Geology and Coal Resources of the Toledo-Castle Rock District Cowlitz and Lewis Counties, Washington

GEOLOGICAL SURVEY BULLETIN 1062

Geology and Coal Resources of the Toledo-Castle Rock District Cowlitz and Lewis Counties, Washington

By ALBERT E. ROBERTS

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A study of resources, principally coal but including oil and gas, clays, and gravel and crushed rock, in Tertiary and Quaternary deposits

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CONTENTS

	Page
Abstract	1
Introduction	2
Location	2
History	2
Acknowledgments	4
Fieldwork	4
Geography	5
Land features	5
Drainage	6
Climate and vegetation	6
Accessibility and culture	8
Stratigraphy	9
General features	9
Tertiary system	13
Eocene series	13
Northcraft formation	13
Cowlitz formation	14
Hatchet Mountain formation	19
Porphyritic basalt sequence	21
Porphyritic andesite sequence	22
Olivine basalt sequence	23
Eocene and Oligocene series	24
Toutle formation	24
Miocene series	32
Middle(?) Miocene volcanic sequence	32
Wilkes formation	34
Quaternary system	37
Pleistocene and Recent series	37
Logan Hill formation	37
Alpine drift	38
Terrace deposits	39
Landslide debris	40
Alluvium	41
Structure	42
Economic geology	43
Coal	43
Physical and chemical properties	46
Coal beds of the Cowlitz formation	46
Leavell bed	46
Schuff bed	46
Unnamed beds	48
Coal beds of the Toutle formation	48
Cedar Creek Nos. 1, 2, and 3 beds	49
Silver Lake bed	50
Walker bed	50
Unnamed beds	51
Coal reserves	51
Oil and gas possibilities	54

Economic geology—Continued — Page
Gravel and crushed rock — 55
High-alumina clay — 55
References cited — 57
Appendix — 59
Index — 71

ILLUSTRATIONS

Page

PLATE 1. Geologic map and structure section of the Toutle quadrangle and the Castle Rock quadrangle east of the Cowlitz River, Washington — In pocket
2. Petrographic correlation of extrusive rocks in the Toledo-Castle Rock coal district — In pocket
3. *A*. Sandstone of the Cowlitz formation overlain by Pleistocene terrace gravels. *B*. Contact of the Toutle and Cowlitz formations — Faces 14
4. *A*. Interbedded basalt flow in the Cowlitz formation. *B*. Sandstone, conglomerate, and water-laid tuff in the lower part of the Hatchet Mountain formation — Faces 15
5. *A*. Porphyritic andesite of the Hatchet Mountain formation. *B*. Platy porphyritic andesite flow of the Hatchet Mountain formation — Faces 24
6. *A*. Olivine basalt of the Hatchet Mountain formation. *B*. Porphyritic basalt of the Hatchet Mountain formation — Follows 24
7. Lapilli tuff and coal beds of the Toutle formation — Follows 24
8. *A*. Middle (?) Miocene basalt showing hyaloophitic texture. *B*. Middle (?) Miocene basalt composed principally of glass showing gas bubbles — Faces 34
9. *A*. Porphyritic andesite of the middle (?) Miocene volcanic sequence. *B*. Contact of Toutle formation and middle (?) Miocene porphyritic andesite — Follows 34
10. Sandstones and siltstones of the Wilkes formation — Follows 34
11. Glacial till in the Logan Hill formation — Faces 35
12. Cedar Creek No. 1 coal bed exposed in Shives' strip pit No. 2 — Faces 50
13. Sections of coal beds from drill holes in T. 11 N., R. 1 E. — In pocket
14. Sections of coal beds in T. 11 N., R. 2 W.; T. 10 N., R. 2 W; T. 10 N., R. 1 W.; T. 10 N., R. 1 E.; T. 9 N., R. 2 W.; and T. 9 N., R. 1 W — In pocket
15. Map showing area favorable for strip mining in secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., Lewis County, Washington — In pocket
16. Diagram showing correlations, ranges in thickness, and pre-upper Miocene erosion of the Cedar Creek Nos. 1, 2, and 3 coal beds — In pocket

FIGURE 1. Index map showing location of the area covered by this report — 3
2. Chart showing relation between runoff and precipitation in the Toledo-Castle Rock coal district, Washington — 7

TABLES

		Page
TABLE 1.	List from megafossils of the Cowlitz formation in the Toledo-Castle Rock coal district, Washington	15
2.	List of megafossils from the Toutle formation in the Toledo-Castle Rock coal district, Washington	25
3.	List of flora from Cowlitz, Toutle, and Wilkes formations in the Toledo-Castle Rock coal district, Washington	30
4.	Data on mines and prospects in the Toledo-Castle Rock coal district, Washington, east of the Cowlitz River	44
5.	Proximate analyses of coal from Toledo-Castle Rock coal district, Washington, east of the Cowlitz River	47
6.	Average of 18 ultimate analyses of Cedar Creek No. 1 coal bed from Cedar Creek stripping area	49
7.	Original lignite reserves in the Cedar Creek stripping area in secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., near Windom, Wash	50
8.	Original reserves of subbituminous coal in the Toledo-Castle Rock coal district, east of the Cowlitz River, Washington	53
9.	Original reserves of lignite in the Toledo-Castle Rock coal district, Washington	54

GEOLOGY AND COAL RESOURCES OF THE TOLEDO-CASTLE ROCK DISTRICT, COWLITZ AND LEWIS COUNTIES, WASHINGTON

By Albert E. Roberts

ABSTRACT

The Toledo-Castle Rock coal district of southwestern Lewis County and north-central Cowlitz County, Washington, includes an area of about 305 square miles in and adjacent to the lower valley of the Cowlitz River. The district is named from the two largest towns, Toledo and Castle Rock, which are located centrally with respect to the coal deposits. The Cowlitz River and its principal tributary, the Toutle River, constitute the main drainage within the mapped area. The climate of the district is moist-temperate, with a mean annual rainfall of 58.30 inches and a mean annual temperature of 50.4° F.

The sequence of rocks exposed in the district ranges in age from early Tertiary to Quaternary and is more than 6,000 feet thick. It includes basalt flows of the Northcraft formation of late Eocene age; sandstone, siltstone, and interbedded basalt flows of the Cowlitz formation of late Eocene age; basalt and andesite flows, breccias, and tuffs of the Hatchet Mountain formation of late Eocene age; conglomerate, sandstone, and siltstone of the Toutle formation of late Eocene and early Oligocene age; andesite and basalt flows of middle(?) Miocene age; sandstone, siltstone, and clay of the Wilkes formation of late Miocene age; outwash sands and gravels and till of the Logan Hill formation of Pleistocene age; and alpine drift, outwash sands and gravels, and associated terrace deposits of Pleistocene age.

The predominant structural feature of the Toledo-Castle Rock coal district is the broad Napavine syncline. The axis of this northwest-plunging syncline extends from the South Fork of the Toutle River through Napavine. The lignite beds of the Toutle formation occupy the axial part of this syncline and the subbitmunious coal beds of the Cowlitz formation are found along the west flank of the syncline.

The rank of the coals in the Toledo-Castle Rock district ranges from lignite to subbituminous, generally depending upon the age of the enclosing formation. The coal in the Cowlitz formation is commonly subbituminous C but it may range from lignite to subbituminous B. The coal in the Toutle formation is lignite. The total reserves of coal in the district are approximately 131.8 million short tons. These reserves are in beds 2.5 or more feet thick with less than 1,000 feet of cover, and include an estimated total of 7.20 million short tons of subbituminous coal and an estimated total 123.78 million short tons of lignite. In secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., a deposit of lignite totaling 8.05 million short tons has a cover of 60 feet or less and could be obtained by strip mining methods.

Seven miles northeast of Castle Rock 8.5 million tons of refractory high-alumina clay has been measured; 9 million tons of clay indicated; and more than 10 million tons of clay inferred. Similar high-alumina clay was found associated with coal beds 9 miles east of Toledo.

Sand and gravel for construction aggregate are obtained from stream channels and terrace deposits adjoining the major streams. Stone is quarried and crushed locally from Eocene and Miocene volcanic rocks.

INTRODUCTION

LOCATION

The Toledo-Castle Rock coal district is in the southwestern part of Lewis County and the north-central part of Cowlitz County, Wash. The district is bounded by meridians 122°30′ and 123° W. and latitudes 46°15′ to 46°30′ N. The mapped area includes about 305 square miles in and adjacent to the lower valley of the Cowlitz River. A few isolated coal outcrops and abandoned prospects or mines are west of the Cowlitz River, but reserves were not computed for that area because of the paucity of coal outcrops and mine data. The district is south of the Centralia-Chehalis coal district and southwest of the Morton coal district. It derives its name from the two largest towns, Toledo and Castle Rock, which are located centrally with respect to the coal deposits.

Figure 1 shows the location of the investigated area and outlines the coal-bearing areas in western Washington which have been mapped and described in publications of the U. S. Geological Survey.

HISTORY

Early traders of the Hudson's Bay Co. who operated barges, bateaus, and canoes along the Cowlitz River noted beds of coal exposed in the river banks. In 1833 one of these men, Dr. Tolmie, made the first known record of these beds. In the summer of 1848 a prospector excavated several tons of this coal which was shipped in 1850 to Oregon City, Oreg., where it was tested by blacksmiths and pronounced unsatisfactory as a smithing coal. An attempt was made in the fall of 1851 at Cowlitz Landing, immediately south of Toledo, to supply coal for the San Francisco market but without much success. Coal from new prospects along the Cowlitz River was shipped to Portland in 1865 to be tested as a boiler and domestic fuel. Ten tons of this coal were also tried in the steamboat, "New World," which plied between Portland and Cascade, Oreg., but the sternwheeler consumed too much of this bulky fuel and the plan to utilize the Cowlitz River coal for this purpose was abandoned.

The use of coal instead of wood as fuel for steam locomotives renewed the district's mining activity in the early 1890's and several prospects were developed into mines; but little is known of these early mines because only a few scattered records were kept. The Idleman and Leavell were the largest mines at this time, but by the turn of

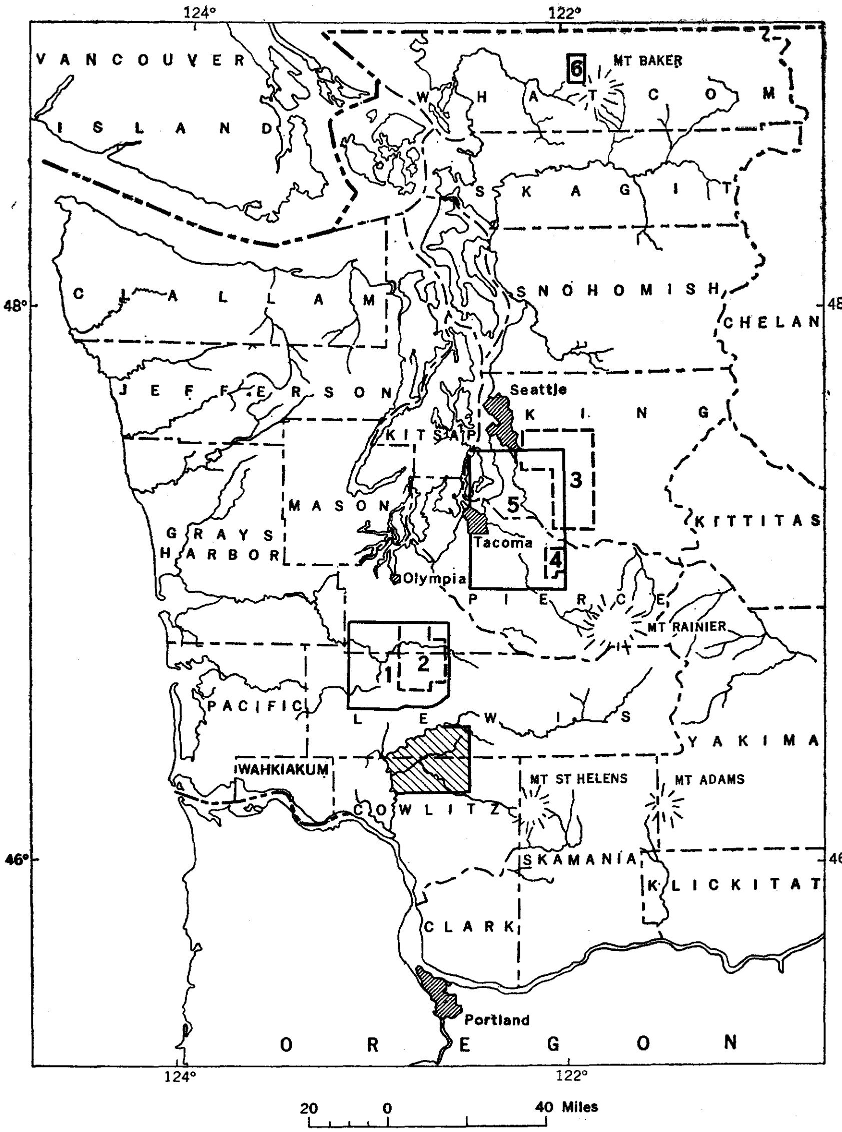


FIGURE 1.—Index map showing area of this report and its relation to other mapped coal fields in Washington. Patterned area, this report; area 1, Centralia-Chehalis district (U. S. Geol. Survey Bull. 1053); area 2, eastern part Centralia-Chehalis district (U. S. Geol. Survey Coal Inv. Map C–8); area 3, King County (U. S. Geol. Survey map of "Coal Fields of King County, Wash.," 1945); area 4, Wilkinson-Carbonado (U. S. Geol. Survey 18th Ann. Rept., pt. 3); area 5, Tacoma (U. S. Geol. Survey Geol. Atlas, folio 54); area 6, Glacier (U. S. Geol. Survey Bull. 541–I).

the century they had limited production or had been abandoned. There was little mining activity in the district during the early 1900's and at present coal is not commercially produced.

Little systematic geologic work has been done in the Castle Rock and Toutle quadrangles, Washington. Landes and Ruddy (1903, p. 225) mentioned briefly a few mines in the Castle Rock quadrangle. Collier (1913, p. 323) added to this list of mines and prospects, and Culver (1919, p. 44) presented a résumé of these mines and generalized geologic descriptions of the coal beds. Marine sedimentary rocks of late Eocene and Oligocene age exposed along the Cowlitz River in the western part of the Castle Rock quadrangle were described by Weaver (1916a, 1937) and Effinger (1938). A geologic investigation by the Geological Survey of two dam sites in the Toutle quadrangle was made by Erdmann and Warren (1938). Nichols (1943) made a preliminary report on the high-alumina clay deposits near Castle Rock, Cowlitz County. In 1945 a study was made of the lignite beds in secs. 15, 16, 21, and 22, T. 11 N., R. 1 E. near Toledo, Lewis County, by the Bureau of Mines and the Geological Survey; the data obtained were published by the Bureau of Mines (Toenges, Turnbull, and Cole, 1947). A geologic investigation of the Mayfield dam site, adjacent to the northeastern part of the mapped area, was made by Erdmann and Bateman (1951).

ACKNOWLEDGMENTS

Invertebrate fossil determinations were made by Ralph Stewart and Harold E. Vokes, and Foraminifera identifications were made by W. W. Rau. Identifications of fossil plants and reports on their stratigraphic significance by Roland W. Brown were especially helpful. A skull fragment was identified as that of a mammoth by Jean Hough. The cooperation of Sheldon L. Glover, supervisor, Division of Mines and Geology, Washington State Department of Conservation and Development, facilitated the work, as did the cooperation of many inhabitants of the area.

FIELDWORK

The present investigation of the coal deposits and geology of the Toledo-Castle Rock coal district was begun in 1951 by the Geological Survey as a part of a systematic survey of the mineral fuel resources of western Washington. This report is based on fieldwork done by the writer during the summer of 1951 and, with the assistance of A. L. Parmer, the summer of 1952.

Field mapping was done on aerial photographs at a scale of 1:48,000 for the Toutle quadrangle and 1:40,000 for the Castle Rock quadrangle. Geology was transferred from the photographs, by means of a vertical projector, to a base map compiled from the

Geological Survey's combined plates of the Toutle and Castle Rock quadrangles.

In 1945 the Bureau of Mines did extensive core drilling in the lignite deposit 9 miles east of Toledo. The drilling consisted of 35 holes churn-drilled through the overburden and cored beneath, totaling 4,279 feet. Three test holes, totaling 1,331 feet, were drilled for the Geological Survey in 1951 to aid stratigraphic studies and to obtain samples of coal for analysis.

GEOGRAPHY

LAND FEATURES

The lowest relief is along the broad terraced valley of the Cowlitz River in the western and northwestern parts of the area. Contiguous to the valley terraces the upland surfaces are those of a submature topography. The valleys were broadened during Pleistocene time by streams larger than the present ones. The Wilkes Hills (named by the author for Charles Wilkes who commanded early nineteenth century exploration parties in the area) east of the Cowlitz River in the Castle Rock and Toutle quadrangles are generally flat-topped and of about the same elevation. The volcanic highlands in the eastern part of the Toutle quadrangle have a youthful topography.

The minimum elevation, approximately 20 feet above sea level, is in the extreme southwestern part of the mapped area. The maximum elevation, 3,286 feet above sea level, is the summit of Signal Mountain in the Green Mountain Range in the southeastern part of the Toutle quadrangle. The predominant topographic feature, immediately adjacent to the southeastern part of the mapped area, is Mount St. Helens, a recent volcano, which has an altitude of 9,671 feet.

The Toutle River valley shows considerable variation in cross section and profile. The variation is directly related to the extent glaciation or stream action has eroded the rock types. The valleys in areas underlain by volcanic rocks are narrower than the valleys underlain by the easily eroded sedimentary rocks. The sides of the valleys of Salmon and Cedar Creeks show the effect of landsliding and slumping (mass wasting) of poorly consolidated sedimentary rocks.

Pleistocene glaciation formed many of the land features in the mapped area. Alpine glaciers extended down the valleys of the Green River and the North Fork of the Toutle River approximately to their junction and down the valley of the South Fork of the Toutle River to the southern border of the Toutle quadrangle. Large quantities of outwash material from these two alpine glaciers formed Silver Lake by damming the outlet of a north-drained basin. Large volumes of melt water and debris, approximately following the present course of the Cowlitz River, came through Winston Creek and spilled into the drainages of Salmon and Cedar Creeks. The debris formed large constructional terraces, and the melt water cut destructional terraces.

DRAINAGE

The Cowlitz River and its principal tributary, Toutle River, are the main streams within the mapped area. The Cowlitz flows southwestward across the northern part of the Castle Rock and Toutle quadrangles and south along the western edge of the Castle Rock quadrangle. The source of the Cowlitz River is the Cowlitz Glacier melt waters on the southeastern slopes of Mount Rainier.

The Toutle River flows westward from its source at Spirit Lake on the northwestern slope of Mount St. Helens and empties into the Cowlitz River about 2 miles north of Castle Rock. The principal tributaries of the Toutle River within the mapped area are the Green River and the South Fork of the Toutle River. The summer flow of the Toutle River is largely melt water from snow fields and glaciers on the northern slope of Mount St. Helens. Some of the melt water flows into the South Fork, but this stream receives most of its water from surface drainage. The Green River, whose headwaters are in the high spurs of the Cascade Range, receives most of its water during the summer from surface drainage and ground-water storage.

Salmon Creek, a westward-flowing tributary that crosses the central part of the mapped area, joins the Cowlitz River 1 mile south of Toledo. Salmon Creek heads near Wilson; most of its water is from surface drainage.

Silver Lake, in the southeastern part of the Castle Rock quadrangle, has a drainage area restricted to its immediately surrounding slopes. Two of the larger streams feeding the lake are Sucker Creek on the south and Hemlock Creek on the east. Silver Lake is drained to the Toutle River by Outlet Creek.

CLIMATE AND VEGETATION

The Toledo-Castle Rock area has a moist-temperate climate. The summer and fall months are mild with little precipitation and the spring and winter months are cool with high precipitation. Mean annual rainfall at Kid Valley, about 1 mile west of the junction of the Green and Toutle Rivers, for the 10-year period 1942–51 was 58.30 inches, and mean annual temperature for the same period was 50.4° F. Light snow falls occasionally during the winter in the Cowlitz and Toutle River valleys, but deep winter snows cover the Cascade Range and its foothills in the eastern part of the mapped area.

High seasonal precipitation (see fig. 2) accelerates erosion and facilitates the chemical breakdown of rocks. This erosion and decomposition develop deeply-weathered bedrock in most of the mapped area.

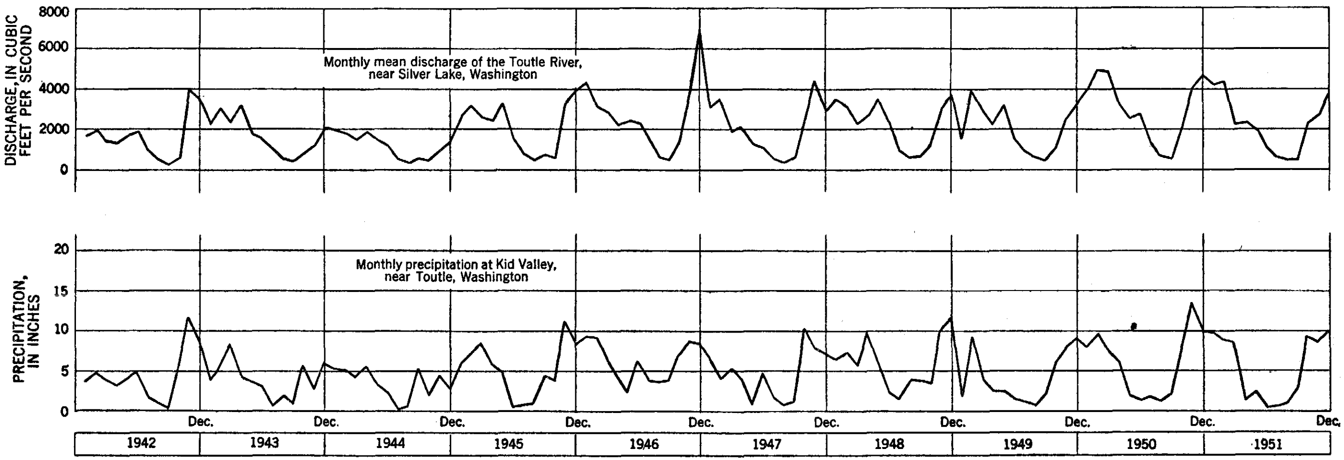


FIGURE 2.—Chart showing relation between runoff and precipitation for the period of 1942–51 in the Toledo-Castle Rock coal district, Washington.

Mass wasting (landslide, slump, and mudflow) of saturated bedrock is common during the months of high precipitation.

Originally, the Toledo-Castle Rock area was heavily timbered except for small open patches along major stream valleys. The predominant forest trees are Douglas-fir (*Pseudotsuga taxifolia*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*). Douglas-fir, the most important timber tree, and western hemlock grow on stream terraces and slopes that have adequate drainage; the western redcedar commonly grows in the poorly drained valley bottoms.

Deciduous trees abound along the banks of streams and lakes and ravines of restricted drainage. The common deciduous trees are bigleaf maple (*Acer macrophyllum*), vine maple (*Acer circinatum*), red alder (*Alnus ruba*), and western black willow (*Salix lasiandra*). Associated with these trees is a dense growth of underbrush whose most common plants are blue elderberry (*Sambucus caerulea*), cascara (*Rhamnus purshiana*), devilsclub (*Oplopanax horridum*), Oregon grape (*Berberis aquifolium*), salal (*Gaultheria shallon*), and wild blackberry (*Rubus vitifolius*).

ACCESSIBILITY AND CULTURE

A double-track railroad connecting Portland, Oreg., and Seattle, Wash., traverses the western boundary of the mapped area and is used jointly by four major railroad companies: Union Pacific; Northern Pacific; Chicago, Milwaukee, St. Paul and Pacific; and Great Northern. The Pacific Highway (U. S. Route 99) follows closely the course of the Cowlitz River from Toledo downstream to Castle Rock and supplies a good, all-weather highway connection with Portland and Seattle. State Highways 1–R and 1–Q provide access to the eastern part of the district from U. S. Highway 99. County and private timber company roads provide further access within the district.

The Toledo lignite deposit lies about 9 miles east of the town of Toledo in southern Lewis County. The deposit is reached by traveling east for 7 miles on State Highway 1–Q from its junction with U. S. Highway 99 at Toledo to a point within 2 miles of the field, then over a gravelled county road that enters the field from the west. The rail transportation nearest to the field is a Weyerhaeuser Timber Co. railroad which runs eastward across the area, about 8 miles south of the deposit. Construction of 4 miles of truck road would be required to transport coal to the rail head of the Cowlitz, Chehalis, and Cascade Railroad at Winston. The nearest mainline railroad runs through Winlock, about 6 miles west of Toledo; delivery of coal to Winlock would require about 15 miles of trucking.

Most coal deposits near Castle Rock are generally within 2 or 3 miles of U. S. Highway 99 and the Northern Pacific Railway. Short truck roads would be required to connect these deposits with the main transportation lines.

Castle Rock and Toledo, the two largest towns in the mapped area, have a combined population of about 1,700. They are located in the extreme western part of the area and are 16 miles apart. Both are supported by lumbering, stock raising, farming, and dairying. The largest cities near the area are Kelso and Longview, 11 and 13 miles south of Castle Rock, and Chehalis and Centralia, 34 and 38 miles north of Castle Rock.

Most cultivated land is in the alluviated or terraced parts of the Cowlitz and Toutle River valleys and on the lower terraces along Salmon and Cedar Creeks. Some of the cut-over land has been cleared for cultivation or grazing, but most of the logged areas have grown up in heavy underbrush and second growth timber.

Logging is the principal industry in the area. Few stands of virgin timber remain and these are being removed, along with many stands of small second-growth trees. Reforestation is now being done, principally by the larger timber companies.

STRATIGRAPHY

GENERAL FEATURES

The sequence of rocks exposed in the Toledo-Castle Rock coal district ranges in age from early Tertiary to Quaternary and is more than 6,000 feet thick. It includes basalt flows of the Northcraft formation of late Eocene age; sandstone, siltstone, and interbedded basalt flows of the Cowlitz formation of late Eocene age; basalt and andesite flows, breccias, and tuffs of the Hatchet Mountain formation of late Eocene age; conglomerate, sandstone, and siltstone of the Toutle formation of late Eocene and early Oligocene age; andesite and basalt flows of middle(?) Miocene age; sandstone, siltstone, and clay of the Wilkes formation of late Miocene age; outwash sands and gravels and till of the Logan Hill formation of Pleistocene age; and alpine drift and associated terrace deposits of Pleistocene age (pl. 1).

The Eocene formations are best exposed along the limbs of the Napavine syncline. Filling the axial part of the Napavine syncline is the Wilkes formation which is the surface formation for most of the northern half of the Castle Rock and Toutle quadrangles. A large part of the mapped area is masked by till and outwash deposits from Pleistocene alpine glaciers.

The sedimentary formations in the Toledo-Castle Rock coal district are the Cowlitz, Toutle, and Wilkes. The Cowlitz and Toutle formations contain alternating marine and nonmarine strata. The fluctuating shoreline of the waters in which these two formations were deposited extended, in general, northward through the center of the Castle Rock quadrangle. Many carbonaceous siltstone beds in these formations, as well as carbonaceous siltstone beds in the Wilkes formation, contain fossil plants which form a chronologic record of the climatic and depositional conditions under which the formations were deposited. For comparison, Roland W. Brown (written communication) made the following brief summary relative to his study of the flora of these formations:

The Eocene vegetation of these areas was adapted to a warm temperate or subtropical climate, influenced by the proximity of the Pacific Ocean and its embayments, the movement of moisture-laden air from the ocean not being intercepted by the Coast Range or Cascade Mountains. The earlier Eocene flora included climbing ferns, palms, shuihsa (*Metasequoia*), katsura (*Cercidiphyllum*), and many broad-leaved dicotyledons not yet identified with certainty but suggestive of present subtropical or warm temperature floras. The later Eocene flora included ferns, palms, shuihsa, katsura, birch, elm, chestnutlike oaks, magnolia, hydrangea, laurel, cinnamon, an aralialike sycamore, and many others.

The Oligocene flora comprised sequoia, shuihsa, pine, hickory, alder, birch, oak, beech, elm, zelkova, sassafras, sweetgum, cherry, sycamore, linden, redbud, rose, hawthorn, katsura, cedrela, maple, dogwood and many others. Comparison of this list with that of the Eocene indicates that by Oligocene time the trend in this region toward a flora of temperate aspect was in full swing. The palms and climbing ferns disappeared and many genera now easily recognized as typically temperate, came in.

The large flora from the Miocene is similar to that from the Oligocene in general aspect, but the species are, for the most part, different. Shuihsa and katsura are rarer, or in many localities, are absent. Fir, pine, other conifers, willow, and poplar assume importance in the census of species. The climate was temperate and the rainfall amounted to 40 or 50 inches annually.

Volcanism was prevalent in the area mapped from late Eocene to middle(?) Miocene time. In the area southeast of the Toutle quadrangle volcanic eruptions occurred during late Tertiary or Quaternary time or both. The Northcraft and Hatchet Mountain formations and the middle(?) Miocene sequence are predominantly extrusive rocks. The Cowlitz and Toutle formations also contain some interbedded basalt flows. Extrusion of these Tertiary flows is believed to have been from fissures because of the lack of well-defined craters or other indications of central eruptions, and because of the presence of dikes—some of which merge into flows. There are limited exposures displaying characteristics of small intercanyon flows, but most exposures indicate that the lava tongues are from larger flows. With the exception of flows in the Cowlitz formation, the source of these volcanic rocks is believed to be east and southeast of the mapped area. The source of the flows in the Cowlitz formation is unknown.

The volcanic rocks are limited to basic rocks ranging from alkalic andesite to basalt. The study of the petrographic features of these rocks, as determined from 57 thin sections, is summarized graphically on plate 2. Shown there also is the stratigraphic relation between the extrusive rocks and the sedimentary units.

The igneous rocks are classified according to the type and the percentage of plagioclase feldspar present. Rocks in which the feldspar is primarily labradorite and which contains less than 5 percent olivine are termed "basalt." Rocks in which the feldspar is andesine are termed "andesite," and rocks in which the composition of the feldspar borders andesine and oligoclase are termed "alkalic andesite." If the feldspar borders andesine and labradorite in composition and the abundance of mafic minerals approaches that of a basalt, the term "calcic andesite" is used. Rocks containing more than 5 percent olivine and more than 35 percent plagioclase are termed "olivine basalt."

The thickness and character of the rock units exposed in the Toledo-Castle Rock coal district are summarized in the following table.

448780—58——2

Exposed rock units in the Toledo-Castle Rock coal district, Washington

Age		Formation	Thickness (feet)	Character of rocks
Quaternary	Recent	Alluvium	0-30	Gravel, sand, and silt along stream courses; includes low-level terraces and fan material. Locally includes swamp deposits.
Quaternary	Recent —?—	Landslide debris	0-50	Debris of Quaternary and Tertiary rocks.
Quaternary	Pleistocene	Terrace deposits	0-70	Terrace deposits of sand and gravel and till; composed chiefly of igneous rocks. Deltaic sands and gravels present locally.
Quaternary	Pleistocene	Alpine drift	0-150	Till deposits.
		Unconformity		
Quaternary	Pleistocene	Logan Hill formation	0-250	Glaciofluvial deposits consisting of gravel, sand, and silt with some till. Decomposed gravels chiefly of locally derived porphyritic volcanic rocks; unit weathered and iron-stained in upper 30 to 60 feet.
		Unconformity		
Tertiary	Pliocene —?—	Wilkes formation	0-760+	Thin-bedded to massive, tuffaceous, carbonaceous, clay, siltstone, sandstone, and conglomerate; chiefly of lacustrine and fluvial origin. Contains beds of fossil wood. Sandstone beds contain characteristic heavy-mineral suite.
Tertiary	Miocene	Middle(?) Miocene volcanic sequence	0-2,000	Black aphanitic to finely porphyritic basalt, vesicular in part and jointed; porphyritic generally, platy andesite.
		Unconformity		
Tertiary	Oligocene —?—	Toutle formation	0-1,200	Massive dark greenish-gray fossiliferous basaltic sandstone and conglomerate with a few tuffaceous siltstone and lapilli tuff beds. Calcareous nodules and beds locally present. Contains lignite coal beds and high-alumina clay deposits. Locally contains interbedded basalt flows.
		Unconformity		
Tertiary	Eocene	Hatchet Mountain formation	0-2,750	Massive flows, flow breccias, tuff breccias, tuffs, and associated pyroclastic sedimentary rocks. Rock sequence thickens rapidly from north to south and from west to east.
Tertiary	Eocene	Cowlitz formation	2,600+	Massive to thin-bedded arkosic sandstone and siltstone containing interbedded carbonaceous material, and coal beds. Sandstone locally fossiliferous and grades laterally into marine siltstone. Locally basaltic sandstone and conglomerate beds. Contains interbedded basalt flows. Thins rapidly to the east.
		Unconformity		
Tertiary	Eocene	Northcraft formation	200+	Porphyritic basalt and flow breccia.
		Base not exposed		

TERTIARY SYSTEM

EOCENE SERIES

NORTHCRAFT FORMATION

The oldest known rocks in the described area are a part of the Northcraft formation. They consist of basalt and andesite flows, flow breccias, and pyroclastic rocks and are exposed in the extreme northeastern part of the Toutle quadrangle near Winston Creek. Approximately 700 to 1,000 feet of similar lava flows, breccias, pyroclastic rocks, and tuffaceous sedimentary rocks exposed in the Centralia-Chehalis coal district were described and named the Northcraft formation (Snavely and others, 1951b).

Detailed geologic mapping in the Centralia-Chehalis coal district extended the Northcraft formation southward from the type area to the volcanic rocks at Alpha, Wash. (Snavely and others, 1958). Alpha is approximately 10 miles from Winston Creek in the northeast corner of the mapped area. The rocks in this area strike S. 35° E. from Alpha to Winston Creek. In the northeast corner of the adjoining Mount St. Helens quadrangle more of the stratigraphic section of this formation is exposed.

Rocks in the Cowlitz River gorge, adjacent to the northeast corner of the mapped area, were tentatively assigned to the Keechelus andesite series of Miocene age (Erdmann and Bateman, 1951, p. 26). The stratigraphic position and petrographic similarities of these rocks compare with those rocks of the Northcraft formation near Alpha; a late Eocene age is suggested for the lowest part of the volcanic unit described by Erdman and Bateman.

In fresh exposures the volcanic rocks of the Northcraft formation are dark olive gray to nearly black, but on weathered surfaces the rock is a reddish-brown. The flows of this formation in the Toutle quadrangle are dense, generally massive porphyritic basalt. Vesicules and fractures are commonly filled with chalcedony, calcite, and zeolite minerals.

Petrographic examination of the rocks of this formation within the mapped area indicates they are hypocrystalline basalt with a porphyritic texture. The phenocrysts are plagioclase and augite in a matrix of plagioclase laths, granules of augite and magnetite, and secondary alteration minerals. The plagioclase phenocrysts are labradorite. Secondary alteration has changed some of the augite to hornblende and chlorite minerals. Some of the alteration products probably were derived from interstitial basaltic glass.

In the type area, just east of the town of Tenino, the Northcraft formation rests on the McIntosh formation of middle to late Eocene age and is overlain by the Skookumchuck formation of late Eocene age (Snavely and others, 1958); therefore a late Eocene age was assigned to the Northcraft formation by these workers. Since no additional information was obtained in the Toledo-Castle Rock coal district, late Eocene is used for this report.

COWLITZ FORMATION

Along the banks of the Cowlitz River in the western part of the Castle Rock quadrangle are beds of marine and brackish-water sedimentary rocks. Weaver (1912) first referred to these beds as the Cowlitz formation and described the megafauna as of Eocene age. In subsequent papers (1916a, 1916b, 1937, and 1942) he added to the description of the formation and the megafauna. Beck (1943, p. 584) described the Foraminifera from 200 feet of section in the upper part of the Cowlitz formation, correlating the fauna with faunas from the Coaledo formation of Oregon and the Tejon and Poway formations of California. At its type locality the formation consists of approximately 4,200 feet of marine, brackish-water, and nonmarine beds with associated coal beds (Weaver, 1937, p. 90).

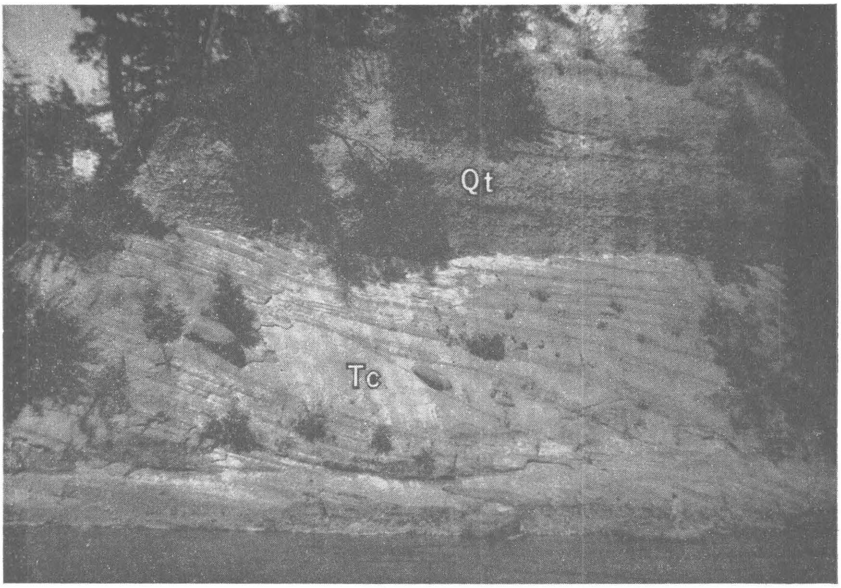
About 2,600 feet of the upper part of the Cowlitz formation is exposed east of the Cowlitz River. The formation is composed of marine sandstone and siltstone; brackish-water siltstone and sandstone; and nonmarine sandstone, siltstone, and coal beds. Associated with the sedimentary rocks are interbedded basalt flows and flow breccias.

In the NW¼ sec. 24, T. 10 N., R. 2 W., the Cowlitz formation consists of massive arkosic sandstone and associated coal beds. West of this locality the continental beds interfinger with brackish-water deposits. In the SE¼ sec. 22, T. 10 N., R. 2 W., marine beds are interfingered with nonmarine and brackish-water beds and in secs. 28 and 33, T. 11 N., R. 2 W., the formation is predominantly marine.

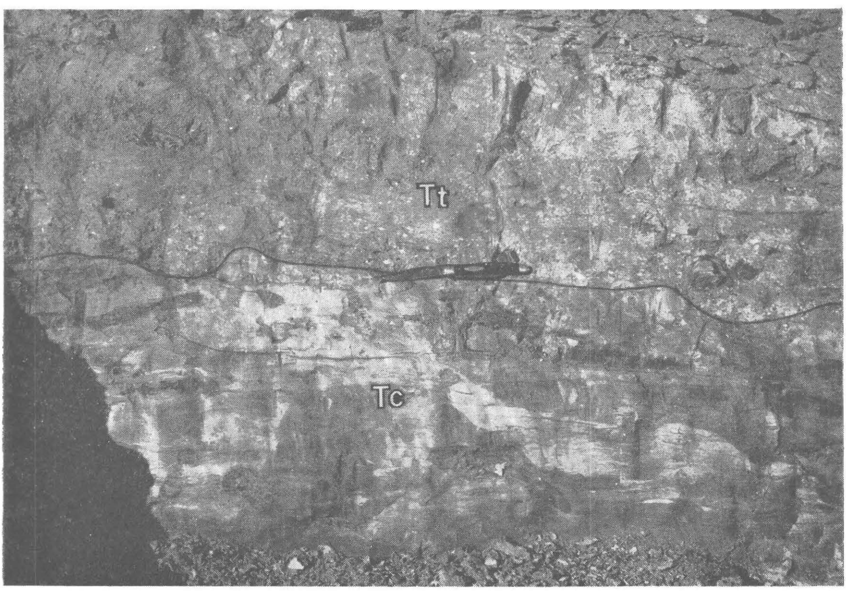
A massive arkosic sandstone bed, 35 to 90 feet thick, is exposed in secs. 20 and 29, T. 12 N., R. 2 E., between two volcanic rock units (Erdmann, 1951, p. 103). This sandstone probably represents the Cowlitz formation on the northeast limb of the Napavine syncline.

The Cowlitz formation consists of massive to faintly bedded sandstone, thin-bedded sandy siltstone, coal beds, and intercalated volcanic flows and breccias. The sedimentary rocks are both arkosic and basaltic but predominantly arkosic. The volcanic flows and breccias indicate short periods of volcanism during late Eocene time.

The sandstone of the formation is generally fine- to medium-grained, friable, and micaceous and locally contains carbonaceous material. The sandstone beds are generally massive and the sorting is fair to poor. The sedimentary rocks show a decrease in grain size to the



A. Long crossbedded arkosic sandstone of the Cowlitz formation (Tc) overlain by Pleistocene terrace gravels (Qt) along the Toutle River in the NW¼ sec. 24, T. 10 N., R. 2 W.



B. Knife rests on contact of the Toutle (Tt) and Cowlitz (Tc) formations in the NE¼ sec. 26, T. 11 N., R. 2 W. on the north bank of the Cowlitz River.

A. Interbedded basalt flow in the Cowlitz formation in a railroad cut in SW¼ sec. 22, T. 10 N., R. 2 W.

B. Coarse-grained basaltic sandstone, conglomerate, and water-laid tuff in the lower part of the Hatchet Mountain formation in the NE¼ sec. 11, T. 10 N., R. 2 W.

northwest. Calcareous concretions and lenticular beds of sandstone are found in some of the better exposures of the formations (see pl. 3A). In fresh exposures the arkosic sandstone is blue-gray and weathers to light yellowish gray. The dark greenish-gray basaltic sandstone weathers to a yellowish brown.

The siltstone is thinly bedded, micaceous, and carbonaceous. It is commonly sandy and is frequently interbedded with fine-grained sandstone forming a thin, alternately light and dark bedded rock. It varies from shallow marine to nonmarine deposits, as indicated by its lithologic character and fossil assemblages (table 1). A partial section measured in sec. 2, T. 10, R. 2 W., that is representative of the shallow water deposits of the Cowlitz formation is given in the appendix on page 62.

TABLE 1.—*List of megafossils from the Cowlitz formation in the Toledo-Castle Rock coal district, Washington*

[Identifications of specimens from locality M-1 by H. E. Vokes; M-2 by C. E. Weaver, Washington Univ. Pub. in Geology, v. 5; and M-3 by Ralph Stewart. Abbreviations: f., fragment; i., incomplete; i. c., internal cast; s., small.]

Species	U. S. Geological Survey Tertiary collecting stations and map reference number		
	—	—	18404
	M-1	M-2	M-3
Gastropods:			
Nerita cowlitzensis Dickerson		×	
washingtoniana Weaver and Palmer		×	
Neritina martini Dickerson		×	
Homalopoma, n. sp., cf. *domenginensis* Vokes	×		
Cirsochilus, n. sp	×		
Turbonilla (*Pyrgolampros*?), n. sp., aff. T. *kernensis* Anderson and Hanna	×		
(*Pyrgolampros*?), n. sp. "B"	×		
Pyramidella vaderensis Weaver and Palmer	×	×	
Odostomia, n. sp	×		
Opalia (*Rugatiscala*) *cowlitzensis* Durham		×	
Acrilla (*Ferminoscala*) *berthiaumei* Durham		×	
Polinices (*Polinices*) *hornii* (Gabb)		×	
(*Euspira*) *nuciformis* (Gabb)	×	×	
(*Euspira*) *nuciformis* (Gabb) *cowlitzensis*	×	×	
(*Neverita*) *secta* (Gabb)	×	×	
(*Neverita*) *weaveri* (Dickerson)	×	×	
Sinum obliquum (Gabb)		×	
Calyptraea diegoana (Conrad)	×	×	
Crepidula pileum (Gabb)		×	
pileum (Gabb) *dickersoni* Weaver and Palmer	×	×	
Turritella uvasana Conrad *olequahensis* Weaver and Palmer	×	×	
vaderensis Weaver and Palmer	×	×	
vaderensis Weaver and Palmer *kincaidi* Weaver and Palmer	×	×	
"*Potamides*" *fettkei* Weaver	×	×	
packardi (Dickerson)	×	×	

TABLE 1.—*List of megafossils from the Cowlitz formation in the Toledo-Castle Rock coal district, Washington*—Continued

Species	U. S. Geological Survey Tertiary collecting stations and map reference number		
	—	—	18404
	M-1	M-2	M-3
Gastropods—Continued			
Cerithiopsis vaderensis (Dickerson)	×	×	
washingtoniana (Dickerson)	×	×	
Elimia lewisiana (Weaver)	×	×	
Ectinochilus (*Cowlitzia*) *washingtonensis* (Clark and Palmer)	×	×	
(*Vaderos*) *elongata* (Weaver)	×	×	
Ficopsis cowlitzensis (Weaver)	×	×	
Echinophoria trituberculata (Weaver)	×	×	
Cymatium washingtonianum (Weaver)	×	×	
cowlitzense (Weaver)	×	×	
etheringtoni (Weaver)		×	
Olequahia washingtoniana (Weaver)	×	×	
Cantharus (*Eocantharus*) *cowlitzensis* Clark		×	
(*Calicantharus*) *perrini* (Dickerson)	×	×	
Siphonalia (*Nassicola*) *bicarinata* (Dickerson)	×	×	
(*Nassicola*) *sopenahensis* (Weaver)	×	×	
Parvisipho lewisiana (Weaver)	×	×	
Urosalpinx tejonensis (Weaver)		×	
hannibali Dickerson	?	×	
Murex packardi Dickerson		×	
cowlitzensis Weaver	cf.	×	
sopenahensis Weaver	×	×	
Pseudoliva kirbyi Clark	×	×	
Molopophorus bretzi (Weaver)	×	×	
Latirus eocenica (Weaver)	×	×	
Whitneyella washingtoniana (Weaver)	×	×	
buwaldana (Dickerson)		×	
Fusinus willisi (Dickerson)		×	
Fulgurofusus washingtoniana (Weaver)		×	
Mitra washingtoniana Weaver	×	×	
Olivella mathewsonii Gabb	×	×	
Bonellitia (*Admetula*) *paucivaricata* (Gabb)	×	×	
Conus vaderensis Weaver and Palmer	×	×	
cowlitzensis Weaver	×	×	
weaveri Dickerson	×	×	
Exilia dickersoni (Weaver)	×	×	
Gemmula barksdalei Weaver		×	
fasteni Weaver and Palmer		×	
Hemipleurotoma pulchra (Dickerson)	×	×	
Nekewis washingtoniana (Weaver)	×	×	
Turricula (*pleurofusia*) *cowlitzensis* (Weaver)	×	×	
(*Pleurofusia*) *ornata* (Dickerson)		×	
Clavus (*Crassispira*) *fryei* (Weaver and Palmer)	×	×	
(*Crassispira*?) n. sp.	×		
Scaphander cf. C. *costatus* (Gabb)	×		
Scaphopods:			
Dentalium sp. cf. *D. stramineum* Gabb	×		
sp. cf. *D. cooperi* Gabb	×		
Cephlopod:			
Aturia sp. cf. *A. myrlae* Hanna	×		

Table 1.—*List of megafossils from the Cowlitz formation in the Toledo-Castle Rock coal district, Washington*—Continued

Species	U. S. Geological Survey Tertiary collecting stations and map reference number		
	—	—	18404
	M-1	M-2	M-3
Pelecypods:			
Acila (*Truncacila*) *decisa* (Conrad)	×	×	
Ennucula, n. sp	×		
Nuculana cowlitzensis (Weaver and Palmer)	×	×	
vaderensis (Dickerson)	×	×	
Yoldia (*Portlandia*) *duprei* Weaver and Palmer	×	×	
Glycymeris sagittata (Gabb)		×	
sagittata (Gabb) *dickersoni* (Weaver and Palmer)	×	×	
eocenica (Weaver)		×	
Barbatia (*Barbatia*) *cowlitzensis* (Weaver and Palmer)		×	
(*Obliquarca*) *suzzaloi* (Weaver and Palmer)	×	×	
(*Obliquarca*) *landesi* (Weaver and Palmer)		×	
Pteria clarki Weaver and Palmer	×	×	
Ostrea idriaensis Gabb	×	×	
idriaensis Gabb *fettkei* Weaver	×	×	
Pecten (*Chlamys*) *landesi* Arnold		×	
(*Chlamys*) *cowlitzensis* Weaver		×	
Brachidontes cowlitzensis (Weaver and Palmer)	×	×	
Crassatella cowlitzensis (Weaver)		×	
(*Landinia*) *washingtoniana* (Weaver)	×	×	
cf. *C. stillwaterensis* Weaver and Palmer, s. i			cf.
Venericardia (*Pacificor*) *clarki* Weaver and Palmer	×	×	
Loxocardium (*Schedocardia*) *brewerii* (Gabb)	×	×	
(*Schedocardia*) *oldroydi* (Weaver and Palmer)	×	×	
(*Schedocardia*) *olequahensis* (Weaver)		×	
Macrocallista (*Costacallista*) *conradiana* (Gabb)		×	
williamsoni Weaver and Palmer	×	×	cf.
andersoni Dickerson		×	?
Pitar californiana (Conrad)		×	
Pitar ? *quadratus* (Gabb)	×	×	
Pitar (*Lamelliconcha*) *eocenica* (Weaver and Palmer)	×	×	
Pitar ? sp., s., i			?
Tivelina vaderensis (Dickerson)	×	×	
Gari cowlitzensis (Weaver and Palmer)		×	
(*Eosolen*) *columbiana* (Weaver and Palmer)		×	
(*Eosolen*) *clarki* (Weaver and Palmer)		×	
Spisula bisculpturata Anderson and Hanna	×	×	
Taras sp., s. i. c			×
Tellina cowlitzensis Weaver		×	
sp	×		
Corbula (*Caryocorbula*) *dickersoni* Weaver and Palmer	×	×	
Cardiomya, n. sp	×		

In his descriptions of the stratigraphy of the Cowlitz formation Weaver (1916a, p. 4; 1937, p. 93) describes intercalated basaltic flows. One of these volcanic flows is well exposed in secs. 9, 16, 22, and 27, T. 10 N., R. 2 W. (see pl. 4*A*). The thickness of the basalt is approximately 40 to 50 feet. The flow, in places, becomes a flow breccia and has the appearance of having piled up. The figure given is therefore a maximum and the actual thickness may be less.

The basalt is dark gray to black and varies from dense to slightly porous. Columnar jointing is common in the flow exposed along the old U. S. Highway 99 in the SW corner sec. 22, T. 10 N., R. 2 W. Flow breccia and associated pyroclastic rocks are exposed in a road cut of U. S. Highway 99 in the SE corner sec. 22, T. 10 N., R. 2 W.

The texture is microscopically seriate to finely porphyritic. The approximate composition, in percent, is plagioclase (labradorite), 46; augite, 26; magnetite, 9; chlorophaeite and chlorite minerals, 9; basaltic glass, 5; olivine, 3; calcite, 2; and a trace of apatite, sphene, zeolite minerals, and epidote.

The labradorite shows very slight or no zoning. The labradorite phenocrysts are tabular, containing inclusions of augite and magnetite and are generally less than 1 mm in length. Augite is present as granules and, less frequently, as small, ragged prisms. Small, scattered granules of olivine are associated with the pyroxene for which it is easily mistaken. The secondary alteration products were formed by hydrothermal solutions acting on the ferromagnesian minerals and the interstitial basaltic glass.

The most extensive list of invertebrate megafossils from the Cowlitz formation was made by Weaver (1942, p. 630). He assigned this fauna to the upper Eocene and correlated it with the type Tejon formation of California. Beck (1943) made a study of the Formanifera from the upper part of the Cowlitz formation along the west bank of the Cowlitz River in the E½SE¼ sec. 28, T. 11 N., R. 2 W., and supported the age of the formation assigned on megafossil evidence by Weaver. He compared the fauna of the Cowlitz formation with that from the upper 900 feet of the type Tejon formation of California; from the Poway formation of California; and from 360 feet of shale 1,790 feet below the top of the Coaledo formation of Oregon.

A foraminiferal assemblage from a marine siltstone exposed in the west bank of the Cowlitz River, sec. 21, T. 10 N., R. 2 W., was studied by W. W. Rau and found to contain the following species, all recorded from the type Cowlitz formation (Beck, 1943):

Collected 600 feet west and 1,500 feet north of the southwest corner of sec. 21, T. 10 N., R. 2 W. Plate 1, locality F–1.

Quinqueloculina imperalis Hanna and Hanna
Robulus inornatus (D'Orbigny)
Vaginulinopsis saundersi Hanna and Hanna

Dentalina colei Cushman and Dusenbury
Dentalina communis (D'Orbigny)
Nonion inflatum Cushman and Dusenbury
Globobulimina pacifica Cushman
Eponides yeguaensis Weinzierl and Applin
Pullenia salisburyi R. E. and K. C. Stewart
Cibicides natlandi Beck

In a new highway cut in the SE¼ sec. 22, T. 10 N., R. 2 W., sedimentary rocks overlie a volcanic breccia. A meager microfauna was obtained from a sandy siltstone at this locality. Some of the forms in the assemblage are not typical, but they compare with species from the type Cowlitz formation. Most of the species also are known from the Skookumchuck formation in the vicinity of Centralia. The assemblage suggests a shallow water and nearshore marine environment. The species identified from this locality are:

Collected 200 feet west and 1,000 feet north of the southeast corner of sec. 22, T. 10 N., R. 2 W. Plate 1, locality F–2.

Quinqueloculina cf. *Q. goodspeedi* Hanna and Hanna
Triloculina gilboei Beck
Robulus inornatus (D'Orbigny)
Dentalina communis (D'Orbigny)
Lagena conscripta Cushman and Barksdale
Bulimina schencki Beck
Eponides yeguaensis Weinzierl and Applin
Anomalina cf. *A. costiana* Weinzierl and Applin
Cibicides cf. *C. hodgei* Cushman and Schenck
cf. *C. mcmastersi* Beck
cf. *C. natlandi* Beck

Carbonaceous siltstone beds of the Cowlitz formation in sec. 9, T. 10 N., R. 2 W., contained the following fossil plants assigned by Roland W. Brown to the late Eocene or early Oligocene:

Asplenium eolignitícum Berry
Polypodium sp.
cf. *Persea* sp.
Fragments of unidentified dicotyledons

HATCHET MOUNTAIN FORMATION

Lava flows, flow breccias, pyroclastic rocks, and tuffaceous sedimentary rocks totaling more than 2,750 feet overlie the Cowlitz formation and are overlain by the Toutle formation in the Toledo-Castle Rock coal district. These rocks, exposed along both flanks of the Napavine syncline, form rugged ridges and mountains. The name Hatchet Mountain formation here designates these rocks. They are typically exposed in the vicinity of Hatchet Mountain in secs. 30

and 31, T. 11 N., R. 2 E., and secs. 25 and 36, T. 11 N., R. 1 E. More than 1,100 feet of these rocks is exposed in the vicinity of Hatchet Mountain; approximately 750 feet is exposed east of Castle Rock at Newell Ridge in secs. 18 and 19, T. 9 N., R. 1 W., and more than 400 feet is exposed in the lower gorge of the Toutle River in sec. 24, T. 10 N., R. 1 W.

Basaltic conglomerate, sandstone, and water-laid tuff are found at the base and in the lower part of the Hatchet Mountain formation. They are best exposed in the NE¼ sec. 11, T. 10 N., R. 2 W. (see pl. 4*B*), and along the Salmon Creek Road from Winston to Wilson in the NW¼ sec. 2, T. 11 N., R. 2 E. Other small patches of these sedimentary rocks were observed near the south end of Silver Lake.

The Hatchet Mountain formation rapidly increases in thickness to the south and east. The change from marine to nonmarine deposition in the Cowlitz formation also occurs in these directions. It is possible that along the southeastern edge of the basin of deposition there is an interfingering relationship between the upper part of the Cowlitz and the lower part of the Hatchet Mountain formations. In the western part of this area this relationship is suggested by the interbedded basalt flows, breccias, and pyroclastic sedimentary rocks in the predominantly arkosic section of sedimentary rocks of the Cowlitz formation. This relationship would only apply to the interbedded volcanic rocks in the upper part of the Cowlitz formation. Volcanic rocks, interbedded in the lower part of the Cowlitz formation that crop out between Ryderwood and Vader, probably correlate with the Northcraft formation. The Hatchet Mountain formation is unconformably overlain by the Toutle formation in sec. 19, T. 10 N., R 1 W. and sec. 22, T. 11 N., R. 1 E., and is unconformably overlain by the Wilkes formation in the north half of the Toutle quadrangle and east half of the Castle Rock quadrangle.

Culver (1919, p. 44) referred to undifferentiated igneous rocks apparently interbedded with Eocene sedimentary rocks in the Toledo-Castle Rock coal district. In a report on the Green River dam site in sec. 8, T. 10 N., R. 2 E., the volcanic rocks of the Hatchet Mountain formation were assigned a Miocene(?) age (Erdmann and Warren, 1938, p. 29). A sequence of basalt flows, pyroclastic rocks, and associated sedimentary rocks totalling more than 5,000 feet thick was mapped in the St. Helens quadrangle of Oregon and Washington (Wilkinson, Lowry, and Baldwin, 1946). This sequence was named the Goble volcanic series and was assigned a late Eocene and possibly early Oligocene age. Detailed mapping betwen the Castle Rock quadrangle and the St. Helens quadrangle may indicate that the Goble volcanic series includes the Hatchet Mountain and parts of the Cowlitz and Toutle formations of this report.

Fossils have not been found in the Hatchet Mountain formation which is composed predominantly of volcanic rocks. The formation overlies and may, in part, interfinger with the upper part of the Cowlitz formation of late Eocene age, and is overlain by the Toutle formation of late Eocene to early Oligocene age; therefore the formation is assigned to the late Eocene.

The Hatchet Mountain formation consists of three relatively distinct petrologic groups of volcanic rocks separated either by thin sedimentary deposits or local erosional unconformities. In chronological order they are the porphyritic basalt sequence, the porphyritic andesite sequence, and the olivine basalt sequence. They are shown on plate 2.

PORPHYRITIC BASALT SEQUENCE

Massive to platy porphyritic basalt, flow breccia, tuff, tuff breccia, and tuffaceous sedimentary rocks are exposed on the ridge extending from sec. 35, T. 11 N., R. 2 W. south to sec. 24, T. 9 N., R. 2 W. The lower gorge of the Toutle River in sec. 24, T. 10 N., R. 2 W., is cut through this series of volcanic rocks. The porphyritic basalt sequence, the lowest stratigraphic unit of the Hatchet Mountain formation (see pl. 2), is more than 400 feet thick in sec. 24, T. 10 N., R. 2 W., and increases in thickness to the south. The sequence thins rapidly to the north and is not present north of sec. 35, T. 11 N., R. 2 W. Approximately 360 feet of these rocks crops out near Wilson, in sec. 10, T. 11 N., R. 2 E., on the northeast flank of the Napavine syncline.

Sedimentary rocks associated with the flows are exposed best in small canyons in secs. 11 and 12, T. 10 N., R. 2 W. (see pl. 4*B*). These discontinuous rocks, composed of pebble conglomerate, tuffaceous sandstone, tuffaceous siltstone, tuff, and tuff breccia, are a maximum of 170 feet thick. Similar sedimentary rocks are exposed just southwest of Winston, in the SW¼ sec. 35, T. 12 N., R. 2 E., and the NW¼ sec. 2, T. 11 N., R. 2 E. Fresh exposures are a dull greenish-gray, with the light gray of the tuff fragments conspicuous on the surface. The beds vary from thin bedded to massive and are well indurated. The coarser grained rocks are generally crossbedded. About 65 percent of the exposed beds are a poorly sorted fine- to coarse-grained sandstone whose surface is made prominently rough by protruding, hard, single grains.

The thicker flows of the porphyritic basalt sequence have well-developed columnar jointing. Rude hexagonal columns are excellently exposed in the lower Toutle River gorge in the SE¼ sec. 24, T. 10 N., R. 2 W., and in the Cowlitz River gorge at the Geological Survey gaging station in sec. 24, T. 12 N., R. 1 E. Flow breccias are closely associated with the flows and frequently can be traced eastward into flows.

The porphyritic basalt sequence ranges from dense massive dark-gray flows, to platy medium-gray flows. Excluding chilled margins, these flows have textures that range from porphyritic to seriate. The texture of the groundmass is commonly trachytic. The phenocrysts make up 3 to 24 percent of the rocks. Plagioclase is the predominant phenocryst (see pl. 6*B*).

An average composition determined petrographically for rocks of the porphyritic basalt sequence is as follows: plagioclase, 51 percent; augite, 27 percent; alteration products, including chlorophaeite, chlorite, biotite, saussurite, and zeolite minerals, 11 percent; magnetite, 9 percent; basaltic glass, about 1 percent; and hypersthene, less than 1 percent.

The plagioclase is labradorite, generally approximating andesine in composition. Inclusions of magnetite and augite are common in the plagioclase crystals. The monoclinic pyroxene is a slightly titaniferous augite.

The groundmass consists of uniformly disseminated equidimensional plagioclase microlites and some granules of augite and magnetite. Secondary alteration has changed some of the plagioclase to saussurite and zeolite minerals. The basaltic glass and pyroxene minerals have been altered to chlorophaeite, chlorite, and biotite.

PORPHYRITIC ANDESITE SEQUENCE

Massive to platy porphyritic calcic andesite, flow breccia, and agglomerate are exposed along the Toutle River in the vicinity of Kid Valley and along the lower part of the Green River within the Toutle quadrangle. This sequence, stratigraphically between the olivine basalt sequence and the porphyritic basalt sequence of the Hatchet Mountain formation (see pl. 2), is more than 1,000 feet thick along the Green River. Near Kid Valley the porphyritic andesite sequence is more than 265 feet thick and consists of two andesite flows separated by an agglomerate (Erdmann and Warren, 1938). The thickness decreases westward; the sequence was not found in the central part of the Castle Rock quadrangle where the olivine basalt sequence rests unconformably on the porphyritic basalt sequence.

The andesite of the Hatchet Mountain formation is in general markedly porphyritic (see pl. 5*A*). The predominant phenocrysts are plagioclase with a few indistinct phenocrysts of augite and hypersthene. On fresh exposures the rocks are medium- to dark-gray; a slight greenish tinge is attributed to hydrothermal alteration of glass and some of the ferromagnesian minerals. Columnar joints and platy cleavage are common in these flows.

An average composition of the porphyritic andesite sequence, determined petrographically, is as follows: plagioclase, 53 percent; augite, 16 percent; hydrothermal alteration products, including chlorophaeite, chlorite, uralite, sausserite, and zeolite minerals, 12 percent; glass, 12 percent; magnetite, 4 percent; and hypersthene, 3 percent. The phenocrysts of plagioclase, augite, and hypersthene average 34 percent of the rock and range in size from 0.1 to 2 mm. The plagioclase phenocrysts are andesine. The hypersthene crystals are commonly surrounded by jackets of augite (see pl. 5*A*).

The trachytic to glassy groundmass contains microscopic crystals of plagioclase and barely discernible and partly developed crystals of pyroxene and magnetite. Fractures in the rock often contain deposits of calcite and chalcedony. Erdmann and Warren (1938, p. 77) reported a few strontianite veinlets, some as much as 4 inches in width.

OLIVINE BASALT SEQUENCE

Massive to semiplaty porphyritic olivine basalt is well exposed at the south end and on both flanks of the Napavine syncline; the best exposures of these extrusive rocks are on Hatchet Mountain in sec. 36, T. 11 N., R. 1 E., where the rocks are 800 feet thick. The olivine basalt sequence is the youngest group of volcanic rocks of the Hatchet Mountain formation. In sec. 35, T. 10 N., R. 1 E., the uppermost olivine basalt flow is overlain by sedimentary rocks of the Toutle formation. Exposures of the contact between the Toutle formation and the olivine basalt sequence are found in Salmon Creek in secs. 34 and 35, T. 11 N., R. 1 E. A core hole in sec. 22, T. 11 N., R. 1 E., drilled by the Bureau of Mines, penetrated the Cedar Creek No. 3 coal bed of the Toutle formation resting on olivine basalt.

The olivine basalt sequence is dark gray to black and generally is in dense massive units with small parts of the units being slightly porous or vesicular. The texture ranges from seriate to glomeroporphyritic but is most commonly porphyritic (see pl. 6*A*). The texture of the groundmass ranges from trachytic to pilotaxitic. In the porphyritic types the predominant phenocryst mineral is olivine; augite is slightly less abundant. Plagioclase phenocrysts are generally rare to absent. The olivine and augite phenocrysts constitute an average of 25 percent of the rock.

An average composition determined petrographically for the olivine basalt sequence is as follows: plagioclase, 44 percent; augite or pigeonite or both, 32 percent; olivine, 8 percent; hydrothermal alteration products, including chlorophaeite, chlorite, biotite, saussurite, nontronite, and zeolite minerals, 8 percent; magnetite, 6 percent; hypersthene, less than 1 percent; and basaltic hornblende, less than 1 percent.

Plagioclase ranges from calcic andesine to labradorite. The orthorhombic pyroxene is hypersthene and the monoclinic pyroxene ranges from augite to pigeonite. Olivine is near the end compound, forsterite, in composition; it is both optically negative and positive and has a large axial angle (2V). Olivine commonly has corroded borders and fracture surfaces (see pl. 6*A*).

The groundmass is given a characteristic peppery appearance by the equidimensional euhedral to subhedral crystals of magnetite. Basaltic hornblende was observed in a few thin sections that did not contain olivine, and it is believed that the basaltic hornblende was formed by deuteric alteration of olivine. Centers of the plagioclase are commonly altered to saussurite and analcite(?). Chlorophaeite, chlorite, biotite, and nontronite have been formed by alteration of the ferromagnesian minerals.

EOCENE AND OLIGOCENE SERIES

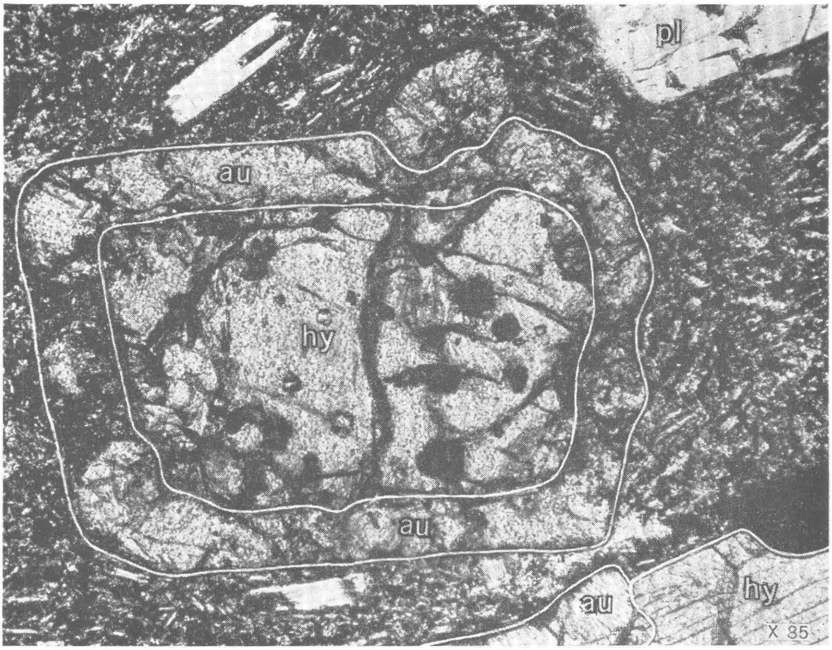
TOUTLE FORMATION

The name Toutle formation here designates marine and nonmarine beds exposed along the banks of the Toutle River from its tributary, Cline Creek, east to Coalbank Rapids, and north along Cedar Creek to Windom. In the mapped area the Toutle formation consists of about 570 feet of basaltic conglomerate, sandstone, siltstone, clay, and associated beds of lignite. Associated locally with the sedimentary rocks are interbedded basalt flows. These are best exposed in sec. 11, T. 9 N., R. 1 E. The formation crops out most along the flanks of the broad northwest-trending Napavine syncline. In the type area at Cline Creek the formation rests unconformably on the Hatchet Mountain formation (late Eocene) and on the Cowlitz formation (late Eocene) in the northern half of sec. 26, T. 11 N., R. 2 W. East of Cline Creek the Toutle formation is unconformably overlain by a vesicular aphanitic basalt flow of middle(?) Miocene age.

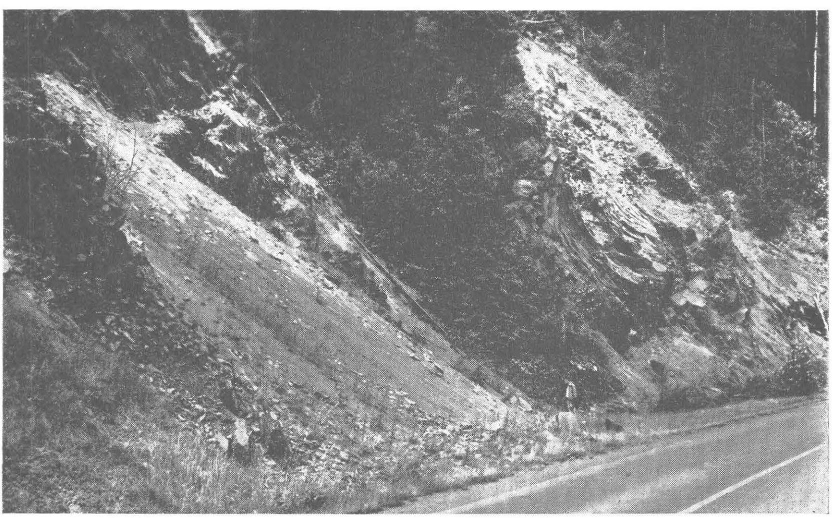
The volcanic extrusions that created the Hatchet Mountain formation were succeeded by deposition in the shallow seas which produced a sharp lithologic break between the Cowlitz and the Toutle formations.

Near Centralia, Snavely and others (1958) described 1,500 feet of strata in the basal part of the Lincoln formation and referred to this unit as the "basaltic sandstone member" of late Eocene to early Oligocene age. The Toutle formation is believed equivalent to this "basaltic sandstone member" on the basis of paleontologic and lithologic similarities (see table 2).

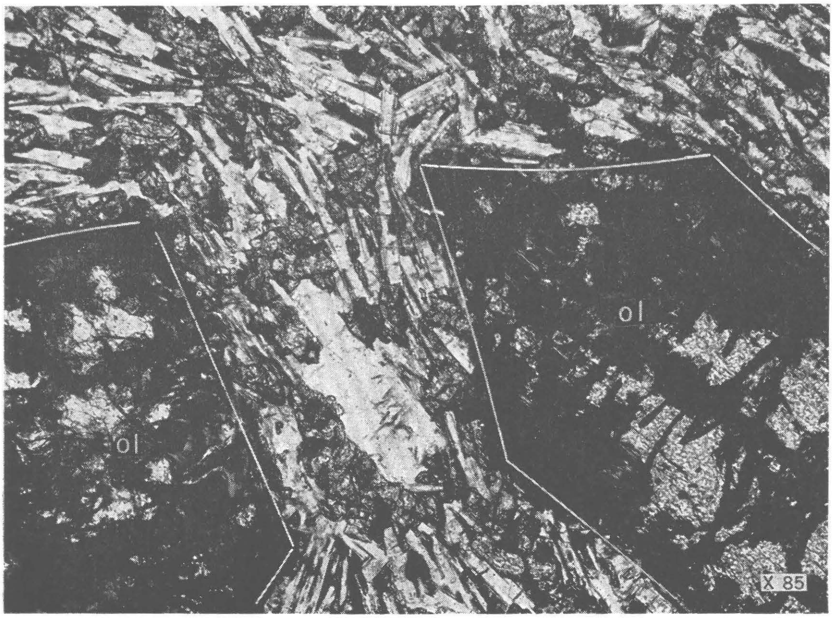
The Toutle formation consists predominantly of poorly sorted conglomerate and sandstone with interbedded tuffaceous siltstone. These sedimentary rocks are almost entirely composed of fragments of basalt, andesite, and red scoria. Immediately east of Cline Creek and in the valley of Cedar Creek the Toutle formation contains beds of massive lapilli tuff (pl. 7). The interbedded tuffaceous siltstone is usually associated with carbonaceous material and in places contains an identifiable fossil flora (see table 3).



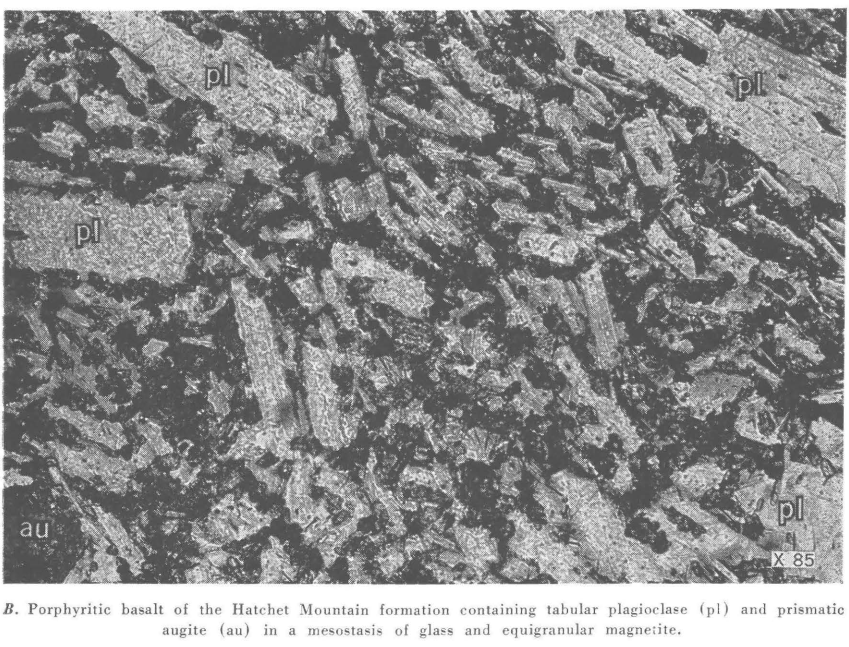
A. Porphyritic andesite of the Hatchet Mountain formation containing hypersthene (hy), augite (au), and plagioclase (pl) phenocrysts in a groundmass of feldspar, augite, magnetite, and glass.



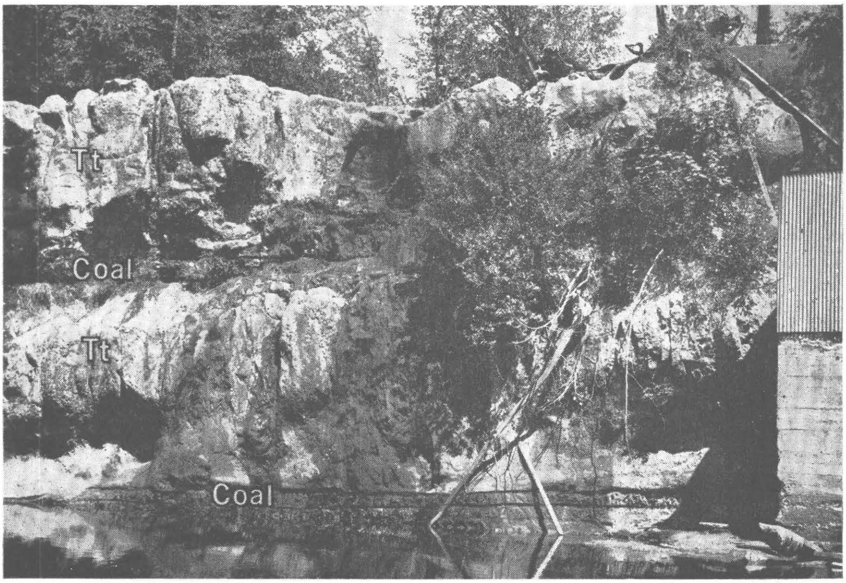
B. Platy porphyritic andesite flow of the Hatchet Mountain formation along the Spirit Lake highway in the SE¼ sec. 11, T. 10 N., R. 1 E.



A. Olivine basalt of the Hatchet Mountain formation containing partly altered euhedral phenocrysts of olivine (ol) in a trachytic groundmass of plagioclase, augite, and magnetite.



B. Porphyritic basalt of the Hatchet Mountain formation containing tabular plagioclase (pl) and prismatic augite (au) in a mesostasis of glass and equigranular magnetite.



Lapilli tuff and coal beds of the Toutle formation (Tt) exposed at the falls in Cedar Creek in the SE¼NW¼ sec. 30, T. 11 N., R. 1 E.

TABLE 2.—*List of megafossils from the Toutle formation in the Toledo-Castle Rock coal district, Washington*

[Identifications of specimens from localities M-4, M-6, M-7, and M-8 by Ralph Stewart; M-5 by W. L. Effinger (Jour. Paleontology, v. 12, no. 4, p. 355-390). Abbreviations: f., fragment; i., incomplete; i. c., internal cast; s., small]

Species	U. S. Geological Survey Tertiary collecting stations and map reference numbers				
	18,402	18,406	18,403 18,407	18,401	18,400
	M-4	M-5	M-6	M-7	M-8
Coral:					
Balanophyllia cf. *variabilis* Nomland		×			
Gastropods:					
Acmaea ocititia Hanna		×			
simplex Dickerson		×			
?*Solariella olequahensis* Weaver and Palmer, worn			×		
Homalopoma? sp		×			
Cirsochilus washingtonianus Effinger		×			
Liotia weaveri Effinger		×			
Melanella (*Melanella*) *clarki* (Dickerson)		×			
sp		×			
Odostomia (*Odostomia*) *winlockiana* Effinger		×			
(*Evalea*) *hiltoni* (Van Winkle)		×			
griesensis Effinger		×			
Epitoneum insecuritum? Hanna			cf.	×	
(*Boreoscala*) *condoni* Dall		×			
Acrilla (*Ferminoscala*) *dickersoni* Durham		×			
Littorina oligocenica Dickerson		×			
Natica (*Natica*) cf. *weaveri* Tegland		×			
Polinices lincolnensis (Weaver)		×			
cf. *P. hornii* Gabb, s			aff.?	×	
Neverita cf. *weaveri* Dickerson, i			×		
nomlandi Dickerson		×			
? *secta* Gabb, i	cf.		i. c.	×	
Euspira? *nuciformis* Gabb, worn	cf.		×		
Calyptraea diegoana (Conrad)		×		cf.	cf.
Hipponix arnoldi Dickerson		×			
Crepdiula pileum (Gabb)		×			
Turbella cowlitzensis Effinger		×			
Alvania lettana (Van Winkle)		×			
Turritella cf. *uvasana* Conrad, f., large			×		
Turritellopsis? *weaveri* (Van Winkle)		×			
Goniobasis? sp				×	
Elimia sp., probably new		×			
Cerithiopsis washingtoniana (Dickerson)		×			
merriami (Dickerson)		×			
Bittium howardi (Dickerson)		×			
Trichotropis alienensis Effinger		×			
Terebellum andersoni (Dickerson)		×			
Cypraeogemmula warnerae Effinger		×			
Ficopsis hornii cf. *cowlitzensis* Weaver (Shoulder possibly more prominent than on typical F. *hornii* from Tejon)			×		
?, f				×	
Trophon calamitus (Hanna)		×			

TABLE 2.—*List of megafossils from the Toutle formation in the Toledo-Castle Rock coal district, Washington*—Continued

[Identifications of specimens from localities M-4, M-6, M-7, and M-8 by Ralph Stewart; M-5 by W. L. Effinger (Jour. Paleontology, v. 12, no. 4, p. 355-390). Abbreviations: f., fragment; i., incomplete; i. c., internal cast; s., small]

Species	U. S. Geological Survey Tertiary collecting stations and map reference numbers				
	18,402	18,406	18,403 18,407	18,401	18,400
	M-4	M-5	M-6	M-7	M-8
Gastropods—Continued					
Galeodea dalli Dickerson		×			
cf. *G. fax* Tegland		×			
Galeodaria trituberculata? Weaver, s., worn			×		
? f.				×	
Phalium cf. P. egberti Schenck		×			
Cymatium? washingtoniana Weaver				×	
? cf. *C. cowlitzense* Weaver, i.	×				
Olequahia? washingtoniana Weaver				×	
Siphonalia packi (Dickerson)		×			
Urosalpinx, n. sp., (Effinger)		×			
Molopophorus cf. *M. antiquatus* Gabb, i.				×	
bramkampi Effinger		×			
stephensoni Dickerson		×		aff.?	
Endopachychilus? f.			×	?	
Latirus eocenica (Weaver)		×			
"*Whitneyella*" *gabbi* (Dickerson)		×			
?*Whitneyella washingtoniana* Weaver, i.			cf.	×	
"*Fusinus*" *gesteri* Dickerson		×			
Marginella (*Cryptospira?*) *instabilata* Hanna		×			
"*Cancellaria*" landesi Van Winkle		×			
Bonellitia cf. *B. paucivaricata* Gabb, i.				×	
Conus cf. *C. warreni* Hendon, Turner (anterior spirals?)			×		
ruckmani Dickerson		×			
sp., i.				×	
Exilia weaveri Dickerson		×			
Spriotropis winlockensis Effinger		×			
Clavatula arnoldi (Van Winkle)		×			
Acteon parvum Dickerson		×			
Volvulella tabor Effinger		×			
Scaphander washingtonensis subsp. *goodspeedi* Effinger		×			
Cylichnina tuneri Effinger		×			
Pelecypods:					
Arca washingtoniana Dickerson		×			
Nuculana merriami (Dickerson)		×		sp.	sp.
Cucullaria (*Porterius*) *gabbi* (Dickerson)		×			
Glycymeris cf. *G. sagittata* Gabb			×	i. c.?	×
andersoni Dickerson		×			
winlockensis Effinger		×			
Barbatia (*Acar*) *reinharti* Effinger		×			
Pedalion clarki Effinger		×			
Ostrea griesensis Effinger		×			
Pecten cf. *P. landesi* Arnold, s., i.				×	f.?
(*Chlamys*) *grunskyi* Hertlein		×			

TABLE 2.—*List of megafossils from the Toutle formation in the Toledo-Castle Rock coal district, Washington*—Continued

[Identifications of specimens from localities M–4, M–6, M–7, and M–8 by Ralph Stewart; M–5 by W. L. Effinger (Jour. Paleontology, v. 12, no. 4, p. 355–390). Abbreviations: f., fragment; i., incomplete; i. c., internal cast; s., small]

Species	U. S. Geological Survey Tertiary collecting stations and map reference numbers				
	18,402	18,406	18,403 18,407	18,401	18,400
	M–4	M–5	M–6	M–7	M–8
Pelecypods—Continued					
Lima bella Dickerson		×			
Mytilus cf. *M. stillwaterensis* Weaver and Palmer				×	sp. f.?
Volsella sp				s., i.	f.?
Crassatella cf. *C. uvasana* Conrad			cf.		
perrine (Dickerson)		×			
sp., s., i			×		
Cardita (*Carditamera*) *weaveri* Dickerson		×			
Lucina (*Here*) *dalli* (Dickerson)		×			
Taras griesensis Effinger		×			
sp		×			
Chama grunskyi Hanna		×			
Laxocardium etheringtoni Effinger		×			
Macrocallista cf. *M. williamsoni* Weaver and Palmer		×			
Pitar cf. *P. californicus* Conrad, large, i			×		
? aff. *P. uvasanus* Conrad, s., i					×
(*Lamelliconcha*) *clarki* Dickerson		×			
? sp., i				×	
Tellina (*Tellina*) *townsendensis* Clark		×			
(*Moerella*) *lincolnensis* Weaver					×
"*Tellina*" *gibsonensis* Van Winkle		×			
Gari martini Dickerson		×			
Semele reagani Dickerson		×			
Solen townsendensis Clark		×			sp. f.
Solena? f			×		
Spisula parkardi Dickerson		×			
mirriami cf. *S. bisculpturata* Anderson and Hanna					×
sp., s., i				×	
Saxicava sp		×			
"*Mya*" *arnoldi* (Dickerson)		×			
Corbula cowlitzensis Dickerson		×			

The generally olive-gray sandstone is composed of fragments of volcanic rock and smaller amounts of feldspar, quartz, and magnetite. Shallow-water marine beds, as exposed in the banks of the Cowlitz River in sec. 26, T. 11 N., R. 2 W., are commonly cemented with calcium carbonate; some calcareous concretions and nodules are present. The nonmarine sedimentary deposits are generally cemented with silica.

Associated with the nonmarine deposits are several beds of massive pumiceous water-laid lapilli tuff. These beds are exposed at the type area of the Toutle formation east of Cline Creek, south of Silver Lake in sec. 14, T. 9 N., R. 1 W., at the falls in Cedar Creek, and in Shives' strip pit No. 2 at Windom. Two beds of lapilli tuff, each about 10 feet thick, are present between the Cedar Creek Nos. 1, 2, and 3 coal beds. Similar beds of water-laid lapilli tuff are in the lower part of the "basaltic sandstone member" of the Lincoln formation near Centralia (Snavely and others, 1958).

Samples of sandstone from the Toutle formation were examined petrographically. These samples were composed of fragments of basalt and andesite, plagioclase (andesine and labradorite), and magnetite with smaller amounts of quartz, biotite, augite, and hornblende. The samples examined also contained fragments of pumice and red scoria. The detrital rock fragments are subangular to subrounded and the detrital mineral grains are angular to subangular.

A composite section of the Toutle formation measured at the type locality is given in the appendix on page 63.

About 6 miles north of the type area, beds of the Toutle formation are exposed along the banks of the Cowlitz River. These sedimentary beds are mainly shallow-water marine, littoral, and lagoonal in character. The formation rests on the Cowlitz formation with a marked change in lithologic character at the contact (see pl. 3*B*). A section was measured from exposures in the banks of the Cowlitz River and is given in the appendix on page 66.

East of Toledo, the Toutle formation is exposed in the stream channel of Cedar Creek, in tributaries with steep gradients, and in coal pits near Windom. The presence of lignite beds in this area prompted an extensive core drilling program by the Bureau of Mines (Toenges and others, 1947). A geologic summary of this drilling and of the surface exposures is as follows:

Geologic age, rock types, and remarks

Recent:

1. Soil and silt, sand, and gravel present in unconsolidated and slightly unweathered terrace channel-fill, and valley-fill deposits.

Wilkes formation:

2. Silty and sandy clays, and light-colored plastic clays, usually with lignite or carbonized wood fragments.

Toutle formation:

3. Weathered siltstones, sandstones, and shales, mostly altered to silty and semiplastic clays, but the original textures are visible.
4. Cedar Creek No. 1 coal bed averaging 25 feet 6 inches thick where not truncated by pre-late Miocene erosion; the bed has an average of 23 feet of coal and 2 feet 6 inches of partings.
5. Poorly sorted water-laid lapilli tuff with abundant large, light-colored pumice or other fragments in a finer grained groundmass. Average thickness is 10 feet. Scattered unweathered igneous rock fragments and bits of coalified wood are locally common. Bed mostly altered to clay with lapilli tuff texture preserved.

6. Cedar Creek No. 2 coal bed about 11 feet thick with an average of 9 feet 9 inches of coal and 1 foot 3 inches of partings. Appears to be as uniform in consistency as Cedar Creek No. 1 bed.
7. Lapilli tuff of 10-foot average thickness. A poorly sorted water-laid lapilli tuff similar to the bed between Cedar Creek Nos. 1 and 2 coal beds but usually has a distinguishing layer of large igneous pebbles near base. Bed generally altered to clay.
8. Cedar Creek No. 3 coal bed of lenticular and variable thickness with many partings. Coal contains fewer partings near top of bed.
9. Siltstone and sandstone of variable thickness. Beds weathered but original texture preserved.
10. High-alumina clay, generally a semiflint blue-gray clay containing granules or concretions of siderite.
11. Basaltic tuffs and tuff breccias, water-laid, usually dark; weathered at top; somewhat fresher at a depth of about 20 feet.

Unconformity.

Hatchet Mountain formation:

12. Basalt-vesicular in hole D–30 where drilled. Porphyritic and variable on surface outcrops.

Marine sandstone beds, exposed in sec. 19, T. 10 N., R. 1. W., at the falls in Cline Creek and at an adjacent road cut (plate 1, locs. M–7 and M–8) contain a poorly preserved megafauna assigned to the Eocene by Ralph Stewart (see table 2). Similar beds in secs. 25 and 26, T. 11 N., R. 2 W., contain a megafauna assigned to late Eocene or early Oligocene by Weaver (1916a), Dickerson (1917), Van Winkle (1918), Clark (1918), Schenck (1928), Tegland (1933), and Effinger (1938). Marine siltstone beds of the Toutle formation at test hole GS–1 contain Foraminifera of late Eocene and early Oligocene age, according to W. W. Rau (species listed on p. 31). A fossil flora collected from carbonaceous siltstone beds was assigned to late Eocene or early Oligocene by Roland W. Brown (see table 3). Collectively, the 3 faunas indicate that the Toutle formation ranges in age from late Eocene to early Oligocene.

Small exposures of the Toutle formation on the south bank of the Cowlitz River in the NW¼ sec. 25, T. 11 N., R. 2 W., yielded a fossil assemblage referred to as the "Gries Ranch" fauna. Dickerson (1917) described a fauna from this locality and made the following observation regarding its character:

> * * * The character of the sediments and the abundance of *Hipponyx ornata*, *Hipponyx arnoldi*, *Patella subquadrata*, *Crepidula* sp. and *Acmea simplex*, sessile shore forms, mark this fauna as a strictly littoral one. In conclusion the fauna appears to belong to a lower facies of the *Molopophorus lincolnensis* zone of Weaver, and its distinctiveness is due in part to its strictly littoral character and in part to having lived in a portion of Oligocene time older than that of the typical *Molopophorus lincolnensis* zone.

TABLE 3.—*List of flora from Cowlitz, Toutle, and Wilkes formations in the Toledo-Castle Rock coal district, Washington*

[Identification by Roland W. Brown]

Species	Formation											
	Wilkes			Toutle							Cowlitz	
	Map reference number											
	P-12	P-9	P-8	P-7	P-11	P-10	P-6	P-5	P-4	P-3	P-2	P-1
Ferns:												
Asplenium eolignitcum Berry												×
magnum Knowlton											×	
Dryopteris sp								×				
Lastrea sp					×	×					×	
Osmunda occidentalis (Berry) Brown				×								
sp				×								
Polypodium sp												×
Woodwardia sp					×			×				
Equisetum sp						×		×				
Conifers:												
Abies sp			×									
Taxodium dubium (Sternberg) Heer		×	×	×								
?Taxodium sp. (wood)									×			
Torreya bonseri (Knowlton) LaMotte			×									
Wood (not further identified)	×											
Monocotyledons:												
Potamogeton heterophylloides Berry									×			
sp				×								
?sp. (seeds)									×			
Dicotyledons:												
Alnus relatus (Knowlton) Brown							×					
Populus sp				×								
Carya sp			×									
Juglans sp				×								
Cercidiphyllum crenatum (Unger) Brown			×									
elongatum Brown					×							
Cinnamomum dilleri Knowlton										×		
Cryptocarya presamarensis Sanborn						×						
Lindera oregona Chaney and Sanborn										×		
Persea lanceolata (Berry) Brown			×									
?Persea sp												×
Hydrangea reticulata MacGinitie										×		
Philadelphus sp										×		
Platanus dissecta Lesquereux			×									
sp					×							
Prunus sp				×						×		
Legume (pods and seeds)				×								
Acer glabroides Brown	×		×									
Ceanothus sp										×		
Vitis washingtonensis (Knowlton) Brown			×									
Tetracera oregona Chaney and Sanborn										×		
Trapa americana Knowlton									×			
Seeds (not further identified)	×											
Wood (not further identified)		×		×	×							

The fact that these small exposures contain a faunal assemblage peculiar to the sedimentary facies they represent has not been given sufficient attention by succeeding workers. In 1918 Van Winkle added 10 descriptions to the fauna and suggested the correlation of this fauna with the fauna of the "Lincoln Creek Beds" (Lincoln formation). Subsequent papers by Clark (1918), Schenck (1928), and Tegland (1933) consider the "Gries Ranch" fauna to be a little older than Weaver's (1916a, p. 28) *Molopophorus lincolnensis* zone of the Lincoln formation. The *Molopophorus lincolnensis* zone included the Oligocene which was later restricted by Durham (1944, p. 112) to the *Turritella olympicensis* zone or middle Oligocene. Effinger (1938) made an extensive study of the "Gries Ranch" fauna and concluded:

> * * * The Gries Ranch fauna and deposits represent a distinct faunal zone younger than the Cowlitz (Eocene) and older than the type Lincoln faunal zones, but are about as closely related to one as to the other.
>
> Although at present there is no apparent means of making a direct correlation between what has generally been considered Oligocene on the West Coast and that of the Gulf region or the type section in Germany, it seems most logical to consider the Gries Ranch zone as lower-most Oligocene in age.

Foraminifera were collected in the Toutle formation from depths of 34 to 73 feet and 152 to 162 feet in test hole GS–1 in the SE¼SW¼ sec. 24, T. 11 N., R. 2 W. and were identified by W. W. Rau. The association of species is similar to that of the *Cibicides hodgei* zone of the nearshore facies of the Lincoln formation near Centralia, as described by Rau (Snavely and others, 1958). The fossils are:

Quinqueloculina sp.
Triloculina sp.
Robulus cf. *R. inornatus* (d'Orbigny)
Nonion cf. *N. planatum* Cushman and Thomas
Elphidium sp.
Valvulineria willapaensis Rau
Eponides yeguaensis Weinzierl and Applin
Ceratobulimina washburnei Cushman and Schenck
Cibicides cf. *C. mcmastersi* Beck

Rau concluded from a study of this small assemblage that several forms are probably new species; others are too poorly preserved for specific identification. However, the presence of typical large forms of *Valvulineria willapaensis* suggests a correlation with the fauna of the lower part of the Lincoln formation exposed in Salzer Valley east of Centralia. This species is also found in the Skookumchuck formation near Centralia, but there it is smaller than the typical form of the Lincoln formation. *Eponides yeguaensis* Weinzierl and Applin is present through the Eocene of western Washington and western Oregon, but it is not known in typical form above the lower Oligocene in this area. This evidence suggests therefore an age of late Eocene to early Oligocene.

MIOCENE SERIES

MIDDLE (?) MIOCENE VOLCANIC SEQUENCE

Lava flows, with associated flow breccias and tuffs totaling more than 2,000 feet, unconformably overlie the Toutle formation in the mapped area and are unconformably overlain by the Wilkes formation. The rocks are well exposed in the Green Mountain Range, in Beigle Mountain north of Gilmore Corners, and in Hollywood Gorge. The middle(?) Miocene volcanic sequence consists of a massive vesicular aphanitic basalt flow and associated flow breccia overlain by a platy porphyritic andesite flow and associated flow breccias and tuffs. Flow breccias are well exposed near the summit of Signal Mountain, near the summit of Mystery Mountain, and along the South Fork of the Toutle River in NE¼ sec. 11, T. 9 N., R. 1 E. Tuffs interbedded with the flows are sporadically exposed in logging road cuts on Signal Mountain. In the extreme southwestern part of the mapped area and in adjacent quadrangles this volcanic sequence increases in thickness and in number of flows.

Culver (1919, p. 55) did not differentiate between the flows exposed at Coalbank Rapids in sec. 19, T. 10 N., R. 1 E., and the flows of late Eocene age exposed west of the mouth of the Toutle River; he considered porphyritic andesite flow to be an intrusive rock. In an investigation of a dam site at Coalbank Rapids, Erdmann and Warren (1938, p. 29) tentatively assigned these volcanic rocks to the Pleistocene. Nichols (1943, p. 6) referred to the flows in the vicinity of the Cowlitz clay mine as middle or late Tertiary(?) in age.

The first extrusion of the middle(?) Miocene volcanic sequence was a dark-gray to black basalt that is generally vesicular. Rude columnar structure and block jointing are common to this flow. The partly glassy to finely porphyritic basalt contains microscopic crystals of several minerals (see pl. 8*A*). Tabular plagioclase crystals make up 15 to 45 percent of the rock and granular pyroxenes 5 to 25 percent of the rock. The plagioclase is alkalic labradorite; generally present as small (less than 1 mm) laths of unequal size. The orthorhombic pyroxene, hypersthene, is not always present. The monoclinic pyroxene, augite, may be in part, pigeonite. Intersertal glass makes up from 15 to 95 percent (average, 30 percent) of the rock; it is dark brown to black, with positive relief. Trichites(?) are common in the glass (see pl. 8*B*). Magnetite, which constitutes 3 to 6 percent of the rock, is present as small euhedral to subhedral crystals and as disseminated dust.

Secondary alteration is not common, but hydrothermal solutions did alter glass to palagonite, and plagioclase to saussurite, clay, and the zeolite minerals. The ferromagnesian minerals and some of the glass were altered to nontronite, chlorophaeite, and the chlorite minerals. In recent unweathered road cuts in sec. 17, T. 9 N., R. 2 E., excellent crystals of zeolite minerals were collected from vugs and fractures in the basalt. Perched, doubly terminated crystals of quartz were observed on long needlelike crystals of natrolite. Some vesicles were filled with euhedral crystals of one or more of the following minerals: analcite, calcite, heulandite, mordenite, quartz, and stilbite.

The porphyritic andesite of the middle(?) Miocene volcanic sequence is petrologically the most distinct igneous rock type in the Toledo-Castle Rock coal district. It is characterized by a light- to medium-gray color and by moderately well to well-developed platy cleavage parallel to the flow planes; the cleavage surfaces display a distinct sheen that is due to the parallel orientation of the phenocrysts. This flow can be seen best in sec. 10, T. 10 N., R. 1 W., on the north side of Tower Road; on the ridges flanking Coalbank Rapids; and on the north and west slopes of the Green Mountain Range (see pl. 9*B*).

The andesite is porphyritic in a hyalopilitic groundmass (see pl. 9*A*). The phenocrysts average 40 percent of the specimens examined and consist of euhedral to subhedral crystals of plagioclase, augite, and hypersthene. The predominant phenocryst mineral is plagioclase that ranges in composition from that of labradorite to that of oligoclase, but it is generally andesine. These plagioclase crystals range from 0.5 to 5 mm in size and may make up as much as 65 percent of the rock. The augite and hypersthene phenocrysts range in size from 0.1 to 2.5 mm and make up 15 to 30 percent of the rock. The augite is commonly twinned and commonly is found as jackets surrounding grains of hypersthene.

The groundmass is composed of microlites of andesine and oligoclase, granules of pyroxene and magnetite, and interstitial glass. The crystals of plagioclase and hypersthene have small inclusions of apatite. Secondary alteration minerals are rare, but chlorite, biotite, chlorophaeite, and palagonite were identified.

The exact age of these volcanic rocks is not known, but in this report they are considered middle(?) Miocene. The reasons for this age designation are: (1) the volcanic rocks uncomformably overlie beds of the Toutle formation of late Eocene to early Oligocene age and underlie beds of the Wilkes formation that contain a late Miocene age flora, (2) an erosion surface having several hundred feet of relief developed on the Toutle formation before extrusion of the volcanic rocks suggesting a long time interval between deposition and uplift of the Toutle formation and extrusion of the basalt, (3) there is a striking petrographic similarity between the middle(?) Miocene basalt of the Toledo-Castle Rock district and rocks referred to the Columbia River(?) basalt of middle Miocene age by Snavely and others (1958) in the Adna (Meskill) quadrangle north of the mapped area.

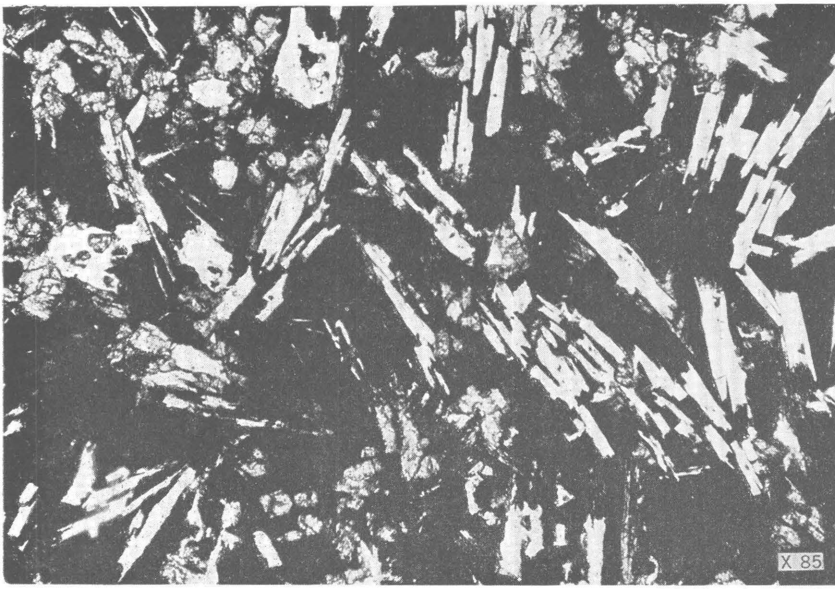
WILKES FORMATION

The name Wilkes formation here designates a sequence of fluvial, lacustrine, and brackish-water deposits consisting of more than 760 feet of semiconsolidated claystone, siltstone, sandstone, and conglomerate. The formation is exposed in Wilkes Hills and along the banks of Salmon Creek and the Cowlitz River near Toledo. A section of the formation that was measured from new road cuts along State Highway 1–Q in secs. 20 and 29, T. 11 N., R. 1 E. (pl. 10) and secs. 3 and 10, T. 10 N., R. 1 E., in the Wilkes Hills is designated as the type area. Near the mouth of Salmon Creek and in Cedar Creek the Wilkes formation rests unconformably on the Toutle formation of late Eocene to early Oligocene age. Where State Highway 1–Q crosses Salmon Creek, the Wilkes formation rests unconformably on volcanic rocks of the Hatchet Mountain formation of late Eocene age. West of the Tower Road in secs. 9 and 10, T. 10 N., R. 1 W., the Wilkes formation rests on volcanic rocks of middle(?) Miocene age.

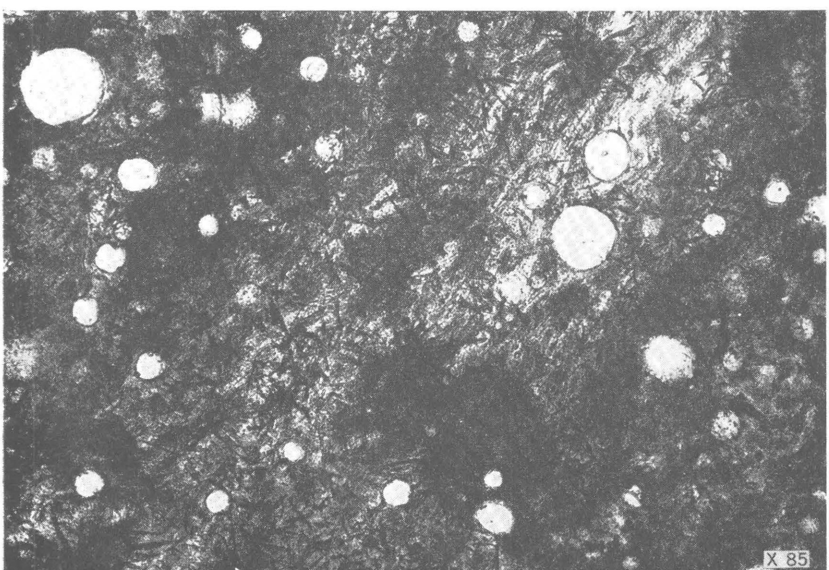
A distinct lithologic or depositional break at the top of the Wilkes formation is difficult to identify. The position of the contact is based primarily on the lack of similarity in composition between the clay, silt, and pebbly sand of the Wilkes formation and the overlying silt, sand, gravel, and till of the Logan Hill formation. Where the beds of the Wilkes formation are overlain by the glacial-outwash and till deposits of the Logan Hill formation, the contact is distinct; but, in the eastern part of the mapped area interbedded sandstone and pebble conglomerate beds of the Logan Hill formation overlie sandstone and pebble conglomerates of the Wilkes formation and here it is difficult to distinguish the contact of the two formations.

Continuous fluvial, lacustrine, and brackish-water deposition accompanied the downfolding of the middle(?) Miocene volcanic rocks and the older Tertiary formations that underlie the Napavine syncline. Deposition of the Wilkes formation occurred during the upper Miocene and may have extended into the Pliocene; the resulting strata attained a measured thickness of more than 760 feet in the area mapped. The thickness of the Wilkes formation increases progressively to the northwest.

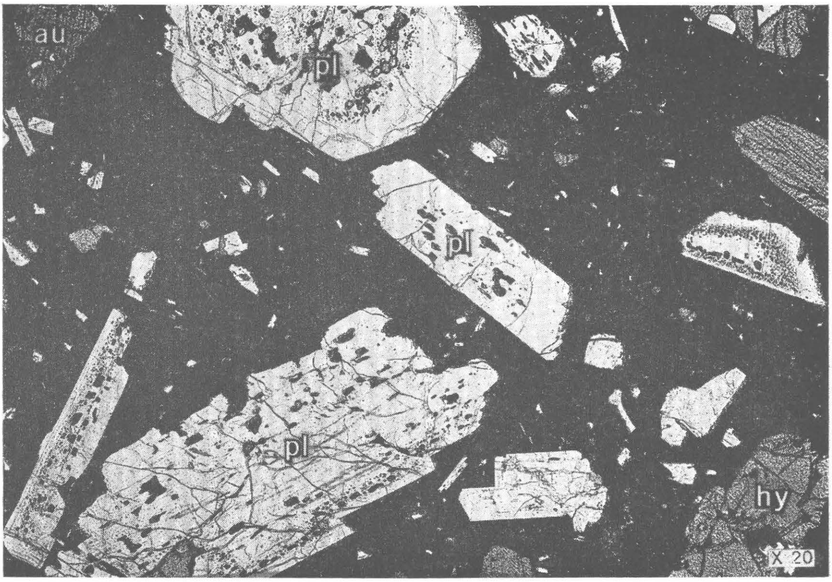
The lithology of the Wilkes formation indicates that these rocks were deposited in a shallow-water environment. Lacustrine deposits of tuffaceous, clayey, carbonaceous siltstone contain well-preserved leaves. Delicate lamination in some of these beds indicates deposition in quiet, ponded water. Some beds, however, contain macerated plant fragments and layers of wood such as now accumulate in the bottom of swamps. Sedimentary structures within the sandstone and conglomerate units suggest their origin as fluvial deposits, and, in places, as deltaic deposits. The fluvial deposits consist of poorly



A. Middle(?) Miocene basalt showing hyaloophitic texture, with crystals of plagioclase and augite in glass.



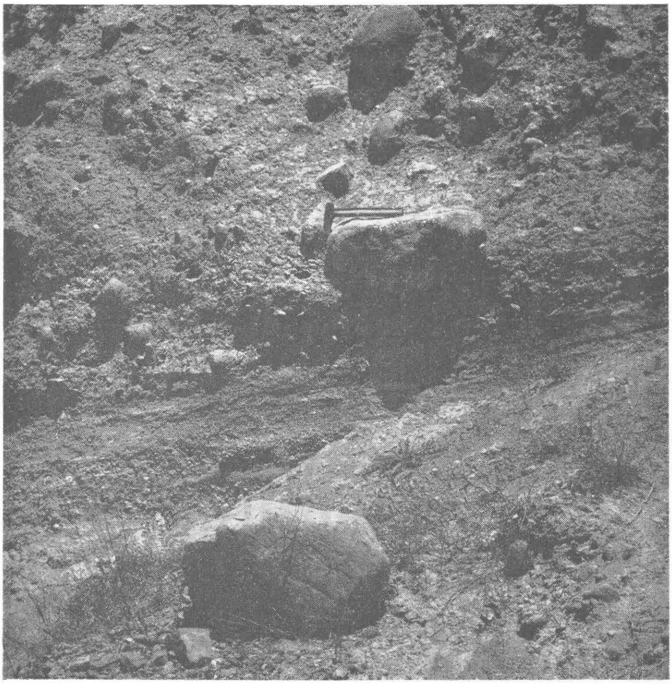
B. Middle(?) Miocene basalt composed mostly of glass and containing gas bubbles surrounded by radiating trichite(?) crystallites.



A. Porphyritic andesite of the middle(?) Miocene volcanic sequence containing large plagioclase (pl), hypersthene (hy), and augite (au) phenocrysts in a groundmass of feldspar, pyroxene, magnetite, and glass.

B. Contact of Toutle formation (Tt) and middle(?) Miocene porphyritic andesite (Tv) along Johnson Creek in the NW¼ sec. 35, T. 10 N., R. 1 E.

Crossbedded sandstone and siltstone of the Wilkes formation in road cut in the NW¼ sec. 29, T. 11 N., R. 1 E.



Glacial till overlying outwash sand and gravel in the Logan Hill formation in the NW¼ sec. 36, T. 12 N., R. 1 E.

sorted sand and thin gravel beds having sharp textural breaks with other units. The deltaic deposits are generally crossbedded and very poorly sorted with sporadic pebbles and cobbles and associated scour-and-fill channels. The Wilkes formation seems therefore to have been deposited in a broad shallow basin that contained lakes and swamps and over which meandering streams deposited sedimentary debris. Ash falls also contributed debris to this basin of deposition.

The Wilkes formation consists predominantly of semiconsolidated tuffaceous siltstone and sandstone, with interbedded conglomerate. Most of the material of the Wilkes formation was derived from explosive volcanoes and from erosion of volcanic flows. A heavy-mineral suite is present in most of the beds of sandstone in the formation. The beds of clay and siltstone are composed primarily of altered volcanic ash of an andesitic composition. The beds of sandstone and conglomerate are generally composed of grains of volcanic fragments, quartz, feldspar, hornblende, chlorite minerals, magnetite, muscovite, augite, volcanic glass, biotite, zircon, and pebbles of pumice, andesite, basalt, chert, and metamorphic rock.

Beds several feet thick consisting of partly coalified wood fragments are common in the lower part of the formation. These beds are exposed in the lower parts of Cedar and Salmon Creeks. Near the base of the formation aquatic shrubs and reedlike plants are found in an upright position. Pieces of wood and plant fragments are found throughout the Wilkes formation. (See table 3.)

The various lithologic units of the Wilkes formation interfinger and grade laterally into one another, so that no one section is typical of the whole formation. Partial sections at the type area were correlated and combined to make the composite section given in the appendix on page 67.

In the lower part of Cedar Creek, in secs. 30 and 31, T. 11 N., R. 1 E. and sec. 36, T. 11 N., R. 1 W., a massive blue-gray tuffaceous clay is exposed near the base of the Wilkes formation. This unit yields many siderite concretions. Most are disc-shaped, some are botryoidal, a few are cigar-shaped, and others are or closely resemble corpolites. These last seem to have been squeezed through an aperture, because they are continuous, contorted, ropelike forms whose surfaces show parallel striations. They range in size from 1 inch or less in length and ⅛ inch or less in diameter to masses more than 12 inches in length and 2 inches or more in diameter. These coprolite-like concretions are found only in one unit of the Wilkes formation and probably have a limited lateral extent; but, they are often found in terrace and alluvium deposits downstream from the outcrop area in the lower part of Cedar Creek. These concretions do not show even microscopic organic structure and consist of granular siderite.

Several ideas concerning the origin of the corprolite-like concretions have been advanced. These include the possibilities that they may have been excrement of carnivores, turtles, or large fishes; or algal nodules; or inorganic accumulations. Determination of their origin is difficult, and perhaps they are of more than one mode of origin.

The enclosing rock unit, a clay, was originally a waterlain volcanic ash. Deposition took place in a shallow lake or swamp. This clay unit is closely associated with beds of carbonized wood up to 2 feet in thickness and throughout this unit the remains of aquatic reedlike plants and shrubs are found, generally in an upright position suggesting rapid burial by volcanic ash fall with intervening periods of slow deposition that permitted plant growth. Some coprolitic forms were found surrounded by carbonaceous material, a fact suggesting that the shape of some concretions resulted from being squeezed through roots and stems of the aquatic plants. A few of these coprolitic forms resemble a braided rope and could have been squeezed through a clump of reeds rather than through a single stem or root.

The fossil plants and wood identified by Roland W. Brown (see table 3) were collected from strata in the lower part of the Wilkes formation east of Toledo. Brown assigned a late Miocene age to the flora from that part of the Wilkes formation and correlated it with the flora from the Latah formation of eastern Washington and western Idaho and the Mascall formation of eastern Oregon, both of late Miocene age. Because no fossils were found in the upper part of the Wilkes formation, a Pliocene age is suggested solely on the basis of its stratigraphic position. According to J. E. Sceva (oral communication), strata composed of tuffaceous claystone, siltstone, and sandstone, lithologically similar to the Wilkes formation, are exposed in the Nisqually River valley near La Grande, Wash. A fossil flora collected from a siltstone bed in the valley was assigned to the late Miocene by Roland W. Brown.

Strata which are wholly or in part equivalent to the Wilkes formation have been identified at several localities in Washington and Oregon. A sequence of fluvial, lacustrine, and brackish-water deposits consisting of as much as 1,000 feet of semiconsolidated siltstone, sandstone, and conglomerate were mapped (Snavely and others, 1958) in the vicinity of Chehalis and referred to as "nonmarine sedimentary rocks." This sequence of rocks was not designated the type section of the Wilkes formation because there are better exposures of the same kinds of rocks in the Toledo-Castle Rock coal district. Weaver (1912, p. 20) applied the name Montesano formation to massive brownish-gray sandstone beds exposed in the vicinity of Montesano, Wash. In a later publication (1937, p. 187) he restricted this formation to beds of late Miocene to middle Pliocene age and excluded the massive sandstone strata of the Astoria formation of early Miocene age. Weaver stated that the Montesano formation was probably deposited during an interval extending from late Miocene to early and middle Pliocene.

Lowry and Baldwin (1952, p. 17) mentioned the resemblance of parts of the Troutdale and Molalla formations and the Fern Ridge tuffs of northwestern Oregon to the fluvial sedimentary rocks in the Toutle River valley east of Castle Rock, Wash. The flora from the Molalla formation is assigned to the Miocene and has affinities with the flora of the Latah and Mascall formations of eastern Washington and Oregon, according to Roland W. Brown (written communication).

QUATERNARY SYSTEM

PLEISTOCENE AND RECENT SERIES

LOGAN HILL FORMATION

More than 150 feet of partly consolidated fluvial deposits of gravel and sand, with minor amounts of silt and clay, near Chehalis, has been described and named the Logan Hill formation (Snavely and others, 1951b). Subsequent mapping west and southeast of the type area revealed deposits of till within the formation; thus, a glaciofluvial origin for the formation was established (Snavely and others, 1958).

In the Toledo-Castle Rock coal district about 250 feet of glaciofluvial and till deposits of the Logan Hill formation is exposed. The base of the formation has an altitude of 850 feet in the eastern part of the mapped area and decreases westward to an altitude of 200 feet. The sources for these deposits probably were a southward continuation of the outwash deposits evident to the north near Chehalis and the glaciofluvial deposits to the northeast, which occur at increasing elevations eastward along the flanks of the Cowlitz River valley.

Between Toledo and Castle Rock at an altitude of about 360 feet is a prominent terrace underlain by the Logan Hill formation. Subsequent erosion by lateral planation of younger Quaternary and Recent streams has removed most of the terrace in the mapped area, but it is a prominent physiographic feature north of the mapped area. In this terrace outwash gravels of the Logan Hill formation are exposed in road cuts on U. S. Highway 99 in secs. 2, 11, and 14, T. 11 N., R. 2 W. A few blocks of basalt, measuring as much as 7 feet in diameter, were removed during road building operations in sec. 14, T. 11 N., R. 2 W. These blocks of basalt are very similar to the basalt of the Hatchet Mountain formation that crops out in the east half of sec. 14, T. 11 N., R. 2 W.

Deposits of till and outwash sands and gravels of the Logan Hill formation are well exposed in the NW¼ sec. 36, T. 12 N., R. 1. E.

(see pl. 11). The till is a compact mixture of boulders, cobbles, and pebbles in a sandy clay matrix. The boulders and cobbles are composed of andesite and basalt similar to those found in the outwash deposits.

A sample of the till in the Logan Hill formation in sec. 29, T. 12 N., R. 2 E., has the following composition, in percent: moderately porphyritic basalt, 56; porphyritic platy andesite, 18; fine-grained basalt, 10; volcanic ejecta (pumice and scoria), 6; gabbro, 3; diorite, 2; metamorphic rock, 2; rhyolite, lapilli tuff, and siltstone, 1 each.

A sample of the outwash gravels in the Logan Hill formation in sec. 10, T. 10 N., R. 2 W., has the following composition, in percent: moderately porphyritic basalt, 58; porphyritic platy andesite, 16; rhyolite, 7; metamorphic rock, 7; volcanic ejecta (pumice and scoria), 5; fine-grained basalt, 4; gabbro, diorite, and granodiorite, 1 each. A few pebbles of agate and chalcedony were noted in the sample.

At the surface the gravel and sand of the Logan Hill formation are deeply weathered and can easily be cut with a knife. The weathered pale-yellow to brownish-red gravel is contained in a silty clay matrix; the cobbles and boulders are composed of andesite and basalt typical of the Northcraft formation and of younger volcanic rocks east of the mapped area. Where the Wilkes formation is overlain by the Logan Hill formation, the contact is extremely difficult to detect because of lithologic similarities. If the rocks have been weathered, the two formations can be distinguished only arbitrarily.

The sands of the Logan Hill formation are poorly sorted, friable, massive to crossbedded, and fine- to coarse-grained. They often interfinger with gravels and commonly contain sporadic pebbles and cobbles. The sand is composed of fragments of volcanic rocks, feldspar, quartz, biotite, augite, and magnetite. The mineral grains are generally angular to subangular, but the volcanic fragments are more rounded.

No fossils were found in the Logan Hill formation in the mapped area. In the Centralia-Chehalis coal district in sec. 7, T. 15 N., R. 2 W., the Logan Hill formation is overlain by gravels of the Vashon drift that are believed to have been deposited approximately during the Wisconsin glacial epoch. Therefore, the Logan Hill formation, being of glaciofluvial origin and overlain by gravels of the Vashon drift, is assigned to the early Pleistocene (Snavely and others, 1958).

ALPINE DRIFT

Alpine glaciers extended down the valleys of the North Fork of the Toutle River and the Green River approximately to their junction and down the valley of the South Fork of the Toutle River to the southern border of the Toutle quadrangle. The glacial deposits east of the Green Mountain Range are best exposed in logging road cuts on the east side of Signal Mountain, and they veneer the sides of the entire valley of the North Fork of the Toutle River. These deposits, known as alpine drift, are mainly moraine dropped by a retreating valley glacier, probably during the late Pleistocene (Wisconsin) stage of glaciation. Outwash material associated with this period of glaciation formed the prominent high terraces downstream and dammed a drainage basin forming Silver Lake.

The deposits of alpine drift are a gray, heterogeneous mixture of angular to subrounded boulders, cobbles, pebbles, and sand in a matrix of clay and silt. The sand and gravel are composed predominantly of volcanic rocks, including a large amount of pumice fragments. The matrix of clay and silt contains rock flour and a large volume of tuffaceous material. The maximum diameter of the boulders is about 3 feet. Some of the boulders and cobbles have faceted surfaces.

TERRACE DEPOSITS

In the Toutle and Castle Rock quadrangles the Cowlitz River has formed a broad terraced valley. The most prominent terrace, known locally as "Leyton Prairie," is east of Toledo and is between 1 and 2 miles wide. The terrace surface is flat to gently undulating and has a slight gradient to the southwest. Drillers' logs of water wells and exposures along the steep bank of these terraces indicate that the gravel fill may be as much as 50 to 70 feet thick.

The terrace deposits are composed primarily of pebbles, cobbles, and boulders in a poorly sorted sandy matrix. Stratification is slight or absent. Crossbedding is common, with dips in a general downvalley direction. There are many scour-and-fill channels of medium- to coarse-grained poorly sorted sand. Most of the deposit is partly cemented with limonite derived from ground water. Although the deposits are young geologically, nearly all have a thin weathered rind.

In the SE¼SE¼ sec. 27, T. 10 N., R. 2 W., a local resident found part of a facial bone of a mammoth in terrace deposits believed to be equivalent to the terrace forming Leyton Prairie. Jean Hough tentatively identified this fossil as *Mammuthus primigenius* (Blumenback). Just south of the Castle Rock quadrangle at Rocky Point, fossil leg bones, probably of a mammoth, were uncovered in new road cuts in similar terrace deposits. These deposits are therefore assigned to the late Pleistocene.

Continental glaciation extended south to the vicinity of Tenino, Wash. (Bretz, 1913), and outwash deposits extend south of Tenino to the vicinity of Centralia. It is believed that during that time of glaciation fluvioglacial material came down the ancient Cowlitz River. This stream became "at grade" west of Salkum, Wash., where it deposited its load of sedimentary debris. These terrace deposits become finer grained south of Leyton Prairie; east of Castle Rock they are poorly sorted crossbedded gravels with more sand in the matrix; and south of the mapped area they are dominantly silt with sand. Lowry and Baldwin (1952, p. 17) refer to similar deposits along the Columbia River near Portland, Oreg., as the "Portland gravels" of Pleistocene age.

A sample of the gravels in these terrace deposits in sec. 11, T. 9 N., R. 2 W., contained the following rock types, in percent: coarse-grained porphyritic basalt, 51; porphyritic andesite, 19; fine-grained basalt, 16; rhyolite, 5; granodiorite, 4; volcanic ejecta (pumice and scoria), 2; metamorphic rock, 2; and gabbro, 1.

During the time these terraces were formed, large volumes of water poured down Cedar and Salmon Creeks. Cedar Creek Falls may have been formed at this time. Terraces along these creeks have a gentle gradient to the southwest and connect with the terrace, Leyton Prairie, in sec. 28, T. 11 N., R. 1 W. South of Salmon Creek and north of the Toutle River in the eastern part of the Castle Rock quadrangle and the western part of the Toutle quadrangle the terrace has been reduced to an erosional feature marked by thin patches of gravel a few feet or less in thickness on an eroded surface of the Wilkes formation.

The Toutle River also played an important part in the formation of terraces during the late Pleistocene. Large volumes of outwash gravel and reworked Alpine drift containing boulders as much as several feet in diameter were deposited near Gilmore Corners in sec. 30, T. 10 N., R. 1 E., damming a broad valley to form Silver Lake. These deposits have two characteristic constituents: a pink glassy hornblende-dacite and a light-gray highly pumiceous hypersthene-hornblende andesite.

Several large erratics of granodiorite were noted near Castle Rock. Lowry and Baldwin (1952, p. 18) discuss similar erratics in the lower Columbia River valley. These erratics were probably ice-rafted down the Columbia River during the last stage of Pleistocene glaciation.

LANDSLIDE DEBRIS

Landsliding is widespread in the mapped area because the permeable, unconsolidated to partially consolidated sands and bentonitic silts and clays of the Wilkes formation are particularly susceptible to mass wasting. Landsliding is prevalent especially in the lower part of the valley of Cedar Creek in secs. 20 and 30, T. 11 N., R. 1 E., where the base of the Wilkes formation is generally at the creek level.

During the winter the creek flows with increased volume on the Toutle formation and erodes laterally in the less resistant Wilkes formation. Heavy rains, despite the great surface runoff, saturate the bentonitic silts and clays and make them semifluid; the weight of the overlying sedimentary rocks causes the mass to move valleyward.

East of Coalbank Rapids on the south slope of Beigle Mountain the Toutle River is joined by the South Fork and flows westward through a narrow gorge in which the gradient averages about 73 feet per mile. The swift waters powerfully erode the banks composed of the Toutle formation and an overlying middle(?) Miocene flow of porphyritic andesite. The action of the stream cuts away the soft tuffaceous sedimentary rocks of the Toutle formation and the overlying volcanic rocks move downward into the stream. Small, well-defined step faults resulting from this activity are found in the overlying flow in the NE¼ sec. 19 and the NW¼ sec. 20, T. 10 N., R. 1 E. Many large blocks of andesite, some measuring 60 by 30 by 20 feet, are now found in the stream bed at Coalbank Rapids. The coal bed from which the name of the rapids was derived is in a landslide.

ALLUVIUM

Deposits of alluvium composed of sand and gravel of igneous rocks, and sand and silt derived from Tertiary sedimentary rocks are found along the larger streams in the mapped area. The Toutle River alluvial deposits are generally restricted to bars of poorly sorted, reworked landslide debris. Most of the alluvium along Cedar and Salmon Creeks is derived from landslide debris of Tertiary sedimentary rocks. There are some terrace gravels and small gravel bars in the lower parts of these two streams. Terrace gravels and floodwater deposits of poorly sorted silt are common along the Cowlitz River, as are large bars of gravel of volcanic and granodioritic rock types. Near Silver Lake the alluvium is primarily reworked sedimentary rocks from the Wilkes formation and some volcanic debris from rocks of the Hatchet Mountain formation and the middle(?) Miocene volcanic sequence.

A deposit of brown silt and clay with some volcanic debris several feet in thickness covers much of the area east and southeast of Gilmore Corners. It seems probable that in very late Pleistocene or early Recent time a large landslide at Coalbank Rapids temporarily dammed the Toutle River and formed a lake. Sediments brought into this lake by the Toutle River and the South Fork of the Toutle River formed the deposit.

Thin deposits of white ash found beneath the soil zone in the banks of the lower Cowlitz and Toutle Rivers are probably the result of eruptions of Mount St. Helens. Erdmann and Bateman (1951, p. 90) described two layers of pumice to the east of the mapped area that may be correlative with the ash deposits along the lower Cowlitz and Toutle Rivers. According to Verhoogen (1937, p. 268), an eruption of Mount St. Helens in 1842 blew pumice fragments as far south as The Dalles, Oreg.

STRUCTURE

The predominant structural feature of the Toledo-Castle Rock coal district is a broad, shallow depression which is known as the Napavine syncline in the Centralia-Chehalis coal district (Snavely and others, 1958). The axis of the Napavine syncline extends northwest from the South Fork of the Toutle River, through Gilmore Corners, to Napavine. The syncline plunges to the northwest and in the mapped area is bounded on the east by the volcanic rocks of the Cascade foothills and on the west by folded sedimentary rocks of the Cowlitz River valley (see pl. 1). The lignite beds of early Oligocene age occupy the central part of this basin and the subbituminous coal beds of late Eocene age crop out along the western flank of the syncline.

Downwarping that formed the Napavine syncline began after the extrusion of lavas in the upper part of the Hatchet Mountain formation. Folding slowly continued during deposition of the Toutle formation, but most of the downwarping took place after the extrusion of middle(?) Miocene volcanic rocks and before deposition of the Wilkes formation. Deformation lessened during deposition of the Wilkes formation and ceased before deposition of the Logan Hill formation.

Several smaller flexures are superimposed on the Napavine syncline. A small anticlinal fold in the Toutle formation and middle(?) Miocene volcanic rocks can be observed readily in Hollywood Gorge in sec. 16, T. 10 N., R. 1 W. Small folds are exposed in the Cowlitz and Toutle formations that form the banks of the Cowlitz River about 2 miles southwest of Toledo.

The Eocene and Oligocene formations display in many places a pattern of jointing that probably represents tensional adjustment during the folding of the Napavine syncline. This pattern is reflected by the rude parallelism of individual streams which have cut channels along joint planes (see drainage pattern on pl. 2). Vertical jointing may be observed at the falls of Cedar Creek in sec. 30, T. 11 N., R. 1 E., in a massive indurated lapilli tuff of the Toutle formation (see pl. 7). The joint pattern has two dominant directions, N. 40°- 65° E. and N. 40° - 50° W. Where the streams traverse post-Oligocene formations, the relationship between the drainage and the joint patterns does not exist. The southerly course of the Cowlitz River along the western border of the mapped area is due to this stream cutting its channel along the strike of the Cowlitz formation, often in interbedded volcanic rocks. Quaternary deposits and beds of the Wilkes formation that cover a large portion of the mapped area mask the presence of faults. The lack of stratigraphic marker beds also makes difficult the detection of faults. Faults of small displacement, probably less than 200 feet, are found in the Toutle and Cowlitz formations in the northwestern part of the mapped area. Faults are reported to have dislocated the coal beds in the Leavell and Huntington-Ely mines. The discernible faults are high-angle normal and reverse ones that trend northwestward.

Individual attitudes of the nonmarine and volcanic rock units are of scant value in determining the structure of the area. In the few outcrops that are several hundred feet in length the strata in several places are undulated and crossbedded (see pl. 3*A*). In small isolated outcrops it is necessary, therefore, to evaluate the attitude of the beds to determine whether the outcrop has structural significance. The structure shown on plate 1 was determined by combining or averaging attitudes, areal distribution of formations, and by the position of formational contacts and coal beds.

ECONOMIC GEOLOGY

COAL

Coal beds crop out along the banks of Salmon and Cedar Creeks and the Cowlitz and Toutle Rivers, and their tributaries; but in most of the mapped area the coal-bearing formations are concealed by younger rocks. Prospecting in the district has been concentrated in valley areas of greatest erosion. A few mines were developed, but because none was in commercial operation at the time of the field investigation, very little information about the mining history of the district could be obtained. Data on the coal beds were obtained by facing-up outcrops in caved prospects, drilling with a jeep-mounted auger, and by diamond core drilling. Locations of the measured sections of the coal beds are given on plate 1; graphic sections are arranged according to township on plates 13 and 14; and data on mines and prospects are listed in table 4.

In many parts of the Toledo-Castle Rock coal district coal beds have been burned at the outcrop and beneath shallow cover, probably by forest fires or fires caused by spontaneous combustion. The depth to which the coal burns depends upon the quality and thickness of the coal, the amount of water in the coal bed, and the porosity and thickness of the cover. As a result of burning, overlying rocks are baked, or even fused to form clinker. In the NE¼ sec. 18, T. 10 N., R. 1 E., and in the NW¼ sec. 20, T. 10 N., R. 1 W., clinker for road metal is quarried in open pits.

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TABLE 4.—*Data on mines and prospects in the Toledo-*

No. on plate 1	Mine or prospect	Location of portal				Type of mine or prospect	Coal bed
		T. (N)	R.	Sec.	Fraction sec.		
1	Chapin prospect	9	1W	18	SE¼SW¼	Slope	Leavell [1]
2	Fuller prospect	10	2W	22	SW¼SE¼	Water level(?)	Unnamed [1]
3	Gleason prospect	11	1E	22	NE¼NW¼	Shaft	Cedar Creek No. 1.
4	Graham Bros. and Medley prospect.	11	1E	15	SE¼SW¼	do	do
5	Hessford prospect	10	2W	27	NE¼SE¼	Slope	Schuff
6	Huntington and Ely mine.	9	2W	24	SW¼NW¼	do	Unnamed [1]
7	Idleman mine	9	2W	11	NE¼NE¼	do	Leavell [1]
8	Leavell mine	9	1W	18	NE¼SW¼	do	do [1]
9	Reed and Simpson prospect.	10	1E	18	NW¼NE¼	Trench	Walker(?)
10	Schuff mine	10	2W	27	SE¼SE¼	Water level(?)	Schuff [1]
11	Shives' strip pit No. 1	11	1E	15	SW¼SW¼	Strip pit	Cedar Creek No. 1.
12	Shives' strip pit No. 2	11	1E	15	NE¼SW¼	do	do
13	Silver Lake mine	10	1E	30	NW¼NW¼	Slope	Silver Lake [1]
14	Smokey Valley prospect.	11	2W	36	NE¼SE¼	Trench	Unnamed [1]
15	Tertling prospect	11	1E	22	NE¼NE¼	Shaft	Cedar Creek No. 3.
16	Walker mine	10	1W	12	SE¼SE¼	Water level(?)	Walker [1]
17	Cowlitz clay mine	10	1W	20	NE¼NW¼	Pit	Unnamed [1]
18	Tower prospect	10	1W	10	SW¼SW¼	Trench	do [1]

[1] Measured section shown on plate 14.
[2] Approximately.

Castle Rock coal district, Washington, east of the Cowlitz River

Formation	Average thickness of coal		Total production (short tons)	Date of operation	Direction and amount of dip	General remarks
	Feet	Inches				
Cowlitz	3	6	None	1947	19° NE	An attempt to relocate the bed mined at the Leavell mine. Caved.
do	1	2	None	[2] 1900	10° NE	Caved.
Toutle	13	6	None	[2] 1900	----------	Shaft reopened and deepened in 1943 by Graham Brothers. Caved and flooded.
do	24	1	None	1943	7° NW	Shaft 28 feet. An 8½-ton sample taken by U. S. Bureau of Mines for washing and burning tests (Bur. Mines Rept. Inv. 3795). Caved.
Cowlitz	1	[2] 4	None	[2] 1913	5° NE	Direction of entry N. 4° W. Workings destroyed by flood of Toutle River in 1933.
do	4	0	Unknown	1886–1948	8° SE	Dip flattened with depth. Direction of entry S. 70° E. High sulfur content. Operated intermittantly. Four tunnels. Also called the Carbondale (Collier, 1913, p. 327) and Hi-Way mines. Flooded.
do	4	[2] 0	2,000	1892–96 1901–03	11° SE	Caved and flooded.
do	4	9	Unknown	1902–08	27° NE	Formerly called the Carbondale (Culver, 1919, p. 52). Dip flattened with depth. Caved and flooded. Mine workings terminated at a fault.
Toutle	[2] 13	0	None	1944	7° NW	Flooded.
Cowlitz	1	11	50	1919–20	3° NE	Workings destroyed by flood of Toutle River in 1933.
Toutle	24	0	500	1947–52	7° NW	Local domestic use.
do	16	10	Unknown	1952	8° NW	Local domestic use.
do	4	0	600	1934–35 1943	5° NW	Also called Coalbank Rapids mine. Direction of workings at portal N. 40° W. Caved.
do	7	10	None	Unknown	35° SW	Caved.
do	6	1	None	1944	----------	Caved and flooded.
do	[2] 13	0	50	1906–09	23° NE	Very woody massive bed. Dip flattens with depth. Caved.
do	5	4	None	Unknown	----------	Section at Cowlitz clay mine (Glover, 1941, p. 81).
do	6	[2] 0	None	Unknown	----------	Section at Tower prospect (Culver, 1919, p. 56).

PHYSICAL AND CHEMICAL PROPERTIES

The coal in the Toledo-Castle Rock district ranges in rank from lignite to subbituminous, generally depending on the age of the enclosing formation. The coal in the Cowlitz formation ranges in rank from lignite to subbituminous class B, but it is commonly subbituminous class C. The coal in the Toutle formation is lignite of low rank. The classifications of the coal by rank are those adopted by the American Society for Testing Materials (1938). Chemical analyses of the various coal beds of the Toledo-Castle Rock district east of the Cowlitz River are given in table 5. Many chemical analyses of the lignite beds in the vicinity of the Cedar Creek stripping area are given in the Bureau of Mines Technical Paper 699.

The coals of the Cowlitz and Toutle formations have a high moisture content (table 5) and break rapidly into small pieces on exposure to air. The beds generally consist of bright- and dull-banded coal with blocky, rectangular, or conchoidal fracture; the texture is commonly xyloidal. The coals generally have a high ash content (table 5) that is due to inherent volcanic debris, and tuffaceous sedimentary partings are commonly associated with the beds.

COAL BEDS OF THE COWLITZ FORMATION

Two commercial and two noncommercial coal beds are known in the Cowlitz formation east of the Cowlitz River along the west flank of the Napavine syncline. Observation of these beds is limited because of covering by Quaternary deposits and landslides. The coal beds are in the upper part of the Cowlitz formation and are referred to in this report as the Leavell, Schuff, and unnamed beds (pl. 14).

LEAVELL BED

The Leavell bed is found only along the western edge of the Napavine syncline where it contains from 30 to 57 inches of coal. The bed is approximately 100 feet stratigraphically below the base of volcanic rocks of the Hatchet Mountain formation. It consists of 2 layers of coal separated by a tuffaceous siltstone parting 4 to 28 inches thick. The bed, which is sporadically exposed in small gullies on the west slope of Newell Ridge just east of Castle Rock, extends south of the mapped area to sec. 12, T. 8 N., R. 2 W., where it is exposed along Ostrander Creek. It is not recognized north of the Idleman mine in sec. 11, T. 9 N., R. 2 W. Analyses of 2 samples from this bed (see table 5) show the coal to range in rank from lignite to subbituminous class B. The coal of highest quality is near the Leavell mine.

SCHUFF BED

The Schuff bed, found only along the western edge of the Napavine syncline, contains 18 tò 24 inches of coal. The bed is about 10 feet stratigraphically above an interbedded basalt flow in the upper part

TABLE 5.—*Proximate analyses of coal from Toledo-Castle Rock coal district, Washington, east of the Cowlitz River*

Map reference No.	Mine or prospect	Coal bed and formation	Classification of coal	Bureau of Mines sample No. and date of analysis	Form of analysis [1]	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Heating value (Btu)
1	Chapin prospect; sec. 18, T. 9 N.,	Leavell bed	Subbituminous B	D-96792 (1952)	A	25.0	32.0	35.9	7.1	0.4	8,240
	R. 1 W., Cowlitz County.	Cowlitz formation.			B		42.7	47.9	9.4	.5	10,990
					C		47.1	52.9		.6	12,130
2	Fuller prospect; sec. 22, T. 10 N.,	Unnamed	Subbituminous B	E-6497 (1953)	A	19.9	19.8	32.5	27.8	.6	7,250
	R. 2 W., Cowlitz County.	Cowlitz formation.			B		24.7	40.6	34.7	.8	9,050
					C		37.8	62.2		1.2	13,860
4	Graham and Medley prospect; sec.	Cedar Creek No. 1 bed	Lignite	C-7246 (1943)	A	32.5	26.6	24.7	16.2	.5	6,200
	15, T. 11 N., R. 1 E., Lewis	Toutle formation.			B		39.4	36.6	24.0	.7	9,190
	County.				C		51.9	48.1		1.0	12,090
7	Idleman mine; sec. 11, T. 9 N., R. 2	Leavell bed	Lignite	D-97231 (1952)	A	39.4	26.4	28.3	5.9	.7	6,160
	W. Cowlitz County.	Cowlitz formation.			B		43.6	46.7	9.7	1.1	10,170
					C		48.3	51.7		1.2	11,260
9	Reed and Simpson prospect; sec. 18,	Walker(?) bed	Lignite	None (1945)	A	23.8	24.9	17.2	34.1	(2)	(2)
	T. 10 N., R. 1 E., Cowlitz County.	Toutle formation			B		32.7	22.6	44.7	(2)	(2)
					C		59.1	40.9		(2)	(2)
10	Schuff mine; sec. 27, T. 10 N., R. 2	Schuff bed	Subbituminous C	D-97232 (1952)	A	22.3	32.0	35.7	10.0	2.5	8,140
	W., Cowlitz County.	Cowlitz formation.			B		41.2	46.0	12.8	3.2	10,480
					C		47.2	52.8		3.7	12,020
13	Silver Lake mine; sec. 30, T. 10 N.,	Silver Lake bed	Lignite	D-99818 (1952)	A	32.0	22.7	17.1	28.2	.9	4,520
	R. 1 E., Cowlitz County.	Toutle formation.			B		33.4	25.1	41.5	1.3	6,650
					C		57.0	43.0		2.2	11,360
14	Smokey Valley prospect; sec. 31, T.	Unnamed bed	Lignite	D-97234 (1952)	A	36.5	28.7	20.7	14.1	.6	6,130
	11 N., R. 1 W., W. M., Lewis	Toutle formation.			B		45.1	32.8	22.1	1.0	9,640
	County.				C		57.9	42.1		1.3	12,380
16	Walker mine; sec. 12, T. 10 N., R. 1	Walker bed	Lignite	D-99819 (1952)	A	38.2	24.9	29.8	7.1	.2	6,810
	W., Cowlitz County.	Toutle formation.			B		40.2	48.3	11.5	.3	11,020
					C		45.4	54.6		.3	12,440
17	Coal outcrop; sec. 19, T. 11 N., R. 1	Unnamed bed	Lignite	E-6228 (1953)	A	36.3	26.3	21.0	16.4	.6	5,510
	W., Lewis County.	Toutle formation.			B		41.3	33.0	25.7	.9	8,650
					C		55.6	44.4		1.3	11,630

[1] A, As received; B, moisture free; C, moisture and ash free.

[2] Not determined.

of the Cowlitz formation; it has several tuffaceous siltstone partings less than 4 inches thick in the section measured. The bed is exposed in the banks of the Toutle River near the Schuff mine which, like the Hessford prospect, was located on this bed (see table 4). Generally, the bed is unsuitable for mining because of its small size and partings. It is not recognized south of the section corner of secs. 26, 27, 34, and 35, T. 10 N., R. 2 W. Analyses of 2 samples from this bed (see table 5) show the coal to range in rank from subbituminous class B to C. The Schuff bed is not thick enough for commercial development; therefore reserves were not calculated for it.

UNNAMED BEDS

The unnamed bed at the Huntington and Ely mine is limited to the southwestern edge of the Napavine syncline where it contains 48 inches of coal and has a 2-inch parting in the middle (Collier, 1913, p. 327). A miner from the Huntington and Ely workings reported finding this bed on the west side of the Cowlitz River in the center of sec. 15, T. 9 N., R. 2 W., where it is stratigraphically below interbedded volcanic rocks in the upper part of the Cowlitz formation. Culver (1919, p. 51) reports the continuation of this bed with an increase in thickness south to the center of sec. 25, T. 9 N., R. 2 W. Collier's report (1913, p. 327) of a high sulfur content in the coal taken from the Huntington and Ely mine is substantiated by an analysis of 4.37 percent sulfur made in 1947 by Metallurgical Laboratory, Seattle, Wash.

The bed exposed at the Fuller prospect and in the railroad cut in the SW¼ sec. 22, T. 10 N., R. 2 W., is 20 feet or more stratigraphically below interbedded volcanic rocks of the Cowlitz formation—a position similar to that of the unnamed bed at the Huntington and Ely mine. This bed extends northwest from Fuller's prospect and is believed to correlate with the carbonaceous shales at fossil locality P–1 (see pl. 1). Because the thickness of the coal at Fuller's prospect is 20 inches and the coal is believed to grade laterally into a carbonaceous siltstone, the bed is not considered minable.

COAL BEDS OF TOUTLE FORMATION

The coal in the Toutle formation in the Toledo-Castle Rock coal district is lignite in rank and contains a high percentage of ash. It is a tough, brown fibrous coal containing many coalified plant fragments. Beds of tuff, tuff breccia, carbonaceous siltstone and bone, which may develop into partings within a short distance, are closely associated with the coal (see pl. 13). The coal has a blocky fracture and splits easily along the bedding planes. Coalified logs are found within the coal beds, and at the portal of the Walker mine the bed is composed predominantly of compressed coalified wood fragments.

At the Cedar Creek stripping area, secs. 15 and 22, T. 11 N., R. 1 E., there are three coal beds in the Toutle formation. They are referred to, from top to bottom, as Cedar Creek Nos. 1, 2, and 3 beds. Test drilling near the Cowlitz clay mine in sec. 20, T. 10 N., R. 1 W., penetrated four unnamed coal beds in the Toutle formation; these beds are believed to have a stratigraphic position similar to that of beds at the Cedar Creek stripping area. Only one coal bed was observed near the Silver Lake mine in sec. 30, T. 10 N., R. 1 E., but miners reported that another bed is below the one mined. Across the gorge from the Silver Lake mine at Coalbank Rapids, in sec. 19, T. 10 N., R. 1 E., the Walker mine operated on a bed of coal quite unlike the bed described (table 4) at the Silver Lake mine; it is probable that the bed at the Walker mine is stratigraphically below the bed at the Silver Lake mine. The relation of the Silver Lake and Walker beds to the Cedar Creek Nos. 1, 2, and 3 beds is not known. One coal bed of minable thickness was observed at the Smokey Valley prospect in sec. 31, T. 11 N., R. 1 W. Considerable test drilling in the intervening areas would be required before satisfactory correlation of coal beds could be made.

CEDAR CREEK NOS. 1, 2, AND 3 BEDS

The Cedar Creek Nos. 1, 2, and 3 beds are just east of the axis of the Napavine syncline, about 9 miles east of Toledo. The beds are generally concealed by Quaternary deposits and the Wilkes formation. Data obtained from an extensive drilling program conducted by the Bureau of Mines (Toenges and others, 1947) to delineate these beds are summarized on plate 16. The Cedar Creek No. 1 bed averages 23 feet of coal within the area drilled, contains about 15 percent ash, and has a heating value of 6,500 Btu (table 6). The Cedar Creek No. 2 bed contains an average of 9.5 feet of coal that is about 20 percent ash and has a heating value of 6,000 Btu. The Cedar Creek No. 3 bed is a lenticular bed with many partings and contains more than 20 percent ash; the coal has a heating value of less than 5,600 Btu. The Nos. 1 and 2 beds are fairly consistent in thickness of coal and partings, but the No. 3 bed is extremely variable in thick-

TABLE 6.—*Average of 18 ultimate analyses of Cedar Creek No. 1 coal bed from Cedar Creek stripping area* [1]

Type of analysis [2]	Moisture	Volatile	Fixed carbon	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu
A	30.3	28.6	26.2	14.9	0.5	6.4	39.2	0.5	39.0	6,680
B		41.1	37.6	21.3	.8	4.3	56.0	.7	17.4	9,590
C		52.4	47.6		1.0	5.4	70.8	.9	21.9	12,200

[1] Analyses of individual beds are available in Bur. Mines Tech. Paper 699.

[2] A, as received; B, moisture free; C, moisture and ash free.

ness. The No. 1 bed has been prospected at the Gleason prospect, Graham Brothers and Medley prospect, and Shives' Nos. 1 and 2 strip pits (see pl. 12 and table 4).

The Cedar Creek Nos. 1 and 2 beds are suitable for strip mining in secs. 15, 16, 21, and 22, T. 11 N., R. 1 E. (see pl. 15). In this area the attitude of the coal beds is approximately the same as the slope of the overburden. Reserves were estimated for the 2 coal beds in this area for 3 categories of thickness of overburden (see table 7). An estimated total of 8,056,000 short tons of lignite suitable for mining by stripping methods was measured.

TABLE 7.—*Original lignite reserves in the Cedar Creek stripping area in secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., near Windom, Wash.*

[Estimates in thousands of short tons]

Bed	Overburden 0 to 20 feet			Overburden 20 to 40 feet			Overburden 40 to 60 feet			Total strippable reserve
	Beds 5 to 10 feet thick	Beds 10 to 20 feet thick	Beds more than 20 feet thick	Beds 5 to 10 feet thick	Beds 10 to 20 feet thick	Beds more than 20 feet thick	Beds 5 to 10 feet thick	Beds 10 to 20 feet thick	Beds more than 20 feet thick	
Cedar Creek No. 1	187	773	897		177	1,445		451	1,925	5,855
Cedar Creek No. 2	570			807			824			2,201
Total										8,056

SILVER LAKE BED

The Silver Lake bed is found along the axis of the Napavine syncline south of Coalbank Rapids. At the Silver Lake mine the bed contains 66 inches of coal, with many partings. It crops out in the center of the NE¼ sec. 24, SW¼ sec. 14, and the NW¼ sec. 25, T. 10 N., R. 1 W., and may be a correlative of the Cedar Creek No. 1 bed to the north and to one of the unnamed beds at the Cowlitz clay mine to the west. A prospect shaft at the Silver Lake mine is reported to have cut a coal bed below the Silver Lake bed.

WALKER BED

The Walker bed, found only along the axial part of the Napavine syncline north of Coalbank Rapids, contains massive lignite and has an observed thickness of 13 to 15 feet. This bed is generally characterized by masses of compressed wood fragments without apparent partings. Only a few feet of the bed are exposed at the caved portal of the Walker mine. It is possible that the bed at the Reed and Simpson prospect in sec. 18, T. 10 N., R. 1 E., which is listed as the Walker bed on table 4, is higher stratigraphically and correlates with the Silver Lake bed, but proof of this correlation could be ob-

Cedar Creek No. 1 coal bed exposed in Shives' strip pit No. 2 in NE¼SW¼ sec. 15, T. 11 N., R. 1 E.

tained only by a test drilling program that would reveal the number and continuity of coal beds near the Walker mine and the Reed and Simpson prospect.

UNNAMED BEDS

Lenticular coal beds of variable thickness are found in the Toutle formation near the Cowlitz clay mine in sec. 20, T. 10 N., R. 1 W. In 1943, the Bureau of Mines drilled 67 test holes in the vicinity of the Cowlitz clay mine to determine the reserves in a high-alumina clay deposit (Nichols, 1945, p. 2). Four beds of lignite from a few feet to 45 feet thick are associated with the clay, but only one or two crop out. Glover (1941, p. 81) reports a section at the Cowlitz clay mine containing a bed of lignite 5 feet 4 inches thick. Culver (1919, p. 56) states that a bed of lignite more than 6 feet thick is exposed in the SW¼ sec. 10, T. 10 N., R. 1 W. A burned coal bed in the NW¼ sec. 20, T. 10 N., R. 1 W., is mined for road metal. In the SE¼ sec. 36, T. 11 N., R. 2 W., a bed of lignite 8 feet thick is exposed in the stream channel.

The lignite beds of the Toutle formation in the center of the Castle Rock quadrangle cannot be traced into the Cedar Creek Nos. 1, 2, and 3 beds of the Toutle quadrangle, but, because both groups are associated with strata of high-alumina clay, the lignite beds of the two areas are here considered to be in the same zone of the Toutle formation.

COAL RESERVES

The total reserves of coal, both lignite and subbituminous, in the Toledo-Castle Rock district are approximately 131.8 million short tons. These reserves are in beds 2.5 feet or more thick for subbituminous and 5 feet or more thick for lignite and both under less than 1,000 feet of cover. The reserves are shown by township, bed, rank, and thickness in tables 7, 8, and 9. The few exposures of coal in the district yield little information about the extent and thickness of the coal beds. Because of this lack of detailed information the measured reserves, which are small, are reported with the indicated reserves. The coal reserves are classed as measured and indicated where the tonnages were computed from measurements taken at outcrops or drill holes for an area within half a mile of the measured bed. Reserves classed as inferred were computed separately by extending the limit of the measured and indicated area on geologic evidence; generally the inferred reserves included the area from ½ to 1 mile from the measured bed.

The estimate of coal reserves was made by plotting on township maps the outcrop of the coal bed, the location of all measured sections, and the subsurface information. Overburden thicknesses were compiled from topographic overlay maps. The area underlain by each coal bed was measured with a planimeter and the average thickness of the bed was estimated from the measured sections. The bed was considered a uniform semicircular lens with a diameter approximating that of the outcrop in the concealed areas between measured sections.

The tonnage of the subbituminous coal was calculated by assuming a weight of 1,770 short tons per acre-foot and was rounded off to the nearest 10,000 tons. The tonnage of the lignite was calculated by assuming a weight of 2,000 short tons per acre-foot and was rounded off to the nearest 10,000 tons. (The large amount of volcanic debris in the lignite gives the coal a specific gravity of 1.47 or a weight of 2,000 short tons per acre-foot.) No reserves were calculated for beds of subbituminous coal less than 2.5 feet thick excluding partings, nor for beds of lignite less than 5 feet thick excluding partings.

In secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., the Cedar Creek No. 1 bed contains 5.85 million short tons of lignite that is considered available by strip mining methods. If this bed were strip mined, then by removing a 10-foot bed of lapilli tuff, 2.20 million short tons of lignite in the Cedar Creek No. 2 bed could be obtained by strip mining. Because of the coal's lower heat value, the many partings that constitute about 50 percent of the bed, and the extremely variable thickness, the Cedar Creek No. 3 bed is not calculated in the strippable reserves. If an average thickness of 12 feet is assumed for the coal in this bed, there is approximately 3.2 million short tons of coal in the Cedar Creek No. 3 bed.

Additional coal beds may be present in both the Cowlitz and Toutle formations within the Napavine syncline. Prospect drilling would be necessary to prove this assumption and to increase the known reserves of the district.

Production of lignite by stripping methods is feasible in the area near Windom, in secs. 15, 16, 21, and 22, T. 11 N., R. 1 E., an area referred to as the Cedar Creek stripping area in this report. The coal at shallow depth, which could not be mined economically by underground methods because of its low quality, numerous partings, and poor roof conditions, might be mined successfully by stripping. Test pits, diamond-drill, and churn-drill holes were made to ascertain the character and thickness of both coal and overburden (Toenges and others, 1947) (see pl. 16).

The strata between the Cedar Creek Nos. 1, 2, and 3 coal beds are tuffaceous, as are many of the thin partings within the beds. Because the reject layers are entirely or partly altered to clay, the washing of the coal must be rigidly controlled. Much of the coal has admixed clay and fragments of volcanic material that would be difficult to remove by washing.

Overburden thickness is quite variable, although structural contours drawn on the base of the Cedar Creek No. 1 coal bed roughly parallel the topographic surface (see pl. 15). The surficial material consists of silt, gravel, sand, plastic clay, and semiplastic clay derived from sandstone and siltstone. Both Tertiary and Quaternary materials are included in the overburden. The thickness of the overburden and coal beds in the Cedar Creek stripping area has been calculated as accurately as possible, but hidden channels cut in the coal beds and slight variations in structure between test holes might modify the calculations.

Utilization of coal from the Toledo-Castle Rock district depends upon development of a satisfactory method of storage. Stock piling by present methods is prohibited by the high moisture content because evaporation causes shrinkage and disintegration of the coal. Not only will oxidation tend to ignite the coal, but the disintegration produces an excessive amount of fine material and a loss of the more valuable coarser sizes. A drying process to reduce the moisture content of the coal to 15 percent or less would make coal storage more feasible, increase the quality, and make transportation of the coal economically possible.

TABLE 8.—*Original reserves of subbituminous coal in Toledo-Castle Rock coal district, east of the Cowlitz River, Washington*

[Overburden less than 1,000 feet]

Reserves, in millions of short tons, in beds of thickness stated—

Township and range	Coal bed	Average thickness (feet)	Area (acres)	Measured and indicated			Inferred		
				2.5 to 5 feet	5.0 to 10 feet	More than 10 feet	2.5 to 5 feet	5 to 10 feet	More than 10 feet
T. 9 N., R. 1 W.	Leavell	4.0	35	0.25					
Do	do	4.0	366				2.59		
Total			401	0.25			2.59		
T. 9 N., R. 2 W.	Leavell	2.5	242	1.07					
Do	do	2.5	458				2.02		
Do	Unnamed	4.0	25	0.17					
Do	do	4.0	156				1.10		
Total			881	1.24			3.12		
Grand total			1,282	1.49			5.71		

TABLE 9.—*Original lignite reserves in Toledo-Castle Rock coal district, Washington*

[Overburden less than 1,000 feet]

Reserves, in millions of short tons, in beds of thickness stated—

Township and range	Coal bed	Average thickness (feet)	Area (acres)	Measured and indicated				Inferred		
				5 to 10 feet	10 to 20 feet	More than 20 feet	Total	5 to 10 feet	10 to 20 feet	Total
T. 11 N., R. 2 W.	Unnamed	5.0	261					2.61		
T. 11 N., R. 1 W.	do	8.0	31					.50		
T. 10 N., R. 1 W.	do	15.0	363		10.88					
Do	do	24.0	44			2.13				
Do	Silver Lake	6.0	1,203	14.44						
Do	Walker	7.0	127					1.78		
Do	do	7.0	121	1.69						
Total, T. 10 N., R. 1 W.				16.13	10.88	2.13		1.78		
T. 10 N., R. 1 E.	Silver Lake	5.5	229	2.52						
Do	Walker	7.0	732					10.25		
Do	do	7.0	700	9.80						
Total, T. 10 N., R. 1 E.				12.32				10.25		
T. 11 N., R. 1 E.	Cedar Creek No. 1.	18.0	913						27.04	
Do	Cedar Creek No. 2.	9.0	913					14.24		
Do	Cedar Creek No. 3.	12.0	913						18.70	
Total, T. 11 N., R. 1 E.								14.24	45.74	
Total reserves, each thickness range.				28.45	10.88	2.13	41.46	29.38	45.74	75.12

Grand total of reserves......116.58 million short tons.

OIL AND GAS POSSIBILITIES

There has been little exploration for oil and gas within the mapped area, but just to the west a test well for oil was drilled to a depth of about 3,500 feet (Glover, 1947). Although a suitable structure for the accumulation of oil and gas was not observed in the mapped area, favorable stratigraphic traps may be present. A few water wells in the area discharge enough gas to be ignited. In the SW¼SE¼ sec. 24, T. 11 N., R. 2 W., at GS–1, gas and connate water under a hydrostatic pressure of 7.7 pounds per square foot were noted. The Bureau of Mines Northwest Experiment Station reported that the gas contains methane, 80.0 percent; nitrogen, 18.8 percent; oxygen, 1.0 percent; and carbon dioxide, 0.2 percent. The high methane content indicates the gas probably originated from coal or carbonaceous beds of the Cowlitz formation.

Post-Eocene formations are not considered possible sources of oil and gas because they are principally nonmarine and have a high content of tuffaceous material. The thick, alternating beds of marine sandstone and siltstone of the Cowlitz formation, however, may contain source and reservoir beds of petroleum. The marine siltstone beds of late middle Eocene age, equivalent to the McIntosh formation (Snavely and others, 1951a), which may be source beds, crop out northwest and northeast of the mapped area and, therefore, may lie at depth beneath the mapped area; oil and gas may have migrated from these beds into porous sandstone beds of the Cowlitz formation.

In 1925 the Castle Rock Oil and Gas Co., a subsidiary of Sunburst Oil and Refining Co., drilled the Quigley No. 1 well 4 miles west of Castle Rock in sec. 18, T. 9 N., R. 2 W., where the Cowlitz formation is exposed on the surface. The test well is reported to have been 3,500 feet deep, but a driller's log is available only to a depth of 2,893 feet (Glover, 1947, p. 15). Several traces of oil were reported in this well.

GRAVEL AND CRUSHED ROCK

Igneous rocks are widespread in the Toledo-Castle Rock coal district and afford an ample supply of rock for construction material. Small quarries throughout the area operate in interbedded basalt flows of the Cowlitz formation, basalt and andesite flows of the Hatchet Mountain formation, and basalt and andesite flows of the middle(?) Miocene volcanic rocks.

Large gravel bars in the alluvium along the Cowlitz River contain workable gravel deposits. At Toledo a drag line operates on one of these gravel bars from the east bank of the Cowlitz River. Small operations for gravel and sand are found all along the Cowlitz River in the mapped area because the rock is fresh, accessible, and requires little or no crushing to form aggregate.

The Quaternary terraces contain suitable material for aggregate, but production from these gravels is small because the overlying soil has more local value. Much open pit mining has been done in these terrace gravels at Gilmore Corners.

In the NE¼ sec. 18, T. 10 N., R. 1 E., and in the NW¼ sec. 20, T. 10 N., R. 1 W., coal beds have been burned at the outcrop and beneath shallow cover. As a result of the burning, overlying rocks are baked or fused to form clinker which is quarried in open pits for road metal.

HIGH-ALUMINA CLAY

Refractory clay has been obtained at the Cowlitz clay mine of Gladding, McBean and Co., which is 7 miles northeast of Castle Rock, Wash., in the NE¼NW¼ sec. 20, T. 10 N., R. 1 W. (Glover, 1941, p. 81). A joint investigation of this clay deposit by the Bureau of Mines and the Geological Survey proved the existence of 8.5 million tons of measured reserves of dry clay; 9 million tons of indicated reserves of dry clay; and more than 10 million tons of inferred reserves of dry clay (Nichols, 1943, p. 1). The clay is in sedimentary beds in the upper part of the Toutle formation, is of high-alumina content, and consists mainly of a carbonaceous white to gray silty, sandy, pebbly material containing siderite nodules, lignite, and tuff breccia. In its massive, bentonitic, dried state the clay is semiflint in hardness and of different thicknesses. The principal clay minerals are kaolinite, gibbsite, montmorillonite, and beidellite-nontronite (Nichols, 1943, p. 1).

Near the Cowlitz clay mine there are two high-alumina clay zones within the Toutle formation. The lower clay zone, a residual deposit resting on a water-lain tuff breccia, has a maximum thickness of 45 feet and consists of blue-gray clay with small inclusions of siderite, dark-gray carbonaceous clays, and thin beds of lignite. The upper clay zone has a maximum thickness of 40 feet and consists of multicolored clays containing siderite oolites, concretions, and carbonaceous material. Erosion has removed much of the upper clay zone in this area. The zones are separated by more than 100 feet of tuffaceous siltstones and sandstones with interbedded carbonaceous beds.

Similar beds of high-alumina clay were noted in the test holes drilled in the lignite deposits 9 miles east of Toledo. Here, the high-alumina clay generally rests on tuffs and tuff breccias beneath beds of lignite similar to the clay deposit at the Cowlitz clay mine. The clay, probably derived from weathering of tuffs and tuff breccias, is partly residual and partly transported. The lignite beds, which stratigraphically overlie the high-alumina clay zones, influenced favorably the leaching ability of percolating ground water. Further exploration for high-alumina clay reserves could be done by drilling in areas known to be underlain by lignite beds of the Toutle formation.

A small unmeasured deposit of ferruginous bauxitic clay lithologically similar to the ferruginous bauxite deposits of northwestern Oregon (Libbey and others, 1945) is in the SW¼NW¼ sec. 13, T. 10 N., R. 2 W. This small deposit was formed by the weathering of volcanic rocks of the Hatchet Mountain formation of late Eocene age. An analysis of this clay shows the following composition: Al_2O_3, 33.7 percent; Fe_2O_3, 14.2 percent; SiO_2, 34.2 percent; TiO_2, 2. 7 percent; and loss on ignition, 14.5 percent. Decomposition of the basalt accompanied by leaching action of groundwater has removed part of the silica and other nonaluminous minerals, probably from late Miocene to the present time. In the western part of Cowlitz County three occurrences of ferruginous bauxite are described briefly by Valentine (1949, p. 17). Sohn (1952) refers to similar deposits in Oregon and Washington as aluminous laterite composed principally of gibbsite, hematite, and minor amounts of minerals such as kaolinite and halloysite.

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APPENDIX

Three test holes were drilled in 1951 for the Geological Survey to obtain stratigraphic information and unaltered samples of coal. The location of these holes is shown on plate 1. Logs of the holes and data from several measured sections of outcropping rocks in the Toledo-Castle Rock district are given in the following pages:

DRILL-HOLE RECORDS

Log of drill hole GS-1, SW¼SE¼ sec. 24, T. 11 N., R. 2 W.

	Thickness (ft-in)		Depth (ft-in)	
Terrace deposits: Soil, bouldery, silty, clayey	5		5	
Toutle formation:				
Sandstone, silty, weathered, brownish-gray	2	2	7	2
Siltstone, very carbonaceous; thin coal stringers		8	7	10
Siltstone, carbonaceous, massive, dark-brown		6	8	4
Sandstone, medium-grained, dark-gray, indurated; disseminated plant fragments	1	9	10	1
Sandstone, fine-grained, indurated, dark-gray	3	6	13	7
Conglomerate, basaltic	1		14	7
Sandstone, basaltic, medium-grained		3	15	
Conglomerate, basaltic	2	6	17	6
Sandstone, medium-grained, indurated, dark-gray; interbedded conglomerate (pebbles as much as 1½ inches in diameter)	14		31	6
Siltstone, massive, indurated, dark-gray, calcareous	3		34	6
Sandstone, massive, dark greenish-gray, fossiliferous, poorly sorted, calcareous; indurated from 47 to 49 feet, 53 to 55 feet, and 58 to 62 feet 6 inches	28		62	6
Conglomerate, basaltic, massive, fossiliferous; coarse sand matrix	2	2	64	8
Sandstone, basaltic, fine-grained, massive, greenish-gray, poorly consolidated; thin interbedded conglomerate beds	5	4	72	
Conglomerate, basaltic, fossiliferous, massive, dark greenish-gray, indurated, calcareous; coarse-grained sand matrix	5	8	77	8
Conglomerate, massive, rust-red, indurated	4	4	81	
Sandstone, basaltic, medium-grained, massive, very dark gray	22	4	103	4
Conglomerate, basaltic, fossiliferous, massive, indurated, calcareous	6	8	110	
Sandstone, basaltic, medium-grained, fossiliferous, massive, dark-gray	57		167	
Sandstone, basaltic, medium-grained, massive, dark greenish-gray; high angle shear planes filled with calcite	2		169	
Sandstone, basaltic, fine-grained, dark-gray, poorly bedded; thin interbedded conglomerate beds	44	4	213	4
Conglomerate, basaltic, massive, dark greenish-gray; basaltic sand matrix and many red, scoria fragments. Note: fault at 217 feet 5 inches	21	8	235	
Sandstone, medium-grained, massive, reddish-brown, indurated; few basalt pebbles	2	6	237	6
Sandstone, basaltic, medium-grained, massive, dark greenish-gray; thin interbeds of conglomerate	7	6	245	
Conglomerate, basaltic, massive, dark greenish-gray; basaltic sand matrix	12		257	
Sandstone, fine-grained, massive, light brownish-gray; occasional megafossils and disseminated plant fragments	94	4	343	4
Sandstone, basaltic, very coarse grained; calcite cement and small veinlets		6	343	10
Siltstone, indurated; dip of 7°		1	343	11
Sandstone, basaltic, fine-grained, massive, very dark gray; many high angle shear planes coated with a thin veneer of calcite	4	11	348	10
Siltstone, massive, dark-gray; many calcite veinlets		6	349	4
Sandstone, basaltic, medium-grained, massive, dark-gray; numerous shear planes	11	8	361	
Sandstone, basaltic, medium-grained, massive, greenish-gray; few megafossils	16		377	
Cowlitz formation:				
Sandstone, basaltic, micaceous, medium-grained, well-bedded, greenish-gray; coaly stringers and carbonaceous siltstone partings, dip of 7°	35		412	
Siltstone, carbonaceous, dark-brown; thin interbedded fine- to medium-grained basaltic sandstone, few calcareous zones as thick as 6 inches	156	4+	568	4
Total depth of hole, 568 feet 4 inches.				

Log of drill hole GS–2, NE¼NW¼ sec. 20, T. 11 N., R. 1 E.

	Thickness (ft-in)		Depth (ft-in)	
Alluvium: Sand, gravel	23	6	23	6
Wilkes formation:				
Claystone, blue; thin carbonaceous layers	10	10	34	4
Toutle formation:				
Siltstone, mottled dark greenish-gray, tuffaceous; disseminated carbonaceous matter	4	4	38	8
Sandstone, olive-gray, medium-grained, basaltic		9	39	7
Siltstone, olive-gray, massive, clayey	2	5	42	
Sandstone, dark greenish-gray, fine-grained, friable	7	6	49	6
Siltstone, dark greenish-gray, clayey	14	5	63	11
Siltstone, very carbonaceous; wood fragments		10	64	9
Siltstone, dark greenish-gray, carbonaceous, clayey	3	1	67	10
Claystone, medium light-gray, plastic	9	2	77	
Claystone, very carbonaceous, silty	1	8	78	8
Lignite		7	79	3
Siltstone, very carbonaceous; dip of 8°		6	79	9
Sandstone, light greenish-gray, fine-grained, silty, bentonitic (?)	2	6	82	3
Sandstone, medium-gray, fine-grained, clayey	13	5	95	8
Siltstone, highly tuffaceous		10	96	6
Siltstone, medium-gray, sandy, poorly sorted	1	9	98	3
Sandstone, medium-gray, fine-grained, silty, tuffaceous	14	2	112	5
Siltstone, dark-brown, very carbonaceous; thin layers of coal	1	3	113	8
Lignite; disseminated pumice fragments		11	114	7
Siltstone, very carbonaceous		1	114	8
Bone		4	115	
Lignite		6	115	6
Sandstone, medium-brown, coarse-grained, poorly sorted, carbonaceous, pumiceous	2	3	117	9
Lignite	2		119	9
Siltstone, carbonaceous, tuffaceous; disseminated small pumice fragments	1	8	121	5
Claystone, blue-green, silty	5	7	127	
Siltstone, carbonaceous; thin layers of coal and bone	1		128	
Lignite; pyrite and pumice fragments; dip 7°	1	7	129	7
Siltstone, dark-brown, carbonaceous, tuffaceous	1	10	131	5
Bone	1	10	133	3
Siltstone, medium-brown, carbonaceous, thin-bedded		7	133	10
Siltstone, dark-brown, very carbonaceous; disseminated pumice fragments and thin layers of coal	2	5	136	3
Siltstone, light-gray, clayey, thin-bedded	1		137	3
Sandstone, medium-gray, fine-grained, silty	7	3	144	6
Sandstone, medium-gray, medium-grained, basaltic, clayey	16		160	6
Lignite		6	161	
Siltstone, dark-brown, carbonaceous		3	161	3
Lignite	1	7	162	10
Siltstone, dark-brown, carbonaceous; thin layers of coal		7	163	5
Bone; layers of coal		2	163	7
Sandstone, dark-brown, fine-grained, carbonaceous		1	163	8
Lignite		5	164	1
Sandstone, medium-gray, medium-grained, tuffaceous	2	5	166	6
Sandstone, dark-gray, fine-grained, thin-bedded, carbonaceous; thin layers of coal		3	166	9
Lignite; few layers of vitrain		6	167	3
Sandstone, dark-gray, fine-grained, carbonaceous; thin layers of coal and pumice fragments		2	167	5
Lignite	1	2	168	7
Lignite, bony	1	10	170	5
Siltstone, dark-brown, carbonaceous	1	2	171	7
Sandstone, dark-brown, fine-grained, carbonaceous, tuffaceous	2	2	173	9
Siltstone, dark-brown, carbonaceous, clayey	1	3	175	
Sandstone, dark greenish-gray, medium-grained, clayey	10		185	
Siltstone, dark-brown, carbonaceous, clayey	10		195	
Sandstone, dark greenish-gray, medium-grained, clayey	16	6	211	6
Siltstone, dark-brown, carbonaceous, clayey	11	6+	223	
Total depth of hole, 223 feet.				

Log of drill hole GS-3, SE¼SW¼ sec. 16, T. 11 N., R. 1 E.

	Thickness (ft)	Thickness (in)	Depth (ft)	Depth (in)
Alluvium: Sand, gravel, and silt	19	4	19	4
Toutle formation:				
Siltstone, dark-brown, carbonaceous; plant fragments	1		20	4
Lignite		4	20	8
No recovery	4		24	8
Conglomerate; small pebbles of volcanic rocks	1	4	26	
Claystone, light bluish-gray; few fragments of sandstone	7	5	33	5
Claystone, greenish-gray, indurated, sandy; plant fragments. Ratio of sand to clay increases with depth	17	10	51	3
Siltstone, dark-gray, carbonaceous; thin layers of coal	8	9	60	
Claystone, medium dark-gray	2		62	
Claystone, olive-gray; thin layers of carbonaceous material	5		67	
Lignite		6	67	6
Siltstone, medium-brown, carbonaceous		6	68	
Siltstone, dark-brown, carbonaceous	5	6	73	6
Lignite		6	74	
Claystone, light bluish-gray; sporadic pebbles	14		88	
Siltstone, dark-brown, tuffaceous		6	88	6
Lignite	5		93	6
Claystone, olive-gray		10	94	4
Siltstone, dark-brown, carbonaceous, clayey	2	4	96	8
Lignite		8	97	4
Siltstone, dark-brown, carbonaceous, tuffaceous; pumice fragments	1	2	98	6
Lignite		7	99	1
Siltstone, dark-brown, carbonaceous, tuffaceous	5	11	105	
Lignite		6	105	6
Siltstone, light-brown, carbonaceous; thin layers of coal	17	11	123	5
Lignite		8	124	1
Siltstone, light-gray to light-brown, clayey	19	11	144	
Conglomerate; decomposed volcanic pebbles	32		176	
Sandstone, dark-brown, carbonaceous, clayey	21		197	
Lignite		6	197	6
Siltstone, medium-brown, carbonaceous	9	10	207	4
Sandstone, greenish-gray, coarse-grained, indurated, poorly sorted; sporadic pebbles of volcanic rocks	21	9	229	1
Conglomerate, greenish-gray, pebble, indurated; volcanic rocks	2	11	232	
Tuff, lapilli, light-gray	31		263	
Sandstone, light greenish-gray, fine-grained, silty		4	263	4
Siltstone, light-brown, clayey	61	2	324	6
Claystone, light greenish-gray	3	6	328	
Siltstone, light-brown, carbonaceous, tuffaceous; thin layers of coal	23		351	
Sandstone, medium-gray, coarse-grained, poorly sorted; sporadic pebbles of volcanic rocks	11		362	
Siltstone, light-brown, carbonaceous	28		390	
Tuff, lapilli, medium-gray, clayey	14		404	
Siltstone, light- to medium-brown, carbonaceous, clayey; few thin layers of coal or carbonaceous material	126		530	
Tuff, lapilli, dark-gray, indurated; pyrite and fragments of red scoria; thin, high angle stringers of calcite. Dip of bed, 13°	3	9	533	9
Hatchet Mountain formation:				
Agglomerate; many high angle fractures filled with calcite	6	3 +	540	
Total depth of hole, 540 feet.				

STRATIGRAPHIC SECTIONS

Partial section of the Cowlitz formation measured in SW¼SW¼ sec 2, T. 10 N., R. 2 W.

	Ft	In
Logan Hill formation:		
Gravels; volcanic rocks; mostly stream-worn; coarse sand matrix	63	
Unconformity.		
Cowlitz formation:		
Siltstone, thin-bedded, light-brown, micaceous; thin irregular interbeds of feldspathic, micaceous, fine-grained, well-sorted, angular- to subangular-grained sandstone. Strike N. 36° W., dip 6° NE		7+
Sandstone, massive, white, friable, micaceous, feldspathic, medium-grained; interbedded siltstones. Sand grains are angular to subround, fair sorting; few dark minerals	9	8
Siltstone, massive- to thin-bedded, light-brown to greenish-gray; thin interbeds of coarse-grained, feldspathic, micaceous sandstone. Sand grains poorly sorted; some heavy minerals and some iron-staining		9
Sandstone, medium- to coarse-grained, massive, white, feldspathic, micaceous, friable; irregular pods or lenses of siltstone. Sand grains are angular to subround, generally subangular. About 8 feet from base of unit, the sandstone becomes very coarse grained with very small pebbles	20	1
Sandstone, fine-grained, partly decomposed, thin-bedded, friable, rust-red, micaceous, feldspathic	2	5
Siltstone, clayey, medium-gray, very thin-bedded; somewhat fissile, strike N. 8° W., dip 9° NE		2
Sandstone, fine-grained, micaceous, thin-bedded, light greenish-gray, friable, feldspathic; partly decomposed, strike N. 18° W., dip 8° NE	3	7
Sandstone, medium-grained, micaceous, massive, bluish-gray, very friable; sand grains angular to subangular, iron-staining at base	4	9
Sandstone, thin crossbedded, medium-grained, feldspathic, very micaceous	1	4
Siltstone, sandy, thin-bedded, light-gray, very micaceous		4
Sandstone, medium-grained, poorly sorted, feldspathic, reddish-brown, irregularly bedded; clayey matrix	1	2
Sandstone, very fine-grained, thin-bedded		1
Siltstone, sandy, micaceous, iron-stained, thin-bedded		2
Sandstone, silty, fine-grained, irregularly bedded, greenish-gray, poorly sorted, feldspathic		5
Siltstone, sandy, light-gray, thin-bedded		1
Sandstone, silty, fine-grained, irregularly bedded, greenish-gray, poorly sorted, feldspathic		2
Siltstone, sandy, faintly bedded, greenish-gray, micaceous		2
Sandstone, fine-grained, feldspathic, micaceous, faintly bedded, greenish-gray; sand grains subangular to subround, fair sorting; many fragments of volcanic rocks	1	5
Sandstone, fine- to medium-grained, thin-bedded; light and dark beds. Unit is very porous, and grains are stained a dark rust-red. Many small springs are located along this unit. Strike, N. 24° W., dip 6° NE	2	1
Siltstone, sandy, thin-bedded, medium-gray, slightly micaceous		2
Sandstone, silty, thin-bedded, medium bluish-gray, fine-grained; thin interbedded carbonaceous siltstone	1	4
Siltstone, sandy, thin-bedded, very dark-gray, finely micaceous; the top 3 inches carbonaceous	1	1
Sandstone, silty, micaceous, generally crossbedded, fine- to medium-grained, faintly bedded, bluish-gray	5	8
Siltstone, sandy, micaceous, olive-gray, very thin-bedded		3
Sandstone, thin-bedded, fine-grained, micaceous, bluish-gray. Strike, N. 35° W., dip, 6° NE		4
Sandstone, fine-grained, some crossbedding; thin alternating light and dark bluish-gray siltstone beds	7	0
Sandstone, fine- to medium-grained, massive to faintly bedded, iron-stained, feldspathic; about ½ inch of limonite crust at top and ½ to 1½ inches of limonite crust at botton of unit	2	8
Sandstone, fine-grained, light-gray, thin-bedded; some crossbedding and a few carbonaceous streaks. Strike, N. 63° W., dip, 8° NE	1	10
Sandstone, medium-grained, feldspathic, faintly bedded, greenish-gray, iron-stained, generally crossbedded		9
Siltstone and sandstone, light and dark gray, fine-grained, alternately bedded		7
Sandstone, fine-grained, thin-bedded, greenish-gray, friable; partly crossbedded with 1-inch limonite crust near base		3
Siltstone, carbonaceous, dark bluish-gray; a few thin, fine-grained sandstone beds. Strike, N. 8° W., dip, 10° NE	1	1

Partial section of the Cowlitz formation measured in SW¼SW¼ sec 2, T. 10 N., R. 2 W.—Continued

Cowlitz formation—Continued	*Ft*	*In*
Sandstone, thin-bedded, fine-grained; thin beds of siltstone and a ½-inch limonite crust at base		7
Sandstone, poorly bedded, iron-stained, medium- to fine-grained; 1-inch limonite crust at base		10
Siltstone, sandy, carbonaceous, bluish-gray, generally massive to faintly bedded, mottled; thin beds of fine-grained sandstone. Some carbonaceous zones, thin coal stringers. Worm (?) tubes	8	3
Sandstone, micaceous, indurated, iron-cemented, fine-grained		6
Sandstone, micaceous, fine-grained, friable, massive, greenish-gray; ½-inch limonite crust at base		10
Siltstone, carbonaceous, massive, mottled dark-gray		8
Sandstone, micaceous, thin-bedded, light greenish-gray, fine-grained; iron stains and limonite zones near base	1	8
Sandstone, silty, carbonaceous, thin-bedded, dark bluish-gray. Strike N. 25° W., dip, 9° NE		5
Sandstone, micaceous, poorly bedded, greenish-gray, friable, fine-grained; thin zones cemented by limonite	2	2
Sandstone, very fine-grained, silty, thin- to variable-bedded, greenish-gray	1	8
Sandstone, medium-grained; thin limonite zone		3
Sandstone, fine- to medium-grained, thin, greenish-gray; distorted bedding	1	10
Sandstone, micaceous, massive, blue-gray, fine-grained. Strike, N. 24° W., dip, 6° NE		5
Sandstone and carbonaceous siltstone, thin-bedded, dark and very dark gray, fine-grained		9+
Base not exposed.		
Total thickness	156	3

Section of Toutle formation measured in N½ sec. 19, T. 10 N., R. 1 W.

	Ft	*In*
Soil and clay, gray to yellow	2	0
Toutle formation:		
Clay, gray and brownish-yellow; weathered sand	4	11
Clay, gray, limonitic; concretions of iron oxides	1	5
Clay, gray, limonitic; weathered sand	22	6
Lignite; small amount of clay	4	6
Clay, carbonaceous; some lignite	3	11
Lignite; small amount of gray carbonaceous clay	9	4
Clay, carbonaceous; a few siderite granules	11	0
Lignite; carbonaceous clay	4	8
Clay, gray, carbonaceous	6	0
Lignite; carbonaceous clay	3	4
Clay, carbonaceous; small amount of lignite	5	10
Clay, gray, carbonaceous	3	8
Clay, gray, carbonaceous; small amount of lignite and siderite; pellets of white clay	14	4
Tuff breccia, slightly altered; gray clay matrix with siderite and angular to round volcanic rock fragments	10	2
Tuff breccia	33	4
Concealed	10	0
Conglomerate, pebbly, in a basaltic coarse-grained to granule sandstone		9
Sandstone, basaltic, coarse-grained, light yellowish-green, indurated, thinly crossbedded; lenses of siltstone and pebbles	2	5
Clay, massive, yellowish-gray		6
Clay, massive, light-gray		6
Clay, massive, yellowish-gray		10
Tuff breccia, basaltic, massive, light greenish-gray; dark-green basaltic coarse-grained sand matrix	3	5
Siltstone, massive, clayey, dark-yellow		10
Sandstone, crossbedded, pebbly, very coarse-grained to granule; sandy siltstone lense	2	10
Sandstone, massive, medium-brown, coarse-grained		9
Siltstone, massive, light greenish-gray		3
Sandstone, massive, medium-brown, friable, medium-grained	3	6
Siltstone, massive, yellowish-gray, tuffaceous	4	6
Sandstone, massive, yellowish-green, indurated, poorly sorted, pebbly, coarse-grained to granule	3	4

Section of Toutle formation measured in N½ sec. 19, T. 10 N., R. 1 W.—Continued

Toutle formation—Continued	*Ft*	*In*
Sandstone, massive, crossbedded, pebbly, coarse-grained to granule	2	6
Conglomerate, pebbly, indurated, crossbedded; small lenses of crossbedded sandstone	7	9
Small erosional unconformity (local).		
Siltstone, tuffaceous, sandy, massive, light yellowish-gray, indurated	5	0
Sandstone, friable, pebbly, massive, coarse-grained, lenticular		6
Siltstone, tuffaceous, clayey, massive, light-gray to medium-brown	2	1
Sandstone, massive, greenish-brown, poorly sorted, induated, silty; lenticular beds	2	3
Small erosional unconformity (local).		
Conglomerate, pebbly, indurated, well-bedded, dark greenish-gray; pebbly, coarse-grained to granule sandstone interbedding	4	0
Sandstone, medium-grained, basaltic, indurated, massive, iron-stained (rust red); pebble lenses	3	6+
Concealed	110	0
Lapilli tuff	53	0+
Concealed	60	0
Siltstone, massive, olive-gray, sandy, tuffaceous		6+
Sandstone, very poorly sorted, medium- to coarse-grained; composed of volcanic rock fragments, feldspar, and a few heavy minerals		3
Sandstone, silty, poorly sorted, basaltic, fine-grained		2
Conglomerate, pebbly, very poorly sorted; subangular volcanic rock fragments		11
Sandstone, fine- to coarse-grained, very poorly sorted, basaltic; abundant pumice fragments		3
Conglomerate; pebble to cobble, silty fine-grained sand matrix	2	4
Sandstone, basaltic, fine- to medium-grained, massive, olive-gray, poorly sorted	1	11
Conglomerate, pebbly, poorly sorted; volcanic rock fragments generally subround	1	5
Sandstone, basaltic, fine- to coarse-grained, very poorly sorted; scattered pebbles near base	1	1
Conglomerate; cobble to boulder, very poorly sorted medium-grained sand matrix		11
Erosional unconformity (local?).		
Sandstone, basaltic, fine- to coarse-grained, massive, poorly sorted; 3 to 18 inches thick		10
Conglomerate, pebbly, poorly sorted, crossbedded; thin discontinuous beds of sandstone, few boulders	2	8
Sandstone, medium-grained, crossbedded, pebbly, basaltic	4	4
Conglomerate, pebbly; massive, poorly sorted; silty fine-grained sand matrix; calcareous cement. Pebbles of volcanic rock generally subangular	2	3
Conglomerate, pebbly; massive, greenish-gray, coarse-grained sand matrix; grades upward to very poorly sorted fine-grained sandstone composed of volcanic rock fragments	1	5
Sandstone, basaltic, fine- to coarse-grained, indurated, poorly sorted, crossbedded; scour-and-fill channels and sporadic pebbles, cobbles, and boulders	11	9
NOTE: The color of all the following units is olive gray.		
Conglomerate; cobble to boulder, volcanic rock fragments and reworked underlying sedimentary rocks		7
Conglomerate, pebbly, faintly bedded, poorly sorted; thin interbeds of sandstone		9
Sandstone, pebbly, basaltic, very fine-grained		7
Conglomerate, pebbly, poorly sorted		8
Conglomerate, cobble to boulder, poorly sorted		11
Conglomerate, pebbly, poorly sorted, irregularly bedded; volcanic rock fragments and reworked underlying sandstone		8
Erosional unconformity (local?).		
Sandstone, basaltic, olive-gray, poorly sorted, fine- to medium-grained	1	10
Conglomerate, pebbly, very poorly sorted; 9 to 14 inches thick		11
Conglomerate, cobbly, very poorly sorted		8
Conglomerate; pebble to cobble, irregular bed, poorly sorted, contains megafossils. Map reference M-8	1	4
Sandstone, basaltic, massive, olive-gray, poorly sorted, fine-grained; a few pebbles of volcanic rock	4	11
Conglomerate; pebble to cobble, very poorly sorted		7
Sandstone, basaltic, fine-grained, massive, olive-gray, poorly sorted; some thin pebble zones and sporadic pebbles throughout. Volcanic rock fragments and feldspar grains are essentially subangular	8	0
Conglomerate, pebbly, very poorly sorted		3
Sandstone, basaltic, fine-grained, massive, olive-gray, poorly sorted; thin layers of coarse-grained sand and pebbles		5
Conglomerate, pebbly, very poorly sorted		4
Sandstone, basaltic, fine-grained, massive, olive-gray, poorly sorted		3
Conglomerate, pebbly, very poorly sorted; silty fine-grained sand matrix		10
Sandstone, massive, bluish-green, poorly sorted, basaltic, fine-grained; small lenses of pebble conglomerates	3	4+

Section of Toutle formation measured in N½ sec. 19, T. 10 N., R. 1 W.—Continued

	Ft	*In*
Toutle formation—Continued		
Concealed (believed to be massive poorly sorted basaltic fine-grained sandstone)	4	6
Sandstone, massive, olive-gray, poorly sorted, basaltic, fine-grained; thin layers of coarse-grained sandstone		6+
Conglomerate, pebble to cobble, massive, poorly sorted	2	10
Conglomerate, pebbly, faintly bedded, poorly sorted		11
Conglomerate; volcanic pebbles, cobbles, and boulders in about equal amounts, very poorly sorted	5	6
Erosional unconformity (local?).		
Conglomerate, pebbly, rust-red, poorly sorted; decomposed; few scattered cobbles and boulders in matrix of silty clay	5	5
Sandstone, fine-grained, massive, olive-gray, poorly sorted, basaltic; some coarse-grained zones and scattered pebbles	4	10+
Concealed	1	0
Sandstone, fine- to medium-grained, basaltic, massive, olive-gray, poorly sorted; indurated, partly calcareous; contains megafossils in thin zones. Few siltstone beds that pinch and swell	24	2+
Siltstone to pebbly conglomerate ("mud-flat" type deposit), massive, indurated, cross-bedded, poorly sorted. Many calcite veinlets up to ½-inch wide	1	1
Sandstone, fine-grained, basaltic, massive, blue-gray, indurated, poorly sorted, calcareous; contains megafossils. Upper 6 inches of unit contains many scour-and-fill channels. Map reference M-7	5	6
Sandstone, very fine- to coarse-grained, lenticular, olive-gray, very poorly sorted; bottom 2 inches are horizontal slickensided surfaces containing small calcite veinlets		9
Conglomerate; irregular bed, poorly sorted, indurated		2
Sandstone, massive, olive-gray, poorly sorted, fine-grained; some small slickensided clay zones. Sand grains essentially of volcanic rock, including abundant red scoria, and feldspar	3	3
Siltstone, blue-gray, tuffaceous, medium-grained; upper 11 inches showing horizontal bedding and crossbedding. Contains small pods of poorly sorted coarse-grained sand and worm(?) tubes filled with fine-grained sand. Small veinlets of calcite	1	5
Sandstone, basaltic, massive, blue-green, coarse-grained; tuffaceous clayey matrix. Grades upward to medium-grained sandstone		5
Sandstone, massive, blue-gray, indurated, basaltic, fine-grained, calcareous; many penecontemporaneous faults		7
Siltstone, sandy; considerable secondary calcite		2
Sandstone, bluish-gray, medium-grained, indurated; calcareous cement		2
Sandstone, bluish-green, basaltic, massive, medium-grained; sorting is fair and grains of volcanic rock and feldspar are subangular to subround		8
Siltstone, tuffaceous; irregular bed		1
Conglomerate, pebbly, massive, bluish-gray; friable, medium-grained poorly sorted sand matrix. Some bedding planes slickensided		10
Conglomerate; irregular bed, poorly sorted; boulders up to 14 inches in diameter	2	2
Tuff breccia, massive, bluish-green, devitrified, waterlain; angular to subrounded boulders (as much as 24 inches in diameter) of porphyritic basalt. This unit increases in amount of cobbles and boulders upward, approaching a conglomerate at top	15	0
Erosional unconformity (local?).		
Hatchet Mountain formation:		
Breccia; basalt flow, partly weathered, porphyritic, amygdaloidal	4	2+
Base not exposed.		
Total thickness	572	10

Section of Toutle formation measured in secs. 23, 24, 25, and 26, T. 11 N., R. 2 W.

	Ft	In
Soil	1	0
Terrace gravels	12	0
Toutle formation:		
Siltstone, tuffaceous, light-gray, thin-bedded; contains fossil leaves; strike N. 10° W., dip 5° NE	1	9
Tuff, massive, white; semi-flint fracturing		1
Siltstone, tuffaceous, massive, greenish-gray	3	2
Sandstone, pumiceous, massive, olive-gray, poorly sorted, fine- to coarse-grained; variable in thickness	2	5
Siltstone, very carbonaceous; contains fossil leaves. Plate 1, locality P–3		3
Siltstone, tuffaceous, white		2
Siltstone, tuffaceous, massive, bluish-gray; slightly carbonaceous at the base. Contains considerable pumice and some bentonitic(?) clay	16	6
Lignite, hard; xyloidal texture; strike N. 15° W., dip 5 to 8° NE		9
Sandstone, massive, dark-gray, carbonaceous, silty, fine-grained; contains carbonaceous matter near base including a few pieces of carbonized wood	3	8
Sandstone, massive, greenish-gray, indurated, poorly sorted, crossbedded, coarse-grained; pebbles and cobbles of volcanic rocks, boulders of siltstone, and pieces of carbonized wood	14	0
Sandstone, basaltic, massive, greenish-gray, crossbedded, lenticular, medium-grained; calcareous sandstone pods roughly alined along bedding planes. Strike, N. 20° W., dip 3° NE. Contains megafossils. (Effinger's loc. A–1424)	4	1
Sandstone, basaltic, massive, greenish-gray, crossbedded, fine-grained; thin layers of pumice pebbles, and scour-and-fill channels of coarse sand and pebbles. Irregular calcareous sandstone pods up to 28 inches thick	2	8
Sandstone, basaltic, massive, dark greenish-gray to olive-green, very poorly sorted fine- to medium-grained; with sporadic pebbles and thin pebble beds	5	6
Conglomerate; cobble to boulder, very irregular bed. Cobbles are vesicular and aphanitic basalt generally 6 to 8 inches in diameter, boulders are as much as 3 feet in diameter. Strike, N. 35° W., dip, 5° NE	3	0
Conglomerate; volcanic pebbles		4
Siltstone, tuffaceous, indurated, faintly bedded, greenish-gray	1	6
Sandstone, massive, dark greenish-gray, indurated, silty, fine-grained; composed of volcanic debris; contains few megafossils	6	9
Siltstone, massive, dark greenish-gray to greenish-purple; sandy with casts of megafossils		6
Sandstone, basaltic, indurated, massive, dark greenish-gray, fine-grained	2	4+
Concealed (believed to be fine-grained basaltic sandstone)	5	4
Sandstone, basaltic, dark greenish-gray, well indurated, silty, fine-grained	2	3+
Sandstone, dark greenish-gray, poorly sorted, coarse-grained, calcareous; very angular grains	1	2
Sandstone, basaltic, massive, dark greenish-gray, poorly sorted, fine-grained		5
Sandstone, basaltic, poorly bedded, dark-gray, indurated, coarse-grained to pebbly, calcareous; strike, N. 36° W., dip, 4° NE		4
Sandstone, basaltic, massive, dark greenish-gray, well indurated, poorly sorted, angular, fine-grained; contains pyrite locally	1	10
Sandstone, basaltic, medium-grained to granule, massive, greenish-gray, poorly sorted	1	1
Sandstone, massive, olive-gray, indurated, calcareous, very poorly sorted		10
Sandstone, massive, olive-green, very poorly sorted; faintly crossbedded with small scour-and-fill channels. Contains a few megafossils. Some small pebble zones	5	2
Sandstone, pebbly, fine-grained, massive, olive-gray, indurated, calcareous, poorly sorted; contains a few well preserved megafossils. Plate 1, locality M–4		8
Sandstone, pebbly, fine-grained, massive, olive-gray, poorly sorted; grains derived from volcanic rock		9
Conglomerate, pebbly, massive, greenish-gray, indurated, calcareous, very poorly sorted; poorly sorted sand matrix. Casts of pelecypod burrowings. Contains pieces of siltstone derived from the Cowlitz formation, as much as 1 inch in diameter along base		7
Conglomerate, very poorly sorted; composed of volcanic rock fragments; basalt pebbles as much as 3 inches in diameter		3
Conglomerate composed essentially of angular fragments of siltstone derived from the Cowlitz formation		2
Contact between Cowlitz and Toutle formations.		
Thickness of measured section	103	3

Composite type section of the Wilkes formation measured in road cuts in secs. 20 and 29, T. 11 N., R. 1 E., and secs. 3 and 10, T. 10 N., R. 1 E.

	Ft	In
1,100 feet south and 800 feet east of NW corner sec. 10, T. 10 N., R. 1 E.		
Concealed.		
Sandstone, mottled orange- to light-gray, medium-grained, clayey, massive; weathered	2	2+
Sandstone, mottled reddish-orange to light greenish-gray, medium-grained (slightly silty to coarse-grained), partly crossbedded, massive, poorly sorted; weathered in upper half and largely altered to clay	10	5
Siltstone, grayish-brown		1
Sandstone, micaceous, medium-grained, iron-stained		2
Siltstone, grayish-brown		1
Sandstone, micaceous, varicolored orange-red to light greenish-gray, medium- to coarse-grained, crossbedded	2	9
Sandstone and siltstone, micaceous, irregularly bedded, coarse- to fine-grained, iron-stained	1	7
Sandstone, coarse-grained to granule, light greenish-gray, massive; has a bentonitic siltstone matrix	2	7
Siltstone, light-purple, massive; slightly sandy and clayey	6	3
Sandstone, friable, coarse-grained, crossbedded, iron-stained; pebbles and granules and lenses of light greenish-gray medium-grained sandstone and siltstone. Also lenses of siltstone fragments and pebble conglomerates. Pebbles composed of volcanic and metamorphic rock, quartzite, chert, and siltstone	23	3+
200 feet south and 400 feet east of NW corner sec. 10, T. 10 N., R. 1 E.		
Concealed	1	2
Conglomerate, pebbly; iron-stained basaltic very coarse-grained to granule sandy matrix	15	0+
Sandstone, micaceous, silty, fine-grained; iron-stained along bedding planes		11
Sandstone, very fine-grained, light greenish-gray, massive	1	0
Sandstone, coarse-grained, crossbedded, friable, iron-stained; many basaltic rock fragments. Scour-and-fill channels of pebble conglomerate in lower half of unit	11	0
200 feet north and 350 feet east of SW corner sec. 3, T. 10 N., R. 1 E.		
Siltstone, sandy, micaceous, platy, iron-stained, thin-bedded	1	7
Sandstone, micaceous, very fine-grained, silty, friable, thin-bedded, iron-stained	1	4
Sandstone, micaceous, very fine-grained, grayish-green, friable, massive	1	6
Sandstone, mottled grayish-green to rust-red, micaceous, poorly sorted, medium-grained, friable, massive	1	5
Siltstone, carbonaceous; thin irregular beds of fine-grained micaceous sandstone containing fossils of leaves and fruit, and coalified wood		9
600 feet north and 400 feet east of SW corner sec. 3, T. 10 N., R. 1 E		
Sandstone, medium-grained, micaceous, greenish-brown, friable, massive; coalified wood fragments	2	4
Sandstone, medium-grained, rust-red; limonite zone		5
Sandstone, very fine-grained, tuffaceous light greenish-brown, friable, massive	2	1
Siltstone, sandy, light grayish-brown, micaceous, massive	6	5
Siltstone, sandy, iron-stained, slightly platy, thin-bedded		9
Claystone, tuffaceous, medium-brown, indurated		2
Siltstone, sandy; iron-stained and cemented, indurated		4
Sandstone, silty, very fine-grained, light greenish-gray, massive		7
Siltstone, thin-bedded, iron-stained		9
Siltstone, clayey, light greenish-gray, massive; very slightly sandy	2	1
Siltstone, clayey, medium-blue, massive	2	4
Sandstone, silty, very fine-grained, poorly sorted, light greenish-blue, massive	8	7
Siltstone, sandy, mottled purplish-brown, massive	2	1
Siltstone, dark-yellow, massive; considerable iron-staining	1	9+
1,800 feet north and 400 feet east of SW corner sec. 3, T. 10 N., R. 1 E.		
Concealed	28	2
Siltstone, sandy and clayey, light-gray, massive; iron-staining in lower half	8	0+
Sandstone, medium- to coarse-grained, friable, greenish-gray, poorly sorted, massive	4	3
Sandstone, silty, very fine-grained, light purplish-gray, friable; mineral grains and many fine-grained fragments of black rock		8
Sandstone, silty, very fine-grained, tuffaceous, micaceous, friable, light greenish-gray, massive	1	7+
2,900 feet east and 2,300 feet north of SW corner sec. 20, T. 11 N., R. 1 E.		
Concealed	57	4
Claystone, tuffaceous, massive, light olive-gray; weathers white	1	9
Siltstone, sandy, tuffaceous, very thin-bedded, light yellowish-gray to medium-brown; closely resembles a varved clay. Becomes very hard on exposed surface; penecontemporaneous deformation		7
Siltstone, clayey, faintly bedded, tuffaceous, light-brown; weathers white (very similar to above unit except not sandy). Excellently bedded in bottom 3 inches; strike N 40° E, dip 3° SE	4	4

Composite type section of the Wilkes formation measured in road cuts in secs. 20 and 29, T. 11 N., R. 1 E., and secs. 3 and 10, T. 10 N., R. 1 E.—Continued

	Ft	In
Sandstone, light olive-brown, silty, very fine-grained, tuffaceous; generally massive with some faint bedding. Penecontemporaneous deformation. Grains of feldspar and biotite and fragments of red scoria and pumice		7
Claystone, light-brown, very tuffaceous, massive; showing considerable penecontemporaneous deformation. Hard with "flintlike" or conchoidal fracture. Weathers straw yellow to white	3	3
Siltstone, thin-bedded, olive-gray, tuffaceous; very thin beds of light-brown clay (similar to varved clay); iron-staining along some bedding planes	1	1
Siltstone, clayey, tuffaceous, massive, medium-brown, finely micaceous, massive; some plant material. Considerable manganese staining in lower part of unit, giving variegated color of brown and yellow with black stain. Weathers yellow	5	7
Limonite; very persistent		1
Sandstone, medium-grained, olive-gray, feldspathic, massive, moderately well-sorted; composed essentially of grains of feldspar, heavy minerals, mica, and fragments of basalt and red scoria		3
Siltstone, sandy, poorly sorted, olive-gray; some penecontemporaneous deformation. Considerable iron-staining		6
Sandstone, dark olive-gray, fine-grained, feldspathic, micaceous; a heavy-mineral suite. Grains subround to round, well sorted. Irregular contact with unit below		11
Sandstone, fine-grained, very massive; composed of fragments of basalt and red scoria and grains of feldspar and mica. Unit is generally rust-red due to iron stain. Friable when fresh. Contains many thin interbedded layers of tuffaceous siltstone	7	8
Limonite, platy to mammillary; many springs along outcrop of this unit		2
Siltstone, tuffaceous, platy, blue-gray; thin sandy layers now altered and iron-stained		6
Siltstone, massive, blue-gray, clayey; volcanic fragments now altered essentially to clay	2	0
Sandstone, tuffaceous, blue-gray, clayey, very fine grained, massive; clay, semiplastic when fresh, probably bentonitic	1	2
Siltstone, clayey, massive, dark bluish-gray; hard and brittle carbonaceous clay containing pressed tubular fossils of plants, shrubs, and small trees. Slickensided depositional surfaces	5	6
Clay, massive, greenish-blue, very tuffaceous; "semiflint" fracture. Weathers olive gray to white, becoming hard and brittle	3	3
Claystone, massive, dark-blue; weathers light gray, semiplastic. Many slickensided depositional surfaces	5	9
Claystone, silty, tuffaceous, mottled green and dark-blue, semiplastic; some disseminated plant fragments	1	9
Claystone, massive, semiplastic, mottled purplish-blue; contains plant fragments	2	3
Siltstone, clayey, sandy, massive, tuffaceous, greenish-gray; tubular fossil plants and coalified wood		9
Claystone, massive, semiplastic, greenish-blue; disseminated fossils of tubular plants and plant fragments	1	8
Sandstone, friable, massive, dark greenish-gray, very fine-grained; grains of basalt and red scoria, and of feldspar, mica, and some heavy minerals. Sorting fair with some silt and fossil plant fragments	1	4
Claystone, massive, semiplastic, dark greenish-gray; fossil wood and plants (up to 5 inches in diameter), some in upright position	7	2+
2,750 feet east and 600 feet north of SW corner sec. 20, T. 11 N., R. 1 E.		
Concealed	20	0
Claystone, plastic, massive; weathered dark yellow	4	1+
Sandstone, very fine-grained, clayey, greenish-gray; grains of basalt and red scoria and of feldspar and mica		2
Claystone, medium-brown, plastic		2
Conglomerate, pebbly, greenish-gray; well decomposed and now essentially clay. Pebbles are volcanic rocks		5
Claystone, sandy, plastic, very fine-grained, olive-gray		4
Sandstone, fine-grained, massive, iron-stained, greenish-yellow; with thin irregularly bedded layers of clay throughout. Some graded bedding near base of unit. Grains of basalt and red scoria, and of feldspar and heavy minerals. Faint bedding at base with concentration of heavy minerals indicating bedding planes. Generally friable where not held together by clay layers	3	2
Siltstone, tuffaceous, carbonaceous, massive to finely laminated, light-brown; contains well-preserved fossil leaves	2	1
Sandstone, greenish-gray, very fine-grained; interbedded light-brown clayey siltstone	1	3
Sandstone, massive, friable, olive-gray, fine-grained; grains of basalt and red scoria, and of feldspar, mica, and heavy minerals. Good sorting; clean, subangular sand grains	1	4
Sandstone, massive, friable, blue-gray, medium-grained, poorly sorted, iron-stained		9

Composite type section of the Wilkes formation measured in road cuts in secs. 20 and 29, T. 11 N., R. 1 E., and secs. 3 and 10, T. 10 N., R. 1 E.—Continued

	Ft	In
Siltstone, sandy, massive, light-brown; considerable clay in matrix. Few fine-grained sandstone partings up to one-eighth inch thick. Bottom 2 inches is very carbonaceous, plant fragments. Strike, N 8° W, dip, 10° SW	3	2
Sandstone, silty, poorly sorted, very fine-grained, mottled olive-gray; disseminated plant fragments		7
Claystone, very dark-brown, carbonaceous		1
Sandstone, clayey, poorly sorted, olive-green, very fine-grained; disseminated plant fragments	3	9
Sandstone, similar to preceding unit but silghtly coarser grained and containing irregular lenses and pods of clayey siltstone. Considerable iron staining	2	1
Sandstone, friable, medium-grained, massive, greenish-gray; interbedded light-brown carbonaceous clayey siltstone	3	1
Sandstone, greenish-gray, massive, very friable, medium-grained; contains sporadic rounded pebbles of rhyolite, generally 1 inch or less in diameter, and heavy-mineral suite. Cross bedding in pebble zones. Scour-and-fill channels filled with very coarse sand and pebbles	9	5
2,900 feet east and 400 feet north of SW corner sec. 20, T. 11 N., R. 1 E.		
Sandstone, silty, massive, crossbedded, fine-grained, greenish-gray; grains of basalt and red scoria, and of feldspar and heavy minerals	2	2
Siltstone, clayey, massive, greenish-gray; limonitic zones	1	9
Sandstone, light greenish-gray, massive, fine-grained, slightly micaceous, indurated; grains of basalt and red scoria, and of feldspar, mica, and heavy minerals	1	5
Siltstone, clayey, micaceous, massive, greenish-gray; considerable iron-staining		5
Sandstone, very fine-grained, massive, mottled greenish-gray; spheroidal type of weathering with iron-stained concentric bands	8	2
2,400 feet west and 320 feet south of NE corner sec. 29, T. 11 N., R. 1 E.		
Sandstone, massive, medium- to coarse-grained, very poorly sorted, olive-green; thin beds of medium-brown clay near top. Locally concentrated layers of heavy minerals (mostly magnetite). Intraformational breccia zone 2 inches thick 25 inches from top. Many siltstone beds about 1 inch thick in middle of unit. Lower half is crossbedded, layers of small pebbles along foreset beds. Pebble conglomerate locally at base	9	5
Sandstone, massive, olive-green, crossbedded, fine- to coarse-grained, poorly sorted, friable; lenticular carbonaceous siltstone (less than 6 inches) near top; unit shows graded bedding	8	1
Siltstone, sandy, blue-gray, poorly sorted, very fine-grained; decomposed essentially to an iron-stained clay	1	1
2,550 feet west and 1,100 feet south of NE corner sec. 29, T. 11 N., R. 1 E.		
Sandstone, silty, very fine-grained, massive, greenish-gray; numerous pieces of coalified wood	6	9
Siltstone, sandy, carbonaceous, massive, greenish-gray; contains numerous layers of plant fragments	2	4
Sandstone, massive, fine-grained, carbonaceous, greenish-gray to olive-gray, crossbedded; some streaks of clayey siltstone. Numerous layers of fossil plants and coalified wood fragments	3	10
Sandstone, pebbly, very poorly sorted, medium-grained, massive, olive-gray; sporadic pebbles of siltstone and decomposed volcanic rocks	3	4
Claystone, sandy, purplish-blue, massive, tuffaceous, semiplastic; contains very fine grains of pumice; plant fragments, coalified wood, some pieces of wood opalized. Weathers blue-green to straw-yellow	13	0+
Base not exposed.		
Thickness of composite section	393	0

INDEX

Page

Acknowledgments 4
Age and general features of rocks 9–12
Alluvium 41
Alpine drift 38–39

Brown, R. W., plant fossils identified 19, 30
  quoted 10

Centralia-Chehalis coal district 2, 3
Clay, high-alumina 55–57
Coal, burning of beds 43
  chemical and physical properties 46
  proximate analyses 47
Coal beds, Cedar Creek Nos. 1, 2, and 3 49–50, 52, 53
  Leavell 46
  Schuff 46, 48
  Silver Lake 50
  unnamed, in Cowlitz formation 48
    in Toutle formation 51
  Walker 50–51
Coal reserves 51–54
Coaledo formation 14, 18
Concretions, corprolite-like 35–36
Cowlitz formation, coal beds 46–48
  distribution and character 14–19
  measured section 62–63

Dickerson, R. E., quoted 29
Drill-hole records 59–61
Drilling program 5

Effinger, W. L., fossils identified 25–27
Eocene series 13–24
Eocene and Oligocene series 24–32

Fieldwork 4–5
Flora, from Cowlitz, Toutle, and Wilkes formations 30
  Tertiary 10
Fossils, Foraminifera from Cowlitz formation 18–19
  Foraminifera from Toutle formation 31
  megafossils from Cowlitz formation 15–18
  megafossils from Toutle formation 25–27
  plants collected from Cowlitz formation 19

Geography, climate and vegetation 6–8
  drainage 6
  land features 5–6
Goble vocanic series 20
Gravel and crushed rock 55
Gries Ranch fauna 29, 31

Page

Hatchet Mountain formation named and described 19–21
  olivine basalt sequence 23–24
  porphyritic andesite sequence 22–23
  porphyritic basalt sequence 21–22
History of mining and geologic study 2–4

Igneous rocks, as classified in this report 11

Keechelus andesite series 13

Landslide debris 40
Latah formation 36
Leyton Prairie 39
Location of coal field 2, 3
Logan Hill formation 37–38

Mascall formation 36
Middle (?) Miocene volcanic sequence 32–33
Mines and prospects, data 44
Miocene series 32-37
Montesano formation 36–37
Morton coal district 2, 3
Mount St. Helens, eruptions 41–42

Napavine syncline 42
Northcraft formation 13–14

Oil and gas possibilities 54–55
Oligocene and Eocene series 24–32

Pleistocene and Recent series 37–42
Poway formation 14, 18

Rau, W. W., Foraminifera identified 18–19, 31
Recent and Pleistocene series 37–42
Reserves. *See under* Coal.
Rocks exposed in district (table) 12

Siderite concretions 35–36
Stewart, Ralph, fossils identified 15, 25–27
Stratigraphic sections 62–69
Stratigraphy 9–42
Structural geology 42–43

Tejon formation 14, 18
Terrace deposits 39–40
Toutle formation, coal beds 48–51
  exposed contact with Hatchet Mountain 23
  high-alumina clay 55–57
  measured sections 63–66
  named and described 24–31

Vokes, H. E., fossils identified 15
Volcanism 10–11

Weaver, C. E., fossils identified 15
Wilkes formation, named and described 34–37
  measured section 67–69
Windom, Wash., strippable area 52