds to ascertain the structural configuration of a selected horizon. Therefore, the axes of folds and traces of faults, as shown on the geologic map (pl. 1), are approximately located. The coal beds are the only stratigraphic horizon markers that can be traced for any distance and the mapping of structure in most parts of the area is based chiefly upon the distribution of the coal beds.

Incomplete surface and subsurface structural data precludes a detailed review of the structural history of the district, but the broader features can be summarized. The part of the structural history with which this report is concerned began in Eocene time with subsidence of a northward-trending geosyncline and the deposition of the McIntosh formation. Upwarping and volcanic activity occurred along the margins of the geosyncline during middle and early late Eocene time. Local uplifting, adjacent to the area mapped, accompanied the extrusion of the flows of the Northcraft formation during the early part of the late Eocene. The geosyncline was divided into a number of separate basins of deposition during this period. There was no major break in sedimentation, however, in the deeper part of the basin which occupied most of the mapped area. The Skookumchuck and Lincoln formations were deposited in later Eocene and Oligocene time and periodic warping of the floor of the basin resulted in an interfingering of nearshore and coal-bearing deposits with marine beds. Most of the present structural features in the area were formed during early Miocene time, a period of marked deformation and erosion. Slight downwarping, accompanied by the deposition of the Astoria(?) formation occurred during middle Miocene time. Local downfolding, with the deposition of the nonmarine sedimentary rocks occurred during the late Miocene and Pliocene(?) time. In late Pliocene time another period of deformation occurred, and the beds laid down in Miocene and Pliocene(?) time were faulted and folded at places near the margins of their basins of deposition. Slight downwarping may have occurred in Pleistocene time and faulting has continued to the present, as evidenced by recent earthquake shocks that probably centered along one or more of the faults in the area.

FAULTS

High-angle faults with either normal or reverse movements dislocate the rock sequences in this district (pl. 2). The principal faults trend northwesterly or westerly and are generally downthrown on the southwest or south sides. Most of the larger faults appear to be the result of movement in the basement rocks that was brought about by regional compression. These faults usually transect the larger folds in the district. Most of the smaller faults and several large normal faults are related to major folds and presumably are due to vertical adjustment of the strata during or following the period of folding. The fault pattern shown on the geologic map (pl. 1) is generalized, as lack of rock outcrops makes it exceedingly difficult to determine the position and continuity of faults.

The four major high-angle reverse faults mapped are the westward trending Doty fault, and the northwestward-trending Kopiah, Newaukum, and Coal Creek faults. Sedimentary rocks adjacent to these faults dip at high angles and in places the beds are overturned to the south or southwest. Coal beds near these faults show evidence of slippage along bedding planes, with zones of pulverized coal as much as a foot thick.

Normal faults with net displacements ranging from a few inches to somewhat more than 1,500 feet offset the strata in the area. The principal normal faults mapped are the Chehalis, Scammon Creek, and Salzer Creek faults. High-angle normal faults with small net displacements are found in most of the mines (pl. 5). Most of these faults have a throw of less than 10 feet, but in some the displacements are greater. The fault planes of the smaller faults are generally well defined and are marked by 1 to 2 inches of gouge; no evidence of horizontal movement was observed.

DOTY FAULT

The Doty fault is a westward-trending high-angle reverse fault which extends from the west edge of the area in the SW¼ sec. 23, T. 14 N., R. 4 W., to the valley of the Chehalis River where it apparently terminates against the Salzer Creek fault. Adjacent to the Doty fault are minor drag folds, and along its downthrown south side steeply dipping strata are common. Vertical displacement along this fault is between 200 and 400 feet, with the greater displacement being in the extreme western part of the area. The Doty fault has been traced several miles west of the mapped area and the stratigraphic displacement appears to increase toward the west, as beds of Miocene age are in contact with Eocene strata.

SALZER CREEK FAULT

The high-angle normal Salzer Creek fault trends westward from Deep Creek in the SE¼ sec. 13, T. 14 N., R. 4 W., almost to South Hanaford Creek in the SE¼ sec. 20, T. 14 N., R. 1 W., a distance of about 14 miles. The fault is downthrown on the north side and the stratigraphic displacement is somewhat more than 1,500 feet west of the Chehalis River valley. Displacement along the fault decreases east of the Chehalis River valley, but the fault is made evident by the offset of the contact between the Lincoln and Skookumchuck formations along the north flank of the Chehalis anticline and on the north side of a small fold in the valley of Salzer Creek in secs. 22 and 23, T. 14 N., R. 2 W.

The location of the fault west of the Chehalis River valley is based principally upon zones of steep or anomalous dips and upon the distribution of coal beds. An excessively thick section of Skookumchuck strata and a repetition of coal beds occurs along the south side of the Lincoln Creek uplift; this duplication of strata is believed to be due to faulting along the Salzer Creek fault. The Salzer Creek fault and the Doty fault form a narrow upthrown block along the south side of the Lincoln Creek uplift. The strata in this block are tilted to the south and cut by transverse faults which have broken across the south flank of the Lincoln Creek uplift. Both the Doty and Salzer Creek faults appear to offset the transverse faults.

SCAMMON CREEK FAULT

The Scammon Creek fault is a northwestward-trending normal fault that can be traced with reasonable certainty from the west edge of the mapped area, just south of the town of Independence, southeastward for a distance of about 10 miles, where it is hidden underneath the alluvium of the Chehalis River. The fault roughly parallels the northeast flank of the Lincoln Creek uplift. The north side of the Scammon Creek fault has been downthrown, and strata on this side dip steeply away from and are generally parallel to the fault trace. Southeast of Teague Creek the Scammon Creek fault cuts beds of the Skookumchuck formation; however, northwest of this creek these beds are in fault contact with the upper part of the Lincoln formation. The omission of strata along this fault indicates the stratigraphic displacement may be somewhat more than 1,000 feet in the area north of Lincoln Creek, but displacement seems to decrease south of Lincoln Creek. A northeastward-trending transverse fault, downthrown on the northwest side, offsets the Scammon Creek fault along Teague Creek.

CHEHALIS FAULT

The Chehalis fault trends westerly from a point near the head of Coal Creek in the NW¼ sec. 35, T. 14 N., R. 2 W. to the valley of the

Chehalis River. This normal fault cuts across the southward-plunging Chehalis anticline and, in the vicinity of Coal Creek, beds of the Skookumchuck formation are upthrown on the south side against strata of the Lincoln formation. The fault has a stratigraphic displacement of somewhat more than 800 feet in the vicinity of Coal Creek. This fault is hidden beneath the Logan Hill formation east of Coal Creek and is concealed by terrace deposits and alluvium in the Chehalis River valley. Movement along the Chehalis fault apparently occurred prior to Miocene time as strata of Miocene age, which crop out west of the Chehalis River, are undisturbed along the projected strike of the fault.

KOPIAH FAULT

The Kopiah fault, the principal northwestward-trending reverse (?) fault, extends for about 21 miles diagonally across the mapped area. Generally, it can be fairly accurately delineated because it dislocates the coal-bearing rocks. The dip of the strata increases rapidly near the fault, and overturned beds are found along the downthrown southwest side of the fault. In the southeastern part of the area the trace of the fault lies near the axis of a former asymmetric anticline; however, in sec. 6, T. 14 N., R. 1 W., the fault changes strike abruptly leaving the fold axis and trends in a westerly direction for about 3 miles. In the vicinity of Centralia it again trends northwesterly and maintains this strike for a distance of about 8½ miles. Just east of the confluence of Hanaford Creek and the Skookumchuck River, the Kopiah fault splits and forms a narrow tilted block that extends northwesterly as far as sec. 19, T. 15 N., R. 2 W. Location of the fault trace across the drift-covered prairie northeast of sec. 19 can only be inferred; however, absence of coal-bearing strata in the Skookumchuck formation in Geological Survey test hole *Ch*–2, near Grand Mound, suggests that this test hole is on the upthrown side of the fault and below the upper coal group. Along the Kopiah fault, juxtapositions of coal beds from different stratigraphic positions indicate that the throw of this fault is about 400 to 500 feet. Northeast of Centralia, where the fault splits, the stratigraphic displacement is approximately 200 to 250 feet on each fault.

NEWAUKUM FAULT

The Newaukum fault trends essentially parallel to the Kopiah fault and is also downthrown on the southwest side. Along most of its trace, the fault is the contact between the Northcraft and the Skookumchuck formations, except south of Lucas Creek where it forms contact between the Northcraft and Lincoln formations. The Newaukum fault parallels the southwest flank of Meridian Hill anticline, but the fault is not recognized north of Elk Creek. The total displacement is thought to be small near Meridian Hill but to increase toward the south. This fault is offset by a westward-trending cross fault in the NE¼ sec. 30, T. 14 N., R. 1 E., and by two northeastward-trending cross faults south of the North Fork of the Newaukum River. The fault extends southward almost to Alpha Prairie where it is covered by the Logan Hill formation.

COAL CREEK FAULT

The Coal Creek fault, a high-angle reverse(?) fault, parallels the southwest side of the Coal Creek anticline and is the contact between the Northcraft and the Skookumchuck formations south of Snyder Creek. North of Snyder Creek the fault trace is covered by gravel of the Logan Hill formation and by Vashon drift. However, the fault is made apparent by the juxtaposition of the older coal beds on the northeast side, with younger beds on the southwest side. The total displacement along the fault is approximately 400 feet. South of Hanaford Creek, in the volcanic rocks of the Northcraft formation, it is difficult to map the fault, but it is believed to extend to the southeast edge of the mapped area, where it dislocates a small anticline just south of the North Fork of the Newaukum River.

FOLDS

The Tertiary strata in the Centralia-Chehalis district have been folded into anticlines and synclines which commonly have a northwestward trend; the beds along these flexures range in attitude from flat-lying to vertical (pl. 2). Strata in the western half of the area are folded into broad open structures whereas strata in the eastern half are generally more closely folded. Many of the folds are probably related to faults in the basement rocks, and a few of the minor folds result from drag along faults. Small flexures are probably common throughout the area; however, the rock exposures within the district are far too few to determine their extent.

Folding has two important economic effects on the area: it greatly increases the area of outcrop of the coal-bearing rocks, and it forms structures that may be favorable for the accumulation of oil and gas.

LINCOLN CREEK UPLIFT

The principal structural feature in the area is the Lincoln Creek uplift which is a broad, complex flexure that is further complicated by faulting. This uplift extends from the west edge of the area in a general southeast direction to the Chehalis River, where it plunges underneath the alluvium. The Salzer Creek and Doty faults roughly parallel the south side of the uplift, and the Scammon Creek fault roughly parallels the north limb. Two transverse faults have broken across the south side of the uplift; the larger one offsets the contact between the Lincoln and Skookumchuck formations more than 1,000 feet horizontally. The dip of the strata along the faulted limbs of the uplift ranges from 20° to 70°. The crest of the Lincoln Creek uplift has minor folds superimposed upon it, but the exact form of these subordinate folds cannot be determined as the rock exposures are too few. Exposures, however, seem to show the presence of two small anticlines along the northeast side of the uplift. The trace of the axis of one small flexure extends from a point near the head of Scammon Creek in the SW¼ sec. 10, T. 14 N., R. 3 W., northwestward for about 1½ miles; it then curves southwestward and apparently dies out near the head of Byron Creek in the SE¼ sec. 6, T. 14 N., R. 3 W. The other fold, which is somewhat more clearly defined, extends from a transverse fault in the SW¼ sec. 14, T. 14 N., R. 3 W., eastward for about 1¼ miles where it curves abruptly and is believed to parallel the southeast strike of the Scammon Creek fault underneath the alluvium of the Chehalis River. The north flank of this fold is poorly defined, but study of exposures seems to reveal structural irregularities resulting from movement along Scammon Creek fault.

Rocks of the Skookumchuck formation form the axial parts of the uplift and strata of the Lincoln formation crop out along both flanks. The Skookumchuck formation along the south side of the uplift has an increased thickness due to duplication of strata by the Salzer Creek fault. As the uplift has a general plunge to the southeast, beds of the McIntosh formation probably are present at shallow depths below the surface in the western part of the mapped area. The structural relief along the flexure varies from place to place but averages somewhat more than 3,000 feet.

CENTRALIA SYNCLINE

The Centralia syncline is a broad, shallow downwarp that extends southeasterly from the west edge of the mapped area to the Salzer Creek fault in sec. 19, T. 14 N., R. 1 W., a distance of about 16 miles. The abrupt steepening of dip along the flanks of this syncline results from movement along the Scammon Creek and Kopiah faults which roughly parallel the southwest and northeast limbs, respectively (pl. 1 and pl. 2, section *A–A′*). North of Lincoln Creek the syncline is complicated by a small synclinal drag fold and is cut by a cross fault in the vicinity of Teague Creek. East of the Chehalis River the axis splits and a subsidiary axis branches off to the south. In Salzer Creek, the upper part of the Skookumchuck formation is exposed along the axial parts of a small asymmetric anticline, which is located between the two branches of the Centralia syncline. This canoe-shaped fold plunges both to the southeast and northwest, is complicated by the Salzer Creek fault on its north limb, and has several minor folds superimposed upon it.

NAPAVINE AND CHEHALIS RIVER SYNCLINES

The Napavine and Chehalis River synclines are the principal downwarps in the southern part of the described area, and at one time they may have been a continuous structural element. The axis of the Napavine syncline trends northwesterly from the south border of the mapped area, in sec. 32, T. 13 N., R. 1 W., along the valley of the Newaukum River to a point about 1 mile south of Chehalis; the Chehalis River syncline extends along the north side of the valley of the Chehalis River from the vicinity of Littell westward to the border of the area in sec. 2, T. 13 N., R. 4 W.

The Chehalis River syncline borders the Lincoln Creek uplift south of the Doty fault. The fold plunges gently to the west and is asymmetric, presumably as a result of steepening of the north limb by movement on the Doty fault. The axial parts of this syncline contain rocks of Miocene age, but they are concealed in most places by deposits of Quaternary age. The thickest section of strata of Miocene and Pliocene (?) age are present in the gentle downwarp of the Napavine syncline. It is difficult to obtain structural data along this flexure as it is mantled by Quaternary deposits, but exposures indicate that the fold has a low plunge to the southeast and that the northeast limb, which borders the Chehalis anticline, is probably steeper than the southwest limb.

CHEHALIS ANTICLINE

The Chehalis anticline is a narrow southeastward-plunging fold that extends from the Salzer Creek fault in sec. 19, T. 14 N., R. 2 W., southeastward to a point about 1 mile south of Coal Creek in the SW¼ sec. 34, T. 14 N., R. 2 W., where it is concealed by the Logan Hill formation. The axis trends about S. 60° E. between the Salzer Creek fault and Coal Creek, but south of Coal Creek it trends about S. 35° E. The axial part of the fold consists of the coal-bearing Skookumchuck formation, and the Lincoln formation is along the flanks. Good exposures along the flanks of the fold can be observed in road cuts within the city limits of Chehalis and also immediately north of the city. The dip of the strata along the flanks ranges from 26° to 70°, the steeper dips being along the northeast limb. The Chehalis fault cuts across the nose of the anticline, bringing the coal-bearing rocks to the surface south of Coal Creek. A small normal fault along the northeast flank of the flexure repeats the Tono No. 1 bed in the NE¼ sec. 28, T. 14 N., R. 2 W. The Chahalis anticline is a southeasterly extension of the Lincoln Creek uplift. The strata in the Chehalis anticline, however, are more intensely folded because the flexure is located between the Salzer Creek fault and Chehalis fault.

TENINO ANTICLINE

The Tenino anticline is the only southwestward-trending fold in the area, and extends from the north border of the area, about 1½ miles north of Tenino, to a point about 4 miles north of Centralia, where it terminates against the Kopiah fault. The fold may be offset by the Coal Creek fault in the vicinity of Frost Prairie but the relationships there are covered by Pleistocene deposits. Sedimentary and volcanic rocks of the McIntosh and Northcraft formations crop out along the axial parts of this structure in the vicinity of Tenino, but south of Frost Prairie these beds plunge southwesterly beneath strata of the Skookumchuck formation. The Tenino anticline is a broad flexure with minor folds superimposed upon its flanks. The exact form of this flexure cannot be determined but exposures indicate that the southeast limb has a low dip toward the Tono basin, and the northwest limb dips more steeply toward a syncline that may underlie the outwash gravels on Mount Prairie.

BLUMAER HILL SYNCLINE

The Blumaer Hill syncline is a shallow southward-plunging fold that trends in a northerly direction along the west side of Blumaer Hill. North of Blumaer Hill the limbs of the fold dip steeply, but south of this area the syncline widens and dips average less than 10°. The southern part of the fold is covered by glacial outwash, but it probably is offset by the Coal Creek fault, and plunges into the Tono basin.

CRAWFORD MOUNTAIN ANTICLINE

The Crawford Mountain anticline is a broad south- to southeastward-trending fold that extends from the northern edge of the mapped area almost to the Skookumchuck River in sec. 7, T. 15 N., R. 1 E. The fold axis plunges to the southeast and is largely obscured by glacial drift north of Scatter Creek. The core of the Crawford Mountain anticline consists of rocks of the McIntosh formation; the highland areas along the flanks of the anticline consist of volcanic rocks of the Northcraft formation. The anticline is cut by a high-angle normal fault that extends from Northcraft Mountain, northeastward to Crawford Mountain.

MENDOTA SYNCLINE

The Mendota syncline extends generally northwestward for a distance of about 12 miles from a point north of Alpha Prairie to Hanaford Creek. North of Mendota the axis has a more northerly trend. In the area between Hanaford Creek and the North Fork of the Newaukum River the trough of the fold is essentially horizontal;

however, the syncline plunges to the southeast away from the Tono basin, and to the northwest away from an eastward-trending cross fault just south of the North Fork of the Newaukum River. South of this fault, which displaces the beds about 400 feet stratigraphically, the axis plunges to the southeast. A cross fault also offsets the axis near the head of Lucas Creek, and the fold terminates against a northeastward trending cross fault in sec. 11, T. 13 N., R. 1 E. North of the North Fork of the Newaukum River the limbs of the Mendota syncline appear to be rather uniform with dips ranging to as much as 87°. Rock exposures are rarely found along the southwest limb of the fold as the bedrock is covered with Quaternary deposits. North of the North Fork of the Newaukum River the syncline consists of rocks of the Skookumchuck formation, but south of the river, beds of the Lincoln formation occupy the axial parts of the fold.

TONO BASIN

The Tono basin is a broad, shallow downwarp with beds that dip generally less than 10°, except along the eastern side, where it abuts against the Coal Creek fault. The margins of the basin are complicated by minor folds that plunge basinward. Many high-angle normal faults have influenced the configuration of the Tono basin, but faulting alone is not responsible for the formation of the structure (pl. 5). The central part of the basin lies chiefly in sec. 21, T. 15 N., R. 1 W., and detailed subsurface information is available for this part of the basin because the Tono No. 1 coal bed has been mined and test drilled extensively in this area.

MERIDIAN HILL AND COAL CREEK ANTICLINES

The narrow Meridian Hill and Coal Creek anticlines plunge to the northwest and are strongly asymmetric with high-angle reverse faults roughly paralleling their southwest limbs. The southwest limbs are steep, with dips as high as 80°, whereas the dips along the northeast limbs range from 13° to 41°. The Meridian Hill anticline plunges into the Tono basin before reaching the valley of Hanaford Creek. North of Snyder Creek the Coal Creek fault lies along the former axis of the Coal Creek anticline. Volcanic rocks of the Northcraft formation crop out along the axial parts of the Coal Creek and Meridian Hill anticlines south of Coal Creek and Elk Creek respectively. The general traces of the axes of these folds are shown in the volcanic rocks, but the axes can only be mapped for a short distance south of Mitchell Creek as very little structural data is obtainable in these rocks.

HANAFORD CREEK SYNCLINE

The Hanaford Creek syncline, a northwestward-trending fold, roughly parallels the west side of Hanaford Creek from a point near the junction of Snyder and Hanaford Creeks southward to the Coal Creek fault where the fold terminates. A small cross fold divides the syncline into two elliptical basins. The north end of the fold plunges to the southeast, away from the Tono basin.

SNYDER CREEK AND THOMPSON CREEK SYNCLINES

The Snyder Creek and Thompson Creek synclines are in the Skookumchuck formation and are shallow, narrow northwestward-trending canoe-shaped folds, separated by several small plunging anticlinal folds. The northern continuation of these synclines is not known with certainty because this area is covered with glacial outwash and alluvium; however, they probably do not extend north of the Skookumchuck River. South of Hanaford Creek the folds plunge northeastward, off the highland areas of volcanic rocks in the Northcraft formation. The dips are moderately steep along the flanks of the folds. The east limb of the Thompson Creek syncline, which terminates against a high-angle normal fault, has dips that range from 30° to 62°.

ECONOMIC GEOLOGY

OIL AND GAS

The presence of a thick sequence of marine sedimentary rocks in the Centralia-Chehalis area motivated the search for oil and gas as early as 1901. Since that date there has been intermittent exploration, and prior to July 1952, 14 test holes have been drilled within the area. The correlations of the rock units in these test holes are shown on plate 4, but as a result of this drilling only small shows of oil and gas have been reported. Ten of the test holes were located with very little or no geologic data and were either poorly located structurally or were not drilled to sufficient depth to be considered satisfactory tests. The locations of two test holes, Union Oil Co. Bannse test hole 1 and Selburn-Washington Oil Corp. Wulz test hole 1, were based on geophysical prospecting.

In some of the test holes thick sections of fine-grained marine sedimentary rock with interbedded sandstone beds suitable for reservoir rock were penetrated. However, structural closure cannot be established at the surface with certainty in most of the areas where tests have been drilled. Paucity of outcrops and the presence of many structural irregularities make it difficult to accurately delineate the structure of the strata.

The McIntosh formation, which includes a thick sequence of fine-grained sedimentary rocks, possibly could be a source bed of petroleum, and sandstone that appears to have sufficient porosity to be potential reservoir rock is commonly interbedded with the fine-grained sedimentary rocks. If there are structural traps, the McIntosh formation may be the most favorable formation in the area in which to test for the accumulation of oil and gas. Rocks of the McIntosh formation are reported to have been penetrated in seven of the tests drilled in the area. Shows of gas were reported in all these test holes and a show of oil was reported from Chehalis test hole 1, drilled on the Lincoln Creek uplift in sec. 17, T. 14 N., R. 3 W.

The sandstone beds in the Skookumchuck formation have porosities as high as 35 percent and permeabilities to as much as 3,500 millidarcies; therefore, these beds are suitable reservoir rocks for petroleum. The zones of finer grained marine sedimentary rocks in this formation are mostly thin and are commonly interbedded with rocks of brackish-water or nonmarine origin; thus they probably should not be considered as potential source beds of petroleum. Small shows of gas and oil have been reported from drill holes in the rocks of the Skookumchuck formation. Most of this gas was probably methane which may have been derived from the coal beds. Small quantities of gas were obtained from coal-bearing rocks equivalent in age to the Skookumchuck formation, penetrated in a test hole drilled for the Geological Survey near Toledo, Wash., in sec. 24, T. 11 N., R. 2 W. The Bureau of Mines gave the following analysis for this gas:

	Percent		*Percent*
Methane	80.0	Hydrogen	0.0
Nitrogen	18.8	Carbon monoxide	0.0
Oxygen	1.0	Ethane	0.0
Carbon dioxide	0.2		
Unsaturated hydrocarbons	0.0		100.0

The Lincoln formation is a thick sequence of fine-grained sedimentary rocks, but these rocks consist of rapidly and periodically deposited tuffaceous material. This type of sedimentation probably does not favor a high concentration of organic material. The formation, therefore, should not be considered as a source bed of oil or gas. The tuffaceous material also reduces the porosity of the rocks in this formation, probably making them too impermeable for reservoir rocks unless fractured. The Lincoln formation would, however, make an effective barrier to migrating oil or gas.

The formations of Miocene age within the mapped areas are chiefly of nonmarine origin and have little possibility as a source of petroleum. The sandstone beds in these formations appear to have sufficient porosity to be suitable reservoir rocks; however, closed anticlinial folds are not known in the formations.

Stratigraphic and structural-stratigraphic traps suitable for the accumulation of oil and gas probably exist within the area. The facies changes in the Lincoln and Skookumchuck formations from near-shore arenaceous deposits in the eastern part of the area to fine-grained clastic sedimentary rocks in the western part could form stratigraphic traps under proper structual conditions. Stratigraphic traps may be present in the Skookumchuck formation down dip from places where the relatively impervious Lincoln formation rests upon the McIntosh formation. This stratigraphic relationship is not present at the surface within the mapped area, but just northwest of Oakville the Lincoln formation rests upon middle Eocene volcanic rocks. The possibility exists that the Lincoln formation may rest upon beds of the McIntosh formation beneath the drift cover in the area between the towns of Gate and Rochester in the northwestern part of the mapped area.

Surface geology indicates that the Lincoln Creek uplift may be favorable for further test drilling and might possibly contain some trapped oil in the McIntosh formation. The surface geology in that area is poorly exposed and landslides are common; therefore, surface structure, interpreted from these exposures, may not reflect correctly the subsurface structure. Deep drilling for oil and gas in the Lincoln Creek uplift should be preceded by shallow test drilling or geophysical prospecting to outline secondary folds within the larger structure.

Reservoir beds suitable for the accumulation of oil and gas may be uptilted along the principal faults in the area. However, additional data regarding the amount of displacement and the nature of the fault zones is needed to properly evaluate the entrapment potentialities of the fault zones. Despite the faulted nature of most of the area mapped, oil seeps are not known to the writers.

GROUND WATER

Potable water is generally found 20 to 40 feet below the surface in the unconsolidated sediments along the valleys of the larger streams and beneath the outwash prairies in the northern part of the mapped area. Fresh water is scarce in the upland areas adjacent to the valley floors and in the Tertiary bedrock. Connate water in the Eocene rocks is generally saline or distasteful, owing to dissolved material acquired from the enclosing rocks or from the coal beds. Most of the slope mines in the district require daily pumping to prevent flooding. Abandoned mine workings commonly are filled to overflowing with downward-migrating water from the land surface, even though they are located as much as 100 feet above the general level of the water table of the adjacent valleys.

Along the flanks of a few of the open folds in the eastern part of the Centralia-Chehalis district, saline water has been flushed out of some of the sandstone beds in the Skookumchuck formation and water of good quality is produced from the wells there. Geological Survey test holes *J* and *K*, drilled on the flanks of the Kopiah fold, produced small quantities of fresh flowing artesian water near the surface, but at depth the water was saline. Rocks of the Lincoln formation yield little water, as the porosity and permeability of this tuffaceous and basaltic sandstone are very low owing to the abundance of volcanic glass and its alteration products. Rock strata of Miocene age in the south-central part of the area, along the Napavine syncline, yield water in substantial quantities, some of which is flowing artesian. Schlax (1947, p. 14–16) described the occurrence of artesian water north of Littell in the Astoria(?) sandstone. In that area the southward-dipping Columbia River(?) basalt confines water in underlying sandstone beds, forming an artesian condition. Several miles southwest of Chehalis, in the valley of the Newaukum River, wells have produced artesian water from nonmarine sedimentary rocks of Miocene and Pliocene(?) age. Confined water in this sequence of rocks is found in sand and gravel interbedded with silt and clay. In the area underlain by the Logan Hill formation small quantities of water are yielded from fresh gravel at the base of the formation. Generally, this water is that which is moving along the top of tight Tertiary bedrock. There is a possibility of obtaining water in quantity from the Logan Hill formation in areas where gravel deposits fill preexisting channels that extend below the level of the present water table. A deep channel filled with gravel and sand of the Logan Hill formation was mapped east of Centralia, extending from its exposure in the railroad cuts 1 mile north of the town, southeastward across Seminary Hill. A well in this channel on Seminary Hill produced 12 gallons of water per minute from a depth of 154 feet. However, the Lincoln formation was penetrated in a water well in this same area, adjacent to the channel, at a depth of about 40 feet and yielded only a negligible quantity of water. Other channels filled with material of the Logan Hill formation probably exist and may be important sources of fresh water. Upper Pleistocene outwash deposits in the northern part of the mapped area are undoubtedly the largest reservoirs of fresh water. The water table in these outwash gravel deposits slopes toward larger streams and ground water drains into these streams. The gravel yields water readily, and Schlax reports that some wells in this area have a specific capacity of nearly 50 gallons per minute per foot of drawdown.

SAND AND GRAVEL

Sand and gravel production has been largely confined to Vashon outwash deposits north and northeast of Centralia. Vashon material is most suitable for road surfacing and aggregate use because it is composed of predominantly fresh and resistant rock types with only a negligible percentage of rotten material. Gravel in the Logan Hill formation and in the terrace deposits along the Newaukum River has been quarried on a small scale, but is not well-suited for construction material because of the high percentage of weathered volcanic rock types. Locally, Recent river gravel deposits along the Chehalis and Newaukum Rivers have been quarried for private use, but, the extent of these deposits is small. In January 1952, the only large operating gravel pits in the Centralia-Chehalis area were located in outwash deposits of the Vashon drift.

CRUSHED ROCK

Igneous rock, both intrusive and extrusive in origin, is quarried in the Centralia-Chehalis area to supply crushed and broken stone for road surfaces and jetty rock. Quarries have been sporadically operated in the volcanic member of the McIntosh formation north of Gate and in the flows of the Northcraft formation in the extreme eastern part of the mapped area. Crushed stone from these two volcanic units has been utilized locally by highway departments of Lewis and Thurston Counties and by local timber companies as surface material for secondary roads and truck roads.

The Columbia quarry, located in the SW¼ sec. 11, T. 15 N., R. 1 E., was formerly an important source of jetty rock. The quarry was operated on a massively jointed gabbro sill approximately 500 feet thick. It is reported that 20 million tons of jetty rock was mined at this quarry.

Quarries in the Columbia River(?) basalt are located along the Chehalis River in T. 14 N., Rs. 3 and 4 W. In 1952, the quarry at Bunker was being worked continuously and there are several other large quarries nearby which are worked intermittently. Quarrying operations in the Columbia River(?) basalt are limited by the 40- to 50-foot thickness of the flows, and in most quarries the top of the underlying Astoria(?) formation has been penetrated. Many small private quarries have been operated on the Columbia River(?) basalt throughout the outcrop belt of this unit.

CLAY PRODUCTS

The Chehalis Brick and Tile Co., located near the city limits of northern Chehalis, manufactures various types of building brick, drain tile, and hollow block. The chief raw material used by this company is landslide debris derived from the Skookumchuck formation. This material is mined at their plant in sec. 29, T. 14 N., R. 2 W.

The bricks produced are various shades of brown or red. However, a light-gray brick is made from weathered feldspathic sandstone of the Skookumchuck formation to which a fire clay is added for binder. This company produced about 4,000 bricks per day in 1951.

Glover (1941) lists analyses of various clay samples from the Centralia-Chehalis area; some appear suitable for commercial use. Most of the clays listed by Glover as being suitable for structural ware are from the intensely weathered upper part of the Logan Hill formation.

COAL RESOURCES

PHYSICAL AND CHEMICAL PROPERTIES

The coal in the Centralia-Chehalis district ranges in rank from lignite to subbituminous B according to the classification established by the American Society for Testing Materials (1951). Most of the coal is of subbituminous C rank. Individual beds range from a few inches to more than 40 feet thick, but the average thickness of most beds is between 6 and 8 feet. When freshly exposed the coal is black to reddish brown, with a bright to dull luster; the streak is either black or reddish brown. Banded coal, consisting of bright and dull coal and bony coal, is present in some beds. A rectangular, blocky, or subconchoidal fracture and original woody texture are common. Coalified and silicified logs and stumps occur in many beds, some in an upright position, indicating that a part of the organic material from which the coal was formed accumulated in place. Partings of bone, tuffaceous siltstone, carbonaceous shale, and tuff are interbedded with the coal beds. When exposed to the air, the coal slacks readily because of its high moisture content, which ranges from 14 to 35 percent. The ash content is also high, ranging from 4.6 to 24.9 percent and averaging about 10 percent. The high ash content of many of the coal beds in this raea is the result of volcanic ash falls during the time of accumulation of the plant material from which the coal is formed. In some of the coal beds fine disseminated grains of pyrite contribute to the sulfur content, which ranges from 0.3 to 4.5 percent. Tuff fragments, grains of quartz, amber, and gypsum are also present in the coal.

Studies of thin sections of coal from the principal coal beds were made by J. M. Schopf at the U. S. Geological Survey coal geology laboratory. His determinations of the composition of the coal, together with photomicrographs are included in this report (p. 143).

The composition of the coal and some data relative to the stratigraphic position and geographic location of the samples are given in the following table. The proximate chemical analyses listed in this table give the composition of the coal as it was received in the laboratory, which form most closely approximates the composition of the coal in the ground. A comparison of the average proximate analysis of coal from the Centralia-Chehalis district with analyses from other coal fields in western Washington is shown in figure 23.

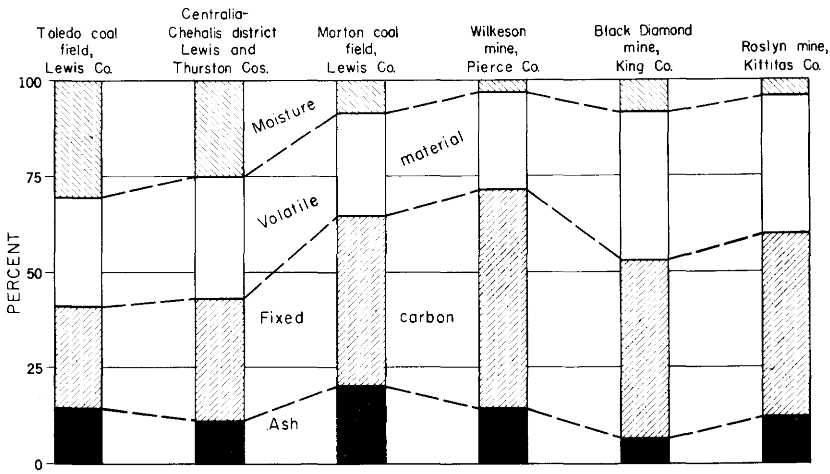

FIGURE 23.—Average proximate analysis of coal "as received" from major coal beds in selected coal fields of western Washington.

HISTORY OF MINING AND PRODUCTION

The occurrence of coal in the Centralia-Chehalis district has been known since the days of earliest settlement; the first mines with a record of production were operating in the late 1870's. Prior to 1905, annual production was not more than 25,000 tons, as most domestic heating was accomplished through the use of wood. Beginning about 1905, and continuing into the early 1920's, coal production expanded greatly, owing to the increased consumption of coal for domestic heating and for railroad operations, and for a number of years more than 300,000 tons was produced annually. Production began to decline about 1930 because oil began to replace coal as fuel for steam locomotives and imports of coal from Utah and Wyoming were increased with the result that only about 100,000 tons of coal was produced annually during the 1930's and not more than 150,000 tons annually during the Second World War. Production in 1951 totaled about 60,000 tons, most supplying domestic fuel for local markets.

A graph showing coal production from the Centralia-Chehalis district and from the entire State for the period 1860 to 1951 is given in

Proximate analyses of coal, as received, Centralia-Chehalis district, Washington

[Samples collected by U. S. Geological Survey and analyzed by U. S. Bureau of Mines, except as otherwise indicated in footnotes. Asterisk (*) before map reference number indicates measured coal section. "Average thickness of clean coal" is based upon best information available in 1952 and is not necessarily the same thickness as in samples used for analyses]

Name of coal bed	Name of mine, drill hole, or location of outcrop	Map reference	Sample No.	Date sampled	Average thickness of clean coal		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	B. t. u.	Location of sample in mine or drill hole
					Feet	Inches							
Golden Glow	Leonard (Chehalis) mine.	25	[1] 9944	1910	5	7	29.1	34.7	28.5	7.67	1.77	7,940	Stump pillar, 250 ft from entrance.
Do	Golden Glow No. 1 mine.	20	[5] B-93899	1943	4	6	31.4	33.3	29.7	5.6	.7	7,970	Tipple sample, 3 tons.
Do	U. S. G. S. drill hole V	GS-V	[5] D-55878	1950	5	1	26.4	36.3	27.7	9.6	1.8	8,250	Depth, 561 to 566 ft.
D & F	D & F mine	14	[5] B-93558	1943	4	6	15.3	34.6	33.7	16.4	4.3	9,000	Tipple sample, 10 tons.
Do	do	14	[5] B-93561	1943	4	6	21.0	32.0	30.1	16.8	3.1	8,110	Do.
Do	do	14	[5] C-1243	1943	4	6	14.0	35.1	32.3	18.6	4.5	8,990	Do.
Tono No. 1	Salzer Valley King mine.	45	[2] A-55443	1929	5	8	29.1	32.0	30.9	8.0	2.5	7,940	Composite of samples A-55440 to A-55442.
Do	Sunshine No. 1 mine	50	[2] A-55520	1929	4	10	30.0	31.2	28.8	10.0	2.0	7,590	Composite of samples A-55517 to A-55519.
Do	Sec. 10, T. 13 N., R. 1 E.	*149	[5] B-93644	1943	6	3	26.0	31.2	28.9	13.9	.6	7,580	Taken off face right at surface.
Do	U. S. G. S. drill hole *E*-2.	GS-E-2	[5] D-48109	1950	3	8	19.5	30.2	35.6	14.7	.6	8,530	Depth, 520 to 526 ft.
Do	Black Prince mine	6	[2] A-56243	1929	9	9	24.9	34.0	35.8	5.3	.3	8,840	Water level at shaft site.
Do	Tono mine	55	[1] 9095	1909	12-16		23.6	31.0	37.3	8.13	.36	8,550	200 ft from gangway, room 12, first level south.
Do	do	55	[1] 9096	1909	12-16		22.7	31.0	38.3	8.02	.37	8,630	Entrance room 8, second level north, lower bench.
Do	do	55	[1] 9573	1909	12-16		21.5	31.8	40.7	6.04	.43	9,170	150 ft upslope, room 7, second level south, upper bench.
Do	do	55	[2] A-55117	1929	12-16		21.9	33.4	37.4	7.3	.5	9,200	Composite of samples A-55112 to 55116.
Do	do	55	[3] B-27320	1938	12-16		21.9	33.3	37.0	7.8	.4	9,090	Composite of samples B-27317 to B-27319.
Do	Old Monarch mine	33	[4] 29570	1917	7	7	27.82	33.66	29.74	8.78	.99	7,942	At the face of the plane.
Do	do	33	[2] A-55757	1929	7	7	26.8	33.6	32.9	6.7	.7	8,370	Composite of samples A-55755 and A-55756.
Do	U. S. G. S. drill hole *K*	GS-K	D-41582	1950	9	3	25.0	33.8	30.8	10.4	1.3	8,160	Depth, 110 to 120 ft.
Do	Richmond mine	42	[1] 9177	1909	12	10	26.7	32.8	32.1	8.41	1.52	8,030	Face of north gangway, first level.
Do	Sheldon mine	46	[1] 9943	1910	7	11+	29.9	34.0	30.4	5.75	.58	7,930	250 ft. east of slope and 40 ft. up rise from first level.
Do	do	46	[4] 29569	1917	7	11+	31.00	32.65	30.55	5.80	.46	7,715	Face, main entry.

Do	Reliance No. 1 mine	40	[2] A-55761	1929	6	8	29.2	32.2	29.9	3.7	.8	7,650	Composite of samples A-55758 to A-55760.
Do	Reliance No. 2 mine	41	[3] B-33032	1938	6	10	35.0	29.2	28.1	7.7	.6	7,000	Composite of samples B-33029 to B-33031.
Do	Wabash mine	58	[2] A-55353	1929	9	5	28.1	31.6	34.1	6.2	.8	8,280	Composite of samples A-55350 to A-55352.
Do	Lincoln mine	26	[5] C-1419	1943	7	----	32.2	31.6	28.6	7.6	.7	7,440	Face of first room, off slope entry, 110 ft. north of entry.
Do	Superior No. 2 mine	53	[1] 9941	1910	9	9	30.5	34.9	26.6	4.95	1.25	7,930	50 ft. up No. 5 chute.
Do	do	53	[4] 29568	1917	9	9	30.8	33.1	27.7	8.4	.8	7,510	Face of entry beyond No. 34 chute.
Do	Non-Pareil mine	31	[2] A-56018	1929	6	9	29.3	32.2	31.0	7.5	.7	7,910	Composite of samples A-56016 and A-56017.
Do	Stoker mine	49	[5] D-8255	1948	7	3	28.7	32.3	30.9	8.1	.9	7,910	Second level west, 850 ft. west of slope, 50 ft. above gangway.
Do	Monarch No. 2 (Fords Prairie) mine.	30	[4] 29564	1917	7	4	29.81	32.88	29.49	7.82	.61	7,547	Main gangway near the last plane.
Do	do	30	[2] A-54767	1929	7	4	29.0	32.4	31.8	6.8	.5	7,970	Composite of samples A-54764 to A-54766.
Do	do	30	[5] D-3090	1948	7	4	24.8	34.1	32.3	8.8	.6	8,260	Third level from No. 6 plane, 1,100 ft. south of plane, face of gangway.
Do	Columbia Collieries mine.	11	[2] A-55764	1929	8	5	28.7	34.3	29.4	7.6	.9	8,130	Composite of samples A-55762 and A-55763.
Tono No. 2	NE¼ sec. 20, T. 15 N., R. 1 W.	*33	D-30869	1949	4	10	24.4	32.4	33.9	9.3	1.9	8,270	Near entry water level; coal weathered.
Upper Thompson.	U. S. G. S. drill hole *G*.	GS-*G*	D-41581	1950	6	1	[6] 16.4	31.8	32.9	18.9	1.9	8,440	Depth, 272 to 283 ft.
Do	SE¼ SW¼ sec. 18, T. 15 N., R. 1 E.	*60	C-96368	1948	12	9	20.7	29.6	36.8	12.9	1.6	8,750	Barber prospect, approximately 200 ft. southeast of Majestic mine.
Do	U. S. G. S. drill hole *K*	GS-*K*	D-44519	1950	4	10	24.1	29.5	28.1	18.3	.6	7,170	Depth, 525 to 533 ft.
Do	Twin City mine	56	[1] 9945	1910	9	9	30.6	31.8	27.9	9.74	.27	7,230	Face, first level gangway, lower bench.
Do	Superior No. 1 mine	52	[1] 9942	1910	9	9	27.2	33.8	28.1	10.92	.33	7,570	10 ft. east of tunnel, upper bench.
Do	Sec. 30, T. 15 N., R. 2 W.	*13	[5] D-3091	1948	8	----	25.8	34.6	30.4	9.2	0.4	8,090	Face prospect drift, 150 ft east of opening.
Do	Crescent No. 2 mine	13	[1] 9940	1910	6	9	32.1	31.9	27.3	8.7	2.97	7,140	Gangway between 17 and 18 chutes.
Do	U.S.G.S. drill hole *CH*-3.	GS-*CH*-3	[5] D-71167	1951	2	2	33.4	32.3	29.7	4.6	1.1	7,530	Depth of 141 to 147.5 ft.
Do	NW¼ sec. 32, T. 15 N. R. 1 E.	*74	[5] D-33783	1949	8	0+	25.1	30.2	31.2	13.5	1.0	7,370	Face prospect, base not exposed.
Do	Black Badger mine	2	D-30894	1949	7	6	19.4	35.3	35.8	9.5	1.3	8,950	25 ft northeast of portal in main entry.
Lower Thompson.	NW¼ SW¼ sec. 9, T. 14 N., R. 1 W.	*121	D-30866	1949	5	4	26.1	31.0	30.9	12.0	1.5	7,810	Weathered face in small prospect pit.

See footnotes at end of table.

Proximate analyses of coal, as received, Centralia-Chehalis district, Washington—Continued

[Samples collected by U. S. Geological Survey and analyzed by U. S. Bureau of Mines, except as otherwise indicated in footnotes. Asterisk (*) before map reference number measured coal section. "Average thickness of clean coal" is based upon best information available in 1952 and is not necessarily the same thickness as in samples used for analyses]

Name of coal bed	Name of mine, drill hole, or location of outcrop	Map reference	Sample No.	Date sampled	Average thickness of clean coal		Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	B. t. u.	Location of sample in mine or drill hole
					Feet	Inches							
Big Dirty	SW¼ NW¼ sec. 10, T. 14 N., R. 1 W.	*127	C-1418	1943	4	6	25.9	30.5	33.5	10.1	0.9	8,320	On rib of main entry, 150 ft nothwest of opening, upper part of bed.
Do	U. S. G. S. drill hole *I*	GS-I	D-34603	1950	24	2	[6] 19.2	31.5	35.0	14.3	.6	8,720	Depth, 146 to 185 ft.
Do	U. S. G. S. drill hole *C-2*.	GS-C-2	[5] D-36934	1950	9	5	[6] 17.4	35.7	32.6	14.3	1.0	9,070	Depth, 23 to 40 ft; upper part of bed eroded.
Do	SE¼ SW¼ sec. 18, T. 15 N., R. 1 W.	*43	[5] C-26027	1944	6	6+	23.8	33.2	32.9	10.1	.4	8,380	Upper part of bed in face of 15-ft drift on outcrop; base not exposed.
Little Dirty	U. S. G. S. drill hole *B*	GS-B	D-30146	1949	3	5	[6] 15.8	36.9	36.4	10.9	2.9	9,680	Depth, 67 to 71 ft.
Do	NW¼ NW¼ sec. 18, T. 15 N., R. 1 W.	*48	[5] C-26029	1944	3	7	22.2	33.1	32.7	12.0	2.3	8,470	Face of 20 ft drift on outcrop.
Do	U. S. G. S. drill hole *DD*.	GS-DD	[5] D-59349	1951	3	6	26.5	33.0	30.4	10.1	.4	8,000	Depth, 31 to 38 ft.
Do	SW¼ SW¼ sec. 10, T. 14 N., R. 1 W.	*129	[5] D-30868	1949	4	6	24.2	32.0	32.6	11.2	.9	8,310	Face of prospect drift 50 ft southeast of portal.
Smith	U. S. G. S. drill hole *D*	GS-D	D-28809	1949	8	6	[6] 19.1	33.8	37.2	9.9	.5	9,350	Depth, 350 to 363 ft.
Do	Belle Slope mine	1	[5] C-23749	1944	8	10	22.6	33.6	33.6	10.2	.5	8,660	Composite of samples C-23747 and C-23748.
Do	Smith No. 3 mine	48	[2] A-56244	1929	5	8	22.4	32.4	32.6	12.6	1.5	8,420	Face of slope 20 ft from prospect mouth.
Do	NE¼ SW¼ sec. 9, T. 14 N., R. 1 W.	*131	[5] D-30867	1949	4	7	26.0	32.5	33.5	8.0	1.1	8,440	Face of prospect trench.
Do	U. S. G. S. drill hole *I*	GS-I	D-35247	1950	6	8	[6] 18.2	31.9	35.1	14.8	.4	8,770	Depth, 288 to 296 ft.
Do	U. S. G. S. drill hole *B*	GS-B	D-30147	1949	8	9	[6] 17.7	33.9	36.5	11.9	.9	9,150	Depth, 129 to 136 ft.
Do	Bucoda No. 1 mine	8	[5] A-54771	1929	6	5	22.1	32.4	36.1	9.4	.4	8,950	Composite of samples A-54768 to A-54770.
Do	Penn-Bucoda strip pit No. 1.	35	[5] C-26030	1944	8	8	22.1	34.7	32.6	10.6	.4	8,660	Outcrop exposed by trench.
Penitentiary	U. S. G. S. hole *I*	GS-I	D-33782	1950	3	10	[6] 17.1	32.4	36.5	14.0	1.6	9,140	Depth, 499 to 506 ft.
Do	U. S. G. S. hole *B*	GS-B	D-30148	1949	4	1	[6] 15.8	36.4	33.1	14.7	2.5	9,300	Depth, 291 to 296 ft.
Do	SE¼NW¼ sec. 13, T. 15 N., R. 2 W.	*19	D-1995	1949	2	7	25.5	30.6	31.2	12.7	4.4	7,530	Face of small prospect.

Mendota	NW¼NE¼ sec. 24, T. 14 N., R. 1 W.	*146	[5] C-64088	1946	10	5	23.8	27.7	32.5	16.0	.8	7,860	Face of prospect trench.
Do	NW¼NE¼ sec. 3, T. 14 N., R. 1 W.	*145	[5] B-93658	1943	7	11	23.4	30.0	32.6	14.0	4 .1	7,990	Face of prospect, 20 ft from opening.
Do	U. S. G. S. drill hole *D*.	GS-D	D-28810	1949	4	10	[6] 14.8	37.1	36.8	11.3	2.1	9,880	Depth, 538 to 546 ft.
Do	Mendota mine	29	[1] 10323	1909	9		19.3	33.8	34.3	12.62	1.17	8,850	Foot of slope, 850 ft from mine mouth.
Do	do	29	[1] 10324	1909	9		20.5	33.5	33.7	12.31	1.28	8,690	Second room, 80 ft from first level north.
Do	do	29	[4] 29565	1917	9		19.75	35.16	31.62	13.47	1.17	8,676	Face, No. 5 north gangway.
Do	Columbia mine	10	D-3092	1948	8	8	21.7	31.1	33.8	13.4	1.2	8,450	Face of room 25, first level east, 1,000 ft southeast of slope.
Do	U. S. G. S. drill hole *I*	GS-I	D-35248	1950	7	10	[6] 17.8	32.3	33.2	16.7	1.3	8,750	Depth, 625 to 635 ft.
Do	U. S. G. S. drill hole *B*.	GS-B	D-30575	1949	4	11	[6] 15.7	35.4	35.3	13.6	2.2	9,510	Depth, 441 to 449 ft.
Do	Boxer mine	7	[5] D-30865	1949	6	4	22.7	32.5	32.0	12.8	2.8	8,060	Southeast rib of slope, 15 ft in by portal.
Do	Perth mine	37	[1] 9178	1909	6	1	25.1	32.3	34.0	8.65	.82	8,170	First level, 120 ft north of slope.
Black Bear	Black Jewel mine	5	[2] A-56242	1929	4	10	17.9	27.8	29.4	24.9	2.6	7,060	Face of water level gangway, 50 ft from mine mouth.
Do	Black Bear mine	3	[1] 9939	1910	5	7	16.0	31.9	28.9	23.2	1.5	7,800	Room 1, first west level.
Do	U. S. G. S. drill hole *J*.	GS-J	D-40920	1950	2	1	[6] 12.0	36.0	34.2	17.8	2.9	9,603	Depth, 992 to 995 ft.
Do	Great Western mine	22	[1] 9987	1910	3	6	22.4	33.6	33.0	10.95	2.40	8,770	Room 10, 100 ft up rise from twenty-fifth level north.

[1] U. S. G. S. Bull. 474, 1911.
[2] U. S. B. M. Tech. Paper 491, 1931.
[3] U. S. B. M. Tech. Paper 618, 1941.
[4] Washington Geological Survey, Bull. 19, 1919.
[5] U. S. Bureau of Mines, unpublished records.
[6] Moisture lost in shipping.

figure 24. The figures used to construct the curve for the Centralia-Chehalis district were obtained from the office of the State mine inspector and from local operators. The figures used to construct the curves for the State were obtained from the annual volumes of the

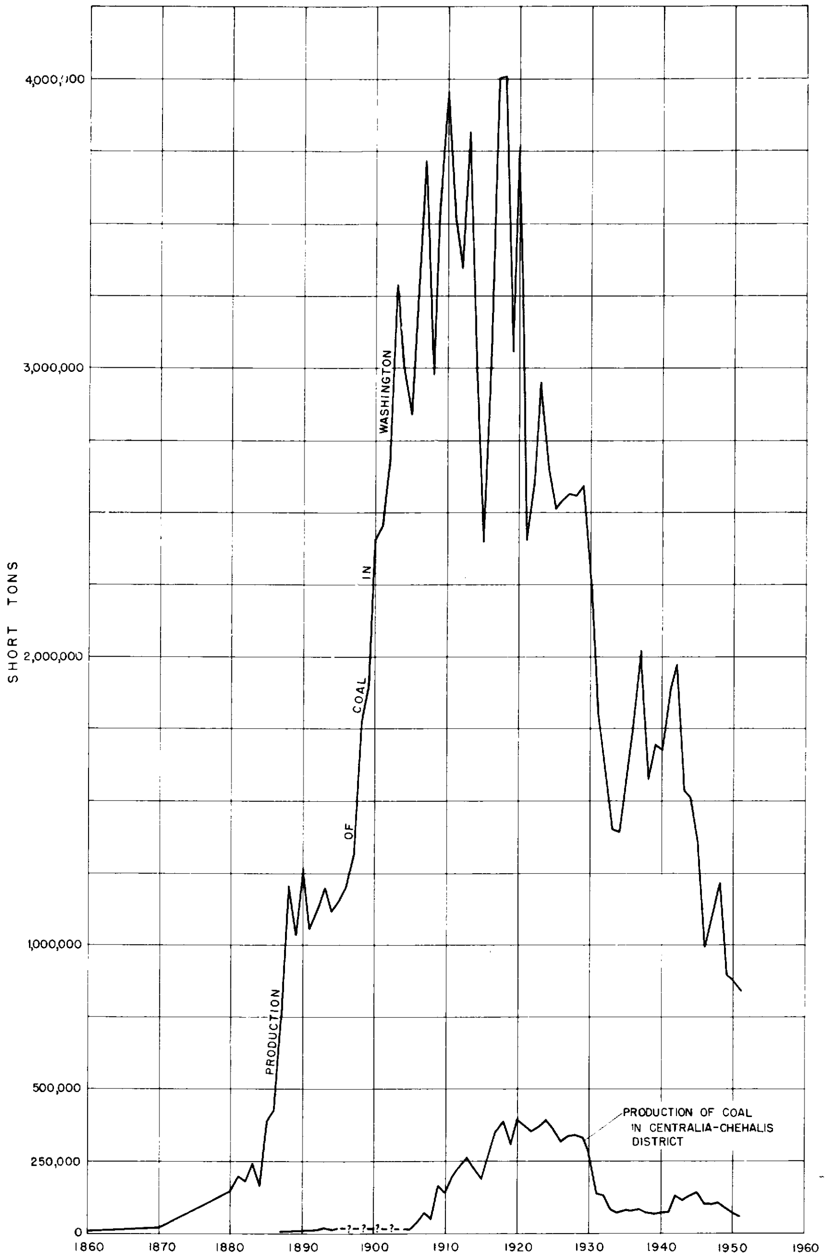

FIGURE 24.—Comparative statistics of coal production.

Mineral Resources of the United States issued by the U. S. Geological Survey and from the Mineral Yearbooks of the U. S. Bureau of Mines, and for the years since 1924 these data include only the production of mines shipping 1,000 tons or more annually.

In all, more than 9 million tons of coal has been mined from beds in the Centralia-Chehalis district from the beginning of mining to January 1, 1952. Of this amount, more than 7.5 million tons has been obtained from the Tono No. 1 bed; most of the remainder has been mined from the Mendota bed.

The available records of 58 mines that have operated in the district at various times in the past are given in the following table. Of this number only four, the Black Prince, Monarch No. 1, Stoker, and Tono, were in operation on January 1, 1952.

METHODS OF UNDERGROUND MINING

Most of the larger mines in the Centralia-Chehalis district have been slope mines, whereas in the smaller mines coal has been mined from "water-levels," or self-draining tunnels. In mines that have been operated in steeply dipping beds a water-level entry was usually first driven along the strike of the bed and chutes were driven up the dip from entry or haulageway. Later, when the coal above the water-level entry was exhausted, a slope would be driven down the dip of the beds, and gangways made off the main slope at various levels and on the strike of the beds. Only a limited amount of mechanical equipment has been employed in mining operations in this district. Electric hoists have been used in the slope mines to bring the mine cars to the surface, but horse or man power has been used in most of the smaller water-level mines to haul mine cars to the surface. Undercutting machines or conveyor equipment are not known to have been used in the district. The room-and-pillar method of mining has been used in the majority of the mines in the district; when the mine is abandoned commonly the pillars are removed, allowing the mine to cave.

Some of the coal produced from the smaller mines generally has been hand picked to remove rock impurities. The larger mines, such as the Tono, Monarch No. 1, Stoker, and Black Prince have installed equipment for washing and screening the coal. In some cases there has been considerable difficulty in removing partings of clay from the coal.

MINING PROBLEMS

Generally, conditions in the area are not favorable for mining. The roof of many of the coal beds is friable sandstone, making extensive timbering necessary in many of the mines. Often as much as 2 to 6 feet of top coal is left to support the roof. Ground water seeps into

Data on mines in the Centralia-Chehalis district, Washington

[Total production during 1951 according to the Washington State coal inspectors annual report: Black Prince No. 3, 12,457 tons; Monarch No. 2, 22,520 tons; Stoker, 6,480 tons; Tono, 11,018 tons]

Map No.	Name of mine	Location of portal				Type of mine	Name of coal bed	Average thickness of clean coal		Date mine abandoned	Direction and amount of dip	General remarks
		T. (N)	R.	Sec.	Fraction sec.			Feet	Inches			
1	Belle Slope	15	1W	34	NE¼SW¼	Slope and water level.	Smith	8	10	1949	14° NE	Many faults of small displacement in mine.
2	Black Badger	14	1W	6	NW¼NW¼	Water level	Upper Thompson.	8	5	1940	8° SE	Dip and strike variable; mine located in small southward-plunging syncline.
3	Black Bear	16	1W	31	SE¼NE¼	Slope	Black Bear	5	7	1912	3°–15° E	Dip flattens to the northeast; coal bed very lenticular and grades into carbonaceous shale to the east.
4	Black Cherry	16	1W	31	NE¼NE¼	Water level?	do	5 (?)		1930's	10° SE	Water-level rock tunnel probably driven to coal bed.
5	Black Jewel	16	1W	32	NW¼NW¼	Slope and water level.	do	4	10	1935	12° SE	Also known as Pleasant Hill mine. Disseminated pyrite in coal.
6	Black Prince No. 3.	15	1W	28	NW¼SE¼	Water level	Tono No. 1 (Black Prince).	11	9		Basin	Mine located in elongate basin; two abandoned portals located along western margin of basin. Present operations adjoin and include workings of Victory mine.
7	Boxer	15	2W	14	NE¼SE¼	do	Mendota	6	4	1940?	9° SE	Mine on lowest bed stratigraphically in this part of area.
8	Bucoda No. 1	15	1W	7	SE¼SW¼	Slope	Smith (Bagley)	6	5	1933	5° SE	Largest workings in NW¼ NE¼ sec. 18; small faults in mine.
9	Christian	15	2W	35	SW¼NW¼	Water level	Mendota	7?		1934?	16° SW	Also known as Holiday mine. Bed contains silicified logs.
10	Columbia	14	1W	10	NW¼	Slope and shaft	do	8	8	1949	4°–8° S	Also known as Smith No. 1 mine; horst along main slope; strike ranges from north to west. Rock slope driven to bed.
11	Columbia Collieries.	15	3W	32	NW¼NW¼	Water level and strip pit.	Tono No. 1 (Foran).	7	10	1930?	5° NE	Bed mined underground and later strip mined. Low dip due to proximity to fault.

12	Crescent No. 1	14	3W	22	SW¼SW¼	Slope	Mendota? (Crescent 10′).	12		1908?	40° S	Also known as Littell mine. Mine operated on lowest bed stratigraphically in this part of the area. Portal not found.
13	Crescent No. 2	14	3W	22	SW¼SW¼	Slope and water level.	Upper Thompson? (Crescent 8′).	6	9	1918?	30°? S	Also known as Brier Hill mine.
14	D and F	15	1E	18	NW¼SW¼	Water level	D and F	4	6	1946	14°–37° W	Mine near fault; dip steepens to east; fault in mine.
15	Empress	14	1W	8	NW¼SW¼	Shaft	Tono No. 1	9	3	1920	4° SW	Formerly called Bennight's mine; 90-foot vertical shaft to coal bed.
16	Eureka	14	2W	2	SW¼NW¼	Water level	Tono No. 1? (Foran).	6	5	1895?	87° S	Also known as China Creek mine.
17	Florence	14	2W	2	NE¼NW¼?	Slope and water level?	Mendota?	6?		1895	85°? S	First mine in district; operated originally as By-Joe mine in 1884.
18	Freeburn	15	1W	28	SW¼SW¼	Slope	Upper Thompson.	12	7	1922?	10° NE	Bed contains many small partings.
19	Gibson	14	2W	23	SE¼NW¼	Water level	Tono No. 1 (Sunshine).	6?		1908?	20°–30° N	On same bed as Salzer Valley King mine.
20	Golden Glow No. 1.	14	2W	23	SW¼SW¼	do	Golden Glow (Leonard).	4	6	1949	7°–17° SE	Fault 1,000 ft along main water-level entry. Mine operated as Wakefield Coal Co. from 1930–36.
21	Golden Glow No. 2.	14	2W	23	SW¼SW¼	Slope	Tono No. 1 (Sunshine).	7	1	1950	7° SE	Workings on same bed as Sunshine No. 1 mine, but dropped 20 feet by small westward-trending fault.
22	Great Western	16	2W	35	NE¼SW¼	do	Black Bear	3	6	1932	0°–2° N	Known as King mine and Scatter Creek mine in 1932. Bed nearly flat lying with minor folds and faults. Mine not operated between 1910 and 1931.
23	K and K	15	1W	34	NE¼SW¼	Strip pit	Big Dirty	17		1948	17° NE	Dirty partings throughout coal bed.
24	Kopiah	14	1W	9	SE¼SE¼	Slope	Mendota	8?		1914?	13° NE	Dip flattens to the northeast.
25	Leonard (Chehalis)	14	2W	28	NW¼SE¼	Water level and slope.	Golden Glow (Leonard).	5	7	1915?	20°–25° E	On bed about 75 feet stratigraphically above bed mined at Reliance mine; dip flattens to east.
26	Lincoln	14	2W	20	NE¼SE¼	Slope	Tono No. 1 (Superior).	7		1945	30° N	Northeastward-trending drainage tunnel joins main slope. Rank of coal is lignite. Operated by Superior Coal Co.
27	Lincoln Creek	15	3W	33	SE¼NW¼	Water level	Tono No. 1 (Foran).	8+(?)		1926?		Also known as Rainier, Galvin, or Rex mines.
28	Majestic	15	1E	18	SW¼SW¼	Slope	Upper Thompson.	10	5	1912	20°–45° W	Mine near fault zone; coal brecciated; many small partings in bed.

Data on mines in the Centralia-Chehalis district, Washington—Continued

[Total production during 1951 according to the Washington State coal inspectors annual report: Black Prince No. 3, 12,457 tons; Monarch No. 2, 22,520 tons; Stoker, 6,480 tons; Tono, 11,018 tons]

Map No.	Name of mine	Location of portal				Type of mine	Name of coal bed	Average thickness of clean coal		Date mine abandoned	Direction and amount of dip	General remarks
		T. (N)	R.	Sec.	Fraction sec.			Feet	Inches			
29	Mendota	14	1W	3	NE¼SW¼	Slope	Mendota	9	0	1926	0°–14° W	Dip flattens westward into the Mendota syncline; westward trending fault.
30	Monarch No. 2 (Fords Prairie).	15	2W	30	NE¼NE¼	do	Tono No. 1 (Foran).	7	4		18°–25° SW	Bed flattens down dip. Operated as Fords Prairie mine.
31	Non-Pareil	15	2W	29	SW¼SE¼	Slope and water level.	do	6	9	1944	48° SW	Also operated as People's and Majestic mines.
32	Northwestern	15	1W	18	NW¼NW¼	Slope	Smith	8?		1920?	7° SW	Adjacent to Bucoda mine, but separated by barrier pillar.
33	Old Monarch	14	1W	17	SE¼NE¼	Slope and water level.	Tono No. 1	7	7	1942	7°–12° SW	Dip flattens toward the southwest.
34	Penitentiary	15	2W	13	NE¼NE¼	do	Penitentiary	3	10	1895?	9° SW	First mine in area; operated by Federal prisoners. Also known as Seatco mine.
35	Penn-Bucoda No. 1.	15	1W	18	NW¼NW¼	Strip pit	Smith	8	8	1947	7° SE	Silicified logs and stumps found in bed.
36	Penn-Bucoda No. 2.	15	1W	18	SW¼NW¼	do	do	9	4	1947	5° SE	Silicified stumps and logs common; coal cut by several faults of small displacement.
37	Perth	15	2W	29	NW¼NW¼	Slope	Mendota	6	1	1910	20° SW	Mine operated on lowest bed in area; bed contains small thrust faults with displacements as much as 3 feet.
38	Potlatch	14	2W	3	NE¼NE¼	do	Tono No. 1?	6+		1912	76°? S	One of the China Creek mines; portal not located with certainty.
39	Quality	15	1W	8	SW¼NW¼	do	Penitentiary	3	8	1944	8° SE	Clean coal with few partings.
40	Reliance No. 1	14	2W	28	SW¼NE¼	Slope and water level.	Tono No. 1 (Superior No. 2).	6	8	1930's	32°–21° E	Operated by Chehalis Coal Co.; first bed below Leonard mine. Dip flattens to the east. Rank of coal is lignite.
41	Reliance No. 2	14	2W	28	SE¼NW¼	Slope	do	6	10	1938	45° NE	Rank of coal is lignite.
42	Richmond	15	2W	34	SW¼SW¼	do	Tono No. 1 (Foran).	7	9	1908	37°–70° SW	Dip flattens to the northwest.

43	Rosenthal	14	2W	29	SE¼NW¼	Slope?	Golden Glow? (Leonard).	4	4	1895?	40° SW	Earliest mine in vicinity of Chehalis. Also known as Loomis mine.
44	Royal	15	1W	30	NE¼SW¼	Water level and strip pit	Mendota	7	10	1944	12° NE	Silicified wood present. Bed mined underground and later strip mined.
45	Salzer Valley King.	14	2W	22	SE¼NE¼	Slope	Tono No. 1 (Sunshine).	5	8	1932	30° N	Also known as Howell or King mine. Oldest mine in Salzer Valley.
46	Sheldon	14	2W	33	SE¼NE¼	do	Tono No. 1 (Superior No. 2).	7	11	1920	33°–35° S	Rank of coal is lignite. Operated as Pacific Red Ash mine 1919–1920.
47	Skookumchuck	15	1W	8	NW¼NW¼	do	Mendota	7	10	1917?	14° SE	Mendota bed contains many partings in this area.
48	Smith No. 3	14	1W	10	NW¼NW¼	do	Smith	5	8	1934	5° W	Silicified fragments in bed; many lenticular partings.
49	Stoker	15	2W	29	NE¼SW¼	Slope	Tono No. 1 (Foran).	7	3		40°–25° SW	Dip flattens to southwest; some mining done on Upper Thompson bed by water-level entry. A 475-ft rock tunnel driven from surface to bed.
50	Sunshine No. 1	14	2W	23	NW¼SW¼	Slope and water level.	Tono No. 1 (Sunshine).	4	10	1936	5° W?	Operated by Wakefield Coal Co. on same coal bed as mined in Golden Glow No. 2 mine.
51	Sunshine No. 2	15	2W	13	NE¼NE¼	do	Penitentiary	3	10	1915	7° SE	One portal 400 ft. east of Penitentiary mine; other water-level portals in first canyon west of Penitentiary mine.
52	Superior No. 1	14	2W	29	NE¼SE¼	Water level	Upper Thompson? (Twin City).	8	8	1911?	38° SW	Mined only the upper bench of coal bed.
53	Superior No. 2	14	2W	29	SW¼NW¼	Slope	Tono No. 1 (Superior No. 2).	9	9	1926	32°–38° SW	Operated as the Murphy and Johnson mines. Mine abandoned owing to inability to control "quicksand" above the coal bed.
54	T and T	14	2W	23	SW¼SE¼	Water level	Tono No. 1 (Sunshine).	6		1948	38°–45° SW	Dip increases towards east; coal reported to have high sulfur content.
55	Tono	15	1W	20	SE¼NE¼	Slope and strip pit.	Tono No. 1	12–16			Basin	Closed basin complicated by normal faults which have a general west strike. Coal largely mined out in western part of basin. Strip pit operated on same bed. Also known as Hanaford mine. Operated by Strain Coal Co. in 1952.

Data on mines in the Centralia-Chehalis district, Washington—Continued

[Total production during 1951 according to the Washington State coal inspectors annual report: Black Prince No. 3, 12,457 tons; Monarch No. 2, 22,520 tons; Stoker, 6,480 tons; Tono, 11,018 tons]

Map No.	Name of mine	Location of portal				Type of mine	Name of coal bed	Average thickness of clean coal		Date mine abandoned	Direction and amount of dip	General remarks
		T. (N)	R.	Sec.	Fraction sec.			Feet	Inches			
56	Twin City	14	2W	29	SE¼NE¼	Slope	Upper Thompson? (Twin City).	9	9	1915?	40° SW	Mine operated on lower bench of coal bed.
57	Victory	15	1W	28	NW¼SE¼	do	Tono No. 1	11+		1927	Basin	Operations along southeast part of small elongate basin; old pillars now being removed by operations in Black Prince mine.
58	Wabash	15	2W	33	NW¼NE¼	Water level	Tono No. 1 (Foran).	9	5	1933	60° SW	A rock tunnel 1,175 feet long driven to reach Tono bed; mine caught fire and burned coal beds to exposures along railroad cuts.

most of the mines and continuous pumping is required to keep pace with inflow of water. Most of the mines fill with water a few weeks after pumping is discontinued. Although the faults in most of the mines have only a small amount of displacement, expensive and time-consuming work often is required to change the grade of the slope when a fault is reached. Many of the coal beds in the Centralia-Chehalis district are not minable under present economic conditions, owing to depth of burial, poor roof rock, high ash content, and poor quality of the coal.

STRIP MINING

Mining by stripping is generally not feasible in most of the district as the coal beds have steep dips and the overburden is too thick. But in the Tono basin in the southwestern part of T. 15 N., R. 1 W. the coal beds have low dips toward the basin and in many places the overburden is thin, and coal has been mined by stripping at the Tono mine in the NW¼ sec. 21, the Penn-Bucoda mine in the NW¼ sec. 18, and the Royal mine in the SW¼ sec. 30. The strip mining operation at the Tono mine was the largest in western Washington; at its maximum production about 21,000 tons of coal was mined per year.

A large tract of land in the Tono basin apparently favorable for strip mining is south of the line of outcrop of the Big Dirty bed in the S½ sec. 18 and the NW¼ sec. 19. In this area the Big Dirty bed, consisting of 15 to 20 feet of coal, has a low dip to the southeast essentially parallel to the slope of the hills.

Near the axes of the broader folds, areas suitable for the strip mining of coal may exist. However, extensive shallow drilling would have to be undertaken to outline these areas with certainty.

STRATIGRAPHIC POSITION AND CHARACTERISTICS OF THE BEDS

The coal beds of the Centralia-Chehalis district occur in the Skookumchuck formation of late Eocene age. The dip of these beds ranges from flat lying to vertical. In the more steeply dipping beds there is usually evidence of bedding plane slippage, and the coal is commonly brecciated. The coal beds are found in two distinct groups, in the upper part and lower part of the formation, separated by about 1,000 feet of non-coal-bearing rocks. At least 13 different coal beds have been mined in the mapped area. The stratigraphic position of these beds in the Skookumchuck formation is represented diagrammatically in figure 25, the thickness of measured sections of these beds is plotted graphically in plate 6, and the suggested correlations of coal beds in shallow test drilling are illustrated in plate 3. The outcrop lines of the principal coal beds are shown on the geologic map (pl. 1); however, these outcrop lines are largely interpretive because the coal is discontinuously exposed and generally obscured by landslide debris, soil, and vegetation.

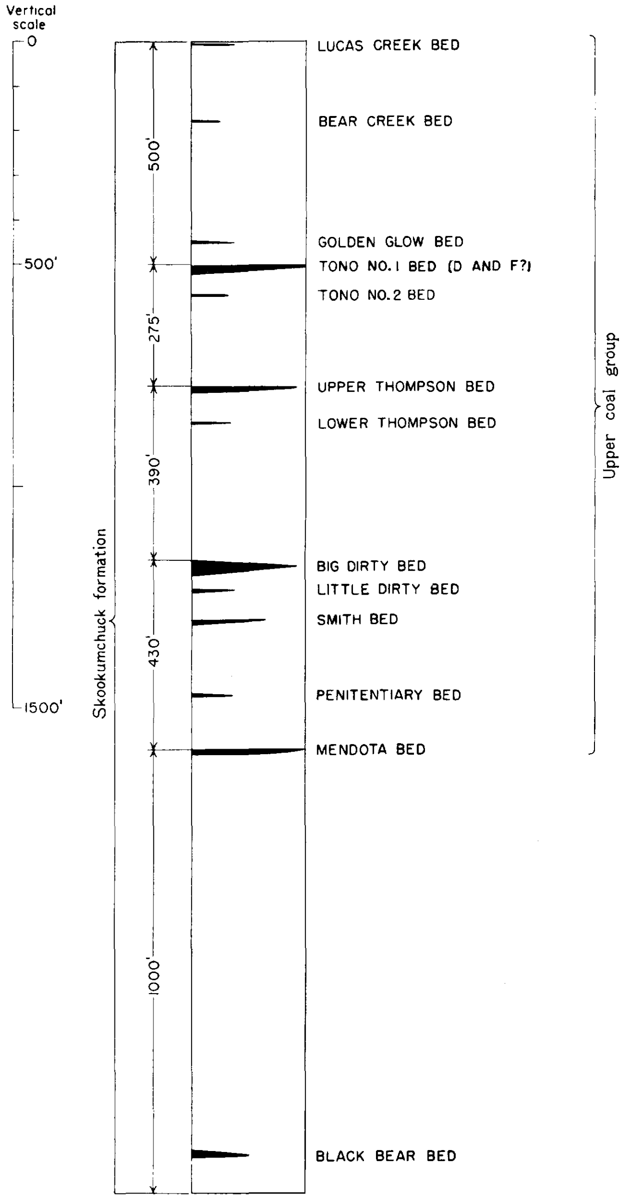

FIGURE 25.—Generalized section showing positions of principal coal beds in the Skookumchuck formation.

The coal beds derive their names from mines or geographic areas where they are particularly well exposed. However, it is a common practice for mine operators to refer to the coal beds by the name of the mines where the beds are worked. Therefore, the same bed often has been referred to by more than one name, giving rise to the probably erroneous belief that more than 13 coal beds are present in the mapped area.

LOWER COAL GROUP

The Black Bear bed is stratigraphically the lowest in the area mapped and is the only bed that has been mined in the lower coal group. Interpretation of drilling records of the Crescent test hole and Great Western Coal Co. diamond drill hole 1 suggests that a 4-foot coal bed overlies the Black Bear bed, and a 12- to 15-foot bed underlies it (pls. 3 and 4). However, as the Black Bear bed is the only bed in the lower coal group known to crop out, the existence of other commercial beds in this group is questionable.

The Black Bear bed is known from abandoned mine workings along the west flank of the Blumaer Hill syncline in secs. 31 and 32, T. 16 N., R. 1 W., from the Great Western mine in the SW¼ sec. 35, T. 16 N., R. 2 W., and from cores taken in U. S. Geological Survey drill holes *A* and *J*. It was also reported to have been penetrated in the Crescent test hole and Great Western drill hole 1. The bed is believed to underlie most of T. 15 N., R. 2 W.; a bed (1 foot, 7+ inches thick) measured in a flooded prospect in the SW¼ sec. 18 is tentatively correlated with the Black Bear bed. The Black Bear bed grades laterally within a short distance into carbonaceous siltstone in the Blumaer syncline. At the portal of the Black Bear mine, the bed contains 5 feet 7 inches of coal and is reported to be of less than minable thickness 1,500 feet east along the main slope. This lateral gradation of the Black Bear coal bed into carbonaceous shale is also made apparent by data obtained from Geological Survey drill hole *N* where a carbonaceous siltstone bed was penetrated in the same stratigraphic position as the Black Bear bed; whereas in drill hole 1 of the Great Western Coal Co. drilled about 1,600 feet to the northwest, this bed was reported to be 9 feet thick (pl. 3).

The Black Bear bed commonly consists of two layers of coal separated by a carbonaceous siltstone parting that ranges in thickness from a few inches to a foot. The bed occurs approximately 100 feet stratigraphically above the Northcraft volcanic rocks. It has an average thickness of 5 feet of coal where it has been mined in the Black Bear and Black Jewel mines, but to the east and south it thins to 2 feet 8 inches in Geological Survey drill hole *A*, 3 feet 10 inches at the Great Western mine, and about 2 feet in drill hole *J*. Analyses of the Black Bear bed characteristically show a high ash content of 18 to 25 percent and a sulfur content of 1.5 to 3 percent, which is high for coal in the Centralia-Chehalis district.

UPPER COAL GROUP

The upper coal group crops out along the flanks of most of the principal folds and is thickest and exposed best east of the Chehalis

River, where correlations between individual coal beds can be made with relative certainty. West of the Chehalis River the coal beds are thin or absent, and, in general, have lost the characteristics on which correlations are based in the eastern part of the area. The bed names used in the western part of the mapped area are, therefore, based largely upon the stratigraphic position of the coal bed rather than upon its physical similarity to a bed in the eastern part of the area. The beds in the upper coal group, listed from oldest to youngest, are: Mendota, Penitentiary, Smith, Little Dirty, Big Dirty, Lower Thompson, Upper Thompson, Tono No. 2, D and F, Tono No. 1, Golden Glow, Bear Creek, and Lucas. Coal has been mined from all these beds but most of the mining has been done in the Mendota and Tono No. 1 beds.

Mendota bed.—The Mendota bed is continuous throughout most of the eastern part of the area lying south of the Skookumchuck River and west of the Snyder Creek syncline, but it is not known to crop out south of the North Fork of the Newaukum River. In the western part of the area the Mendota bed crops out along the south side of the Lincoln Creek uplift and is tentatively recognized as far west as Geological Survey drill hole *X* on Deep Creek. On the north side of the Lincoln Creek uplift, the bed is known to crop out at one place on the south flank of a small flexure in the SW¼ sec. 14, T. 14 N., R. 3 W. The bed is thickest and best exposed in the vicinity of Kopiah and Mendota, where it was mined at the Mendota, Columbia, and Kopiah mines. In these mines the bed ranges from 9 to 11 feet thick and contains thin tuffaceous partings. The bed thins progressively east of Mendota and contains about 6 feet 4 inches of coal at the Boxer mine in sec. 14, T. 15 N., R. 2 W., and 5 feet of coal at the Perth mine in sec. 29, T. 15 N., R. 2 W. Throughout most of the eastern part of the area the Mendota bed has an average thickness of 7 to 8 feet and usually contains two distinct partings of carbonaceous shale near the middle. West of the Chehalis River on the north side of the Lincoln Creek uplift, in sec. 14, T. 14 N., R. 3 W., the Mendota bed contains about 3 feet 10 inches of coal. The bed has a greater thickness along the south side of the uplift and is reported by Landes and Ruddy (1903, p. 224) to contain 11 feet of coal at the Crescent No. 1 mine. The bed thins west of this mine, and 2 feet 10 inches of coal was cored in Geological Survey drill hole *X*, in sec. 25, T. 14 N., R. 4 W.

Thin irregular lenses of what locally is called "cannel" coal are present in the Mendota and Columbia mines. This "cannel" coal has a waxy luster and shows evidence of having been sheared. A piece of this coal is easily ignited with a match and burns with a long smoky yellow flame. An analysis of the "cannel" coal (as received) gives a heat value of 12,380 B. t. u., a volatile content of 58.7 percent, and a moisture content of 7.8 percent. This coal resembles the pitch coal described by Diller (1899, p. 370–376) from the Coos Bay coal field of Oregon. He concluded that the pitch coal is an asphalt because it shows none of the characteristics of coal. Petrographic studies by Schopf show the presence of mobile amorphous waxes in the coal. The "cannel" coal, therefore, may be formed by a concentration of these waxy substance along sheared zones in the Mendota bed.

Penitentiary bed.—The Penitentiary bed occurs only along the western edge of the Tono basin and northeastern flank of the Kopiah fault where it contains 35 to 48 inches of coal. Where measured, the bed contains several tuffaceous siltstone partings, each generally less than 3 inches thick. The bed is of minable thickness in the vicinity of Bucoda, where the Penitentiary, Sunshine No. 2, and Quality mines were operated in it. It is not recognized south of Geological Survey drill hole *I* or as far east as drill hole *D*. Three analyses of this coal show a high sulfur content, which ranges from 1.6 to 4.4 percent.

Smith bed.—The Smith bed crops out discontinuously throughout most of the eastern part of the district, but it is not known west of South Hanaford Creek. In the vicinity of Mendota the Smith No. 3 mine, Belle Slope mine, and several prospects were operated on this bed. The Smith bed was strip mined south of Bucoda at the Penn-Bucoda strip pits 1 and 2. Generally this bed is characterized by the presence of masses of bony or silicified logs and stumps, which are commonly rich in brown limonite or pyrite. Some of the coal contains finely-disseminated pyrite, which can be seen with the aid of a hand lens. The bed ranges in thickness from 5 to 12 feet, of which 4 feet 6 inches to 9 feet 6 inches is coal. The reduced thickness of the bed in several areas can be attributed to contemporaneous deposition of channel sands during the accumulation of the plant material. This is evident in the Smith No. 3 mine, where a 2- to 3-foot lens of sand grades laterally into coal within a short distance. In other areas where the Smith bed does not attain an average thickness of 8 or 9 feet, scour channels are present along the roof of the bed. In Geological Survey drill holes *B* and *D*, in the Belle Slope mine, and in the Penn-Bucoda strip pits, the Smith bed contains a 6- to 15-inch siltstone or sandstone parting near the roof of the seam; above this parting is 8 to 24 inches of coal. Mining operations in this bed are difficult in some areas because of the abundance of silicified logs and stumps.

Little Dirty bed.—The Little Dirty bed crops out in several areas along the western margin of the Tono basin; it probably does not extend farther east than the center of the Tono basin or farther south than Kopiah. The bed is exposed along the railroad cuts near Wabash

Junction, 1 mile north of Centralia, and was penetrated in Geological Survey drill hole *DD*, in sec. 29, T. 15 N., R. 2 W. Northeast of the Tono basin the bed was not found in drill hole *D*. The bed ranges from 2½ to 8 feet in thickness, but usually about one-half of this thickness consists of partings. A few tons of coal have been mined from this bed where it is exposed a short distance south of the Penn-Bucoda strip pit 1, in the NW¼ sec. 18, T. 15 N., R. 1 W.

Big Dirty bed.—The Big Dirty bed is the thickest coal bed and the most distinct stratigraphic marker in the Skookumchuck formation. It is characterized by abundant partings that are usually tuffaceous. This bed is exposed in prospect pits and crops out throughout most of the eastern part of the Centralia-Chehalis district but is not known to crop out west of the Chehalis River or south of Salzer Creek and the North Fork of the Newaukum River. There has been no large mining operation on this bed; strip mining, attempted at the K and K strip pit, proved unsuccessful because of numerous partings in the coal. There are many prospects on this bed in the SW¼ sec. 18, and in the NW¼ sec. 19, T. 15 N., R. 1 W., and immediately west of the Columbia mine. In the southwestern part of the Tono basin, the bed ranges in thickness from 18 to 40 feet, with partings composing one-third of the thickness. The bed attains its maximum thickness along the western margin of the Tono basin, where it consists of approximately 20 to 29 feet of coal. The Big Dirty bed thins rapidly near the margin of the basin of deposition of the coal-bearing rocks and also in the Thompson Creek and Snyder Creek synclines, where there is less than 5 feet of coal. The bed thins rapidly northeast of the Tono basin; only 9 feet of coal is present in Geological Survey drill hole *M* and 3 feet in drill hole *D*.

The Big Dirty bed is discontinuously exposed along the Kopiah fault and usually consists of two benches of coal separated by 8 to 10 feet of siltstone or sandstone. The bed maintains a rather uniform thickness along this fault; measuring 23 feet 7+ inches thick near Kopiah, 25 feet 6+ inches in SW¼ sec. 35, T. 15 N., R. 2 W., and 18 feet 10+ inches in sec. 29, T. 15 N., R. 2 W. Partings of siltstone and bone comprise more than half the thickness of the bed at the northernmost locality.

Lower Thompson bed.—The Lower Thompson bed is poorly exposed east of South Hanaford Creek, and it has been prospected only in a few places and penetrated in several test holes. Generally the bed is unfavorable for mining because of its lenticular character and many partings. The bed ranges in thickness from 7 to 11½ feet, with 3 to 10 feet of coal, and it attains its maximum thickness in the Tono basin and in the northern part of the Thompson Creek syncline. The bed thins to 3 feet of coal at Geological Survey drill hole *G* in sec. 30, T. 15 N., R. 1 E., in the southern part of the Thompson Creek syncline, and to 5 feet of coal in the SW¼ sec. 9, T. 14 N., R. 1 W., near the Kopiah mine.

Upper Thompson bed.—The Upper Thompson bed persists throughout most of the district, extending from the Majestic mine in the northeastern part of the area to the Crescent No. 2 mine in the southwestern part. The Freeburn, Black Badger, and Twin City mines also mined this bed and a small amount of coal has been taken from the Upper Thompson bed at the Stoker and Monarch mines. Two or three rather persistent tuffaceous siltstone partings commonly occur near the middle of the bed. These partings range in thickness from a few inches to about 1 foot, and in places grade laterally into bony coal in a short distance. The numerous thinner partings in the bed usually lens out in a few feet or grade into carbonaceous material. The lateral variation within the Upper Thompson bed is apparent from a comparison of the measurements made in sec. 30, T. 15 N., R. 1 E. (pl. 6, locs. 61–67). Where measured the bed ranges in thickness from 2 to 16 feet, averaging about 10 feet thick. It contains from 2 to 12 feet of coal, and averages about 8 feet of coal. In the southwestern part of the area, along the south side of the Lincoln Creek uplift, the bed thins from 11 or more feet at the Crescent No. 2 mine (in the SW¼ sec. 23, T. 14 N., R. 3 W.) to less than 3 feet thick 3 miles to the west. The bed is not known to be of commercial thickness along the north side of the uplift.

Tono No. 2 bed.—The Tono No. 2 bed is known from outcrops and drill holes in the Tono basin and in the north end of the Hanaford Creek Syncline, where it ranges in thickness from 4 to 5 feet. The bed has been mined on a small scale a quarter of a mile west of Tono. The Tono No. 2 bed has not been found outside the Tono basin, but it may be represented by the 2 to 4 feet of coal and bony coal found about 35 feet stratigraphically below the D and F bed in Thompson Creek Coal Co. drill holes 1, 2, and 3 (pl. 3).

D and F bed.—The D and F bed is present in the northeastern part of the area mapped but is of minable thickness only in the northern part of the Thompson Creek syncline. At the D and F mine the bed measures 5½ feet thick, with 4½ feet of coal. A correlative of the D and F bed was cored in Thompson Creek Coal Co. drill hole 1, where it contains 5½ feet of clean coal. Many tuffaceous partings increase the thickness of the bed toward the southern part of the Thompson Creek syncline, but in that area the thickness of coal is less than 18 inches. The D and F bed is not known to crop out west of the axis of the Snyder Creek syncline, but it may be a correlative of the Tono No. 1 bed exposed west of the Coal Creek fault.

Tono No. 1 bed.—The Tono No. 1 bed is the most continuous and extensively mined bed in the Centralia-Chehalis district. It also has coal of better quality than most beds in the district, and was the only bed being mined during January 1952; the Monarch No. 1, Stoker, Tono, and Black Prince mines operated in this bed. Eleven other mines have been worked on the Tono No. 1 bed (p. 106), and more than 7½ million tons of coal have been mined from it. Many drill records and data from underground workings throughout the Tono basin show that the bed maintains a uniform thickness of 16 to 18 feet; most is rather clean coal. The Tono No. 1 bed is not known with certainty east of the Tono basin, but core drilling in this area may reveal that the bed thins to the east and that it is a correlative of the D and F bed. West of the Tono basin the bed thins to a thickness of 8 to 12 feet in the vicinity of Centralia and 6 to 7 or more feet south of Salzer Creek in secs. 22, and 23, T. 14 N., R. 2 W., and 7 to 10 feet in the Chehalis anticline, north of Chehalis.

West of the Chehalis River the Tono No. 1 bed crops out along the north side of Lincoln Creek uplift and extends almost to the western edge of the mapped area. The bed has been mined at the Lincoln and Columbia Collieries mines and contains 5 to 6½ feet of coal. On the south side of the uplift the bed is tentatively mapped as far west as the center of sec. 20, T. 14 N., R. 3 W. Where measured along this flank the coal ranges from 5½ to 8 feet thick.

Golden Glow bed.—The Golden Glow bed occurs about 60 to 100 feet stratigraphically above the Tono No. 1 bed. The Golden Glow bed is known to crop out only along the flanks of the small anticline in Salzer Valley and in the Chehalis anticline. The bed was worked at the Golden Glow No. 1 mine in section 23, T. 14 N., R. 2 W., at the Leonard mine in section 28, and probably at the Rosenthal mine in section 29. The bed ranges in thickness from 4 feet 4 inches to 5 feet 7 inches; it contains 3 feet 7 inches of coal where measured in the Golden Glow No. 1 mine. A bed 4 feet 10 inches thick which contains 2 feet 3 inches of coal was penetrated in Geological Survey drill hole *K* in sec. 7, T. 14 N., R. 1 W., and is a correlative of the Golden Glow bed.

Bear Creek bed.—The Bear Creek bed crops out only in the southeastern part of the mapped area south of the North Fork of the Newaukum River along the southwest flank of the Mendota syncline. In outcrops along Bear Creek and its tributaries the bed ranges from 6 feet 5 inches to 3 feet 9 inches thick; however, less than 30 inches of coal was measured in this bed. A prospect was opened on this bed in the NE¼ sec. 26, T. 14 N., R. 1 W., and a few tons of coal were mined for local use. However, the coal proved to be too bony, and operations were abandoned.

Lucas bed.—The Lucas bed is stratigraphically the highest minable coal bed in the Centralia-Chehalis district. Where it was measured in the NE¼ sec. 12, T. 14 N., R. 2 W. and in the SE¼ sec. 36, T. 14 N., R. 1 W., it crops out 2 to 6 feet below the base of the Lincoln formation and ranges in thickness from 4½ to 5½ feet. The bed consists of bony coal with thin siltstone partings. The Lucas bed is believed to be continuous in the southeastern part of the area mapped, north of Lucas Creek, and it parallels the contact between the Skookumchuck formation and the overlying basaltic sandstone member of the Lincoln formation.

ESTIMATE OF RESERVES

The total reserves of coal remaining in the ground in the Centralia-Chehalis district on January 1, 1952, are estimated to be 3,544 million tons. These reserves are in beds 2.5 feet or more thick and are within 3,000 feet of the surface. The distribution of the reserves in the 13 townships of the district by individual beds and by categories according to the thickness of the bed, amount of overburden, and relative abundance of reliable information is shown in the following table.

To prepare the estimate a map was made of each coal bed; on this was plotted the outcrop of the bed, the location of all measured sections, and the drill holes that had been drilled into the bed. The boundaries between 1,000-, 2,000-, and 3,000-foot depths of overburden were also plotted on the bed maps, as were areas included in each thickness category, and areas included in the measured and indicated and inferred reserve categories.

The weighted average thickness was obtained within each category shown on the bed maps. Subtotals were prepared to show the reserves contained in beds falling within the following thickness ranges: more than 10 feet, 5 to 10 feet, and 2½ to 5 feet. Partings of more than ⅜ inch thick were omitted in determining the thickness of coal in individual measured sections. Beds composed of alternating thin layers of coal and partings were omitted if the partings made up more than half of the total thickness, or if the ash content exceeded 33 percent. The calculations of reserve tonnage were based on the weight of 1,770 short tons per acre-foot and were rounded off to the nearest 10,000 tons.

The reserve data are reported in two separate classes as follows: measured and indicated reserves and inferred. These classes are based on the relative abundance of reliable information that was available concerning the presence of coal at a distance from points of positive information and on knowledge of the continuity of the individual coal bed. Measured reserves were computed from dimensions revealed in outcrops, prospects, mine workings, and drill holes. The points of observation and measurements are no more than half a mile apart and the extent of the coal is so well defined that the reserve

Estimated coal in place in the Skookumchuck formation, Centralia-Chehalis district, Washington, January 1, 1952

[In millions of short tons]

Township and coal bed	Coal less than 1,000 ft below the surface										Coal 1,000–2,000 ft below the surface			Coal 2,000–3,000 ft below the surface			Remaining coal in place, less than 3,000 ft below the surface	Recoverable reserves, less than 3,000 ft below the surface, assuming 40 percent recovery
		Beds exceeding 120 in. in thickness		Beds 60–120 in. thick		Beds 30–60 in. thick					Beds exceeding 30 in. in thickness			Beds exceeding 30 in. in thickness				
	Area, in acres	Average thickness (feet)	Original reserves	Average thickness (feet)	Original reserves	Average thickness (feet)	Original reserves	Total original reserves	Depletion by mining, losses by burning in the mine or at the outcrop (tons)	Remaining reserves	Area, in acres	Average thickness (feet)	Total reserves	Area, in acres	Average thickness (feet)	Total reserves		
Measured and indicated reserves																		
T. 13 N., R. 2 W.																		
Golden Glow	56					4.5	0.44	0.44		0.44	1,250	3.5	7.74	393	3.0	2.09	10.27	4.11
Tono No. 1	41			8.0	.58			.58		.58	1,145	7.0	14.18	1,727	6.2	18.94	33.70	13.48
Total	97				.58		.44	1.02		1.02	2,395		21.92	2,120		21.03	43.97	17.59
T. 14 N., R. 1 W.																		
Lucas Creek	496					4.5	3.95	3.95		3.95							3.95	1.58
Tono No. 1	3,425			7.7	46.68			46.68	956,250	45.72	4,919	6.2	53.98				99.70	39.88
Upper Thompson	2,604					2.5	11.52	11.52		11.52							11.52	4.61
Lower Thompson	2,689			6.0	28.56			28.56	2,500	28.55							28.55	11.42
Big Dirty	3,060	15.8	85.58					85.58		85.58	525	14.0	13.01				98.59	39.43
Smith	3,130			5.8	32.13			32.13	137,500	32.00	1,457	8.0	20.63				52.63	21.05
Mendota	217	10.0	3.84					3.84		3.84	1,545	7.5	20.51	323	7.5	4.29	28.64	11.46
Do	2,377			7.7	32.39			32.39	2,239,500	30.15							30.15	12.05
Total	17,998		89.42		139.76		15.47	244.65	3,335,750	241.31	8,446		108.13	323		4.29	353.73	141.48

T. 14 N., R. 2 W.																		
Lucas Creek	459					3.0	2.44	2.44		2.44							2.44	.98
Golden Glow	5,039					4.4	39.24	39.24	28,500	39.21	3,263	4.5	25.99				65.20	26.08
Tono No. 1	12,258			7.5	162.73			162.73	987,750	161.74	4,769	7.8	65.84	1,266	7.5	16.81	244.39	97.76
Upper Thompson	7,761			7.0	93.68			93.68	13,500	93.67	3,668	7.4	48.04	103	6.5	1.19	142.90	57.16
Big Dirty	628	16.0	17.78					17.78		17.78	3,502	10.0	61.98				79.76	31.91
Mendota	581			5.0	5.13			5.13	53,750	5.08	1,855	4.5	14.77				19.85	7.94
Total	26,726		17.78		261.54		41.68	321.00	1,083,500	319.92	17,057		216.62	1,369		18.00	554.54	221.83
T. 14 N., R. 3 W.																		
Tono No. 1	695			7.8	9.60			9.60		9.60	1,473	5.5	14.34	1,534	5.0	13.57	37.51	15.00
Do	1,177					3.7	7.71	7.71		7.71							7.71	3.08
Upper Thompson	1,868			6.4	21.16			21.16	12,250	21.15	1,717	5.9	17.93	1,446	4.5	11.52	50.60	20.24
Mendota	604			5.7	6.09			6.09		6.09							6.09	2.44
Do	2,318					3.7	15.18	15.18		15.18	2,647	3.1	17.33	1,986	3.3	11.60	44.11	17.64
Total	6,662				36.85		22.89	59.74	12,250	59.73	5,837		49.60	4,966		36.69	146.02	58.40
T. 14 N., R. 4 W.																		
Mendota	220					3.0	1.17	1.17		1.17							1.17	.47
T. 15 N., R. 1 E.																		
D and F	215					4.5	1.71	1.71	15,000	1.70							1.70	.68
Upper Thompson	61	11.5	1.24					1.24		1.24							1.24	.49
Do	1,040			9.5	17.49			17.49		17.49							17.49	7.00
Lower Thompson	813			5.3	7.63			7.63		7.63							7.63	3.05
Total	2,129		1.24		25.12		1.71	28.07	15,000	28.06							28.06	11.22
T. 15 N., R. 1 W.																		
D and F	734					4.5	5.85	5.85		5.85							5.85	2.34
Tono No. 1	770	13.5	18.45					18.45	13,245,000	5.21							5.21	2.08
Tono No. 2	865					4.2	6.43	6.43		6.43							6.43	2.57
Upper Thompson	2,697	10.7	51.08					51.08	15,250	51.06							51.06	20.42
Do	2,136			9.5	35.92			35.92		35.92							35.92	14.37
Lower Thompson	2,385			6.0	25.23			25.23		25.23							25.23	10.09
Do	416					3.0	2.21	2.21		2.21							2.21	.89
Big Dirty	4,091	23.8	172.35					172.35		172.35							172.35	68.96
Little Dirty	612					3.0	3.25	3.25		3.25							3.25	1.30
Smith	4,949			6.6	57.81			57.81	565,250	57.25							57.25	22.90
Penitentiary	2,161					3.6	13.77	13.77	35,000	13.73							13.73	5.50
Mendota	8,124			6.6	94.90			94.90	10,000	94.89	2,828	6.2	31.04				125.93	50.37
Black Bear	52					2.5	.23	.23		.23							.23	.09
Total	29,992		241.88		213.86		31.74	487.48	13,870,500	473.61	2,828		31.04				504.65	201.86

Estimated coal in place in the Skookumchuck formation, Centralia-Chehalis district, Washington, January 1, 1952—Continued

[In millions of short tons]

Township and coal bed	Coal less than 1,000 ft below the surface										Coal 1,000–2,000 ft below the surface			Coal 2,000–3,000 ft below the surface			Remaining coal in place, less than 3,000 ft below the surface	Recoverable reserves, less than 3,000 ft below the surface, assuming 40 percent recovery
		Beds exceeding 120 in. in thickness		Beds 60–120 in. thick		Beds 30–60 in. thick					Beds exceeding 30 in. in thickness			Beds exceeding 30 in. in thickness				
	Area, in acres	Average thickness (feet)	Original reserves	Average thickness (feet)	Original reserves	Average thickness (feet)	Original reserves	Total original reserves	Depletion by mining, losses by burning in the mine or at the outcrop (tons)	Remaining reserves	Area, in acres	Average thickness (feet)	Total reserves	Area, in acres	Average thickness (feet)	Total reserves		
Measured and indicated reserves—Continued																		
T. 15 N., R. 2 W.																		
Tono No. 1	1,849			8.7	28.48			28.48	2,167,250	26.31	666	7.4	8.72				35.03	14.01
Upper Thompson	1,584			7.5	21.03			21.03		21.03	1,105	7.5	14.67				35.70	14.28
Big Dirty	1,486	13.1	34.47					34.47		34.47	1,565	7.5	20.77				55.24	22.10
Little Dirty	1,226					3.5	8.03	8.03		8.03	1,116	3.0	5.93				13.96	5.58
Penitentiary	335					3.6	2.13	2.13	1,250	2.13							2.13	.85
Mendota	3,614			6.5	41.58			41.58	22,000	41.56	1,846	5.6	18.30				59.86	23.94
Total	10,094		34.47		91.09		10.16	135.72	2,190,500	133.53	6,298		63.39				196.92	78.76
T. 15 N., R. 3 W.																		
Tono No. 1	2,533			7.4	33.18			33.18	155,000	33.02	6,578	6.9	80.34	298	5.0	2.64	116.00	46.40
Upper Thompson	1,228			5.0	10.85			10.85		10.85							10.85	4.34
Mendota	586					4.0	4.12	4.12		4.12	435	4.0	3.08				7.20	2.88
Total	4,347				44.03		4.12	48.15	155,000	48.00	7,013		83.42	298		2.64	134.06	53.62
T. 15 N., R. 4 W.																		
Tono No. 1	787					4.3	5.99	5.99		5.99	943	4.5	7.51	469	5.0	4.15	17.65	7.06

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T. 16 N., R. 1 W.																		
Black Bear	264					3.8	1.78	1.78	29,000	1.75							1.75	.70
T. 16 N., R. 2 W.																		
Black Bear	615					3.0	3.26	3.26	243,250	3.02							3.02	1.21
Total measured and indicated reserves	99,931		384.79		812.83		140.41	1,338.03	20,934,750	1,317.11	50,809		581.63	9,545		86.80	1,985.54	794.20
Inferred reserves																		
T. 13 N., R. 1 E.																		
Tono No. 1	2,732			5.0	24.17			24.17		24.17							24.17	9.67
T. 13 N., R. 2 W.																		
Tono No. 1														5,519	5.2	50.80	50.80	20.32
T. 14 N., R. 1 E.																		
Tono No. 1	1,910			5.5	18.59			18.59		18.59							18.59	7.43
Do	147			5.0	1.30			1.30		1.30							1.30	.52
Mendota	68	10.0	1.20					1.20		1.20							1.20	.48
Total	2,125		1.20		19.89			21.09		21.09							21.09	8.43
T. 14 N., R. 1 W.																		
Tono No. 1	680			6.0	7.22			7.22		7.22	3,372	6.0	35.81				43.03	17.21
Upper Thompson	453					2.5	2.01	2.01		2.01	9,028	2.5	39.95				41.95	16.78
Lower Thompson	437					4.0	3.09	3.09		3.09	9,398	4.4	73.19				76.29	30.51
Big Dirty	368	10.0	6.51					6.51		6.51	10,206	10.0	180.64				187.16	74.86
Do	254			5.0	2.25			2.25		2.25							2.25	.90
Little Dirty	82					2.5	.36	.36		.36							.36	.15
Smith	103			6.0	1.09			1.09		1.09	2,115	6.4	23.96	8,496	5.5	82.71	107.76	43.11
Penitentiary	113					3.0	.60	.60		.60							.60	.24
Mendota	1,440			8.5	21.67			21.67		21.67	2,179	7.5	28.93	8,550	7.5	113.50	164.09	65.63
Do	100					2.5	.44	.44		.44							.44	.18
Do	271	10.0	4.80					4.80		4.80							4.80	1.92
Total	4,301		11.31		32.23		6.50	50.04		50.04	36,298		382.48	17,046	13.0	196.21	628.73	251.49

Estimated coal in place in the Skookumchuck formation, Centralia-Chehalis district, Washington, January 1, 1952—Continued

[In millions of short tons]

Township and coal bed	Coal less than 1,000 ft below the surface										Coal 1,000–2,000 ft below the surface			Coal 2,000–3,000 ft below the surface			Remaining coal in place, less than 3,000 ft below the surface	Recoverable reserves, less than 3,000 ft below the surface, assuming 40 percent recovery
		Beds exceeding 120 in. in thickness		Beds 60–120 in. thick		Beds 30–60 in. thick					Beds exceeding 30 in. in thickness			Beds exceeding 30 in. in thickness				
	Area, in acres	Average thickness (feet)	Original reserves	Average thickness (feet)	Original reserves	Average thickness (feet)	Original reserves	Total original reserves	Depletion by mining, losses by burning in the mine or at the outcrop (tons)	Remaining reserves	Area, in acres	Average thickness (feet)	Total reserves	Area, in acres	Average thickness (feet)	Total reserves		
	Inferred reserves—Continued																	
T. 14 N., R. 2 W.																		
Golden Glow														1,595	4.0	11.29	11.29	4.52
Tono No. 1	1,316			7.8	18.17			18.17		18.17	706	8.0	10.00	461	8.0	6.53	34.70	13.88
Upper Thompson	3,886			6.9	47.46			47.46		47.46	3,590	6.8	43.21	2,490	7.0	30.85	121.52	48.61
Big Dirty											4,078	5.0	36.09				36.09	14.44
Mendota	689					2.5	3.04	3.04		3.04	11,500	3.4	69.20	3,850	3.2	21.80	94.04	37.61
Total	5,891				65.63		3.04	68.67		68.67	19,874		158.50	8,396		70.47	297.64	119.06
T. 14 N., R. 3 W.																		
Tono No. 1	1,871			7.5	20.21	4.0	2.46	22.67		22.67	918	7.7	12.51	318	6.0	3.38	38.56	15.42
Upper Thompson	2,289					3.6	12.68	12.68		12.68	1,871	5.0	16.55	947	6.5	10.89	40.12	16.05
Mendota	1,303					3.8	8.76	8.76		8.76	1,546	3.7	10.12	563	5.0	4.98	23.86	9.55
Total	5,463				20.21		23.90	44.11		44.11	4,335		39.18	1,828		19.25	102.54	41.02
T. 15 N., R. 1 E.																		
Lower Thompson	461			5.5	4.49			4.49		4.49							4.49	1.80
Big Dirty	1,986					4.0	14.06	14.06		14.06							14.06	5.63
Total	2,447				4.49		14.06	18.55		18.55							18.55	7.43

T. 15 N., R. 1 W.																		
D and F	689					3.5	4.27	4.27		4.27							4.27	1.71
Upper Thompson	705			9.5	11.85			11.85		11.85							11.85	4.74
Lower Thompson	1,423					4.0	10.08	10.08		10.08							10.08	4.03
Do	2,076			5.5	20.21			20.21		20.21							20.21	8.08
Big Dirty	2,397	11.9	50.38					50.38		50.38							50.38	20.15
Do	2,784					4.0	19.75	19.75		19.75							19.75	7.90
Little Dirty	754					2.5	3.34	3.34		3.34							3.34	1.34
Smith	5,778			6.2	63.41			63.41		63.41							63.41	25.36
Do	1,215					2.9	6.24	6.24		6.24							6.24	2.50
Penitentiary	2,266					3.0	12.03	12.03		12.03							12.03	4.81
Mendota	2,266					2.9	11.63	11.63		11.63							11.63	4.65
Black Bear	665					2.5	2.94	2.94		2.94							2.94	1.18
Total	23,018		50.38		95.47		70.28	216.13		216.13							216.13	86.45
T. 15 N., R. 2 W.																		
Black Bear	17,976					2.5	79.54	79.54		79.54							79.54	31.81
T. 15 N., R. 3 W.																		
Tono No. 1	796			7.5	10.57			10.57		10.57	5,332	5.6	52.85				63.42	25.37
Do	1,538					4.0	10.89	10.89		10.89							10.89	4.36
Upper Thompson											2,960	2.5	13.10				13.10	5.24
Mendota	579					3.0	3.06	3.06		3.06	1,893	3.0	10.05				13.11	5.24
Total	2,913				10.57		13.95	24.52		24.52	10,185		76.00				100.52	40.21
T. 15 N., R. 4 W.																		
Tono No. 1											2,629	3.7	17.22	269	4.0	1.90	19.12	7.65
T. 16 N., R. 1 W.																		
Black Bear	80					2.5	.35	.35		.35							.35	.14
Total inferred reserves	66,946		62.89		272.66		211.62	547.17		547.17	73,321		673.38	33,058		338.63	1,559.18	623.67
Grand total: measured, indicated and inferred	166,877		447.68		1,085.49		352.03	1,885.20	20,934,750	1,864.27	124,130		1,260.01	42,603		425.43	3,544.72	1,417.87

tonnages computed are judged to be accurate within 20 percent or less of the true tonnage. Less than 7 percent of the total estimated coal in the Centralia-Chehalis district is classified as measured. This figure is small because there has been little mining of the coal and the area lacks outcrops; however, expansion of mining and additional drilling will substantially increase the measured reserves. Indicated reserves were computed partly from specific measurements and partly from projection of visible data for no more than 2 miles from the outcrop or points of observations. The reserve table shows that approximately 50 percent of the total estimated reserves in the district is included in this class. Inferred reserves were based largely on broad knowledge of the geologic character of the individual coal beds and on the assumed continuity of the coal, for which there is geologic evidence. All the coal that lies more than 2 miles from the outcrop is included in the inferred class. About 43 percent of the total estimated coal reserves in the district is inferred reserves.

Measurements of the mined-out areas of the Tono, Mendota, Kopiah, and Old Monarch mines compared with the record of past productions for these same mines indicate that an average of at least 40 percent of the coal has been recovered in the areas mined. The remainder of the coal originally in the ground is lost in mining, or lost by fires underground or at the outcrop. Therefore, the recoverable reserves of coal in the Centralia-Chehalis district are estimated to be 40 percent of the coal remaining in the ground. New mining techniques may modify this recovery figure but the change presumably would not be large.

DESCRIPTION OF RESERVES BY TOWNSHIP

T. 16 N., R. 2 W.

Most of T. 16 N., R. 2 W. (pl. 6) is covered by glacial drift, and the only coal beds known to crop out are those of the lower coal group, which is exposed in the extreme southeastern part of the township. The only commercial coal bed known in this township is the Black Bear bed, mined at the Great Western mine in sec. 35. No outcrops of this bed are known, but it has been measured in the Great Western mine where it was 3 feet 9 inches thick.

Driller's logs of the Crescent test hole and the Great Western drill hole may be interpreted to show that a 4–foot coal bed overlies the Black Bear bed, and a 12– to 15–foot coal bed underlies it. These records are questioned, however, as the beds are not known to crop out.

Coal localities in T. 16 N., R. 2 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
Crescent	SW¼SE¼ sec. 32	Unnamed	4		Crescent well; depth, 526 ft; reported thickness.
GW-1	SE¼SW¼ sec. 36	do	4		Great Western drill hole 1; depth, 103 ft; reported thickness.
1	NE¼SW¼ sec. 35	Black Bear	3	9	Great Western mine; caved.
GW-1	SE¼SW¼ sec. 36	do	9		Great Western drill hole 1; depth, 231 ft; reported thickness.
Crescent	SW¼SE¼ sec. 32	Unnamed	15		Crescent well; depth, 791 ft; reported thickness.
GW-1	SE¼SW¼ sec. 36	do	12		Great Western drill hole 1; depth, 334 ft; reported thickness.

T. 16 N., R. 1 W.

Most of T. 16 N., R. 1 W. (pl. 6) is underlain by rocks older than the coal-bearing formation and coal is present only in secs. 31 and 32. The Black Bear bed, which is stratigraphically the lowest minable bed in the district, crops out along the west limb of the Blumaer Hill syncline, about 100 feet above the top of the Northcraft formation. This bed was mined at the Black Bear and Black Cherry mines in sec. 31 and at the Black Jewel mine in sec. 32. The bed is about 8 feet thick at the portal to the flooded Black Jewel mine and contains 4 feet 10 inches of coal. Approximately 1,500 feet to the east, along the main slope, the bed is reported not to be of minable thickness as it contains many partings of carbonaceous siltstone. In Geological Survey drill hole *A*, located about 1,500 feet east of the outcrop of the Black Bear bed, 3 feet 4 inches of coal was penetrated in this bed.

Coal localities in T. 16 N., R. 1 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
2	SE¼NE¼ sec. 31	Black Bear	5	11	Black Bear mine; caved. Inaccessible.
3	NW¼NW¼ sec. 32	do	8	2	Black Jewel mine; flooded. Bed exposed at portal.
GS-*A*	NW¼SW¼ sec. 32	do	3	8	Geological Survey drill hole *A*; depth, 183 feet.

T. 15 N., R. 4 W.

The Skookumchuck formation crops out in parts of secs. 23 and 24; and in secs. 25 and 26 (pl. 6). In this part of the mapped area most of the coal-bearing near-shore strata are largely supplanted by fine-grained offshore deposits and the coal beds are missing. The only bed known to crop out in the township is the Tono No. 1 bed. It is exposed only in NW¼NW¼ sec. 25, in a ravine where it is 5½ feet thick and contains about 5 feet of coal.

T. 15 N., R. 3 W.

In T. 15 N., R. 3 W. (pl. 6) the coal-bearing Skookumchuck formation crops out in both the southwestern and northeastern parts but Quaternary deposits conceal the coal beds in the latter area. The only bed of commercial significance exposed in this township is the Tono No. 1, which was seen only at the portal to the caved Columbia Collieries mine in sec. 32. This bed was also mined at the Lincoln Creek mine in sec. 33; however, this mine is now caved and the bed cannot be studied. The bed contains about 8 feet of coal at each of these mines. A coal bed 2 feet 8 inches thick is present about 50 feet stratigraphically below the Tono No. 1 bed, near the caved portal of the Lincoln Creek mine, but it is not of commercial value because of the high percentage of bone.

The Tono No. 1, Upper Thompson, and Mendota beds are probably present under the cover of outwash gravel and alluvium in the northeastern part ofthis township, for they crop out immediately to the east, in T. 15 N., R. 2 W.

Coal localities in T. 15 N., R. 3 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
5	N½NW¼ sec. 32	Tono No. 1 bed	8	5	Columbia Collieries; caved. Bed exposed near portal. Small area was strip mined.
6	SE¼NW¼ sec. 33	do	8		Lincoln Creek mine; caved. Inaccessible.
7	SE¼NW¼ sec. 33	Unnamed	2	8	Exposed near portal to Lincoln mine. Faced outcrop.

T. 15 N., R. 2 W.

T. 15 N., R. 2 W. (pl. 6) is largely underlain by strata of the Skookumchuck formation, but outcrops of coal beds are chiefly restricted to the southwestern and eastern parts of the township. In the central and northwestern parts of the township coal is known to crop out near the center of sec. 9, and is exposed in a prospect in the SW¼ sec. 18. The exposed thickness of coal in these two sections is less than 20 inches; however, 3 feet of coal has been reported to be present in the prospect in sec. 18. The stratigraphic position of these coal outcrops suggests they are in the lower coal group and may be equivalent to the Black Bear bed.

In the eastern part of the township the Big Dirty, Smith, Penitentiary, and Mendota beds of the upper coal group are discontinuously exposed along a broad, shallow syncline, which plunges eastward into the Tono basin. Exploitation in this part of the township has been mostly limited to prospects, but the Boxer mine on the Mendota bed in the SE¼ sec. 14 produced small quantities of coal for local use. The Penitentiary and Sunshine No. 2 mines in the NE¼ sec. 13 were operated on the Penitentiary bed. The Penitentiary mine is the oldest mine in this part of the district and was first operated by Federal prisoners. In the central part of the township the coal-bearing beds of the upper part of the Skookumchuck formation have been removed by erosion along the axial parts of the Tenino anticline, but in the southwestern part of the township the upper coal group is exposed along the downthrown southwestern side of the Kopiah fault. South of this fault, the Tono No. 1, Upper Thompson, Big Dirty, Little Dirty, and Mendota beds crop out in a narrow northwestward-trending belt. All of these beds have been prospected in this part of the township, but only the Tono No. 1 and the Mendota beds have been mined. Fords Prairie, Monarch No. 1, Stoker, Wabash, Non-Pareil, and Richmond mines are located on the Tono No. 1 bed, but in January 1951 only the Stoker and Monarch No. 1 mines were operating. The Perth mine, now abandoned, produced coal from the Mendota bed.

Coal beds of the upper coal series thin noticeably from east to west across the township. The Tono No. 1 bed, reported to be 12 feet 10 inches thick at the Richmond mine, thins to 7 feet 4 inches of clean coal at the Monarch No. 1 mine; a distance of about 3 miles.

Coal localities in T. 15 N., R. 2 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
8	SE¼NE¼ sec. 30	Tono No. 1	8		Monarch No. 1 mine. (Fords Prairie mine)
9	NE¼SW¼ sec. 29	do	7	10	Stoker mine.
10	SW¼SE¼ sec. 29	do	8	5	Non-Pareil mine; caved.
11	SW¼NE¼ sec. 33	do	11	3	Wabash mine; burned and caved.
12	SW¼SW¼ sec. 34	do	13	10	Richmond mine; caved.
13	NE¼NE¼ sec. 30	Upper Thompson	9	3	Prospect; just east of portal of Monarch No. 1 mine.
14	NE¼SW¼ sec. 29	do	11	10	Stoker mine; rock tunnel.
15	SW¼NW¼ sec. 29	Big Dirty	18	10	Poorly exposed in creek bed.
16	NW¼SW¼ sec. 35	do	25	6	Uppermost part of outcrop burned.
GS-*DD*	NE¼SW¼ sec. 29	Little Dirty	7	4	Geological Survey drill hole *DD*; depth, 30 ft.
17	NW¼NE¼ sec. 33	do	8	10	Railroad cut.
18	NW¼SW¼ sec. 35	do	10	4	Outcrop.
19	SE¼NW¼ sec. 13	Penitentiary	3	7	Prospect; caved.
20	SE¼NE¼ sec. 13	do	5	8	Outcrop in creek bed.
21	NE¼NE¼ sec. 13	do	4	9	Sunshine mine No. 2; caved.
22	NW¼NW¼ sec. 29	Mendota	6		Perth mine; brecciated by thrust faulting.
23	NW¼NW¼ sec. 29	do	7		Part of Perth mine(?); caved.
GS-*DD*	NE¼SW¼ sec. 29	do	4	1	Geological Survey drill hole *DD*; depth, 350 ft.
24	SW¼NE¼ sec. 35	do	8	8	Small prospect; bed displaced by east-west fault.
25	NE¼SE¼ sec. 14	do	7	9	Boxer mine, flooded. Bed exposed at portal.
26	NW¼SE¼ sec. 36	do	9	3	Outcrop, bed similar to that mined at Royal mine.
27	SE¼SE¼ sec. 36	do	9	6	Outcrop.
28	NE¼SW¼ sec. 18	Black Bear(?)	1	7	Prospect; flooded and partly caved.

T. 15 N., R. 1 W.

The Skookumchuck formation in T. 15 N., R. 1 W. (pl. 6) contains all the workable coal beds known in the Centralia-Chehalis district except the three above the Tono No. 1 bed. The coal-bearing rocks underlie most of the township and are absent only in the extreme northeastern and southeastern corners where older volcanic rocks crop out. The low flat-topped hills of the township are capped with gravels of the Logan Hill formation, which conceal large areas of coal-bearing rock. The Tono basin is the major structural feature in the area, and relatively detailed information concerning the distribution and character of the coal beds is available from test holes, prospects, and mines.

The Tono No. 1 bed is the most extensively mined bed in the township, and the Tono mine, which mined this bed, has produced more coal than any mine in the district. As of January 1952, the Tono and Black Prince were the only mines operating in this township; both worked Tono No. 1 bed.

The Tono No. 1 bed is composed of good quality coal and underlies most of sec. 21 and parts of secs. 20 and 28. In these sections the bed maintains a rather uniform thickness of 14 to 18 feet. In most localities the roof is friable sandstone, requiring 2 to 6 feet of coal to be left for support.

The Upper Thompson bed underlies much of the township but has been mined only at the Freeburn mine in sec. 28, where it contains more than 12 feet of coal. Elsewhere in the township this bed ranges from 6 to 13 feet thick.

The Big Dirty bed has been mined at the K and K strip pit in sec. 34, but this operation was abandoned because the bed dips steeply and contains many partings of tuffaceous siltstone. At this strip pit the Big Dirty bed contains about 17 feet of coal, but the thickness of coal varies throughout the township, ranging from 2 to 29½ feet, depending upon the amount of partings.

Strip mining has been employed at the Penn-Bucoda strip pits in sec. 18 where about 9 feet of coal was mined from the Smith bed. The Belle Slope mine in sec. 34 and several small prospects elsewhere in the township were located on this bed.

The Penitentiary bed is known from Geological Survey drill holes *B* and *I* and surface exposures in the western part of the township, and has been mined at the Quality mine in sec. 8. Where measured, it was 3 to 4½ feet thick. This bed is probably of minor commercial value as it contains more than 3 feet of coal in only a few places.

The Mendota bed underlies much of the township and was found in Geological Survey drill holes *B*, *D*, and *I*. It was mined at the Royal strip pit in sec. 30 and at the Skookumchuck mine in sec. 8. At both mines the bed contains about 8 feet of coal with several tuffaceous siltstone partings.

In addition to the beds listed above, the Lower Thompson and Little Dirty beds crop out and have been prospected at several localities but are usually of little commercial value. A coal bed 4½ feet thick was found at depth in Geological Survey drill hole *J*. This bed is tentatively correlated with the Black Bear bed, but it does not contain a commercial thickness of coal in this township.

Coal localities in T. 15 N., R. 1 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
TC-2	SW¼NE¼ sec. 14	D and F	4		Thompson Creek drill hole 2; depth, 167 ft.
TC-1	SE¼SE¼ sec. 11	do	5	8	Thompson Creek drill hole 1; depth, 182 ft.
WU-4	NE¼NE¼ sec. 14	do	3	6	Washington Union drill hole 4; depth, 201 ft.
GS-*E*2	NW¼SW¼ sec. 24	do	4	6	Geological Survey drill hole *E*2; depth, 521 ft.
29	NW¼NW¼ sec. 25	do	4		Outcrop.
30	SE¼NE¼ sec. 20	Tono No. 1	16	11	Tono mine.
31	NE¼NW¼ sec. 21	do	17	11	Strip pit. Tono mine.
32	NW¼SE¼ sec. 28	do	14	8	Black Prince mine.
33	SW¼NE¼ sec. 20	Tono No. 2	5		Prospect; caved. Bed exposed at portal.
WU-2	NW¼NW¼ sec. 21	do	4	1	Washington Union drill hole 2; depth, 71 ft.
34	SW¼SW¼ sec. 27	do	2	11	Outcrop in small ravine.
35	SW¼SW¼ sec. 28	Upper Thompson	16	8	Freeburn mine; caved.
WU-2	NW¼NW¼ sec. 21	do	5		Washington Union drill hole 2; depth, 275 ft.
WU-1	NW¼NW¼ sec. 21	do	11	6	Washington Union drill hole 1; depth, 241 ft.
TC-2	SW¼NE¼ sec. 14	do	12	4	Thompson Creek drill hole 2 363 ft.
TC-1	SE¼SE¼ sec. 11	do	13	4	Thompson Creek drill hole 1 depth, 398 ft.
WU-4	NE¼NE¼ sec. 14	do	11		Washington Union drill hole 4; depth, 426 ft.
TC-3	NE¼NW¼ sec. 24	do	11	5	Thompson Creek drill hole 3 depth, 191 ft.
WU-5	SE¼NW¼ sec. 24	do	11		Washington Union drill hole 5 depth, 62 ft.
36	NW¼NE¼ sec. 36	do	10	8	Prospect trench; caved.
37	NW¼NE¼ sec. 36	do	6	6	Do.
38	SW¼NW¼ sec. 20	Lower Thompson	6	4	Railway cut.
WU-2	NW¼NW¼ sec. 21	do	9		Washington Union drill hole 2; depth, 360 ft.
WU-1	NW¼NW¼ sec. 21	do	10	5	Washington Union drill hole 1; depth, 335 ft.
39	NE¼NW¼ sec. 33	do	5		Outcrop in small ravine.
40	NW¼NE¼ sec. 33	do	5	2	Outcrop.
41	SW¼NE¼ sec. 22	do	6	1	Outcrop in creek bed.
TC-3	NE¼NW¼ sec. 24	do	8	4	Thompson Creek drill hole 3; depth, 288 ft.
WU-5	SE¼NW¼ sec. 24	do	7	6	Washington Union drill hole 5; depth, 148 ft.
42	NW¼NE¼ sec. 36	do	9	4	Prospect trench; caved.
43	SE¼SW¼ sec. 18	Big Dirty	20	1	Prospect; good exposure.
GS-*C*2	NE¼NW¼ sec. 19	do	16	1½	Geological Survey drill hole *C*2; depth, 23 ft. Upper part of bed removed by erosion.
WU-3	SW¼NW¼ sec. 20	do	36	4	Washington Union drill hole 3; depth, 235 ft.
GS-*I*	SW¼SW¼ sec. 33	Big Dirty	38	6	Geological Survey drill hole *I*; depth, 146 ft.
WU-1	NW¼NW¼ sec. 21	do	22	3	Washington Union drill hole 1 depth, 651 ft.
44	SW¼SE¼ sec. 33	do	6	8	Outcrop; base unexposed.
45	SW¼NE¼ sec. 33	do	6	3½	Outcrop; base unexposed.
GS-*M*	NE¼SW¼ sec. 15	do	22	3	Geological Survey drill hole *M*; depth, 202 ft.
46	NW¼SW¼ sec. 34	do	7	7	Prospect trench; partly caved.
47	NE¼SW¼ sec. 34	do	25		K and K strip pit; flooded and caved.
GS-*D*	SW¼NE¼ sec. 15	do	8	4	Geological Survey drill hole *D*; depth, 139 ft.

Coal localities in T. 15 N., R. 1 W.—Continued

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
WU-5	SE¼NW¼ sec. 24	Big Dirty	7	1	Washington Union drill hole 5; depth, 438 ft.
48	NW¼NW¼ sec. 18	Little Dirty	5		Prospect; partly caved.
WU-3	SW¼NW¼ sec. 20	do	8	11	Washington Union drill hole 3; depth, 336 ft.
GS-*B*	NW¼SE¼ sec. 8	do	4	7	Geological Survey drill hole *B*; depth, 67 ft.
GS-*I*	SW¼SW¼ sec. 33	do	7	11	Geological Survey drill hole *I*; depth, 229 ft.
49	NW¼SW¼ sec. 23	do	3	4	Outcrop in creek bed.
50	SW¼NW¼ sec. 18	Smith	10		Penn-Bucoda strip pit, No. 2.
51	NW¼NW¼ sec. 18	do	9	9	Penn-Bucoda strip pit, No. 1.
GS-*B*	NW¼SE¼ sec. 8	do	9	7	Geological Survey drill hole *B*; depth, 125 ft.
GS-*I*	SW¼SW¼ sec. 33	do	7	7	Geological Survey drill hole *I*; depth, 288 ft.
52	NE¼SW¼ sec. 34	do	10	10	Belle Slope mine; flooded.
GS-*D*	SW¼NE¼ sec. 15	do	12	2	Geological Survey drill hole *D*; depth, 350 ft.
53	NW¼NW¼ sec. 26	do	11	2	Outcrop in ravine.
54	NW¼SW¼ sec. 26	do	7	8	Prospect.
55	NE¼NE¼ sec. 31	Penitentiary	4		Prospect; caved.
56	SW¼NW¼ sec. 8	do	4	6	Quality mine, caved. Bed exposed at portal.
GS-*B*	NW¼SE¼ sec. 8	do	4	5	Geological Survey drill hole *B*; depth, 291 ft.
GS-*I*	SW¼SW¼ sec. 33	do	6	10½	Geological Survey drill hole *I*; depth, 499 ft.
57	NE¼SW¼ sec. 30	Mendota	10	3	Royal strip pit; bed poorly exposed.
58	NW¼NW¼ sec. 8	do	9	1	Skookumchuck mine; caved.
GS-*B*	NW¼SE¼ sec. 8	do	9	4	Geological Survey drill hole *B*; depth, 441 ft.
GS-*I*	SW¼SW¼ sec. 33	do	10	1	Geological Survey drill hole *I*; depth, 625 ft.
GS-*D*	SW¼NE¼ sec. 15	do	7	9	Geological Survey drill hole *D*; depth, 537 ft.
GS-*J*	NE¼SW¼ sec. 30	Black Bear	4	6	Geological Survey drill hole *J*; depth, 991 ft.

T. 15 N., R. 1 E.

All except the southwestern part of T. 15 N., R. 1 E. (pl. 6) is underlain by rocks older than the coal-bearing formation. The upper coal group crops out along the southern parts of the Thompson Creek and Snyder Creek synclines. Only three minable coal beds are believed to be present in this township as the beds in the lower part of the upper coal group thin and decrease in value east of the Tono basin. In this township the coal-bearing rocks onlap older volcanic flows and coarse-grained clastic rocks, which crop out east of Thompson Creek. They probably occupy the same stratigraphic position as the lower part of the upper coal group farther west.

Considerable prospecting but little exploitation work has been done in secs. 18, 30, 31, and 32. Only two small mines operated in this area; the D and F mine on the D and F bed, and the Majestic mine on the Upper Thompson bed, both in sec. 18. The D and F bed was measured at one locality and contained more than 5 feet of coal. This bed may be a correlative of the Tono No. 1 bed to the west. The Upper Thompson bed crops out and has been prospected at many points; 17 measurements have been made on this bed, which ranges from about 8 to 16 feet thick. The bed usually contains many tuffaceous siltstone partings which would make mining operations difficult. Good quality coal is found in this bed in sec. 31, but it has not been mined because of the inaccessibility of the area.

The Lower Thompson and the Big Dirty beds were measured at several localities along the east limb of the Thompson Creek syncline, and although the beds range in thickness from 6½ to a little more than 7 feet they contain abundant partings and are of little commercial value. However, in the extreme eastern part of the township, along the west limb of Snyder Creek syncline, these beds are probably of better quality.

Coal localities in T. 15 N., R. 1 E.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
59	NW¼SW¼ sec. 18	D and F	5	7	D and F mine. Flooded, difficultly accessible.
60	SE¼SW¼ sec. 18	Upper Thompson	12	9	Barber prospect. Trench located south of portal of Majestic mine.
61	NE¼SW¼ sec. 30	do	9	1	Outcrop in small ravine.
62	NE¼SW¼ sec. 30	do	12	2	Prospect tunnel, not located with certainty. Inaccessible.
63	NW¼SW¼ sec. 30	do	10	2	Good exposure along Snyder Creek.
64	NW¼NE¼ sec. 30	do	12	6	Prospect tunnel. Inaccessible.
65	NW¼SE¼ sec. 30	do	8	11	Faced outcrop in ravine.
GS-*G*	NW¼SE¼ sec. 30	do	10	5	Geological Survey drill hole *G*, depth, 271 feet.
66	NW¼SE¼ sec. 30	do	11	11	Prospect. Faced outcrop.
67	SW¼NE¼ sec. 30	do	8	9	Prospect. Inaccessible.
68	SE¼NE¼ sec. 31	do	9	5	Prospect. Faced outcrop.
69	SE¼SE¼ sec. 31	do	12	1	Outcrop in ravine.
70	SE¼SE¼ sec. 31	do	10	8	Outcrop, well exposed.
71	NE¼NE¼ sec. 31	do	10		Prospect, flooded. Base not exposed.
72	NW¼SW¼ sec. 32	do	8	4	Faced outcrop. Top not exposed.
73	NW¼SW¼ sec. 32	do	13	11	Faced outcrop; base not exposed.
74	NE¼NW¼ sec. 32	do	16	2	Poor outcrop; measurement uncertain.
75	SE¼NW¼ sec. 32	do	10	1	Prospect trench. Base not exposed.
GS-*G*	NW¼SE¼ sec. 30	Lower Thompson	6	10	Geological Survey drill hole *G*; depth 352 feet.
76	NE¼SW¼ sec. 32	do	6	5	Prospect. Base not exposed.
77	NW¼SE¼ sec. 32	Big Dirty	7	2	Outcrop. Dirty coal and bone.

T. 14 N., R. 4 W.

Strata of the Skookumchuck formation that crop out in T. 14 N., R. 4 W. (pl. 6) are composed largely of offshore marine rocks, and only one coal bed of commercial thickness is known. A bed 5 feet 3 inches thick was cored in Geological Survey drill hole *X*, at a depth of 230 feet, and it is tentatively correlated with the Mendota bed. It has not been observed at the surface, but a caved prospect about 1,000 feet north of drill hole *X* is probably located on the bed. No coal beds of commercial thickness were found west of Deep Creek and this creek marks the approximate western boundary of minable coal in the southwestern part of the mapped area.

T. 14 N., R. 3 W.

Correlation of coal beds exposed in T. 14 N., R. 3 W. (pl. 6) with those that crop out east of the Chehalis River can be only tentatively made, as outcrops of coal are rare and many of the beds have lost their identifying physical characteristics. Therefore, names of the coal beds in T. 14 N., R. 3 W. have been assigned on the basis of their stratigraphic positions.

Strata of the Skookumchuck formation are exposed throughout most of this township; however, these beds are largely offshore marine facies occurring in the lower part of the formation and coal beds of commercial thickness are found only in the near-shore facies in the upper part of the formation that crops out along the flanks of the Lincoln Creek uplift. Many of the coal beds exposed west of the Chehalis River are not of commercial thickness because they thin and grade westward into fine-grained clastic rocks.

The Tono No. 1 bed crops out only along the south side of the Lincoln Creek uplift and has been prospected in secs. 22 and 23. This bed is 6½ feet thick where measured in a tributary to Coal Creek in the SW¼ sec. 23, and is 4½ feet thick 1 mile farther west in the SW¼ sec. 22; west of this point the bed is too thin to be mined. The Tono No. 1 bed has been inferred as being present north of the Salzer Creek fault in secs. 23 and 24, and along the north side of the Lincoln Creek uplift in secs. 3, 11, 12, and 13, however, no outcrops were seen in these areas as the bed is covered by Quaternary deposits and alluvium.

The Upper Thompson bed was observed only in exposures along the south side of the Lincoln Creek uplift where it has been prospected and mined in secs. 22 and 23. On the north side of the uplift in the SW¼ sec. 13, a caved prospect is probably on the Upper Thompson bed; its reported thickness is 5 feet. Along the south side of the uplift, the Upper Thompson bed contains about 7 feet of coal where measured in sec. 23, and a similar thickness has been reported from the Crescent No. 2 mine in the SW¼ sec. 22. At both these localities the bed contains several thick siltstone partings which limit its commercial use.

Coal has been mined from the Mendota bed at the Crescent No. 1 mine in sec. 22, and this bed is also known from incomplete exposures near Coal Creek. The bed is reported to contain 12 feet of clean coal at the Crescent mine and is characterized by many tuffaceous siltstone partings. The only exposure of the Mendota bed on the north side of the uplift is a prospect in sec. 14; at this locality the bed contains only about 4 feet of coal.

Coal localities in T. 14 N., R. 3 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
78	SW¼SW¼ sec. 22	Tono No. 1	4	8	Also known as "6-foot bed" at Crescent mine.
79	SW¼SW¼ sec. 23	do	6	6	Outcrop; clean coal.
80	NE¼SW¼ sec. 20	Upper Thompson	2	7	Outcrop; correlation questionable.
GS-*CH*3	NW¼SE¼ sec. 20	do	2	4	Geological Survey drill hole *CH*3; depth 142 feet.
81	SE¼SE¼ sec. 20	do	3	4	Outcrop; little value.
82	SW¼SW¼ sec. 22	do	9	7	"8-foot bed" at Crescent No. 2 mine.
83	SW¼SW¼ sec. 23	do	2	11	Outcrop; many partings.
84	SW¼SW¼ sec. 23	do	11		Outcrop partially exposed.
85	NE¼SE¼ sec. 20	Mendota	4		Outcrop; dirty bed.
86	SW¼SW¼ sec. 22	do	12	10	"10-foot bed" at Crescent No. 1 mine. Not exposed.
87	SW¼SW¼ sec. 23	do	7		Outcrop, incompletely exposed; pumiceous partings.
88	SE¼SW¼ sec. 23	do	7	10	Outcrop. Same bed as locality No. 87; partially exposed.
89	NE¼SW¼ sec. 14	do	5	8	Flooded prospect. Low dip near anticlinal axis.

T. 14 N., R. 2 W.

The coal-bearing Skookumchuck formation is exposed in three separate areas in T. 14 N., R. 2 W. (pl. 6) : in the northeastern part, along the Kopiah fault; in the vicinity of Salzer Creek; and in the vicinity of Coal Creek. Five major coal beds have been recognized in this township and these beds have been prospected and mined at many localities; however, most of this work was undertaken in the early 1900's and many of the openings on the beds are now caved.

COAL IN THE NORTHEASTERN PART OF THE TOWNSHIP

The upper coal group trends in a northwesterly to westerly direction across the northeastern part of the township, roughly paralleling the trace of the Kopiah fault. The dip of the beds is nearly vertical along the south side of the fault, but the beds have a gentler dip north of the fault and in sec. 12, which is about a mile south of the fault. The area has been well prospected and many small water-level mines have excavated the beds in secs. 2, 3, and 12. However, only a few truck loads of coal have been mined in this area during recent years. The three largest mines in this part of the township are the Florence and Eureka mines, in sec. 2, and the Potlatch mine in sec. 3. Exposures of coal beds are rarely found because their outcrops have been mined or prospected, and these openings are now caved. The Potlatch and the Eureka mines apparently worked the Tono No. 1 bed, which is 8½ feet thick where measured and contains 6½ feet of coal.

The Upper Thompson bed is not known with certainty in this area, but a partly exposed bed in a similar stratigraphic position was measured at one point and contained 3 feet 2 inches of brecciated coal. No outcrops of the Big Dirty bed were found in the northeastern part of the township as this bed is cut out by the Kopiah fault in secs. 1, 2, and 3. The Big Dirty bed is undoubtedly present at depth south of the fault as it crops out immediately north of the township. Culver (1919, p. 77) described a prospect containing 5½ feet of coal in the NE¼ sec. 3; this bed is tentatively correlated with the Upper Thompson bed. The Florence mine is believed to be on the Mendota bed, which is exposed north of the Kopiah fault. This bed, which has been seen in two localities, contains 5 feet of coal and is characterized by two 6- to 12-inch partings of tuffaceous siltstone.

The Lucas bed crops out a few feet below the base of the Lincoln formation and has been prospected at several places in the NE¼ sec. 12. A few wagon loads of coal were mined on the Towner place; however, this bed contains only 3 feet of coal and is of little commercial value.

COAL IN THE VICINITY OF SALZER CREEK

A small northwest plunging anticlinal fold brings the coal beds to the surface in secs. 22 and 23. The Golden Glow bed, which was mined at the Golden Glow No. 1 mine, was measured at one locality and contained 3½ feet of coal in two benches, separated by 12 inches of bone. This bed has been prospected extensively in the NW¼SW¼ sec. 23 where it occupies a small shallow basin. The overburden in this area is thin, and a part of the Golden Glow bed may be minable by stripping. Most of the mining was on the Tono No. 1 bed, and the Salzer Valley King, Gibson, Sunshine No. 1, T and T, and Golden Glow No. 2 mines worked this bed in the past. The Tono No. 1 bed was measured at 3 localities and consists of 5 to 7 feet of coal. The coal is of good quality, but at the T and T mine it was reported to have a sulfurous odor when burned. There was no mining in this part of the township in 1951.

COAL IN THE VICINITY OF COAL CREEK

An area of rather extensive mining was formerly centered about the lower valley of Coal Creek, in secs. 20, 28, 29, and 33. The mines in this area were favorably located in that they were less than 5 miles from markets in Centralia and Chehalis; however, in January 1952 none of the mines in this area were in operation. The coal beds of the upper coal group are exposed along the limbs and southeastward plunging nose of the Chehalis anticline.

A coal bed 5½ feet thick and containing 4 feet 7 inches of coal was found in Geological Survey drill hole *V* and is believed to be equivalent to the Golden Glow bed. This bed was also mined at the Leonard mine in sec. 28.

The Tono No. 1 bed has been mined at the Superior No. 2, Reliance, Sheldon, and Lincoln mines, and varies in thickness from 7 to 10 feet. The bed has an average thickness of about 7 feet of clean coal and contains few or no partings. Good exposures of this bed were measured at a prospect about 800 feet east of the Lincoln mine in sec. 20 (loc. 93) and in an unnamed slope in sec. 28 (loc. 94). The Sheldon mine in sec. 33 is located on the Tono No. 1 bed, in the upthrown block south of the Chehalis fault.

The Superior No. 1 and Twin City mines in sec. 29 were operated on the Upper Thompson bed, which in this area contains more than 8 feet of coal with many thin siltstone partings. At the Twin City mine only the lower part of this bed was mined. The Upper Thompson bed has also been measured at an outcrop in sec. 28 and at this locality the upper part of the bed consists chiefly of bony coal.

No outcrops of the Mendota bed have been observed in the vicinity of Coal Creek, but the presence of this bed is inferred because it occurs in nearby areas.

Coal localities in T. 14 N., R. 2 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
90	Center NE¼ sec. 12	Lucas	4	1	Towner prospect; caved.
GS-V	NE¼NE¼ sec. 33	Golden Glow	5	5	Geological Survey drill hole V; depth, 560 ft. Correlation tentative.
91	SW¼SW¼ sec. 23	do	4	10	Golden Glow No. 1 mine; caved.
92	SW¼NW¼ sec. 29	Tono No. 1	9	10	Superior No. 2 mine; caved.
93	SE¼SE¼ sec. 20	do	7	4	Prospect. Accessible.
94	SW¼NE¼ sec. 28	do	7	5	Unnamed slope near Reliance No. 1 mine. Accessible.
95	NW¼SE¼ sec. 28	do	6	11	Reliance No. 1 mine; caved.
96	SE¼NE¼ sec. 33	do	8	3	Sheldon mine; caved.
97	SE¼NE¼ sec. 22	do	5	10	Salzer Valley King mine; caved.
98	SW¼SW¼ sec. 23	do	7	2	Golden Glow No. 2 mine; flooded.
99	SW¼SW¼ sec. 23	do	5	2	Sunshine No. 1 mine; caved.
100	SW¼NW¼ sec. 2	do	8	6	Prospect; accessible.
101	SE¼SW¼ sec. 23	do	6	3	T and T mine; partly caved.
102	SE¼NE¼ sec. 29	Upper Thompson	9	8	Twin City mine; caved. Mined lower part of bed.
103	NE¼SE¼ sec. 29	do	4	5	Superior No. 1 mine; caved.
104	SE¼NW¼ sec. 28	do	9	5	Outcrop in canyon west of Reliance No. 1 mine. Accessible.
105	NE¼NE¼ sec. 3	do	6	6	Prospect described by Culver; correlation tentative.
106	SE¼NW¼ sec. 2	do	5	7	Outcrop partly exposed. Brecciated.
107	NW¼NW¼ sec. 2	Mendota	7	1	Outcrop inaccessible; many partings.
108	NW¼NE¼ sec. 1	do	8	2	Prospect; coal weathered.

T. 14 N., R. 1 W.

The upper coal group is thickest in the northwestern part of the T. 14 N., R. 1 W. (pl. 6) and 10 different coal beds are exposed along the limbs of the Mendota syncline and the southwestern side of the Kopiah fault. The coal-bearing rocks are folded into narrow northwestward-trending anticlines and somewhat broader synclines. Movement on the Kopiah reverse fault, which trends diagonally across the township and follows the axis of a former anticline, cuts out a part of the upper coal series and steepens the dip of the beds along the downthrown side.

The Lucas and Bear Creek beds, which occur near the top of the upper coal group, crop out and have been prospected in the extreme southwestern part of the township. The outcrops of coal beds are generally inaccessible, but detailed examinations were made at several localities on the south side of the valley of the Newaukum River in secs. 25 and 26, and along Bear Creek in secs. 26 and 36. A few tons of coal have been mined from these beds by the local ranchers for fuel, but the nature of the beds examined indicates the coal is of subcommercial value.

The Tono No. 1 bed crops out south of the Kopiah fault but has been removed by erosion north of the fault except in the down-faulted block south of the North Fork of the Newaukum River. This bed has an average thickness of 9½ feet, which is largely good quality coal. The Old Monarch mine in sec. 17 was the largest mine in this township to operate on the Tono No. 1 bed. The Empress mine in sec. 8 also worked the Tono No. 1 bed, and Geological Survey drill hole *K* just northwest of this mine penetrated the bed. The only mining done on the Tono No. 1 bed south of South Hanaford Creek was at the Shaeffer prospect in sec. 26; the bed is well-exposed in the stream bed of the Newaukum River in this same section.

The Upper Thompson bed is exposed in a few places along the southwest side of the Kopiah fault and has been worked at the Black Badger mine which is located in a small syncline in sec. 6. The bed is a little more than 10 feet 5 inches thick in this mine and contains 7½ feet of coal. The Lower Thompson bed also occurs along the southwest side of the Kopiah fault but has not been mined because of its poor quality. Only several prospects in sec. 9 are known to be on this bed.

The Big Dirty bed is one of the most widespread beds in this township and its physical characteristics make it the best stratigraphic marker in the upper coal group. No mines are located on this bed, but several prospects near Mendota and Kopiah tested it. The total thickness of the bed is as much as 23 feet 7 inches; however, about one-half of this thickness is partings. Some coal was mined at the Gumbo prospects in sec. 10, and a part of the bed may be strippable in this area as the overburden is probably thin.

The Smith No. 3 mine, immediately south of Mendota, worked the Smith bed. In this mine the bed varied considerably in thickness, owing to channelling in the upper part of the bed. Many small faults offset the bed and bony masses rich in limonite or pyrite commonly occur in the coal.

The Mendota bed in this area supported two of the largest mines in the Centralia-Chehalis district, the Mendota and Kopiah mines.

Between these two mines, the Columbia mine also operated on the same bed. Where measured, the bed has an average thickness of about 10 feet, mostly coal. More coal has been mined from this bed than any other coal bed in the township. The bed commonly contains disseminated tuffaceous material that forms an undesirable fused slag in some types of coal stokers.

Coal localities in T. 14 N., R. 1 W.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
109	SW¼NW¼ sec. 25	Lucas	6	3	Accessible. Faced outcrop in small ravine.
110	NE¼SE¼ sec. 36	do	5	8	Outcrop; somewhat difficult to reach.
GS-*K*	NE¼SE¼ sec. 7	Golden Glow?	4	10	Geological Survey drill hole *K*, depth, 23 ft.
111	SE¼NE¼ sec. 26	Bear Creek	3	9	Small strip pit. Readily accessible.
112	NW¼SW¼ sec. 25	do	3	2	Outcrop in ravine; no present value.
113	NW¼NW¼ sec. 36	do	6	5	Accessible; very bony.
114	SE¼SW¼ sec. 35	do	4		Outcrop in creek bed; accessible.
GS-*K*	NE¼SE¼ sec. 7	Tono No. 1	9	2	Geological Survey drill hole *K*, depth, 110 ft.
115	SE¼NE¼ sec. 17	do	7	7	Old Monarch mine; inaccessible.
116	SE¼NW¼ sec. 22	do	5	8	Outcrop; partly exposed.
117	NW¼NE¼ sec. 26	do	12	1	Good outcrop in stream bed.
118	SW¼SE¼ sec. 23	do	9	9	Exposure along abandoned logging grade.
119	NW¼NW¼ sec. 6	Upper Thompson	10	5	Black Badger mine, caved. Bed exposed at portal.
120	NW¼NW¼ sec. 6	do	11	9	Outcrop in ravine; accessible.
GS-*K*	NE¼SE¼ sec. 7	do	7	6	Geological Survey drill hole *K*, depth, 525 ft.
121	NW¼SW¼ sec. 9	Lower Thompson	8	4	Prospect trench; partly caved.
122	NW¼NW¼ sec. 6	Big Dirty	18		Outcrop in ravine.
123	SE¼NW¼ sec. 6	do	20	3	Faced outcrop in ravine.
124	NW¼NE¼ sec. 16	do	18	6	Prospect trench; accessible.
125	SW¼SE¼ sec. 4	do	7	1	Outcrop in ravine; very bony.
126	SW¼SW¼ sec. 10	do	23	7	Outcrop; poorly exposed.
127	SW¼NW¼sec. 10	do	8	1	Gumbo prospects caved. Partial section measured at portal. Reported to be 17 ft thick.
128	NW¼NE¼ sec. 2	do	8		Prospect, top and bottom of bed not exposed.
129	SW¼SW¼ sec. 10	Little Dirty	5	6	Prospect. Inaccessible.
130	SW¼NE¼ sec. 6	Smith	8	8	Outcrop in ravine; coal brecciated.
131	NE¼SW¼ sec. 9	do	11	7	Faced outcrop; bed is overturned.
132	SE¼SW¼ sec. 9	do	6	4	Prospect; base of bed not exposed.
133	NW¼NE¼ sec. 9	do	6	7	Outcrop, poorly exposed.
134	NW¼NW¼ sec. 10	do	5	10	Smith No. 3 mine. Accessible. Upper part of bed cut out by overlying sandstone channel.
135	SW¼SW¼ sec. 3	do	6	11	Outcrop in ravine.
136	NE¼SW¼ sec. 3	do	5	1	Faced outcrop, near Mendota mine.
137	SE¼NW¼ sec. 15	do	4	2	Outcrop. Difficultly accessible
138	NE¼SE¼ sec. 10	do	4	10	Outcrop. Difficultly accessible.
139	SE¼SW¼ sec. 14	do	5	10	Exposure in abandoned logging grade.
140	SE¼NE¼ sec. 23	do	5	3	Faced outcrop.
141	NE¼NW¼ sec. 24	do	5	7	Do.
142	NE¼NW¼ sec. 10	Mendota	9	7	Columbia mine. Inaccessible.
143	NE¼SW¼ sec. 3	do	9	10	Mendota mine. Inaccessible.
144	NE¼SW¼ sec. 3	do	10	4	Do.
145	NW¼NE¼ sec. 3	do	8	2	Prospect. Not located with certainty.
146	NW¼NE¼ sec. 24	do	10	8	Prospect. Inaccessible.

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T. 14 N., R. 1 E.

Rocks older than the coal-bearing formation are exposed in all but the extreme northwestern and southwestern parts of T. 14 N., R. 1 E., (pl. 6) and coal beds crop out only in the latter area. The Mendota bed is believed to be present in sec. 19, but outcrops of this bed have not been seen. There has been little prospecting and no development of the coal beds in this township owing to the inaccessibility of the area of outcrop. Only two measurements of coal were made in this township, both on the Tono No. 1 bed, which contains 5½ feet of coal.

Coal localities in T. 14 N., R. 1 E.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
147	SW¼NE¼ sec. 30	Tono No. 1	6	1	Difficultly accessible. Outcrop in ravine.
148	SE¼SE¼ sec. 33	do	6	8	Difficultly accessible. Poorly exposed outcrop.

T. 13 N., R. 1 E.

The southeasternmost exposures of the upper coal group are in secs. 2, 3, 10, and 11, T. 13 N., R. 1 E. (pl. 6) where these rocks are poorly exposed along the limbs of the Mendota syncline. In this township the coal group contains only one major bed which, on the basis of stratigraphic position, is tentatively correlated with the Tono No. 1 bed. This bed has been measured at two localities in sec. 10 and contains an average of about 6 feet of coal. A part of the bed in sec. 11 may be burned as a basalt sill occupies approximately the same stratigraphic position.

Minable coal beds probably are present in the western and southern parts of the township but are buried under a thick cover of Quaternary deposits.

Coal localities in T. 13 N., R. 1 E.

Map reference	Location	Coal bed	Approximate thickness		Remarks
			Feet	Inches	
149	SE¼NE¼ sec. 10	Tono No. 1	6	11	Caved prospect.
150	SE¼NE¼ sec. 10	do	5	8	Faced outcrop; base not exposed.

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MICROSCOPICAL CHARACTER OF CENTRALIA-CHEHALIS COAL

By J. M. Schopf

INTRODUCTION

Coal of the Centralia-Chehalis district includes banded coal of subbituminous rank. Microscopic examination of hand specimens, taken from eight coal beds in the district, shows the considerable variety of plant materials that enters into the composition of the coal. These include coarse woody remains that may be recognized megascopically as vitrain, slight amounts of the friable charcoallike material known as fusain, and attrital plant components and mineral impurities that cannot be identified without recourse to microscopic study. The banded character of the coal evidently is due principally to the presence of the larger woody streaks; in some instances mineral-rich attrital layers, by their contrasting luster, may also contribute to a banded appearance.

The more finely textured coal, interspersed between vitrain bands, is known as attrital coal. It often has a microstriated appearance but the individual particles composing it are very tiny. The particles are of many different kinds and for this reason attrital coal is much more variable than vitrain in its composition. It includes all plant products present in woody tissues that have been highly degraded, together with a highly varied assembly of materials common to leaves and to the small plant parts. It also includes the remains of fungi responsible for partial decay, and substances that are too altered or degraded for botanical identification, although these often present a characteristic microscopic appearance that permits comparative study. Among such materials opaque attritus is of greatest importance effecting utilization characteristics, but this component, like fusain, is virtually lacking in the specimens examined. Some waxy components, such as spore coats and plant cuticles, retain features by which they may be identified, but most of the attrital coal in this suite of specimens also contains amorphous waxes that evidently are not in their original form. Mobile waxy matter has frequently invaded plant tissues to serve essentially as an organic petrifying medium by protecting them from collapse under pressure. In none of the examples do the waxes constitute as much as five percent of the coal specimens, but no estimate of the amounts present in any of the coal beds should be ventured. These materials are the most apparent source of protobituminous substances in the coals and if they are present in a high enough concentration, commercial recovery of the coal waxes might be feasible.

The microscopic composition of the coal was determined by a study of thin sections.

Maximum definition and maximum effective color contrast in light transmission occurs when subbituminous coal sections are prepared about ten or twelve microns thick (1 micron=about 1/25,000 of an inch). Sections of greater thickness tend to show loss of visible detail in denser constituents, and sections thinner than this show some loss of color contrast between "red" and "yellow" elements in the coal.

The accompanying selection of photomicrographs will serve best to indicate the nature of the differences inherent in these coals. As reproduced in monochrome the illustrations fail to present the brilliant color contrasts so evident in the thin sections. Chiefly they show textural configurations with opaque areas black; dark-red translucent structures as dark-gray; orange coloration, lighter gray; and lemon yellow or pellucid areas (waxes, pollen coats, cuticles, transparent mineral grains, voids and cracks) nearly white. The natural coloration will be appropriately noted in discussion of the figures. The illustrations have been arranged according to the beds from which they were derived and source locations are noted in captions for the plates.

COAL FROM TONO UPPER BENCH

Plate 7 illustrates microcomponents in a coal lump 60 millimeters thick, taken from the Upper Bench of Tono No. 1 bed at Tono strip pit.

Figure 1 shows attrital coal containing an unusual fungus structure, possibly sclerotial (*s*?). All white areas appear yellow in the section; dark areas are reddish except for fungal walls which have a brownish cast. All portions shown would be classed as translucent attritus. Note that magnification of figure 1 is twice that of figure 2.

Figure 2 illustrates a characteristic form of fungal sclerotium (*s*) in a thin streak of translucent attritus, between two anthraxylon streaks (*an*). Cell walls of the sclerotia are nearly opaque but cell lumens are filled with yellow translucent waxy matter. Margins of anthraxylon bands are retouched for distinctness as the difference in translucency between the anthraxylon and humic matter of the translucent attritus is almost imperceptible at this magnification.

Figure 3 shows two different types of fungal sclerotia (*s*) and one form which may represent a fungus spore (*s*?) in a matrix of translucent attritus (*at*). In this area strands of fungal hyphae may be described as pinpoint circles, or ellipses, when viewed at higher magnification. The edge of one yellowish translucent wax body (*w*) is shown. The light flecks in the rather uniform-textured matrix and white cell lumens in sclerotia are filled by yellowish translucent waxy matter. Figure 3 is at the same magnification as figure 1.

Figure 4 shows in its upper portion a dark-brownish translucent mass composed of a spongy, fine-celled network that probably represents fungal plectenchyma (*fu*). A small sclerotium (*s*) is centrally placed, in a matrix of translucent attritus (*at*). Yellow translucent waxy strands (*w*) may represent folded thin-walled pollen grains in cross section. Figure 4 is much more highly magnified than figures 1 and 3.

Figure 5 shows a varied assortment of structures composing translucent attritus (*at*). A folded, yellowish translucent band of cuticle (*cu*) is centrally placed adjacent to a brownish translucent area of possible fungal plectenchyma (*fu*?). A lower band includes reddish translucent resinous or secretory bodies, judging from their form. Amorphous yellow waxy matter is intercalated between resinous globules and accounts for most of the "white" areas in the fungal(?) area. Figure 5 has the same magnification as figure 2.

Figure 6 shows a sclerotium (*s*), of the same type as shown in figure 2, representing a smaller example photographed at higher magnification. The evident cell lumens are yellowish and wax filled, and the surrounding attritus (*at*) is similar to that in figure 2.

Figure 7 shows a remarkably elongate example of a dense large sclerotium (*s*) that probably is conspecific with those shown in figures 2 and 6. A strand of anthraxylon (*an*) above the sclerotium is of lighter translucency than the humic matter of the adjacent attritus. The dense dark patches in the lower central part of the figure may represent an unusual occurrence of opaque attritus in this coal. This photograph is taken at twice the magnification of that for figure 6 and the same as that for figure 2.

Figure 8 shows portions of several horizontally elongate waxy blebs, from which material has migrated into vertical cracks as a result of vertical pressure. The origin of these waxy blebs is unknown but probably they are not original characteristics of a particular species of plant. Vestiges of woody tracheal elements are present in the sigmoid structure included at the left, within the larger bleb shown in Figure 8*b*, to suggest that the material is a secondary aggregation. The waxy material has a fine-grained texture when observed with subdued transmitted illumination, but this is scarcely apparent in the photographs which were printed in the endeavor to bring out also some of the visible detail in the surrounding red translucent attrital material (*at*). Some flakes and splinters of humic coal evidently tend to spall from the cracks that are opened under pressure by plastic flow of the wax so that, although the connection with the wax body is evident in the section, in the photograph it presents a ragged interrupted appearance.

COAL FROM TONO LOWER BENCH

Plate 8 illustrates microcomponents of a coal lump 106 millimeters thick from the Lower Bench of the Tono No. 1 bed at the Tono strip pit.

Figure 1 shows an anthraxylon strand (*an*) and sclerotium (*s*) (of the same type as those shown in pl. 7, figs. 2 and 7) in a matrix of translucent attritus (*at*). A moderately large wax body (*w*) and many smaller ones occur in the attritus. The light area in the center of the anthraxylon strand is occasioned merely by local thinness of the section; the lighter marginal halos at top and bottom of the anthraxylon (orange red in the original section) are caused by minor differences of composition. Note the greater tendency for fracture lines to form in the anthraxylon during section preparation.

Figure 2 illustrates translucent attritus (*at*) containing darker fungal structures (*fu*) (possibly spores or thick-walled resting mycelium) and one thick-walled compressed pollen grain or spore. The probable insignificant difference between the composition of red translucent humic matter of the attritus and the thinnest shreds normally identified as anthraxylon (*an*) is emphasized by this picture. An anthraxylon fragment shown here merges toward the right with humic matter of the attritus. Only minor vestiges of cell structure, much compressed, remain in the anthraxylon streak as an indication of plant tissue derivation. The pollen coat, the waxy fillings of fungal structures and small waxy bodies all appear about equally yellow; the humic matter and anthraxylon equally red. The magnification for this illustration is much greater than that for figure 1.

Figure 3 also illustrates attritus containing a variety of sclerotia (*s*) and other fungal remains. An elongate structure with orange margin and red translucent interior (*root*) probably represents an oblique section of a small rootlet which had grown into the degraded plant debris during the peat stage. It now constitutes a small streak of anthraxylon (compare with figs. 1 and 2, pl. 11).

Figure 4 shows the central portion of an anthraxylon band of woody derivation containing waxy and resinous cell inclusions. The latter appear white in the illustration but are bright yellow in the original section; the resins are of orange translucency and frequently contain tiny bubbles or vesicles. Only those cells that contain solid organic fillings retain a semblance of their original form. The resinous cells appear indigenous to the wood but the waxy fillings may have been introduced into the dead wood during the peat stage. Magnification of figure 4 is the same as that for figures 3 and 1.

Figure 5 shows a cluster of small "humic", reddish translucent resins(?), with waxy interstitial material, central wax body (*w*), and anthraxylon strands (*an*) above and below. Additional waxy matter and a small aggregation of fungal hyphae appear in the lower left central portion of the figure. The magnification of figure 5 is twice that of figures 1, 3 and 4.

Figure 6 illustrates a concentration of yellow waxy matter (*w*) containing cell-wall fragments, not visible here, that show xylary pitting. Grayish areas are all bright yellow; the black areas all are reddish and consist of humic and anthraxylous material. The extreme contrast in translucence of waxy matter and humic material is such that the inherent structure of both cannot be fully shown in the same photograph. The magnification is the same as that for figures 4, 3, and 1.

COAL FROM THE UPPER THOMPSON BED

Plate 9 illustrates the microcomponents in a coal lump 82 millimeters thick taken from the Upper Thompson coal bed at the Stoker mine.

Figure 1 shows attrital coal with two cellular sclerotia (*s*) and one simple sclerotium. All white filling material in the sclerotia is yellowish in the original section and of waxy character (*w*). One isolated waxy body (*w*) also is shown, and waxy material of more indefinite form appears at the top of the illustration. Most of the smaller white dots also are waxy and appear bright yellow in the thin section. Small fungal hyphae are visible in the original preparation but are difficult to distinguish in the monochrome photograph.

Figure 2 shows well-preserved woody tissue (anthraxylon) from a thick vitrain band. All cells have collapsed with the elimination of cell cavity space; one wood ray shows as a darkened ragged streak extending obliquely through the tissue. All normal layers of the primary and secondary cell wall originally present in the wood can be distinguished, to indicate that both cellulose and lignin have contributed to the coal. This illustration is magnified about two and one-half times more than figure 1.

Figure 3 shows more highly degraded anthraxylon from a different area of the same band illustrated in figure 2. A row of reddish translucent resinous inclusions (*r*) occur in the middle of the illustration and a ray with somewhat similar but darkened reddish translucent filling is shown below. Dark rims occur along the crack (*ox*) in this area of the coal that are presumed to be the result of oxidation due to drying before the section was prepared. The magnification is the same as for figure 2.

Figure 4 shows woody tissue from the same band specimen, in an intermediate stage of degradation. Two rays are distinguishable, each somewhat granular and darkened in appearance. Granular material also occurs within the compressed cell lumens. Probably this granularity represents a form assumed by the lignin residue after intervening cellulosic material has been somewhat depleted. The magnification of figure 4 is the same as that for figures 2 and 3.

Figure 5 (*a* and *b*) shows a marginal part of the anthraxylon or vitrain band illustrated in figures 2 and 4. The red to orange anthraxylon is far more translucent than the adjacent attrital coal. For this reason photographic illustrations of the two portions require differing exposures to bring out inherent textures. Although both parts are reddish the attrital coal shows darker coloration. The margin of the anthraxylon (*an*) does not show as clearly defined cellular structure as portions more centrally located, and the contact between attrital coal and anthraxylon is very ragged. Waxy bodies (*w*) occur exclusively in the attrital coal, sometimes nearly in contact with the woody portion. Sclerotia (*s*) also are present in the attrital portion but have never been observed inside the wood. Figure 5, similar to figure 1, is less highly magnified than figures 2, 3, and 4.

Figure 6 shows a somewhat different and probably the most highly decayed portion of the same anthraxylon or vitrain band shown in figures 2, 3, and 4. The intracellular portions, particularly those at the corners of adjoining cells, stand out prominently as more highly translucent orange polyangular points. Possibly these may represent another type of lignin-derived residue inasmuch as the intracellular material, known to be most concentrated at these points in mature modern wood, is also highly lignified. An oxidation zone (*ox*) at the termination of a minor crack is shown as a darkened central area. It is of interest to note that the intracellular points in this area are not effected to nearly the same extent as the adjacent materials that are presumably of more mixed lignocellulosic derivation. Magnification of figure 6 is the same as that for figures 2 to 4.

COAL FROM UPPER THOMPSON AND LITTLE DIRTY BEDS

Figures 1 and 2 on plate 10 illustrate additional microcomponents from the Upper Thompson coal bed at the Stoker mine, similar to those given on plate 9.

Figure 1 shows attrital coal with some peculiar fungal structures (*fu*) in the upper portion, which are apparently tubular and too thick walled to represent ordinary vegetative mycelium but are not organized as coherent sclerotia. Their walls are dark brown with lumens occasionally wax filled. Centrally in the illustration two layers of yellow cuticle (*cu*) are shown. The lower cuticular layer feathers out toward the right and resembles some of the other amorphous waxy materials also present in the area of this illustration. A wax filled sclerotium (*s*) of simple structure is shown in the lower portion of the figure. The magnification is greater than that of the attrital materials shown on plate 9 and corresponds to the magnification of the woody structures shown on that plate.

Figure 2 illustrates other attrital components at lower magnification, comparable to that of figures 1 and 5 of plate 9. Sclerotia (*s*) and waxes (*w*) are shown as in previous illustrations, but the two resins (*r*) in the central part of the figure differ in their orange translucence and in the presence of scaleriform bars centrally placed in both of the resinous bodies. These bars signify that the resins originated as secondary fillings of tracheids or vessels in wood which has been subsequently disintegrated so that only isolated cells are distinguishable, as such, under favorable circumstances. Much of the attrital coal must be formed of similar degradation products but only in a few instances, such as shown here, is there sufficient evidence to indicate its origin. The dark matrix of figure 2 is dominantly reddish.

Figures 3 to 7 of plate 10 illustrate microcomponents of a lump 76 millimeters thick out of the Little Dirty coal bed obtained from its outcrop on Holiday Road. Organic components similar to those of the other coal beds are present and, in addition, there are noteworthy concentrations of disseminated pyrite.

Figure 3 illustrates an assortment of fungal materials including wax-filled sclerotia (*s*), isolated yellow wax bodies (*w*), and black opaque areas representing pyrite. The matrix is generally humic and reddish.

Figure 4 illustrates a similar occurrence of disseminated pyrite (*py*) in a thin anthraxylon band as it appears at high magnification. Simple crystallites of pyrite show a square outline in profile, but others may appear rounded. Presumably the rounded outlines are a result of aggregation of many micron-size pyritic crystals. Some of the outlines tend to be hexagonal owing to the oblique orientation of cubical crystals to the plane of the section. Few of the crystals and aggregates exceed 8 microns in diameter, and many pyritic crystals are no longer than one or two microns in size.

Figure 5 shows a concentration of disseminated pyrite with some of the crystallites intergrown and rudely alined to correspond with the grain of the wood that contributed to the anthraxylon or vitrain band in which they occur. Areas of such concentration are still relatively small in the specimen studied so that very fine crushing would be necessary in order to reduce the pyrite concentration by commercial methods of preparation.

Figure 6 illustrates some of the same structures shown in figure 3 at higher magnification, including a simple thick-walled sclerotium (*s*) with its yellow translucent waxy filling (*w*) and pyritic granules similar to and at the same magnification as those shown in figure 4. Vegetative fungal mycelium can be distinguished in the lower central portion of figure 6.

Figure 7 shows disseminated pyrite at lower magnification, similar to that illustrated in figure 5. The alinement of pyrite grains again is due in part to deposition within woody tissues so that the grain of the wood is roughly indicated and probably further emphasized by subsequent compression of the band as it was transformed into coal.

COAL FROM BIG DIRTY BED

Plate 11 illustrates microcomponents from a lump 115 millimeters thick out of the Big Dirty coal bed, at the Kostick prospect. Figures 1 and 2 illustrate materials derived from a small compressed rootlet intercalated in attrital coal. The root periderm (*pd*) is largely intact and figure 1 shows best the characteristic structure of this tissue. The central cylinder inside the periderm (*xy?*) probably includes both xylem and phloem, but none of the cellular outlines in this area are preserved. The root periderm is orange or light-reddish color and lacks waxes or suberized lamellae; it contrasts with the darker translucence of the surrounding translucent attritus which shows a normal complement of sclerotia (*s*) and waxy bodies. The relation of this rootlet to the surrounding matrix is best shown at lower magnification in figure 2. About half of its horizontal extent is shown and the thickness of the rootlet-derived coal (*root*) is indicated. The periderm band is continuous around the central darkened translucent area in the original section. The central tissues were very delicate in a root so small as this and these are extremely condensed in comparison with the original. However, degree of compression cannot be accurately judged from the ellipticity of this outline since the cylindrical organ may have been sectioned more or less obliquely.

Figures 3 and 4 illustrate materials derived from a small compressed twig or stem. The stem periderm (*pd*) is likewise largely intact and figure 3, taken at higher magnification, should be compared with the root periderm shown in figure 1. Of outstanding significance are the yellow waxy suberin layers that separate the individual cork cells shown in figure 3. The xylem and phloem area (*xy?*) inside the periderm is similar to that of the rootlet shown in figures 1 and 2, but some darkened resinous bodies (*r*) are also present. On the lower side the suberin appears to have flowed together, perhaps owing to dissolution of humic cellular material, leaving a more concentrated waxy deposit (*w*). The relation of the small stem or twig to the surrounding coal, and a magnification corresponding to that of the rootlet shown in figure 2, is shown in figure 4.

Figure 5 shows an area of attrital coal with translucent mineral grains (*m*) and yellow waxy bodies (*w*) interspersed in it. The red translucent humic matrix contains very few identifiable plant structures.

Figure 6 illustrates some of the yellow translucent waxy bodies, so characteristic of the attrital coal from this bed, as they appear at higher magnification. The variety of outline and of inclusions in these waxy bodies is noteworthy. Most of the inclusions large enough to observe closely are spherical in outline and probably represent gas or liquid filled vesicles whose significance is unknown. Probably they originated as the waxes were originally formed within secretory cells of some plant. The matrix surrounding the wax bodies is dark red and of humic nature although it appears black in the photograph owing to the extreme contrasting density, in comparison with the waxy bodies.

Figure 7 illustrates a characteristic assortment of the waxy bodies (*w*) typical of attrital coal from this hand specimen of the Big Dirty coal bed. Magnification is the same as for figures 2, 4, and 5. These waxes, like detrital mineral matter, almost certainly dull the luster of the coal when observed megascopically and they may thus be partly responsible for the name that is given this coal bed. Mineral impurities are not abundant in the hand specimen which was examined.

Figure 8 shows thin strands of attrital anthraxylon (*an*) occurring in attrital coal. The thinner central strand shows waxy inclusions with projections extending into small vertical cracks both above and below. Evidently these cracks and the inflow of waxy material is a result of compression during coalification. The attrital coal (*at*) shows a considerable amount of amorphous waxy matter dispersed in it.

Figure 9 shows a heavy cuticle in attrital coal with dentate or "peg" projections on the upper side which originally extended along the intracellular lines of the epidermis of the plant tissues that it covered. A wax body (*w*) also appears close above it in the attrital debris.

Figure 10, from a photograph taken at lower magnification similar to that of figure 8, shows a considerable concentration of waxy cuticular material (*cu*). Some of the cuticular bands may have been attached to leaves and others to small twigs that had not yet formed any periderm. Anthraxylon (*an*), probably derived from one of these twigs, can be observed. All of this coal would be classed as attrital, and all except the anthraxylon as translucent attritus, by the usual microquantitative criteria.

COAL FROM MENDOTA, SMITH, AND BLACK BEAR BEDS

Figure 1, in plate 12 is from a mineralized area of the hand specimen 118 millimeters thick from the Mendota coal bed at the Boxer mine. This specimen shows much mineral matter (*m*) occurring in discontinuous veins that are more pronounced in the horizontal plane. The considerable difference in hardness between the mineral matter and the coal made preparation of thin sections from this specimen relatively difficult and introduced additional difficulty in preparing effective illustrations. Observation of the feather edges of coal showed that this specimen is nearly all anthraxylous (*an*) and derived from a large tree trunk. The wood is not exceptional but it is characterized by a large number of red translucent resinous bodies. The illustration has been prepared to show occurrence of mineral matter at relatively low magnification in one area of this wood. Although the mineral grains may have filled individual cells of woody tissue originally, both mineralization and subsequent compression make it difficult to interpret the structure. Probably the mineral was introduced late in the peat stage after the wood had been considerably compressed to interfere with petrifaction. Some splits in the softened peaty tissue evidently were produced by pressures associated with crystal growth during mineralization.

Figures 2, 3, and 4 illustrate constituents of the Smith coal bed taken from a hand specimen 112 millimeters thick obtained at Belle Slope mine.

Figure 2 illustrates attrital coal with one large sclerotium (*s*) and many other types of smaller sclerotial and sporelike fungal bodies. Waxy bodies (*w*) are present as in other examples of the Washington coal; a few lathlike tabular and slightly irregular mineral fragments (*m*) are shown.

Figure 3 illustrates the boundary between an anthraxylon band (*an*) containing red translucent resins in the ray areas (*r*), and attrital coal. The boundary between the attritus and anthraxylon is somewhat indefinite in this instance, probably owing to the degradation of fungi whose sclerotia (*s*) are present in the adjoining attrital debris.

Figure 4 illustrates a type of dispersed mineral occurrence usually associated with kaolinite (*ka?*). Evidently the clayey mineral matter was introduced in solution during the peat stage to infiltrate vegetable tissues and preserve vestiges of cellular form in these areas after they had been somewhat compressed. Figure 4 is at the same magnification as figure 3, both being twice the magnification of figure 2.

Figures 5, 6, and 7 represent structures derived from a hand specimen obtained from the Black Bear coal bed at the same location as the sections illustrated on plate 13.

Figure 5 shows a strange type of vegetable tissue (*fu?*) appearing brownish in this section and reminiscent of fungal remains. It is embedded in the attrital coal (*at*) and may represent a portion of some woody bracket fungus.

Figure 6 shows at higher magnifaction a portion of the same structure illustrated by figure 5. The light areas shown are actually yellowish and wax filled like most of the fungal sclerotia found in Washington coals; there is a suggestion of dense filamentous structure (plectenchyma) simulating the tissues of higher plants.

Figure 7 illustrates attrital coal with one large mineral grain (*m*) and other light areas filled with yellow translucent waxy matter (*w*). Cells filled with red translucent humic matter are embedded in the waxy layer transversing the central part of the figure that appears to be derived from the mesophyll of a wax infiltrated leaf. The dense red translucent material beneath this layer gives no clue to its origin, but it includes a wax-filled secretory mass (*se*) with an outline reminiscent of secretory passages in plant tissues.

COAL FROM BLACK BEAR BED

Plate 13 illustrates microcomponents from the hand specimen lump, 68 millimeters thick, from the Black Bear coal bed at Black Jewel mine.

Figures 1, 2, and 3 illustrate different views of one exceptional piece of coalified tissue from this coal bed. Figures 1 and 3 are reproduced at twice the magnification of figure 2, which will be discussed first. This woody tissue is of a diffuse-porous angiospermic type. The terminal wood of an annual ring (*ar*) is shown traversing the figure, the smaller cells appearing to represent the last increments of the annual growth. Large vessels (*v*) occur in radially alined groups of one to three or four. The many wood rays are evenly distributed in the radial plane, roughly corresponding to the vertical dimension of the illustration.

The same structures are shown more highly magnified in figures 1 and 3 and some differentiation is observed within the outlines of the vessels. Most of the contents of the vessels consists of red humic matter that fills them and has protected them from compression. In a few instances partial fillings of yellow waxy matter also occur within the vessels. The humic matter seems generally to outline bladderlike areas attached to the walls of the vessels and probably correspond to tyloses (*ty*), such as are common in modern angiospermic woods. The wood rays are generally prominently outlined by the yellow waxy fillings of the cells. The cell lumens of fibers likewise may be wax filled but their evident thick walls of dark brownish red translucency distinguish them from the thinner parenchymatous (cellulosic) walls of ray cells. The intercellular (middle lamella) material is lighter red in the fibrous areas.

In general this unusually well preserved specimen shows greater optical density of indigenous wall material than is normally associated with anthraxylon and in other areas, more difficult to illustrate, the structure merges with that characteristic of fusain. The denser appearance of the secondary walls shown here may be associated with preservation as semifusian, which, in part, might explain the excellent tissue preservation and general freedom from effects of early compression. In any event both the humic and waxy infiltrates must have been introduced some time during the peat stage. One possible secretory duct (*se?*) may be observed in figure 3 that is wax filled like the cells in much of the adjoining tissue. This affords a slight indication that some of the waxy matter may be indigenous to this wood, but most of it certainly cannot be so considered. The humic infiltration material likewise must have been brought in from outside. A rather similar type of preservation has previously been illustrated from coal of the Coos Bay field (Schopf, Am. Jour. Botany, v. 34, fig. 19, p. 340, 1947).

Figure 4 illustrates a band of anthraxylon (*an*) with a dark brownish tissue adjoining (*fu*), suggestive of fungal derivation. Translucent attritus occurs both above and below this band.

Figure 5 illustrates a characteristic incipient cleat with strongly darkened margins traversing an anthraxylon band (an). New fractures, formed in preparation of the section, are shown both at the top and bottom of the figure but lacking the marginal dark areas. Such oxidation rims are commonly observed on natural fractures within the coal in these preparations and frequently are seen in similar sections of low rank coal where special precautions to retain bed moisture have not been observed. Probably in course of normal handling much surface area in these coals becomes oxidized in this fashion and this accounts for a slightly different luster in moist coal at the face and the coal lumps after they have been exposed to air. Minor amounts of disseminated pyrite are shown in the attritus above and below the anthraxylon band in figure 5, and three tiny pyritic aggregates are shown, slightly above the middle, within the band of anthraxylon. Figure 5 is at the same magnification as figures 4 and 2.

Figure 6 shows a portion of an impure attrital layer with numerous detrital mineral grains in the specimen from the Black Bear coal bed. Not all of the light spots represent mineral grains; many of them are of a yellow translucent waxy character. The attrital matrix here is principally red humic matter, but it appears black in the illustration owing to the contrasting density of yellow and pellucid granules in the coal. Figure 6 is magnified considerably less than the other illustrations on this plate.

Figure 7, taken at relatively high magnification, illustrates the occurence of pyritic crystallites and aggregates in translucent attritus of the Black Bear coal. In monochrome illustrations the distinction between dense organic areas, such as that indicated as humic (*hu*) and the irregular aggregate indicated as pyritic (*py*), frequently is obscure. The light areas shown in this figure consist chiefly of amorphous yellow translucent waxy matter. The individual crystallites of pyrite are generally less than 5 microns in diameter and many are smaller. Unless the dissemination of pyrite is sufficient to give a significantly greater bulk density to the coal, this mineral matter cannot be greatly reduced by preparation procedures. In any event no clean separation of pyrite can be expected under these circumstances.

SUMMARY

All of the hand specimens examined microscopically consisted principally of anthraxylon and translucent attritus. Very little fusain and a negligible amount of opaque attritus was observed. Anthraxylon and translucent attritus are relatively reactive coal constituents and the coals they dominate are inherently most suited for chemical utilization, since these constituents contribute the least amount of relatively inert organic residue.

Anthraxylon occurs both in bands of megascopic sizes (vitrain) and in microscopic strands and a great variation in the preservation

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of original plant structure can be observed. Although both anthraxylon and humic degredation matter of translucent attritus appear red in thin sections, the anthraxylon tends to be a little more translucent and show somewhat more orange coloration. Anthraxylon also has a slightly greater tendency to form dense oxidation rims along cracks as a result of partial drying. Perhaps this is owing in part to its greater inherent friability and to the presence of more numerous incipient cleat separations that dry out first.

Translucent attritus in these specimens is dominated normally by humic degradation matter, appearing red in thin sections, with obscure vestiges of tissue derivation. Remains of fungi, consisting of abundant but inconspicuous vegetative mycelium and more obvious spores and very evident sclerotia are abundant in many instances and constitute the most characteristic group of phyterals in the attritus. Cell walls of fungal remains tend to appear brownish and most dense of the common materials in this coal to the passage of transmitted light. Of all the essentially translucent components, they are likely to be chemically least reactive.

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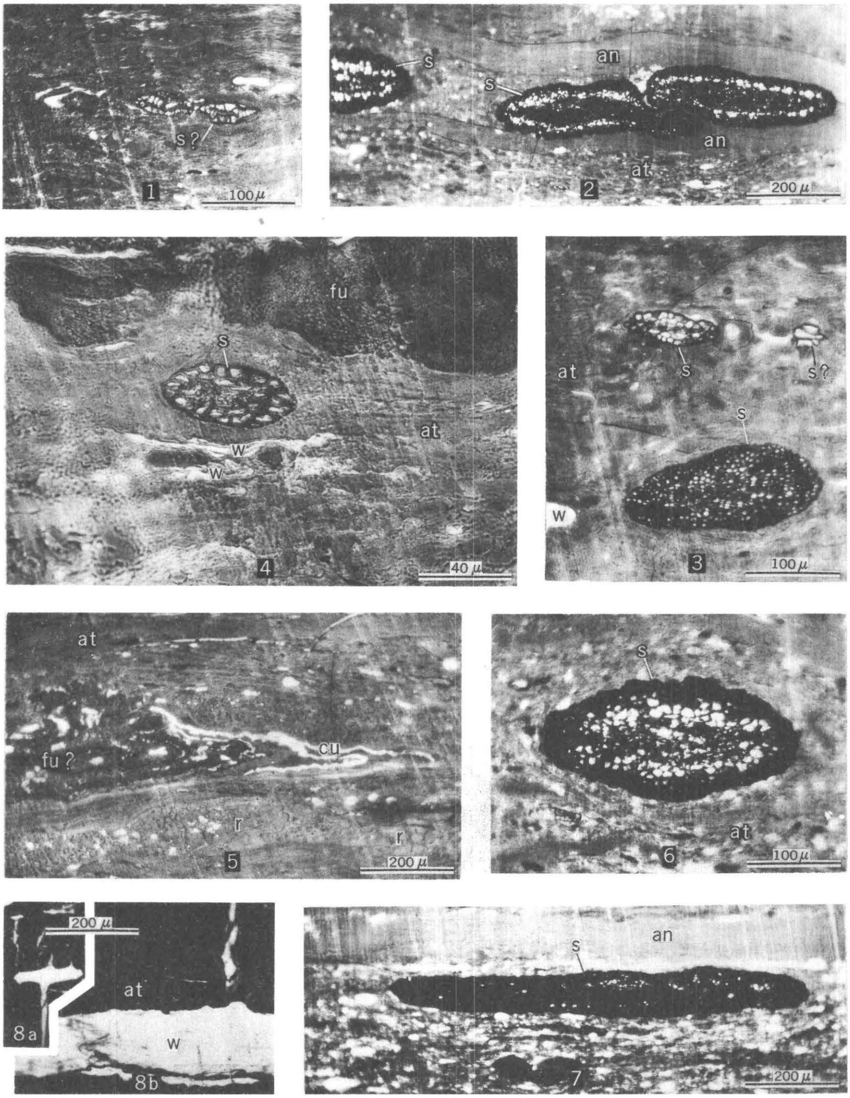
PLATES 7–13

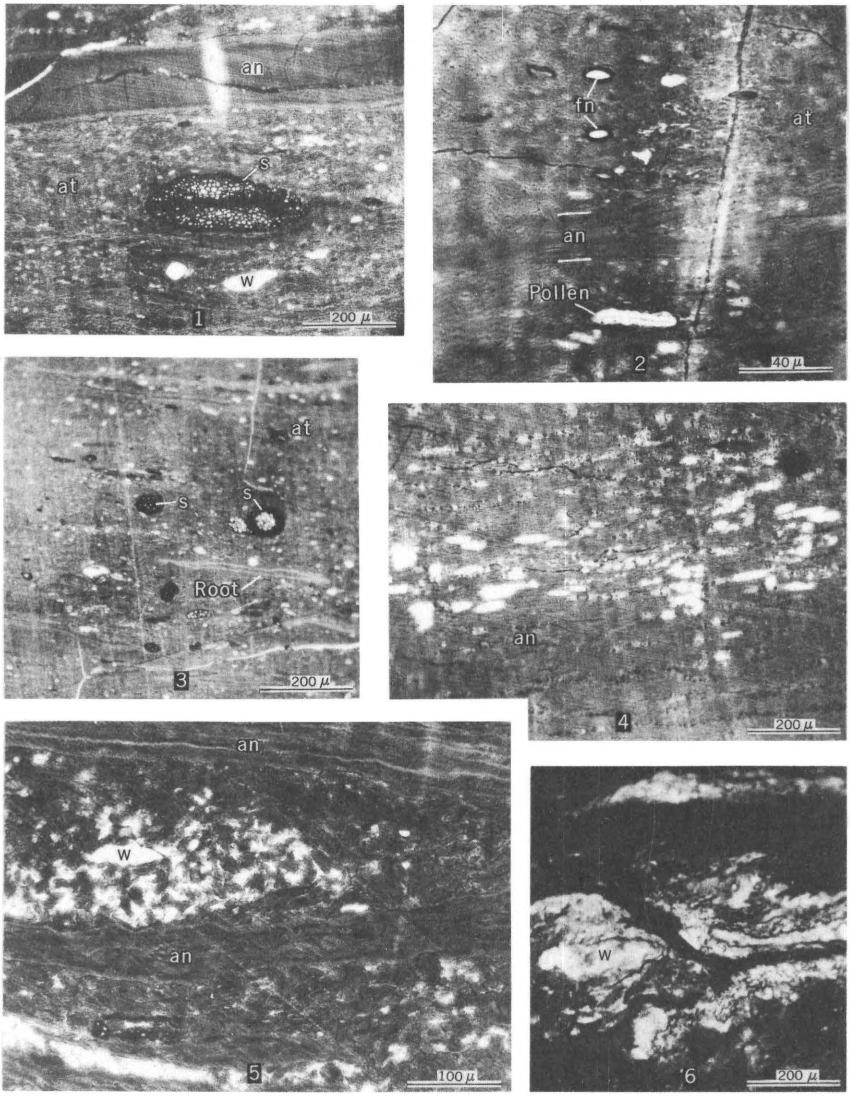
PLATE 7

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURES 1–8. Coal from Upper Bench, Tono No. 1 bed; microcomponents in lump, 60 mm thick, from Tono strip pit. In NW¼NW¼ sec. 21, T. 15 N., R. 1 W., Thurston County, Wash.



COAL FROM THE TONO UPPER BENCH



COAL FROM THE TONO LOWER BENCH

PLATE 8

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURES 1–6. Coal from Lower Bench Tono No. 1 bed; microcomponents in lump, 106 mm thick, from Tono strip pit. In NW¼NW¼ sec. 21, T. 15 N., R. 1 W., Thurston County, Wash.

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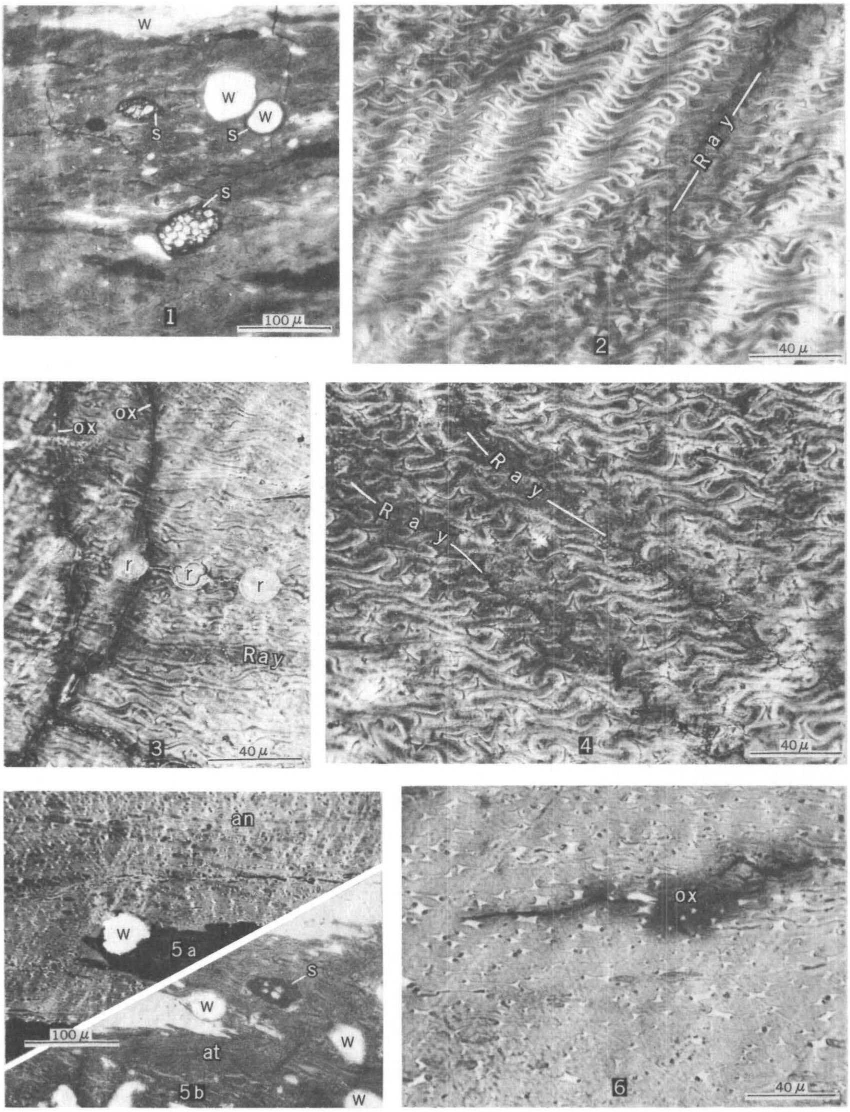
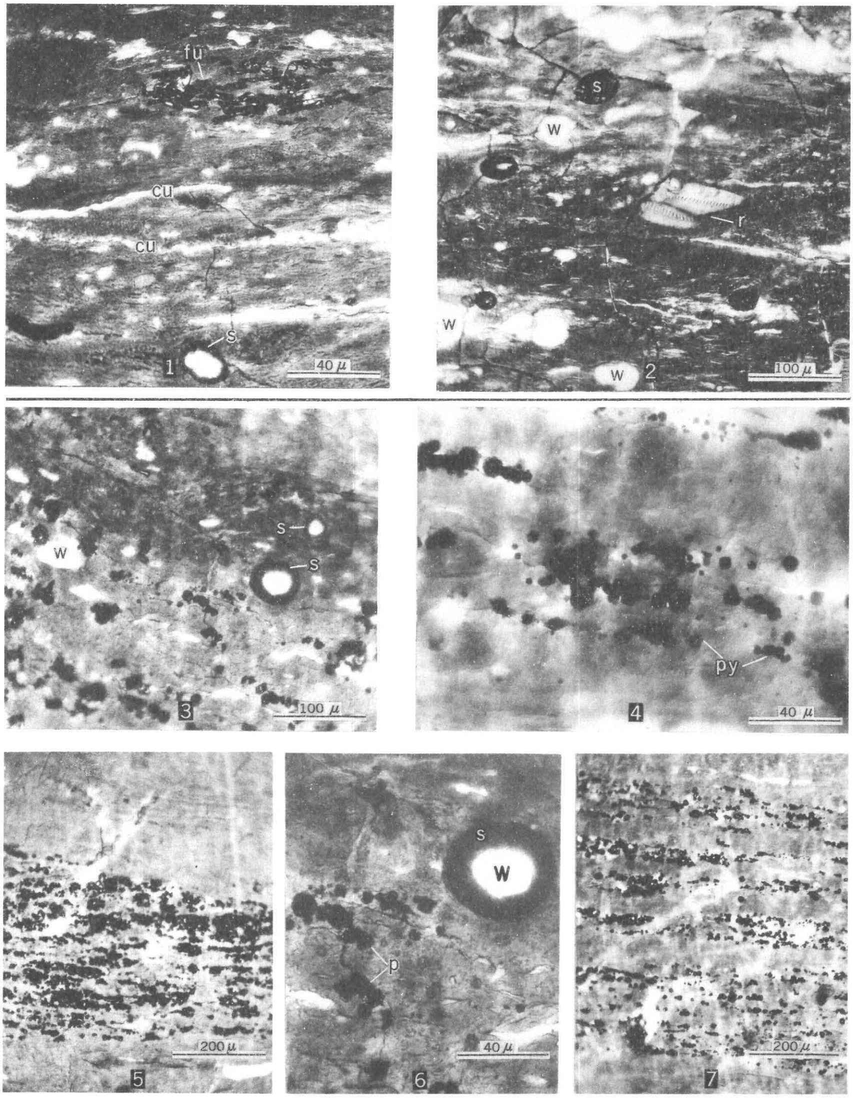
PLATE 9

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURES 1–6. Coal from the Upper Thompson bed; microcomponents in lump, 82 mm thick, from Stoker mine. In NE¼SW¼ sec. 29, T. 15 N., R. 2 W., Lewis County, Wash.



COAL FROM THE UPPER THOMPSON BED



COAL FROM UPPER THOMPSON AND LITTLE DIRTY BEDS

PLATE 10

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURES 1–2. Coal from the Upper Thompson bed. See legend for plate 9.

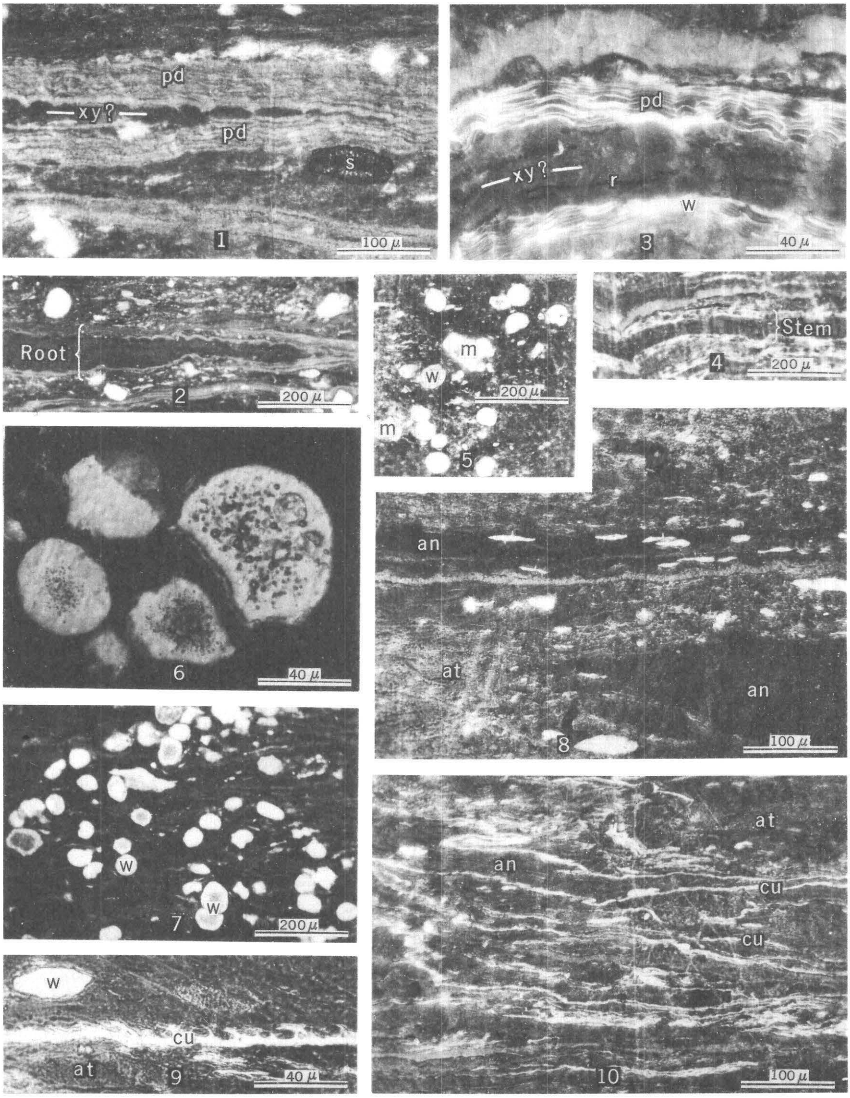
3–7. Coal from the Little Dirty bed; microcomponents in lump, 76 mm thick, from Holiday Road outcrop. In NW¼SW¼ sec. 35, T. 15 N., R. 2 W., Lewis County, Wash.

442728—58——13

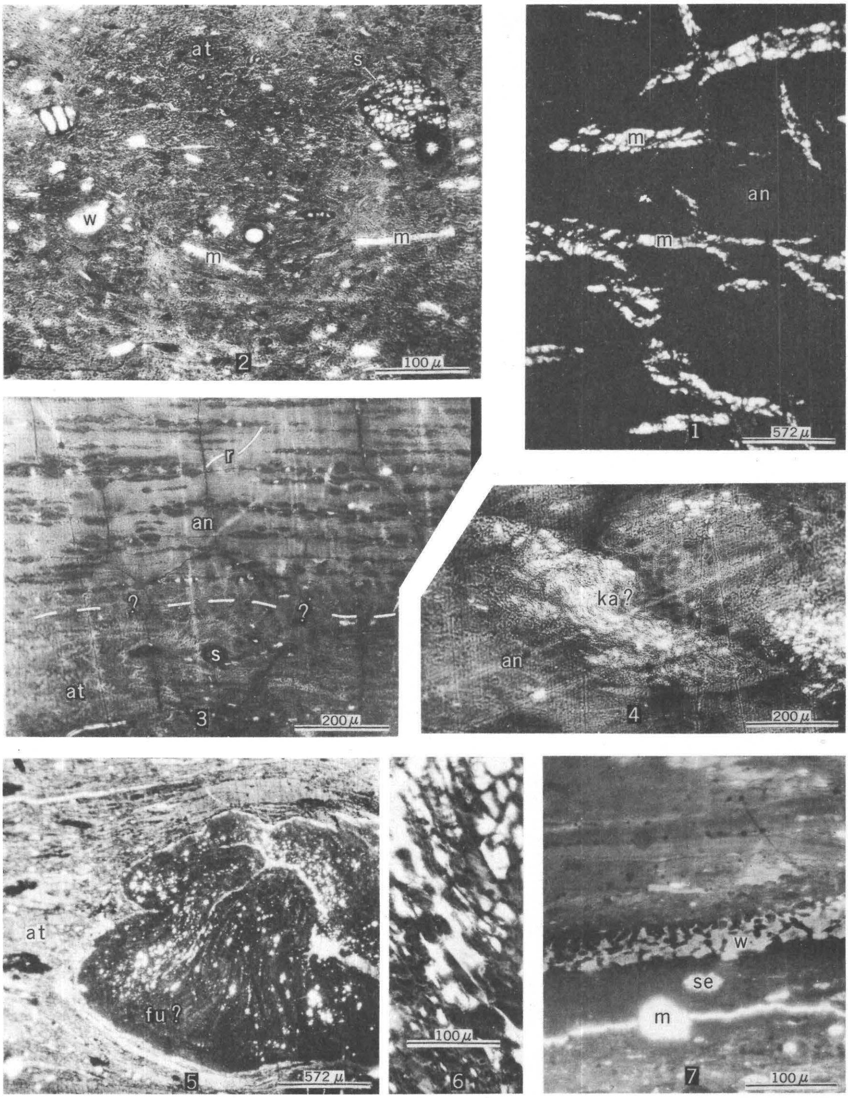
PLATE 11

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to the banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURES 1–10. Coal from the Big Dirty bed; microcomponents in lump, 115 mm thick, from Kostick prospect. In NW¼NE¼ sec. 16, T. 14 N., R. 1 W., Lewis County, Wash.



COAL FROM THE BIG DIRTY BED



COAL FROM THE MENDOTA, SMITH, AND BLACK BEAR BEDS

PLATE 12

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to the banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURE 1. Coal from the Mendota bed shows mineralized area in lump, 118 mm thick, from Boxer mine. In NE¼SE¼ sec. 14, T. 15 N., R. 2 W., Thurston County, Wash.

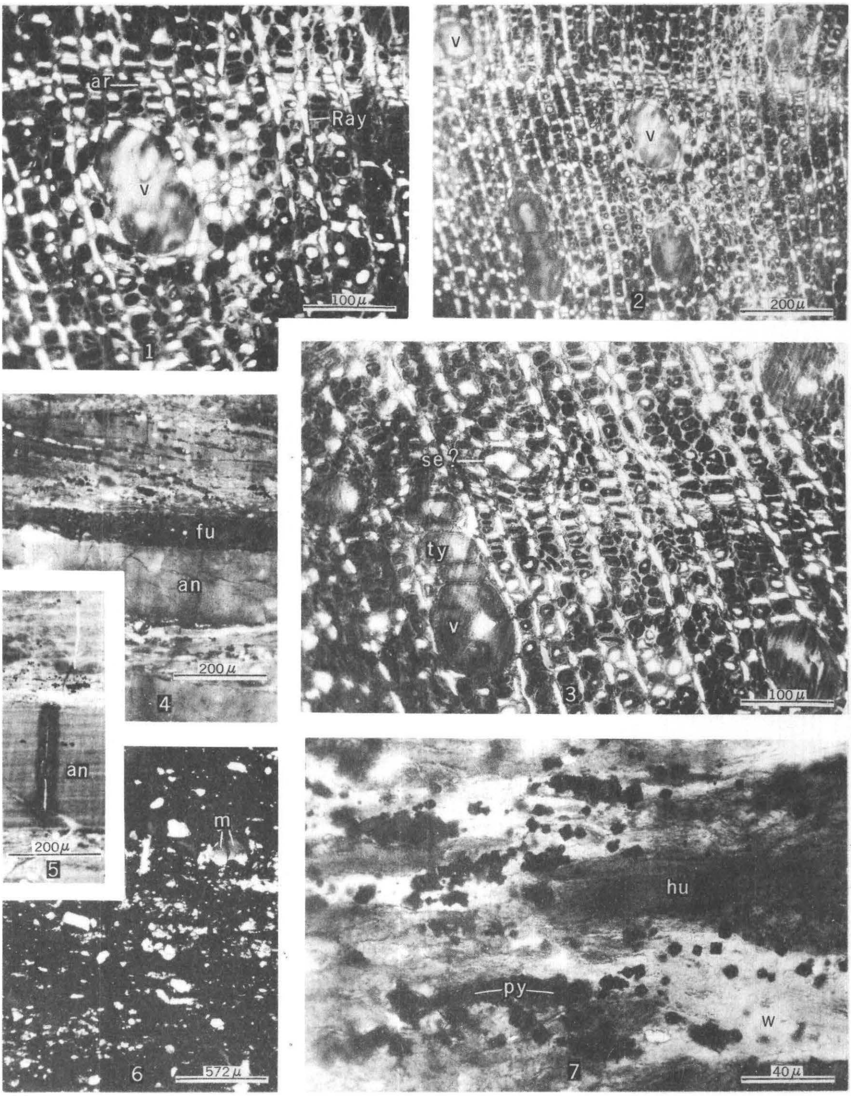
2–4. Coal from the Smith bed; microcomponents in lump, 112 mm thick, from Belle Slope mine. In NE¼SW¼ sec. 34, T. 35 N., R. 1 W., Lewis County, Wash.

5–7. Coal from Black Bear bed. See legend for plate 13.

PLATE 13

[Scale of magnification given in each figure inset. All figures illustrate structures sectioned normal to the banding, photographed by transmitted light. For specific discussion see accompanying text]

FIGURES 1–7. Coal from the Black Bear bed; microcomponents in lump, 68 mm thick, from Black Jewell mine. In NW¼NW¼ sec. 32, T. 16 N., R. 1 W., Thurston County, Wash.



COAL FROM THE BLACK BEAR BED