Geology and Coal Resources of the Cumberland, Hobart, and Maple Valley Quadrangles, King County, Washington

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GEOLOGY AND COAL RESOURCES OF THE CUMBERLAND, HOBART, AND MAPLE VALLEY QUADRANGLES, KING COUNTY, WASHINGTON

By JAMES D. VINE

ABSTRACT

The Cumberland, Hobart, and Maple Valley quadrangles, King County, Wash., are 11 to 32 miles southeast of Seattle along the east side of the Puget Sound lowland and the west side of the Cascade Range. The area is underlain by Tertiary and Quaternary sedimentary, volcanic, and intrusive rocks covered in places by surficial deposits. Geologically and geographically the mapped area may be divided into two main areas—the Green River area to the south, and the Tiger Mountain-Taylor Mountain upland area to the north.

The Puget Group includes the oldest rocks known to crop out in this area. In the Green River area the Puget Group was not subdivided in mapping; it includes about 6,200 feet of nonmarine sedimentary rocks that range in age from early Eocene to early Oligocene. In the Tiger Mountain–Taylor Mountain upland areas, rocks of the same age crop out but are about 14,000 feet thick and are subdivided into four formations. Three of the formations are in the Puget Group—the Tiger Mountain, Tukwila, and Renton Formations. The underlying Raging River Formation is excluded from the Puget Group partly because it contains marine fossils. Marked changes in thickness and lithology of the strata suggest that deposition was in a trough which subsided nearly twice as fast in the northern part of the area as in the southern part. Very little mixing of sediment occurred between the two areas.

In the southern part of the area, the undifferentiated Puget Group is almost continuously exposed in the canyon of the Green River. More than half the sequence is sandstone; siltstone, carbonaceous claystone, and coal make up the rest. Coal beds are numerous, and some beds have been traced in underground mines for several miles. Most of the commercially important coal beds are in two zones, the Kummer and Franklin coal zones. The Kummer coal zone comprises about 1,200 feet of strata in the upper part of the sequence; the Franklin coal zone includes about 3,000 feet in the middle of the sequence. Correlation of strata from the canyon to outlying areas is based on a sequence of floral stages established by Wolfe in 1968 from abundant fossil leaves in the finer grained rocks.

In the northern part of the area, volcanic sandstone, siltstone, and conglomerate as much as 3,000 feet thick make up the Raging River Formation. These strata locally contain abundant marine fossils, including Foraminifera referable to the *Bulimina jacksonensis* zone of Rau and several species of *Turritella*, *Venericardia*, *Pitar*, and other mollusks. The characteristically dark gray sandstone beds are composed largely of reworked volcanic material and commonly contain as much as 50 percent plagioclase feldspar and plagioclase-rich lithic grains.

As much as 2,000 feet of nonmarine sandstone and coal beds conformably overlies the Raging River Formation and is assigned to the Tiger Mountain Formation, the lowest formation in the Puget Group. The upper part of the Tiger Mountain Formation is interstratified with, and overlain by, the Tukwila Formation. The Tukwila Formation, about 6,800 feet thick, is made up of interbedded units of volcanic sandstone and siltstone, tuff, lapilli tuff, tuff-breccia, and volcanic conglomerate and relatively thin units of arkosic sandstone, carbonaceous claystone, and impure coal. The Tukwila Formation is conformably overlain by, and interfingers with, nonmarine arkosic sandstone, siltstone, and coal beds that make up the Renton Formation, at least 2,185 and possibly as much as 4,000 feet thick. The Renton Formation is the youngest formation in the Puget Group and is characterized by rather friable sandstone beds whose principal cement is kaolinite. The Renton Formation in the study area was a commercial source of coal and clay in the past and still contains large resources of both.

The Puget Group is conformably overlain by, and locally intertongues with, a thick section of unnamed volcanic rocks that farther east constitute most of the volcanic sequence in the southern Cascade Range. These rocks range from tuff, tuff-breccia, and lava flows on the east to volcanic sedimentary rocks on the west. Fossil leaves from the main lower part of the unnamed volcanic rocks were assigned to the upper Kummerian Stage of early Oligocene age. Locally, the Puget Group is unconformably overlain by flat-lying to gently dipping upper Tertiary sedimentary deposits, which occupy the same stratigraphic position but were never coextensive with the Hammer Bluff Formation of Miocene age. A generally northward trend of folding is evident in most of the Eocene and Oligocene rocks.

Pre-Vashon drift of Pleistocene age is exposed locally along the Cedar River, but most of the three-quadrangle area is blanketed by the Vashon Drift of Pleistocene age, which was deposited in the Puget Sound lowland by the last continental ice sheet as it moved south. The ice sheet was as much as 3,000 feet thick where it lay against the front of the Cascade Range, and it completely disrupted the normal drainage pattern from the mountains. During the recession of the ice, several meltwater rivers flowed across the area and left a series of broad gravel terraces and channels that are now abandoned. Many glacial lakes were formed: some in depressions in the ground moraine, others in kettle holes. At least one temporary lake was formed by an ice block in the valley of Issaquah Creek. Lake deposits include silt, sand, and, locally, peat.

Dark-greenish-gray porphyritic andesite sills, probably of Oligocene age, intruded the sedimentary rocks in many places. A greenish-gray prophyritic hornblende andesite or dacite in Issaquah Canyon may be a volcanic vent related to the rocks of the Tukwila Formation.

Known resources of coal are estimated to be about 600 million tons, of which 78 percent is bituminous and 22 percent is subbituminous. Potential coal resources are much greater and are estimated to be about 5 billion tons. The Renton Formation and the upper part of the undifferentiated Puget Group contain the principal clay resources of the area. Deposits of outwash gravel in the Vashon Drift are important sources for sand and gravel. Construction stone, quicksilver deposits, silica-sand deposits, and petroleum prospects are of minor economic importance in the area.

INTRODUCTION

PURPOSE AND SCOPE OF INVESTIGATION

An investigation of the geology of Cumberland, Hobart, and Maple Valley quadrangles, King County, Wash., was begun in July 1959 in cooperation with the Washington Department of Conservation, Division of Mines and Geology. The objectives of the project were fourfold: (1) to prepare a detailed map of the bedrock of the area, showing outcrops and geologic structure on a topographic base; (2) to determine the stratigraphic relation between the sequence of coal-bearing rocks in the Cumberland quadrangle on the south and the dominantly volcanic rocks in the Hobart quadrangle on the north; (3) to map the coal beds and calculate the coal resources of the area; and (4) to examine the clay deposits and other mineral resources of the area and evaluate their potential.

Two preliminary reports (Wolfe and others, 1961; Vine, 1962b) and two preliminary maps (Vine, 1962a; Gower and Wanek, 1963) have been published as part of the cooperative project. A report describing the basis for, and the definition of, new floral stages has also been published (Wolfe, 1968).

LOCATION AND ACCESSIBILITY OF THE AREA

The Cumberland, Hobart, and Maple Valley quadrangles are in central western Washington along the east margin of the Puget Sound lowland and the west flank of the Cascade Range. The central business district of Seattle is about 11 miles northwest of the nearest corner of the Maple Valley quadrangle and about 32 miles from the southeast corner of the Cumberland quadrangle (fig. 1). Near Preston, U.S. Highway 10 passes within half a mile north of the Hobart quadrangle. In 1961 the State Highway Department began construction of a new highway to connect U.S. Highway 10 near Preston with U.S. Highway 99 near Tacoma. The new road passes southwestward across the area from the northeast corner of the Hobart quadrangle to the southeast corner of the Maple Valley quadrangle (fig. 1). A network of State and county roads, many paved with asphalt, provide access to most of the lowland area. The most important of these are shown in figure 1. However, access to the upland is limited chiefly to private roads and roads maintained by Government agencies. No unauthorized travel is permitted within the boundary of the city of Seattle Cedar River watershed. The area north of the watershed is administered jointly by the Washington Department of Forestry and Weyerhaeuser Co., each of whom controls large parts of the land and access roads in the area.

FIELDWORK AND ACKNOWLEDGMENTS

A. A. Wanek, assisted by J. D. Vine and P. J. Pattee, began the fieldwork for the present investigation in July 1959. In 1960 J. D. Vine, H. D. Gower, and C. L. Rice continued the fieldwork. Vine and Gower each did additional fieldwork in 1961. D. C. Wiese and Kenji Sakamoto assisted in the laboratory and with the compilation of coal data. F. Stearns MacNeil and W. W. Rau rendered great aid in identifying the invertebrate fossils and interpreting the age and environment of deposition. J. A. Wolfe joined the writer in the field to obtain additional collections of fossil leaves.

To the city of Seattle Water Department the writer expresses his thanks for access to the Cedar River watershed and for cooperation on numerous occasions. He also thanks the many others who provided access to restricted forest roads, especially John Buchanan, District Forester for the Washington Department of Forestry at North Bend, and Donald Dowling, Branch Forester for the Weyerhaeuser Co., Snoqualmie Falls Branch. The assistance of Ernest Seliger in locating several abandoned coal mines and obscure coal outcrops in the Cumberland quadrangle is appreciated. Thanks are also extended to the many private landowners, mine operators, and other individuals in the area whose courtesy and cooperation facilitated the investigation.

Unpublished data and the coal-mine maps of W. C. Warren and his associates were made available to the writer from their investigation of the King County coal fields in 1943 and 1944 as were the coal resource data and compilation sheets prepared for the recent detailed estimate of coal resources for the State (Beikman and others, 1961).

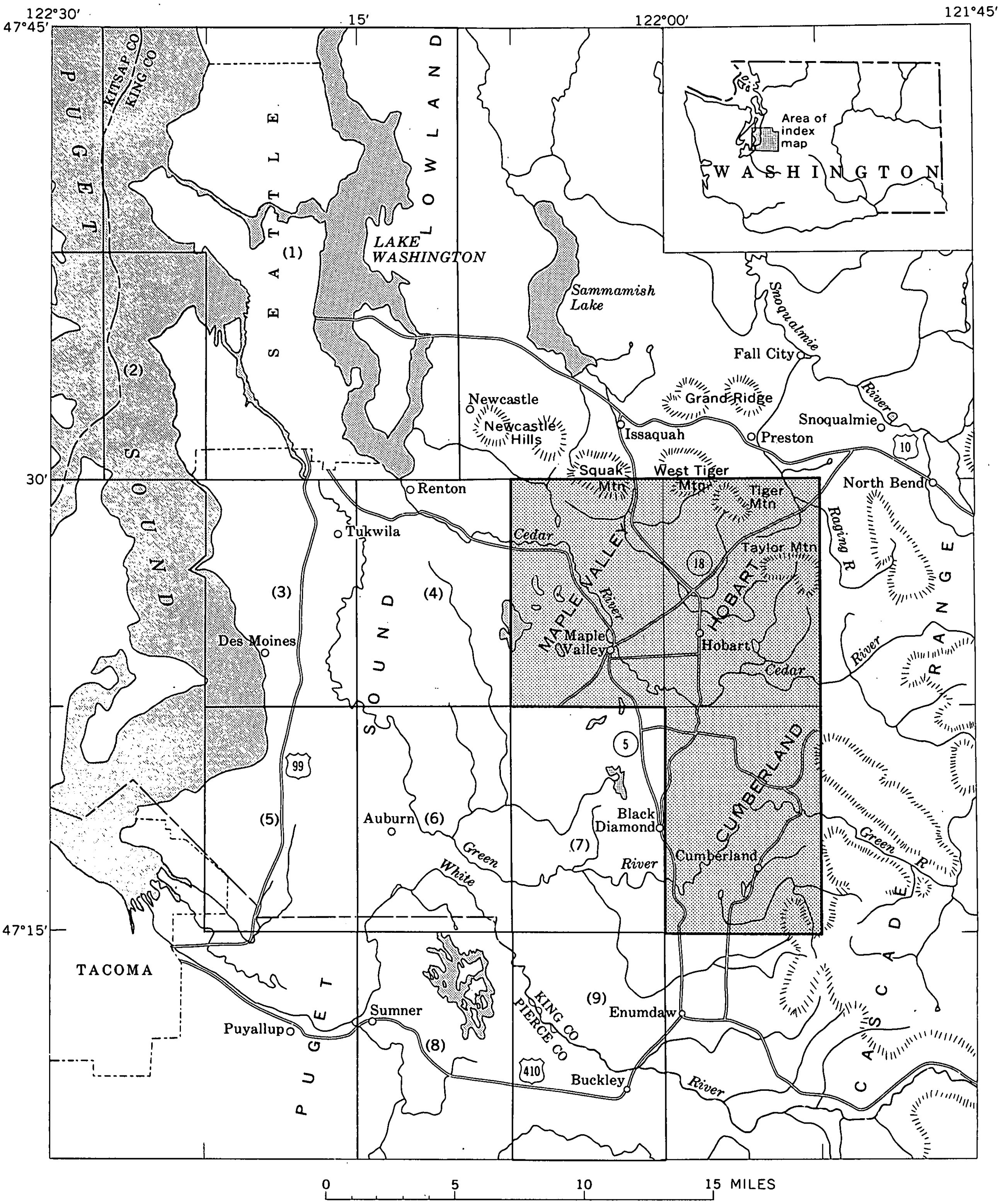

FIGURE 1.—Index map of western Washington, showing area of this report (heavy boundary) and areas of other recently published geologic maps. 1, Seattle and vicinity (Waldron and others, 1962); 2, Duwamish Head (Waldron, 1967); 3, Des Moines (Waldron, 1962); 4, Renton (Mullineaux, 1965a); 5, Poverty Bay (Waldron, 1961); 6, Auburn (Mullineaux, 1965b); 7, Black Diamond (Mullineaux, 1965c); 8, Sumner (Crandell, 1961); 9, Buckley (Crandell and Gard, 1959).

GEOGRAPHY

TOPOGRAPHY

The Cumberland, Hobart, and Maple Valley quadrangle boundaries encompass a wide variety of landforms of little to moderate relief and, locally, undrained depressions. Altitudes in the area range from about 120 feet at the lowest point on the Cedar River to 3,004 feet at the top of Tiger Mountain. The western front of the Cascade Range forms a prominent escarpment that ranges in altitude from 1,400 to 2,700 feet along most of the east side of the Cumberland quadrangle. The Tiger Mountain–Taylor Mountain upland area, which extends in a northwesterly direction across the northern two-thirds of the Hobart quadrangle and the northeast corner of the Maple Valley quadrangle, is part of a western spur of the Cascade Range. These mountains, as well as many of the lesser outlying hills, owe their relief to the resistance of the underlying bedrock, whereas the subdued relief of most of the lowland areas is due to the cover of glacial deposits.

Two major rivers traverse the area and bring generally clear water from the snowfields and catchment basins high in the Cascade Range. On the north, the Cedar River heads directly south of Snoqualmie Pass, which is crossed by U.S. Highway 10. The headwaters of the Green River are due south of the Cedar River. The Cedar River flows into the south end of Lake Washington, whereas the Green River empties into Puget Sound. Issaquah Creek and its tributaries, Fifteenmile Creek and Holder Creek, head in the Tiger Mountain area and flow into Sammamish Lake. Tributaries of the Raging River, including Deep Creek, drain the northeastern part of the Tiger Mountain–Taylor Mountain upland area and flow into the Snoqualmie River, which is the next major stream north of the Cedar River. Coal Creek and Deep Creek, in the southeast corner of the Cumberland quadrangle, empty into Fish Lake and Deep Lake, respectively, neither of which has a surface outlet. The underground seepage from these lakes probably is returned to the surface from springs southeast of the Green River.

CLIMATE AND VEGETATION

The Cumberland, Hobart, and Maple Valley quadrangles are characterized by abundant precipitation (about 40 to 80 inches per year), high humidity, mild temperatures, and a long growing season. This climate results in a prolific growth of vegetation. The native forests of conifers once included many valuable stands of Douglas-fir (*Pseudotsuga menziesi*) and western redcedar (*Thuja plicata*). Locally, individual fir and cedar trees are more than 8 feet in diameter and 200 feet high. Most of the virgin timber was cut long ago, and a second growth is in various stages of development. Within the first few years after an area has been logged, it can become a virtually impenetrable thicket of young trees, shrubs, and ferns. Blackberry thickets commonly spring up along the margins of clearings and may cover roads and mine dumps. Thickets of devilsclub (*Oplopanax horridum*) form locally on saturated ground. In time, broadleaf trees, including vine maple (*Acer circinatum*), red alder (*Alnus oregona*) and bigleaf maple (*Acer macrophyllum*), become dominant and are gradually overshadowed in turn by the conifers, including western hemlock (*Tsuga heterophylla*). Douglas-fir and western redcedar eventually return to the logged-over areas, though not so quickly as some of the less valuable conifers.

ECONOMIC DEVELOPMENT

Economic development of the Cumberland, Hobart, and Maple Valley quadrangles has been closely connected with the economic growth of Seattle and Tacoma. Coal fields near the Green River and at Cedar Mountain were first developed early in the 1880's to meet the demand for fuel in the nearby cities. The origin of the villages of Black Diamond, Ravensdale, Georgetown, Cumberland, Bayne, Kangley, and Durham was due partly to the coal industry. The lumber industry, which has long been basic to the economy of the Northwest, found this area particularly valuable because of its nearness to markets and transportation. Clay deposits and sand and gravel deposits have also been developed largely because of the nearness to markets. Farming is not so important in this area as in many others because the soils formed on glacial till are rocky and poorly drained, and those formed on glacial outwash gravel are excessively rocky and too permeable to hold moisture near the surface. However, some of the soils formed on lacustrine sand and silt deposits—especially in the area near Hobart and near Issaquah Creek—support small farms. Because of its proximity to the nearby metropolitan area, the land is attractive for suburban residential and resort use, particularly along the main roads, on the Cedar River alluvial plain, and near the many small lakes.

PREVIOUS WORK

In 1853 coal was found near the present city of Renton. By 1886 (Willis, 1886), several of the coal fields in the King County area had been described in some detail. In Willis' (1886, p. 759–760) report, reference is made to the "Coal measures of the Puget Sound basin," which are exposed along the Green River "from the contact with eruptive rocks on the east to the drift beds on the west." White (1888, 1889) first used the name Puget Group for the coal-bearing rocks in the Puget Sound lowland and described many fossils from these rocks. He mentioned that the fossil flora of these rocks was examined by a Professor Newberry, who was able to recognize several distinct horizons. In later reports (Willis, 1897, 1898a) the name Puget Group is used extensively to refer to the nonmarine coal-bearing rocks exposed throughout the Puget Sound lowland.

In 1912 Evans reported in detail on the coal fields of King County. In that report he called the coal-bearing rocks of Eocene age the Puget Formation, which he subdivided, from oldest to youngest, into what he termed the Bayne, Franklin, and Kummer series. The subdivision was based on the local recognition of two thick units of sandstone exposed along the Green River near the former townsites of Franklin and Kummer. On the map that accompanies the report, Evans showed many areas of both intrusive and extrusive igneous rocks of various ages. In the text (Evans, 1912, p. 44–45) he discussed these rocks in terms of lava flows, dikes and sills, and laccoliths and their relationship to the coal-bearing rocks. He recognized that in some areas thick masses of igneous rock lie below the coal-bearing rocks, and in other areas such masses lie above.

Weaver (1916, p. 84, 232–235) gave the name Enumclaw Volcanic Series to the andesitic lava and interbedded tuff and clay that lie on the "estuarine Eocene deposits" along the western escarpment of the Cascade Range, and his map shows that these volcanic rocks extend from Fall City on the north to Enumclaw and the Carbon River on the south. They probably include the unnamed volcanic rocks of the present report.

The name Puget Group became firmly established in geologic literature and is frequently mentioned in the various works of C. E. Weaver. In discussing the age of the Puget Group, Weaver (1937, p. 55) stated:

> It is probable that the lowest strata in the Puget Group date back into the early Eocene and that the entire sequence was deposited during the middle and late Eocene and possibly to a small extent in the very earliest part of the Oligocene epoch.

In a preliminary geologic map of the coal fields of King County, Warren, Norbisrath, Grivetti, and Brown (1945) followed previous usage by applying the name Puget Group to the coal-bearing rocks but extended the name Keechelus Andesitic Series to the "tuffs and flows of basic andesite" that overlie the Puget Group in the eastern part of King County. They (Warren and others, 1945) included with the Keechelus Andesitic Series certain dikes and sills of andesite that are especially common in the Green River area. However, they mapped the thick sequence of "andesitic tuffs and volcanic breccias" that Evans (1912, p. 45) had regarded as a laccolith below the Jones coal bed as an "Eocene volcanic series." Rocks in the Raging River area that lie below the volcanic series were designated the Cowlitz(?) Formation because of the local occurrence of marine fossils thought to resemble fauna from the Cowlitz Formation (Weaver, 1912, p. 13) of southwestern Washington. Warren, Norbisrath, Grivetti, and Brown (1945) also mapped separately, without using a formal name, certain beds of volcanic conglomerate, tuffaceous sandstone, and sandy shale that locally contain marine fossils of Oligocene and Miocene age. Significantly, they (Warren and others, 1945) suggested the possibility of correlation between the rocks of the Puget Group in the Green River area and the combined Cowlitz(?), Eocene volcanic series, and Puget Group in the area north of the Cedar River. A comparable situation occurs on South Prairie Creek in the Buckley quadrangle, where Crandell and Gard (1959) mapped a bed of volcanic conglomerate within the Puget Group.

Waldron (1962), mapping in the Des Moines quadrangle south of Seattle, gave the name Tukwila Formation to the rocks that Warren Norbisrath, Grivetti, and Brown (1945) mapped as the Eocene volcanic series. He also gave the name Renton Formation to the overlying coal-bearing rocks and assigned both formations to the Puget Group; thereby, he extended the use of the name Puget to rocks of nonmarine volcanic origin as well as to the coal-bearing sandstone and shale beds previously identified with the name Puget. Wolfe, Gower, and Vine (1961) listed seven floral zones that can be recognized in rocks of the Puget Group that range in age from from early Eocene through middle and late Eocene into earliest Oligocene. In the vicinity of Tiger Mountain and Taylor Mountain, Vine (1962b, p. 14–16) extended the use of the names Renton Formation and Tukwila Formation to the principal coal-bearing and volcanic rocks, respectively. In that area Vine (1962b, p. 12, 13) named the coal-bearing rocks that constitute the base of the Puget Group the Tiger Mountain Formation, citing evidence from the fossil floras that these rocks are entirely within the sequence of Puget Group rocks exposed along the Green River. Marine rocks below the Tiger Mountain Formation were designated the Raging River Formation by Vine (1962b, p. 7–11) because they are separated from, and are not directly correlative with, the upper Eocene rocks of the Cowlitz Formation.

The Pleistocene geology of the Puget Sound lowland has been studied extensively. Notable works include those of Willis (1898b), who gave the name Vashon

Drift to the youngest glacial deposits; Bretz (1913), who made a regional study of the Puget Sound lowland; Mackin (1941), who described the diversion of Cascade drainage and the relation between Cascade and continental glaciers; and Crandell, Mullineaux, and Waldron (1958), who described the sequence of pre-Vashon drift sheets. Detailed mapping and classification of Quaternary deposits, with emphasis on the engineering properties of various materials, have been completed in the Buckley quadrangle (Crandell and Gard, 1959) and in the Renton, Auburn, and Black Diamond quadrangles (Mullineaux, 1965a, b, c).

STRATIGRAPHY

RAGING RIVER FORMATION AND PUGET GROUP

Because of the marked difference in lithology and thickness of strata between the Tiger Mountain–Taylor Mountain upland area on the north and the Green River area on the south, the stratigraphic sequence is described separately for each area. The Green River area is described first because the floral stages established there provide a standard for comparison. In the Green River area the Puget Group was not subdivided in mapping (pl. 1) because no stratigraphic markers were found to distinguish the units. Rocks exposed in the Tiger Mountain–Taylor Mountain upland area are nearly equivalent in age to the Puget Group in the Green River area but are about twice as thick and can be subdivided into four formations, three of which are included in the Puget Group. The fourth formation, the Raging River Formation, which forms the base of the exposed sequence on the north, was excluded from the Puget Group because it contains marine fossils. The three overlying nonmarine formations included in the Puget Group are, from oldest to youngest, the Tiger Mountain Formation, the Tukwila Formation, and the Renton Formation. Of these, the Tiger Mountain and Renton Formations are most typical of the Puget Group as originally described (White, 1888, 1889; Willis, 1897, 1898a). Rocks in the Tukwila Formation compose a wedge or tongue of epiclastic volcanic rocks within the coal-bearing sequence of the Puget Group.

GREEN RIVER AREA

PUGET GROUP

The Green River area includes almost all the Cumberland quadrangle. Although most of this area is underlain by the Puget Group, bedrock outcrops are limited because of the cover of Quaternary deposits. The best exposed outcrops of the Puget Group are in the central and southwestern parts of the Cumberland quadrangle, where the Green River has cut a canyon 100–300 feet deep. These outcrops continue west about 2 miles into the Black Diamond quadrangle (Mullineaux, 1965c).

In the Green River area the Puget Group is composed of nonmarine sedimentary rocks containing coal beds that are locally useful as marker beds for stratigraphic and structural control. The group is about 55 percent feldspathic or arkosic sandstone, 35 percent siltstone, and 10 percent shale, carbonaceous claystone, coal, and minor conglomerate. The clastic rocks are generally poorly sorted, except locally in the upper part of the group.

The Puget Group is exposed in a series of folds that extends from the axis of the Lawson anticline to the axis of the Kummer syncline (pl. 1). The youngest rocks of the group crop out along the axis of the Kummer syncline, where they are overlain by unnamed volcanic rocks of Oligocene age. Although that contact is concealed in the canyon of the Green River, there is no evidence of an unconformity. The oldest rocks of the Puget Group occur along the axis of the Lawson anticline, but the base of the group is not exposed, and the total thickness is not known.

Many previous workers have measured stratigraphic sections along these folds. Willis (1897) ascribed a thickness of 5,800 feet to Puget strata; Evans (1912, p. 42–49, pls. 18–20) made a transit survey and measured about 8,400 feet; Weaver (1937, p. 57–61) described in detail the transit survey made while he was assisting Evans; and Warren, Norbisrath, Grivetti, and Brown (1945) estimated the thickness to be at least 6,500 feet. The present writer found that the measurement by Evans (1912, p. 42–49) and Weaver (1937, p. 57–61) was accurate for the upper part but was too great for the lower part. The Puget Group exposed in the canyon of the Green River is estimated herein to be about 6,200 feet thick. The discrepancies have doubtless resulted from the difficulty in correlating strata on opposite limbs of folds in the absence of distinctive marker beds.

Evans (1912, p. 42) divided the rocks of the Puget Group exposed in the canyon of the Green River into three lithologic units which he called, beginning with the oldest, Bayne, Franklin, and Kummer series. Weaver (1937) used the same divisions but classified them as formations instead of series. The boundary between the two younger units was defined by Evans as the base of a "light-colored massive sandstone with nodules or boulders of harder sandstone" which he called the Kummer sandstone. This sandstone underlies the Kummer No. 0 coal bed and crops out in the canyon of the Green River on opposite limbs of the Kummer syncline. The boundary between the two older units was defined as the base of the "close-grained massive sandstone" that crops out beneath the county bridge at the Green River Gorge, SW¼ sec. 17, T. 21 N., R. 7 E., and was called the Franklin sandstone by Evans. These units are not mappable outside the immediate vicinity of the canyon; however, two of the names have been preserved by grouping the coal beds in the Green River area into the Kummer and Franklin coal zones. The Kummer coal zone is defined to include the coal beds that lie above the Kummer sandstone bed, and the Franklin coal zone is defined to include the coal beds that lie between the Kummer and Franklin sandstone beds. No commercially important coal beds are known to lie below the Franklin sandstone bed.

Southwest of Walker Lake the upper 300 feet of the Puget Group contains abundant volcanic debris, and the sandstone beds grade into, and intertongue with, the unnamed volcanic rocks. The contact is arbitrarily mapped at the top of the highest stratigraphic occurrence of quartz-rich micaceous sandstone. Along the road in the NE¼ sec. 33, T. 21. N., R. 7 E., west of Walker Lake, the transition from quartz-rich micaceous sandstone below to volcanic sandstone above occurs within a few inches. North of Walker Lake, a volcanic sandstone as much as 40 feet thick occurs about 650 feet stratigraphically below the top of the Puget Group. It is mapped as a tongue of unnamed volcanic rock within the Puget Group because of its distinctive lithology. Isolated outcrops of unnamed volcanic rock—one east of Cumberland in the NW¼ sec. 26, T. 21 N., R. 7 E.; another half a mile northwest of Bayne; and several in the area north and northwest of Sugarloaf Mountain—are also possibly tongues of volcanic rock within the Puget Group but cannot be distinguished from the main mass of post-Puget unnamed volcanic rocks. Directly south of the mapped area, near the center of the W½ sec. 6, T. 20 N., R. 7 E., the upper contact of the Puget Group is exposed at the top of a hard claystone bed in the roadcut.

A composite stratigraphic section of the Puget Group, compiled from the exposures in the canyon of the Green River, is described below and illustrated on plate 2. The thickness of each unit was estimated in the field, and the strike and the dip of beds were recorded for key points. The key points were plotted originally on aerial photographs and later transferred to the topographic map. Stratigraphic intervals between key points were later measured from geologic cross sections. The estimated thickness of each stratigraphic unit between key points was then adjusted to the intervals measured from the cross sections. Intervals between coal beds from the Harris bed to the Franklin No. 10 bed were measured directly from mine maps of workings adjacent to the Green River. Measurements for other intervals were made as follows: Base of section to top of Franklin No. 9 coal bed measured on west limb of Lawson anticline; top of Franklin No. 9 coal bed to base of Franklin No. 10 coal bed measured on west limb of anticline in NW¼ sec. 8, T. 21 N., R. 7 E.; Franklin No. 10 coal bed to Gem coal bed measured on west limb of anticline in NE¼ sec. 19, T. 21 N., R. 7 E.; Gem coal bed to top of the Kummer sandstone bed measured south of Franklin fault on east limb of Kummer syncline; top of the Kummer sandstone bed to top of exposed section measured on west limb of syncline.

The sandstone beds range from very fine to coarse grained and locally granular, but fine-grained sandstone is probably most common. Most beds contain poorly sorted sandstone and 10–20 percent silt and clay in the matrix. Typically, the grains are subangular to subrounded. Although quartz is the dominant constituent, making up as much as 65 percent of the rock, feldspar is fairly abundant and makes up 10–40 percent of the rock. Quartz and feldspar together make up 80–90 percent of the sand-size fraction. In general, plagioclase feldspar is most abundant in the lower part of the sequence, and potash feldspar is most abundant in the upper part. Lithic grains, including chert and rock fragments, generally constitute less than 10 percent of the rock. The more friable sandstone is cemented only by the finer grained minerals in the matrix, including clay, whereas the harder sandstone is generally cemented by authigenic ankerite, calcite, or quartz. Some sandstone beds contain spherical and elliptical calcareous concretions and concretionary lenses. The concretions range from a few inches to 5 feet in diameter. Concretionary lenses are commonly 6 inches to 2 feet thick and 6–15 feet long. A bed of glauconitic sandstone 2–3 feet thick crops out in the canyon of the Green River in the SW¼ sec. 11, T. 21 N., R. 7 E., and in the strip pit on the Big Elk coal bed in the SW¼ sec. 34, T. 22 N., R. 7 E. The glauconitic sandstone at both localities contains brackish-water mollusks.

Most sandstone beds in the Puget Group weather to massive cliffs. The internal stratification of these beds is commonly obscured by the weathered rind that forms on the surface, but in general the coarser grained rocks are cross-stratified, and the cross-strata range from about 1 to 20 feet in length (fig. 2). The finer grained sandstone beds and siltstone beds are generally cross-laminated or horizontally laminated. In places the siltstone beds are so inconspicuously stratified that they have a thick-bedded appearance. A thinly interbedded alternating sequence of different lithologies locally gives a striped appearance to the outcrop (fig. 3).

Convolute bedding was observed locally. Some sandstone beds are characterized by intraformational breccia

FIGURE 2.—Cross-stratified sandstone in the undifferentiated Puget Group exposed in the canyon of the Green River, west of the center of sec. 25, T. 21 N., R. 6 E.

consisting of angular fragments of dark-gray sandy siltstone embedded in a sandstone matrix. One intraformational breccia zone exposed in the canyon of the Green River in the NW¼ sec. 8, T. 21 N., R. 7 E., is about 80 feet thick. Ripple marks were observed in only a few places, probably because such features tend to be obscured by weathering.

Siltstone is generally medium to dark gray and sandy. Commonly, it occurs in beds as much as 2 feet thick interstratified with standstone. More rarely, siltstone beds occur as massive-weathering beds as much as 20 feet thick. Locally, siltstone is interlaminated with sandstone. Most siltstone is carbonaceous, and all gradations exist between carbonaceous siltstone, carbonaceous claystone, and impure coal. Carbonaceous siltstone associated with coal commonly contains well-preserved fossil leaves. Beds of soft carbonaceous claystone less than 1 foot thick are also associated with many of the coal beds.

A peculiar hard, brittle claystone occurs in beds as much as 17 feet thick at several places in the Green River area. Its color varies with the amount of carbonaceous matter from light gray to very dark gray, but it is locally reddish brown because of siderite pellets. One characteristic common to most outcrops is subrounded light-gray spots 1–5 mm long. Kaolinite, gibbsite, and boehmite are the principal constituents of the clay-size fraction. Pellets of siderite as much as 1 mm thick make up as much as 35 percent of the rock. The claystone deposits have been considered as potential ore for alumina (Nichols, 1946) and are mined at two localities for use in refractory clayware. Both the Kummer clay deposit in sec. 26, T. 21 N., R. 6 E., and the Blum clay deposit in sec. 31, T. 21 N., R. 7 E., both underlie the Kummer No. 0 coal bed and are therefore probably the same bed. Positive correlation with other beds has not been made.

The only beds of conglomerate, other than intraformational breccia, that were observed in the Puget Group in the Green River area are composed of volcanic rock. A volcanic conglomerate 20 feet thick composed of subangular to subrounded pebbles and cobbles of porphyritic andesite(?) crops out south of Landsburg in the SW¼ sec. 19, and NW¼ sec. 30, T. 22 N., R. 7 E. This bed is similar to some beds in the Tukwila Formation and may be a tongue of that formation, but it is thought to be stratigraphically below the Franklin coal zone. Similar volcanic conglomerate beds crop out in the canyon of the Green River. One is about 2 feet thick and is in the north-central part of sec. 17, T. 21 N., R. 7 E.;

FIGURE 3.—Horizontally interstratified sandstone and siltstone in the undifferentiated Puget Group overlying the Ravensdale No. 5 coal bed, exposed in an abandoned strip pit south of the center of sec. 36, T. 22 N., R. 6 E.

the other is about 1 foot thick and crops out in the SW1/4 sec. 9, T. 21 N., R. 7 E. Both beds are thought to underlie the Franklin coal zone.

The stratigraphic positions of the principal coal beds in the canyon of the Green River are shown on plate 2. These are grouped into two zones designated the Franklin coal zone and the Kummer coal zone. Some individual coal beds can be traced as much as 2–3 miles beyond the canyon of the Green River, but many cannot be traced into isolated areas. Although the Kummer coal zone is largely confined to the Kummer syncline, the Sunset coal beds in the vicinity of Coal Creek, the beds northwest of Sugarloaf Mountain, and the beds near Palmer Junction may be correlative with it. Most of the other economically important coal beds in the Cumberland quadrangle probably correlate with the Franklin coal zone. A detailed description of the coal beds and their correlation is given in the section "Economic geology."

To better define the lithology and to find a means of subdividing the sequence, rock samples were collected from the undifferentiated Puget Group for laboratory study. Many petrographic techniques were used in testing, including magnetic-mineral-grain separation, staining of feldspar grains, and analysis of the clay-mineral fraction. Magnetic mineral grains were separated from disaggregated sandstone samples by use of a Frantz isodynamic magnetic separator. Magnetic minerals identified were chiefly ankerite and related carbonate minerals plus mica, but a few grains of red garnet and black tourmaline were identified in samples taken from the upper part of the sequence. The feldspar staining of the disaggregated sandstone samples showed that plagioclase is several times more abundant than potash feldspar in the lower part of the sequence and that the reverse is true in the upper part of the sequence.

The mineralogy of the clay-size fraction [1] was most useful in establishing lithologic zones within the Puget Group in the Green River area. Mostly sandstone beds were sampled, although a few finer grained rocks were also sampled. Samples were selected primarily from outcrops of known stratigraphic position. An attempt was made to select samples representative of their strata, but this was not always possible. The study did show a very consistent change in the mineralogy of the clay-size fraction from the bottom of the stratigraphic sequence sampled to the top. The samples and results are listed in table 1, and the clay minerals determined are shown graphically along the side of the stratigraphic column on plate 2.

The clay-mineral suite was found to change progressively with age through the stratigraphic sequence in the Green River area. Mica (illite) occurs throughout the sequence. In addition to mica (illite), the lower part of the Puget Group is characterized by about equal amounts of kaolinite, randomly interlayered illite-montmorillonite, and a regularly interlayered clay mineral which is probably chlorite-montmorillonite. Stratigraphically higher in the group, the regularly interlayered clay mineral is absent. At a still higher level, the randomly mixed illite-montmorillonite is absent, and kaolinite is more abundant. In the upper part of the sequence, montmorillonite occurs as a discrete mineral. Mica (illite) is absent in the overlying unnamed volcanic rocks, and kaolnite is a minor constituent; montmorillonite is the principal clay mineral in some areas, and chlorite the principal mineral elsewhere. Chlorite does not occur as a discrete mineral anywhere in the Puget Group of the Green River area.

The sedimentary rocks in the Puget Group of the Green River area were probably derived chiefly from the erosion of a granitic or metamorphic terrane. Beds of volcanic conglomerate and the volcanic material locally mixed in the upper 300 feet of the Puget Group are exceptions; however, altered volcanic rock occurs as partings as much as 2 feet thick in some coal beds below the McKay bed. The partings consist of fine-grained tuff to lapilli tuff and probably represent single episodes of volcanic activity during which volcanic ash fell upon the accumulation of plant material in a coal swamp. Volcanic ash probably fell during the time intervals represented by sandstone and siltstone between coal beds, too, but was so diluted by the nonvolcanic sediment that this ash is not classified as volcanic detritus in the field.

In the Green River area, Wolfe (1968) recognized a sequence of floral stages ranging in age from early Eocene in the lower part of the Puget Group to early Oligocene in the basal part of the unnamed volcanic rocks that overlie the Puget Group. The lowest stage, the Franklinian Stage, includes all the rocks exposed in the canyon of the Green River below the base of the Franklin No. 11 coal bed. This stage includes the Chalk Bluffs flora (MacGinitie, 1941), which is the same age as the "Capay" Stage of the Pacific Coast standard marine sequence (Weaver and others, 1944). The second stage, the Fultonian Stage, is divided into a lower and an upper part. The flora of the lower part of the Fultonian Stage is best represented in rocks directly overlying the Franklin No. 12 coal bed and may be equivalent to the lower part of the "Domengine" Stage. The upper part of the Fultonian Stage includes beds from about 100 feet above the Franklin No. 12 coal bed to the base of the Big Dirty coal bed and may be correlative with the upper part of the "Domengine" Stage. The third stage, the Ravenian Stage, includes rocks between the base of the Big Dirty coal bed and the base of the Kummer sandstone bed. This stage is divided into a lower and an upper part. The lower part of the Ravenian Stage includes the McKay coal bed and probably correlates with part of the "Transition beds" of the standard Pacific Coast section (Weaver and others, 1944). The upper part of the Ravenian Stage probably includes the "Tejon" Stage and the lowermost part of the Keasey Stage. The fourth stage, the Kummerian Stage, is also divided into a lower and an upper part. The lower part includes all the rocks of the Puget Group in the canyon of the Green River above the base of the Kummer sandstone bed and is equivalent to most of the lower part of the Keasey Stage. It is regarded by Wolfe as earliest Oligocene in age. The upper part of the Kummerian Stage is in the lower part of the unnamed volcanic rocks that overlie the Puget Group in the canyon of the Green River and is believed to be equivalent to the uppermost Keasey or lower "Lincoln." Therefore, it also is early

[1] The laboratory procedure was as follows: A 10–30-g split of each rock sample was crushed to about −50 mesh, covered with distilled water in a 250-ml beaker, and placed in an Acoustica ultrasonic vibrator and stirred for about 10 minutes to keep the finer sediment in suspension. The suspended sediment was decanted, and the coarse fraction was again covered with water and returned to the vibrator. This procedure was repeated until the decanted fluid was clear. The suspended fine sediment was placed in a centrifuge to settle the fraction larger than 2 microns. The remaining suspension was decanted and returned to the centrifuge to settle remaining particles larger than 0.2 microns. After decanting the excess water, a slurry was prepared of the clay-size fraction (>0.2 and <2 microns) and placed on a glass slide to dry. The mineral composition of the clay-size fraction was identified by using a Philips Norelco X-ray diffractometer equipped with a Geiger counter detector and continuous recording instrument. The slide was exposed to copper $K\alpha$ radiation (λ=1.5418 A) with a nickel filter and scanned from 2° 2θ to 38° 2θ. The observed peaks are recorded in angstrom units, and the relative intensities of the peaks visually compared. Identification of the clay minerals followed, in general, the procedures outlined by Warshaw and Roy (1961). As many as four separate runs were made—for the untreated sample, for the glycolated sample, and for samples heated to 400° C and then to 550° C.

TABLE 1.—*Description of samples analyzed for clay-mineral constituents*

[Clay minerals estimated to nearest number of parts in 10 from the X-ray diffractometer analysis of the $<2\ \mu$ fraction of the rock. Clay minerals abbreviated, as follows: K, kaolinite; I, illite or mica; M, montmorillonite; C, chlorite; V, vermiculite; I–M, randomly interlayered illite-montmorillonite; M–C, randomly interlayered montmorillonite-chlorite; RML, a regular mixed-layer clay characterized by (001) *d*-spacing greater than 21 A]

Sample No. (pl. 2)	Field No.	Location	Stratigraphic position	Interval to stratigraphic marker	Lithology	Clay minerals
1	GC60–22C	Center of sec. 36, T. 21 N., R. 6 E.	Unnamed volcanic rocks.	150 ft above base	Sandstone, volcanic; clay, and granules; unsorted, pale yellowish gray.	2 K, 8 M.[1]
2	V–14	NE¼ sec. 25, T. 21 N., R. 6 E.	Puget Group, undifferentiated.	75 ft below Kummer No. 5 coal bed.	Sandstone, fine-grained, yellowish gray, feldspathic, micaceous; interlaminated with medium-gray siltstone.	9 K, 1 I.
3	C–135	SE¼NE¼ sec. 26, T. 21 N., R. 6 E.	do.	120 ft below Kummer No. 3 coal bed.	Carbonaceous shale	5 K, 3 M,[1] 2 I.
4	C–132	NE¼SE¼ sec. 26, T. 21 N., R. 6 E.	do.	100 ft above Kummer sandstone bed.	Sandstone, medium-grained, very light gray, micaceous, feldspathic.	6 K, 2 I, 2 M.[1]
5	V–13	NE¼ sec. 25, T. 21 N., R. 6 E.	do.	60 ft above Kummer sandstone bed.	Siltstone, light olive gray; interlaminated with very fine-grained yellowish gray sandstone; carbonaceous films.	5 K, 3 I, 2 M.[1]
6	V–22	SE¼NE¼ sec. 26, T. 21 N., R. 6 E.	do.	Kummer clay bed, directly below Kummer No. 0 coal bed.	Claystone, flinty; brownish gray with white spots as much as 1 mm long.	10 K.
7	C–134	SW¼ sec. 19, T. 21 N., R. 7 E.	do.	Base of Kummer sandstone bed.	Sandstone, fine- to medium-grained, very pale orange, micaceous, feldspathic; contains ankerite cement.	8 K, 1 I, 1 I–M.
8	V–12	NW¼SW¼ sec. 19, T. 21 N., R. 7 E.	do.	do.	Sandstone, medium- to coarse-grained, micaceous, arkosic; contains ankerite cement.	6 K, 3 I, 1 I–M.
9	GC61–23	SW¼ sec. 19, T. 21 N., R. 7 E.	do.	460 ft above Gem coal bed	Sandstone, coarse-grained, yellowish gray, feldspathic.	6 K, 1 I, 3 M.[2]
10	V–10	NW¼SW¼ sec. 19, T. 21 N., R. 7 E.	do.	180 ft above Harris coal bed	Sandstone, coarse-grained, yellowish gray, micaceous; contains carbonaceous films and ankerite cement.	10 K.
11	GC60–23B	SE¼SW¼ sec. 19, T. 21 N., R. 7 E.	do.	125 ft above Gem coal bed	Sandstone, very fine-grained, light gray	9 K, 1 I.
12	GC60–23A	do.	do.	60 ft above Gem coal bed	Sandstone, medium- to coarse-grained, light gray.	8 K, 1 I, 1 I–M.
13	V–8	SW¼NE¼ sec. 19, T. 21 N., R. 7 E.	do.	150 ft above McKay coal bed	Sandstone, fine-grained, grayish orange, feldspathic, micaceous; cemented with ankerite.	6 K, 2 I, 2 I–M.
14	C–131B	NE¼SE¼ sec. 18, T. 21 N., R. 7 E.	do.	10 ft above No. 12 coal bed	Sandstone, fine- to medium-grained, very pale orange, micaceous; contains carbonaceous films.	5 K, 2 I, 3 I–M.
15	GC60–25	SE¼NE¼ sec. 19, T. 21 N., R. 7 E.	do.	10 ft below No. 12 coal bed	Sandstone, very fine-grained, pale orange, micaceous, arkosic.	5 K, 3 I, 2 I–M.
16	V–5	NE¼NE¼ sec. 19, T. 21 N., R. 7 E.	do.	12 ft below No. 12 coal bed	Sandstone, very fine-grained to fine-grained, yellowish gray, micaceous, arkosic.	5 K, 1 I, 1 I–M, 3 RML.[3]
17	GC60–26	SW¼NW¼ sec. 20, T. 21 N., R. 7 E.	do.	150 ft above No. 10 coal bed	Sandstone, fine- to medium-grained, very pale orange, micaceous, arkosic.	4 K, 2 I, 3 I–M, 1 RML.[3]
18	GC61–24B	SE¼NW¼ sec. 8, T. 21 N., R. 7 E.	do.	30 ft below No. 9 coal bed	Sandstone, fine- to medium-grained, yellowish gray, micaceous, arkosic.	3 K, 1 I, 3 I–M, 3 RML.[3]
19	GC61–25C	SW¼NE¼ sec. 8, T. 21 N., R. 7 E.	do.	125 ft below No. 9 coal bed	Lapilli tuff, light olive gray; parting 4 ft below top of carbonaceous unit.	2 K, 1 I, 3 I–M, 4 RML.[3]
20	GC61–24D	SE¼NW¼ sec. 8, T. 21 N., R. 7 E.	do.	250 ft below No. 9 coal bed	Sandstone, fine-grained, yellowish gray, volcanic.	3 K, 1 I, 3 I–M, 3 RML.[3]
21	GC61–26C	NW¼SE¼ sec. 8, T. 21 N., R. 7 E.	do.	1,400 ft above base of Green River section.	Sandstone, fine- to medium-grained, yellowish gray, micaceous, feldspathic.	4 K, 2 I, 3 I–M, 1 RML.[3]
22	V–1	SW¼SW¼ sec. 17, T. 21 N., R. 7 E.	do.	Franklin sandstone bed	Sandstone, medium-grained, yellowish-gray, micaceous, arkosic; contains ankerite cement.	3 K, 2 *I*, 3 I–M, 2 RML.[3]
23	GC61–26A	NE¼SE¼ sec. 8, T. 21 N., R. 7 E.	do.	1,200 ft above base of Green River section.	Sandstone, very fine grained to fine-grained, yellowish-gray, arkosic.	6 K, 4 I.
24	V–16	do.	do.	850 ft above base of Green River section.	Sandstone, fine-grained, light-olive-gray, hard, calcareous; contains ankerite.	3 K, 1 I, 3 I–M, 3 RML.[3]
25	V–27	do.	do.	670 ft above base of Green River section.	Claystone, silty, brownish-gray to brownish-black; contains calcite, ankerite, and small smooth pelecypod molds.	3 K, 1 I, 3 I–M, 3 RML.[3]
26	C–128	do.	do.	265 ft above base of Green River section.	Sandstone, fine-grained, yellowish-gray feldspathic, micaceous, calcareous.	5 K, 2 I, 2 I–M, 1 RML.[3]
27	GC61–27B.	do.	do.	200 ft above base of Green River section.	Claystone, medium-gray; laminated with light gray; nonfissile.	3 K, 1 I, 3 I–M, 3 RML.[3]
28	C–127	do.	do.	10 ft above base of Green River section.	Sandstone, fine-grained, very pale orange, arkosic, micaceous.	3 K, 1 I, 3 I–M, 3 RML.[3]
29	H–49A	SW¼NE¼ sec. 3, T. 22 N., R. 7 E.	Renton Formation	1,750 ft above base	Sandstone, fine- to medium-grained, pale-yellowish-brown, arkosic, micaceous.	10 K.
30	H–181	NE¼NE¼ sec. 3, T. 22 N., R. 7 E.	do.	1,335 ft above base	Sandstone, medium-grained, yellowish-gray, micaceous, arkosic.	6 K, 2 I, 2 I–M.
31	H–178D	NW¼NE¼ sec. 3, T. 22 N., R. 7 E.	do.	10 ft above base	Sandsone, medium- to coarse-grained, yellowish-gray, micaceous, arkosic.	9 I, 1 V.
32	H–50	NE¼NE¼ sec. 4, T. 22 N., R. 7 E.	Tukwila Formation	200 ft below top	Sandstone, volcanic, fine- to coarse-grained, medium-gray.	3 K, 7 M.[1]
33	H–177	NE¼SW¼ sec. 34, T. 23 N., R. 7 E.	do.	300 ft above bed F	Sandstone, volcanic, medium-grained, dark-greenish-gray.	9 C, 1 I.
34	H–249	SE¼SE¼ sec. 34, T. 23 N., R. 7 E.	do.	Bed F	Sandstone, medium-grained, yellowish-gray, micaceous.	3 K?, 1 I, 2 RML,[3] 4 C.
35	H–240	SE¼SE¼ sec. 32, T. 23. N., R. 7 E.	do.	650 ft below bed F	Sandstone, volcanic, fine- to medium-grained, greenish-gray.	2 I–M,[4] 8 C.[5]
36	H–176C	NE¼ sec. 34, T. 23 N., R. 7 E.	do.	100 ft above bed E	Siltstone, volcanic, light-olive-gray; contains carbonaceous films.	4 K, 2 I, 1 RML, 3 V.
37	H–125	NE¼NW¼ sec. 35, T. 23 N., R. 7 E.	do.	Bed D	Coaly shale	7 K, 3 M.
38	H–68	SW¼NW¼ sec. 27, T. 23 N., R. 7 E.	do.	450 ft below bed D	Tuff-breccia boulder consisting of about 30 percent plagioclase, 20 percent altered mafic minerals, and 50 percent matrix.	10 V.
39	H–70E	SE¼NW¼ sec. 27, T. 23 N., R. 7 E.	do.	Top bed C	Carbonaceous shale	2 I, 8 M.[1]

See footnotes at end of table.

TABLE 1.—*Description of samples analyzed for clay-mineral constituents*—Continued

Sample No. (pl. 2)	Field No.	Location	Stratigraphic position	Interval to stratigraphic marker	Lithology	Clay minerals
40	H-72	SW¼NE¼ sec. 27, T. 23 N., R. 7 E.	Tukwila Formation	Top bed C	Sandstone, medium-grained, light-olive-gray, arkosic, micaceous.	6 K, 1 I, 3 C.
41	H-71B	do	do	Base bed C	Claystone, gray	4 K, 6 M.[1]
42	H-166A	NE¼NW¼ sec. 26, T. 23 N., R. 7 E.	do	750 ft below bed C	Sandstone, volcanic, tuffaceous, light-greenish-gray.	3 K, 3 I, 2 M,[1] 2 RML.[6]
43	H-86	SW¼SW¼ sec. 22, T. 23 N., R. 7 E.	do	600 ft above base of main body.	Tuff, medium-grained, olive-gray	10 RML.[7]
44	H-48B	E½SE¼ sec. 20, T. 23 N., R. 7 E.	do	530 ft above base of main body.	Sandstone, volcanic, medium-grained, dark-greenish-gray.	10C
45	H-87	SW¼ sec. 22, T, 23 N., R. 7 E.	do	400 ft above base of main body.	Tuff, coarse-grained, greenish-gray; subeuhedral plagioclase grains 1-3 mm wide.	10 RML.[8]
46	H-88	do	do	200 ft above base of main body.	Tuff, fine-grained; crystal grains, greenish gray.	10 V.[9]
47	H-89	do	do	100 ft above base of main body.	Tuff, very fine grained, light-olive-gray	10 RML.[8]
48	H-90	do	Tiger Mountain Formation.	Member B	Sandstone, fine- to medium-grained and granular, yellowish-gray.	1 I, 9 RML.[8]
49	H-304	NE¼SE¼ sec. 21, T. 23 N., R. 7 E,	do	Member B	Sandstone, fine-grained to granular, dark-gray, carbonaceous, arkosic.	3 K, 1 I, 1 RML, 2 M,[1] 3 C.
50	H-261A	NW¼NW¼ sec. 21, T. 23 N., R. 7 E.	do	25 ft above base of Member B	Sandstone, medium-grained, grayish-orange, arkosic.	2 I, 8 K.
51	H-91	SW¼ sec. 22, T. 23 N., R. 7 E.	Tukwila Formation	Member B	Tuff, fine- to coarse-grained, crystalline, olive-gray.	10 RML.[10]
52	H-262B	Center of SW¼ sec. 16, T. 23 N., R. 7 E.	Tiger Mountain Formation.	Member A	Sandstone, fine-grained, greenish-gray, calcareous, arkosic.	3 K, 3 I, 1 RML, 3 C.
53	H-93A	NW¼ sec. 16, T. 23 N., R. 7 E,	Tukwila Formation	10 ft above base of Member A	Sandstone, volcanic, medium-grained, grayish-orange.	5 RML,[10] 5 V.
54	H-321	SE¼NE¼ sec. 8, T. 23 N., R. 7 E.	Tiger Mountain Formation.	50 ft below top of lower main body.	Sandstone, fine-grained to very fine grained, dark-gray, micaceous, calcareous.	3 K, 1 I-M, 2 RML,[7] 4 M.[1]
55	H-263	SW¼SE¼ sec. 16, T. 23 N., R. 7 E.	do	150 ft below top of lower main body.	Sandstone, medium-grained, gray, micaceous, arkosic, calcareous.	4 K, 2 I, 3 I-M, 1 RML.[3]
56	H-22	NW¼NW¼ sec. 16, T. 23 N., R. 7 E.	do	900 ft above base	Sandstone, fine-grained, light-gray, speckled, micaceous.	3 K, 1 I, 3 I-M, 3 RML.[3]
57	H-151	NE¼NE¼ sec. 22, T. 23 N., R. 7 E,	do	800 ft above base	Sandstone, fine-grained, light-olive-gray	3 K, 2 I, 2 I-M, 2 C, 1 RML.[3]
58	H-20	NE¼NW¼ sec. 16, T. 23 N., R. 7 E.	do	400 ft above base	Sandstone, fine-grained, pale-brown, calcareous.	5 K, 2 I, 3 I-M.
59	H-150	Center of N½ sec. 22, T. 23 N., R. 7 E.	do	300 ft above base	Sandstone, fine-grained, yellowish-brown, micaceous; contains fossil leaves.	1 K, 1 I, 4 I-M,[4] 4 RML.[3]
60	H-84	SE¼SE¼ sec. 16, T. 23 N., R. 7 E.	do	250 ft above base	Sandstone, volcanic, very fine grained, greenish-gray, micaceous.	2 K, 2 I, 3 M-C?, 3 RML.[3]
61	H-95	SW¼ sec. 9, T. 23 N., R. 7 E	do	100 ft above base	Sandstone, very fine grained, silty, micaceous, light-olive-gray.	4 I, 6 C.
62	H-77	SE¼SE¼ sec. 16, T. 23 N., R. 7 E.	do	10 ft above base	Sandstone, medium-grained, light-olive-gray, arkosic, micaceous.	3 K, 1 I, 2 I-M, 3 RML,[3] 1 C.
63	H-18	N½SW¼ sec. 9, T. 23 N., R. 7 E.	Raging River Formation.	50 ft below top; clay prospect	Claystone, dark-gray, silty	2 K, 1 I, 3 I-M, 3 RML,[3] 1 C.
64	H-96	SW¼ sec. 9, T. 23 N., R. 7 E	do	165 ft below top	Sandstone, volcanic, fine-grained, dark-bluish-gray; contains many rounded green grains of celadonite or glauconite.	5 K, 3 I,[11] 2 C.
65	H-97	do	do	220 ft below top	Sandstone, very fine grained to fine-grained, yellowish-brown, fossiliferous.	2 I, 8 V.
66	H-323	NW¼SW¼ sec. 9, T. 23 N., R. 7 E.	do	400 below top of the formation	Siltstone, sandy, medium-gray, hard, calcareous; contains marine fossil remains.	4 K. 1 I, 3 I-M. 1 C. 1 RML.
67	H-311	do	do	600 ft below the top	Sandstone. medium-grained, yellowish-gray.	1 I. 9 C. trace of I-M.
68	H-312	SW¼ sec. 10. T. 23 N., R. 7 E.	do	700 ft below the top	Sandstone, fine- to medium-grained, medium-gray; contains marine fossils.	5 K. 2 I.[11] 3 C.
69	H-313	SW¼SW¼ sec. 10, T. 23 N., R. 7 E.	do	815 ft below the top	Sandstone, coarse-grained to very coarse grained, medium-dark-gray, very hard dolomitic matrix.	6 K, 4 I-M.
70	H-16A	NE¼SW¼ sec. 15, T. 23 N., R. 7 E.	do	1,000 ft below top	Sandstone, volcanic, fine- to coarse-grained, hard.	9 C, 1 I.
71	H-15B	SE¼NW¼ sec. 15, T. 23 N., R. 7 E.	do	1,200 ft below top	Sandstone, volcanic, fine-grained, medium-light-gray.	6V, 4 I.
72	H-310	NE¼NW¼ sec. 9, T. 23 N., R. 7 E.	do	1,640 ft below top	Claystone, silty, dark-greenish-gray, hard, massive.	3 K, 3 I, 4 C.

[1] The *d*-spacing for the (001) montmorillonite peak is between 14 and 15 A for the untreated sample and expands to 16 to 17 A on glycolation.

[2] The *d*-spacing for the (001) montmorillonite peak is about 12 A for the untreated sample and expands to nearly 17 A on glycolation.

[3] The *d*-spacing for the (001) peak of the regular mixed-layer clay is 25–29 A and expands slightly on glycolation. This may be regularly interstratified chlorite-montmorillonite.

[4] The illite-montmorillonite peak is broad.

[5] The *d*-spacing for the 14A chlorite peak expands slightly on glycolation.

[6] The *d*-spacing for the (001) peak of the regular mixed-layer clay is about 21.5 A for the untreated sample, but it expands slightly on glycolation and collapses to 14.2 A on heating to 550°C.

[7] The *d*-spacing of peaks at about 14.3, 9.5, and 7.2 probably represent the (002), (003), and (004) peaks of a regular mixed-layer clay that does not expand on glycolation but decreases in spacing on heating to 550°C. This may be regularly interstratified chlorite-vermiculite.

[8] The regular mixed-layer clay is similar to that in sample 51. See footnote for that sample (footnote 10).

[9] The *d*-spacing for the (001) 14 A vermiculite peak does not swell on glycolation but collapses completely on heating to 550°C.

[10] The *d*-spacing for the (001) integral series of peaks for the regular mixed-layer clay is about 28.5, 14.4, 9.5, 7.2, and 4.8 A for the untreated sample. These expand on glycolation to about 30, 15, and 7.5 A, and collapse on heating to 550°C to about 23 to 26 A and 12 A. This may be a regularly interstratified chlorite-vermiculite.

[11] The clay mineral listed as illite may in part be celadonite.

Oligocene in age. Wolfe (1968) describes in detail the basis for subdividing the Puget Group into floral stages and suggested their correlations with equivalent rocks in other parts of the west coast.

TIGER MOUNTAIN–TAYLOR MOUNTAIN UPLAND AREA

Sedimentary and volcanic rocks in the Tiger Mountain–Taylor Mountain upland area have an aggregate thickness of about 14,000 feet, more than twice that in the Green River area. Marine strata occur in the lower part, and volcanic detritus is abundant in the lower and middle parts. The presence of marine and volcanic rocks and the greater thickness characterize the northern sequence and distinguish it as a different lithofacies from the sequence to the south.

RAGING RIVER FORMATION

The oldest sedimentary rocks in the Tiger Mountain–Taylor Mountain upland area occur directly southwest of the Raging River (pl. 1). These rocks were not differentiated from other Eocene sedimentary strata or from the Puget Group by most early workers in the region, though the lack of coal beds was noted. Warren Norbisrath, Grivetti, and Brown (1945) were the first to record marine fossils from these strata, and on the basis of a preliminary study of the fauna, they suggested a possible correlation with the Cowlitz Formation of southwestern Washington. However, because of the wide geographic separation from other marine strata of Eocene age in western Washington and the need to distinguish these rocks from the nonmarine strata of the Puget Group, these rocks were named the Raging River Formation (Vine, 1962b, p. 7–11), after the Raging River which crosses the northeast corner of the Hobart quadrangle. The type area of the Raging River Formation is in secs. 9, 10, 15, and 16, T. 23 N., R. 7 E., where streams tributary to the Raging River have eroded canyons through the mantle of glacial drift and exposed some discontinuous rocky ledges (pl. 1). Less than 1,000 feet of strata is exposed continuously in any one outcrop, and the base of the formation is not exposed; therefore, the total thickness is not known. By projection of outcrops into a generalized section, however, the thickness is estimated to be as much as 3,000 feet. This estimate of thickness is uncertain because outcrops are inadequate to deduce the pattern of faulting and because igneous intrusions occur in the lower part of the sequence.

The principal outcrops of the Raging River Formation are on the southwest side of the valley of the Raging River and extend from U.S. Highway 10, about 2 miles north of the mapped area near the town of Preston, to the valley of Deep Creek on the south. The outcrops are in a belt about 4 miles long and less than 1 mile wide. One small isolated outcrop of the formation occurs about 1 mile west of this belt in a small anticline at Tiger Mountain. Natural exposures are almost entirely limited to stream canyons where the mantle of glacial drift has been removed by recent erosion. A roadcut on U.S. Highway 10 about 500 feet northwest of the Preston overpass contains very fine grained hard siliceous sandstone overlying an igneous sill. This sandstone is similar to beds of the Raging River Formation near intrusive rocks in the mapped area but is not typical of the formation.

The Raging River Formation is characterized by massive outcrops of thick-bedded siltstone, sandstone, and conglomerate. The constituents of these clastic rocks are dominantly of volcanic origin. Most outcrops of the fine-grained rocks are extremely hard, especially in the lower part of the formation, where the rocks have been intruded by igneous sills. The medium- to coarse-grained sandstone and chert-pebble conglomerate are locally friable. In the lower part of the Raging River Formation, the strata next to the igneous sills have been partly recrystallized to a rock that has an intergranular texture and is partly replaced by calcite and silica.

Metamorphic rocks, generally regarded as pre-Tertiary in age, crop out about 4 miles northeast of the mapped area, near North Bend. They unconformably underlie the Tertiary sedimentary rocks there and throughout the northern Cascade Range. In the mapped area the Raging River Formation may therefore unconformably overlie pre-Tertiary metamorphic rocks.

The contact of the Raging River Formation with the overlying Tiger Mountain Formation was placed at the top of a silty claystone unit that is 160 feet thick and contains marine mollusks and Foraminifera where exposed in a trench in the SW¼ sec. 9, T. 23 N., R. 7 E. Although the silty claystone is transitional with the overlying unfossiliferous micaceous siltstone and sandstone, the contact is mappable.

The upper part of the Raging River Formation is almost continuously exposed in the unnamed tributary creek that flows northeastward across the W½ sec. 9, T. 23 N., R. 7 E., and in clay prospect trenches near the southeast bank of the creek. A stratigraphic section was measured along this creek and is described on page 57.

The 160 feet of silty claystone that forms the top of the Raging River Formation is particularly well exposed in the prospect trenches. A bed of sandstone, about 3–5 feet thick, at the base of the silty claystone, forms a distinctive marker because it has been altered and recemented with a green mineral (celadonite or glauconite) and contains abundant *Turritella uvasana* cf. subsp. *hendoni* Merriam and root tubes. This bed is continuous and easily recognized in the creek (altitude about 1,775 ft), in the prospect trench, and along the road for a distance of about 2,000 feet along the strike. Underlying the green cemented sandstone is about 500 feet of mostly very fine grained volcanic sandstone and siltstone. Except for 30 feet of horizontally stratified sandstone in the upper part, the strata throughout this part of the section are uniformly massive weathering, medium to dark gray, thick bedded, and well indurated and contain rather abundant marine fossils. The next underlying part of the section, about 250 feet thick (altitude about 1,565–1,665 ft), is distinctly coarser grained and more friable than the overlying part. The horizontally stratified sandstone is generally medium to coarse grained, although locally it is granular to conglomeratic. Dark-colored chert pebbles are dominant in the conglomerate. Carbonaceous silty laminae are locally present in the sandstone beds, but the strata are generally thick bedded and massive weathering. Beds of siltstone interstratified with the beds of sandstone are also locally soft and friable. No fossils were found, and this part of the Raging River Formation could possibly be of nonmarine origin. However, the dominant horizontal stratification and the lack of crossbedding or channeling preclude a fluvial origin for these strata. Below the coarse-grained sandstone, and siltstone, glacial drift conceals an estimated 700 feet of strata. Farther downstream the strata exposed along this unnamed creek—from near the margin of the Hobart quadrangle northward for some distance into the Fall City quadrangle (from altitudes of about 1,170 to 890 ft)—have been intruded by igneous sills and altered to a hard compact rock. Erratic dips and shear zones suggest that the normal stratigraphic sequence has been disturbed. For this reason, only a small part of the strata exposed in the lower part of the creek below the glacial drift are described in stratigraphic section 2.

Southeastward along the strike the top of the Raging River Formation is not exposed in the large tributary creek that flows east and northeast across the N½ sec. 16 and the SW¼ sec. 10, T. 23 N., R. 7 E. Anomalous dips and the structually low position of the Tiger Mountain Formation in the NE¼ sec. 16 suggest that the upper part of the Raging River Formation has been faulted or that there is unrecognized intertonguing of lithologies. Whether faulting has duplicated or removed part of the sequence has not been determined. Thick-bedded dark-gray very fine grained sandstone and siltstone containing marine fossils are exposed along and up the slope from the old logging road that closely parallels the 1,300-foot contour line on plate 1. In the creek bed at about the 1,420-foot contour (pl. 1)—near the section corner common to secs. 10 and 16—and extending downstream to about the 880-foot contour, a partial stratigraphic section of the Raging River Formation can be observed. (See description on p. 58.)

A bed of medium-grained gray volcanic sandstone at an altitude of about 1,220 feet contains *Cristispira pugetensis* Allison, a turritellid. This species was also found, but in greater abundance, at locality 648 on the nose of the Raging River anticline, about 600 feet southwest of the center of sec. 15, T. 23 N., R. 7 E. Although the precise stratigraphic position of locality 648 is not known, it is probably at least 1,000 feet below the top of the formation. If *C. pugetensis* proves to have a narrow stratigraphic range, it may be possible to correlate its occurrences in stratigraphic section 3 and at locality 648. Moreover, if the *C. pugetensis* in stratigraphic section 3 is about 1,000 feet below the top of the formation, there must be several hundred feet of the upper part of the Raging River Formation missing, and the 700-foot covered interval of stratigraphic section 2 must be represented by part of stratigraphic section 3.

Farther southeast, part of the Raging River Formation is exposed in the channel of a tributary that flows across the NW¼ sec. 15, T. 23 N., R. 7 E. Dark-gray very fine grained volcanic sandstone crops out where the old logging road crosses the creek, at an altitude of about 1,260 feet, and the outcrop continues upstream to an altitude of about 1,360 feet. Below the road the bedrock is mostly concealed down to an altitude of about 1,030 feet, where an igneous sill is exposed. A second sill crops out at an altitude of about 960 feet, and there are exposures of altered sandstone between the two sills. Below the second sill, altered fine- to medium-grained gray sandstone laminated with siltstone and claystone are exposed down to about 870 feet. None of these strata have been correlated with strata in the previously described sequences.

Upstream on the same creek, between altitudes of about 1,510 and 1,560 feet, nearly vertical beds of micaceous sandstone typical of the sandstone beds in the Tiger Mountain Formation crop out. Because these strata seem to be on strike with the Raging River Formation, they might represent a tongue of nonmarine rocks coming into the marine sequence; however, the steep dips indicate concealed structural complications, and the stratigraphic relations are uncertain.

Additional exposures of the Raging River Formation occur along the old logging road in the west half of sec. 15, T. 23 N., R. 7 E. About 100 feet of interbedded fine- to course-grained sandstone and chert-pebble conglomerate crop out along the roadbank about 1,000 feet northwest of the center of sec. 15. These rocks are similar to the beds of chert-pebble conglomerate near the base of stratigraphic section 3 in SW¼ sec. 10, but projection of the strike suggests that they are much higher stratigraphically. Dark-gray massive very fine grained to medium-grained sandstone and siltstone of the Raging River Formation also crop out in cuts along the Bonneville Power Authority right-of-way, but these exposures were not correlated with a stratigraphic section.

Fossiliferous rocks of the Raging River Formation crop out in a small isolated area in the core of a small anticline on the south slope of Tiger Mountain, NW¼ sec. 17, T. 23 N., R. 7 E. These strata have been intensely altered by hydrothermal solutions to kaolinized reddish, hematitic quartzose rock. Only the preservation of numerous marine fossils allowed these rocks to be recognized as Raging River Formation.

The Raging River Formation is characterized by horizontal stratification. Many outcrops along the streams are so thick bedded, massive, and well cemented that the strike and dip are almost impossible to measure. Locally, sandstone beds are laminated with siltstone or claystone. Such primary structures as ripple marks, cross-stratification, convolute bedding, channeling, and graded bedding were not seen.

Chert concretions were observed in a sandstone bed near the base of the sequence in stratigraphic section 3. Calcareous concretions about 1–5 cm in diameter in siltstone or silty claystone occur in the highest unit in stratigraphic section 2 and also in the new highway cuts in the south-central part of sec. 15, T. 23 N., R. 7 E. The cores of these concretions commonly contain fossil remains, such as fragments of crabs or echinoid shells. Spheroidal weathering occurs locally in outcrops of massive sandstone.

Though the rocks in the Raging River Formation range from claystone to conglomerate, very fine grained sandstone and siltstone are the most abundant rock types. Generally, the clastic grains are angular and unsorted, and no clear distinction is apparent between clasts and matrix, except where the matrix has been preferentially altered or replaced. Plagioclase feldspar and lithic grains rich in plagioclase generally make up more than 50 percent of the sand-size fraction and may make up as much as 90 percent. Analysis of the plagioclase from one sample indicated a composition of An_{20}. The large percentage of plagioclase and lithic grains indicates an origin from plagioclase-rich volcanic rocks; these rocks are therefore classified as volcanic sandstones or volcanic wackes. The percentages of quartz and chert grains, mafic materials, and opaque minerals vary; grains of potash feldspar are rare. The coarse-grained sandstone beds and the pebble-conglomerate units contain a greater amount of chert grains than the finer grained rocks.

The matrix of friable sandstone beds is chiefly chlorite, vermiculite, and kaolinite but includes limonite in the zone of weathering. The matrix of hard sandstone and siltstone beds also contains clay minerals, as well as variable amounts of quartz, calcite, and, locally, dolomite. In some rocks carbonate has replaced selected mineral grains, and the petrographic study of thin sections showed carbonate to range from 10 to 25 percent of the rock. X-ray diffractometer studies showed quartz replacement of the matrix to be moderately common in most samples. Carbonaceous fragments occur as opaque material, as films on mineral grains, and probably as a dispersed constituent of the matrix in many of the darker rocks.

Near igneous intrusions the proportion of quartz or calcite as cement and as a replacement of large mineral grains increases in the Raging River Formation. Where the formation is exposed on the south side of Tiger Mountain, the rock is almost entirely altered to quartz, clay, and iron oxides. Partial alteration to a green mineral related to celadonite or glauconite has occurred in a sandstone bed in the upper part of stratigraphic section 2. Individual grains show various degrees of alteration and replacement. Some grains have been completely replaced by the celadonitelike mineral, and their original boundaries have been modified, apparently by swelling accompanied by radial fracturing. In other parts of the formation, the matrix and many of the plagioclase grains have more commonly been partly altered and replaced by chlorite or by a mixture of chlorite and vermiculite. In some places the chlorite is a swelling variety.

Marine echinoids, gastropods, pelecypods, scaphopods, and Foraminifera have been collected and identified from several horizons in the upper few hundred feet of the Raging River Formation. In addition, woody fragments of trees and leaves were found associated with the marine fossils, but specific species could not be identified. Fossils were not found in the lower, more altered part of the sequence. Table 2 lists the megafossil forms that were identified in material studied by F. Stearns MacNeil (written commun., 1959, 1960). Referring to this collection, he stated: "There seems to be little question that this is a middle Eocene fauna." The megafossil collection was taken from the highest sandstone bed near the top of the Raging River Formation (fossil loc. 649). A claystone sample taken from about

TABLE 2.—*Fossil invertebrates from the Raging River Formation*

[Identifications by F. Stearns MacNeil (written commun., 1959, 1960). Localities arranged by probable stratigraphic position, youngest on right]

	Locality						
	648	643	644	645-6	647	1037	649
ECHINODERMA							
Eupatagus n. sp. aff. *E. carolinensis* Clark and *E. ocalensis* Cooke	×						
GASTROPODA							
Ficopsis cf. *F. redmondi crescentensis* Weaver and Palmer							×
Megistostoma gabbiana (Stoliczka)	×						
Pseudoliva lineata Gabb	×						
Scaphander cf. *S. costatus* (Gabb)	×						
Sinum aff. *S. occidentis* Weaver and Palmer				×			
Turritella cf. *T. andersoni* Dickerson var.?		×					
Turritella cf. *T. buwaldana* Dickerson	×						
Turritella sp. aff. *T. uvasana olequahensis* Weaver and Palmer and *T. uvasana sargeanti* Anderson and Hanna				×			
Turritella uvasana cf. subsp. *hendoni* Merriam						×	×
Turritella aff. *T. vaderensis* Weaver and Palmer				×			
Turritella cf. *T. vaderensis* Weaver and Palmer and *T. buwaldana* Dickerson			×				
Cristispira pugetensis Allison	×						
Turritella sp. a small form comparing closely with both *T. buwaldana coosensis* Merriam and *T. uvasana hendoni* Merriam	×						
PELECYPODA							
Acila (*Truncacila*) *decisa* (Conrad)			×	×?			
Corbula sp				×			
Crassatella uvasana cf. *C. uvasana mathewsoni* (Gabb)		×					
Gari aff. *G. hornii* (Gabb)				×			
Macoma sp		×					
Mytilus dichotomus Cooper	×						×
Mytilus cf. *M. dichotomus* Cooper						×	
Nitidavenus sp. frag. resembles *N. conradi* (Dickerson)							×
Nuculana aff. *N. cowlitzensis* Weaver and Palmer				×			
Ostrea sp					×		
Pitar (*Lamelliconcha*) *avenalensis* Vokes		×?					×
Pitar cf. *P.* (*Lamelliconcha*) *eocenica* (Weaver and Palmer)	×						
Pitar uvasana coquillensis Turner						×	
Pitar sp	×			×?			
Pitaria cf. *P. soledadensis* Hanna							×
Plagiocardium (*Shedocardia*) *breweri* (Gabb)	×						
Pteria cf. *P. pellucida* (Gabb)	×						
Solen cf. *S. parallelus* (Gabb)					×		
Solena sp	×						
?*Taras* sp	×						
Tellina soledadensis Hanna				×?			×
Venericardia frag. probably *V. hornii* Gabb							×
Venericardia (*Pacificor*) cf. *V.* (*P.*) *weaveri* Verastegui and *V.* (*P.*) *lira* Verastegui				×			
Venericardia sp				×			
SCAPHOPODA							
Dentalium cf. *D. stramineum* Gabb	×						

LOCALITY DESCRIPTION

648, Center NE¼SW¼ sec. 15, T. 23 N., R. 7 E.
643, Center NE¼SE¼ sec. 9, T. 23 N., R. 7 E.
644, SE¼NE¼SE¼ sec. 9, T. 23 N., R. 7 E.
645-6, NE¼SE¼SE¼ sec. 9, T. 23 N., R. 7 E.
647, NE¼NE¼NE¼ sec. 16, T. 23 N., R. 7 E.
1037, NE¼NW¼ sec. 17, T. 23 N., R. 7 E.
649, SW¼NE¼SW¼ sec. 9, T. 23 N., R. 7 E., Hobart quadrangle, King County, Wash.

35 feet stratigraphically above the megafossil collection yielded a good collection of microfossils. Table 3 lists the microfossils identified by W. W. Rau (written commun., 1961). About the microfossils, he stated:

This combination of foraminiferal species from locality 649 is known to occur in late middle to early late Eocene rocks of the Pacific Coast Tertiary sequence. The assemblage can be referred to the B–1A or lower A–2 zones of Laiming (1940) and to the upper Ulatisian Stage or possibly lower Narizian Stage of Mallory (1959). Locally it is referable to the *Bulimina* cf. *B. jacksonensis* zone of Rau (1958) contained in the McIntosh Formation of southwest Washington.

TABLE 3.—*Foraminifera from the Raging River Formation*

[Identification by Weldon W. Rau (written commun., 1961), from a claystone sample from locality 649, about 35 ft. stratigraphically above the megafossils from the same locality]

Cyclammina sp.
Gaudryina jacksonensis coalingensis Cushman and G. D. Hanna
Quinqueloculina imperalis Hanna and Hanna
Quinqueloculina cf. *Q. minuta* Beck
Robulus cf. *R. texanus* (Cushman and Applin)
Robulus spp.
Marginulina subbullata Hantken
Dentalina cf. *D. consorbrina* d'Orbigny
Dentalina spp.
Amphimorphina californica Cushman and McMasters
Bulimina cf. *B. jacksonensis* Cushman
Gyroidina orbicularis planata Cushman
Eponides yeguaensis Weinzerl and Applin
Cibicides cushmani Nuttall
Cibicidoides coalingensis (Cushman and G. D. Hanna)

Comparison of the fossil collections from the Raging River Formation with those from other Eocene marine strata in Washington provides a suitable means for correlation but does not seem adequate to restrict the age of the formation to one or more of the informal Eocene subepochs—early, middle, and late. Most of the Raging River Formation is probably older than the Cowlitz Formation of southwestern Washington that Henriksen (1956) regarded as late Eocene. However, the Raging River Formation is probably equivalent to part of the McIntosh Formation of western Washington (Snavely and others, 1951a), which ranges in age from middle to late Eocene in the Centralia-Chehalis area (Rau, 1958) and is entirely of late Eocene age in the Doty-Minot Peak area (Pease and Hoover, 1957). Waldron (1962) described marine and nonmarine volcanic sedimentary rocks of middle Eocene age in the Duwamish Valley in the Des Moines quadrangle. These rocks probably correlate at least in part with rocks of the Raging River Formation.

PUGET GROUP

TIGER MOUNTAIN FORMATION

A sequence of nonmarine sedimentary rocks about 2,000 feet thick overlies the Raging River Formation with apparent conformity. The sequence is characterized by micaceous arkosic sandstone beds interstratified with siltstone and coal beds. Evans regarded these rocks as part of the Puget Group but indicated (Evans, 1912, p. 66) that the coal beds could not be correlated with those in any of the better known areas. Warren, Norbisrath, Grivetti, and Brown (1945) mapped these rocks with the underlying marine rocks as Cowlitz(?) Formation. However, physical and fossil evidence indicates that this sequence correlates with rocks of the Puget Group in the Green River area. The sequence can be separated on the basis of lithology from the underlying Raging River Formation and from the overlying volcanic rocks. Vine (1962b, p. 12–13) therefore included these rocks in the Puget Group and named them the Tiger Mountain Formation. The type area for the Tiger Mountain Formation is on the east and southeast slopes of Tiger Mountain and on the north slope of Taylor Mountain, SW¼ sec. 9, sec. 16 S½ sec. 17, N½ sec. 20, sec. 21, and sec. 22, T. 23 N., R. 7 E. This is an area of fairly steep dips and of discontinuous outcrops, so the stratigraphic sequence is incompletely known.

The contact of the Tiger Mountain Formation with the underlying Raging River Formation is exposed along the road to the Tiger Mountain lookout tower and in prospect trenches on the south side of the road, SW¼ sec. 9, T. 23 N., R. 7 E. The contact there is transitional from marine fossil-bearing claystone below to nonmarine micaceous sandstone above.

The upper part of the Tiger Mountain Formation intertongues with the partly equivalent and partly younger Tukwila Formation, also of the Puget Group. Where individual members of each formation were mapped separately, the contacts are conformable. The top of the highest member of the Tiger Mountain Formation is arbitrarily placed at the contact above which volcanic rocks predominate (pl. 2).

The Tiger Mountain Formation is known only from outcrops in the Tiger Mountain–Taylor Mountain upland area, principally in the northeastern part of the Hobart quadrangle. The belt of outcrops can be traced a short distance northward into the Fall City quadrangle and eastward into the North Bend quadrangle. In the Green River area, about 10 miles to the south, strata of equivalent age are mapped as part of the undifferentiated Puget Group. Strata of equivalent age do not crop out in the mapped area west of Tiger Mountain.

The Tiger Mountain Formation is exposed chiefly in narrow canyons cut through the glacial drift by postglacial streams. Beds of sandstone form massive ledges and cliffs along the steep canyon slopes; beds of siltstone, claystone, and coal are generally concealed by Quaternary deposits, though a few scattered exposures occur in roadcuts and coal prospects.

North of Deep Creek, the Tiger Mountain Formation is exposed in scattered outcrops on both flanks of the Taylor syncline. The most complete sequence is exposed on the east flank, where the formation is about 2,000 feet thick, as described in stratigraphic section 4 (p. 58). In this section the stratigraphic interval from the base of the Tiger Mountain Formation to the top of its highest member is 2,825 feet, but in its upper part this interval includes two members of the Tukwila Formation, which together are 825 feet thick.

The base of the Tiger Mountain Formation is not exposed on the south side of Deep Creek, and the lower strata are poorly exposed. The upper members, however, crop out between the more resistant ledges of the Tukwila Formation, with which these upper members are interstratified, as shown in stratigraphic sections 5 (p. 59) and 6 (p. 60).

Sandstone in the Tiger Mountain Formation differs from that in the underlying Raging River Formation by the presence of mica flakes and the plant remains and by the absence of marine fossils. In general, the proportion of quartz to feldspar grains also increases. Throughout most of the Tiger Mountain Formation the sandstone beds range from arkosic to locally quartzose, but mica flakes are generally present throughout. The mica ranges from muscovite to biotite and commonly is altered to chlorite. Grain size of the sandstone is mostly very fine to coarse and locally includes granules and pebbles; the average grain size is medium to coarse. The grains are generally angular to subangular and poorly sorted. Quartz makes up about 60 to 85 percent of relatively fresh rock and as much as 95 percent of hydrothermally altered rock. Locally, quartz content is as low as 20 percent in volcanic sandstone. A typical sandstone of the Tiger Mountain Formation contains 10–30 percent feldspar; plagioclase is three to four times more abundant than potash feldspar. Other constituents are mainly micaceous minerals, ferromagnesian minerals, metallic minerals, and translucent to opaque grains, including chert. The matrix generally contains grains of the same minerals as compose the bulk of the rock plus interstitial fine-grained clayey minerals and carbonaceous matter. Calcite and other carbonate minerals generally make up less than 1 percent of the rock. Coalified fragments of woody material are abundant locally. In an exposure of member A along an old railroad grade west of the S¼ corner of sec. 17, T. 23 N., R. 7 E., the grains of the sandstone are coated with a black substance that contains both iron and carbon. This may be a dried organic extract, which could have been derived from coaly and carbonaceous siltstone beds in the Tiger Mountain Formation or possibly from bituminous matter in the Raging River Formation.

Beds of sandstone in the Tiger Mountain Formation are generally cross-laminated; the scale of cross-lamination, including the length of cross strata and the thickness of sets, varies according to the average grain size of the rock. Beds of coarse-grained sandstone and pebble conglomerate are associated with cross-laminated sets as much as 5 feet thick, whereas beds of fine- to medium-grained sandstone are cross-laminated in sets 0.5–1 foot thick. Beds of siltstone are locally cross-laminated in sets less than 2 inches thick. The lower bounding surface of the sets of cross strata is curved or planar and is generally not a surface of erosion (fig. 4), although trough-type cross strata with lower bounding surfaces of erosion are present locally. Horizontal stratification is also fairly common in the Tiger Mountain Formation, especially where finer grained sandstone and siltstone beds are interbedded (fig. 5). Current ripple marks and intraformational conglomerate, composed of angular to subrounded pebbles and cobbles of siltstone, are locally present in beds of sandstone.

Alteration of micaceous minerals to chlorite is common throughout the Tiger Mountain Formation. The minerals of the matrix, however, include both chlorite and montmorillonite in most of the area. Also, kaolinite characterizes the matrix of the Tiger Mountain Formation in the area between the axis of the Taylor syncline and the Tiger Mountain fault (pl. 1). The kaolinite is thought to be related to the hydrothermal alteration that is most intense next to the Tiger Mountain fault. The hydrothermal alteration is accompanied locally by an increase in the proportion of quartz to feldspar, probably as a result of the alteration of feldspar to kaolinite and perhaps also from the addition of some silica.

Fossil plants are rather abundant in the Tiger Mountain Formation, but only in a few of the clayey siltstone beds were the leaf impressions satisfactory for the detailed identification and classification necessary for stratigraphic control. Leaf impressions in sandstone beds are generally too coarsely textured for generic or specific identification; those in carbonaceous claystone and coaly beds are generally too matted for separation. Two fossil-leaf localities (USGS paleobot. locs. 9813, 9814) about 1½ miles apart and near the top of the main body of the Tiger Mountain Formation contain

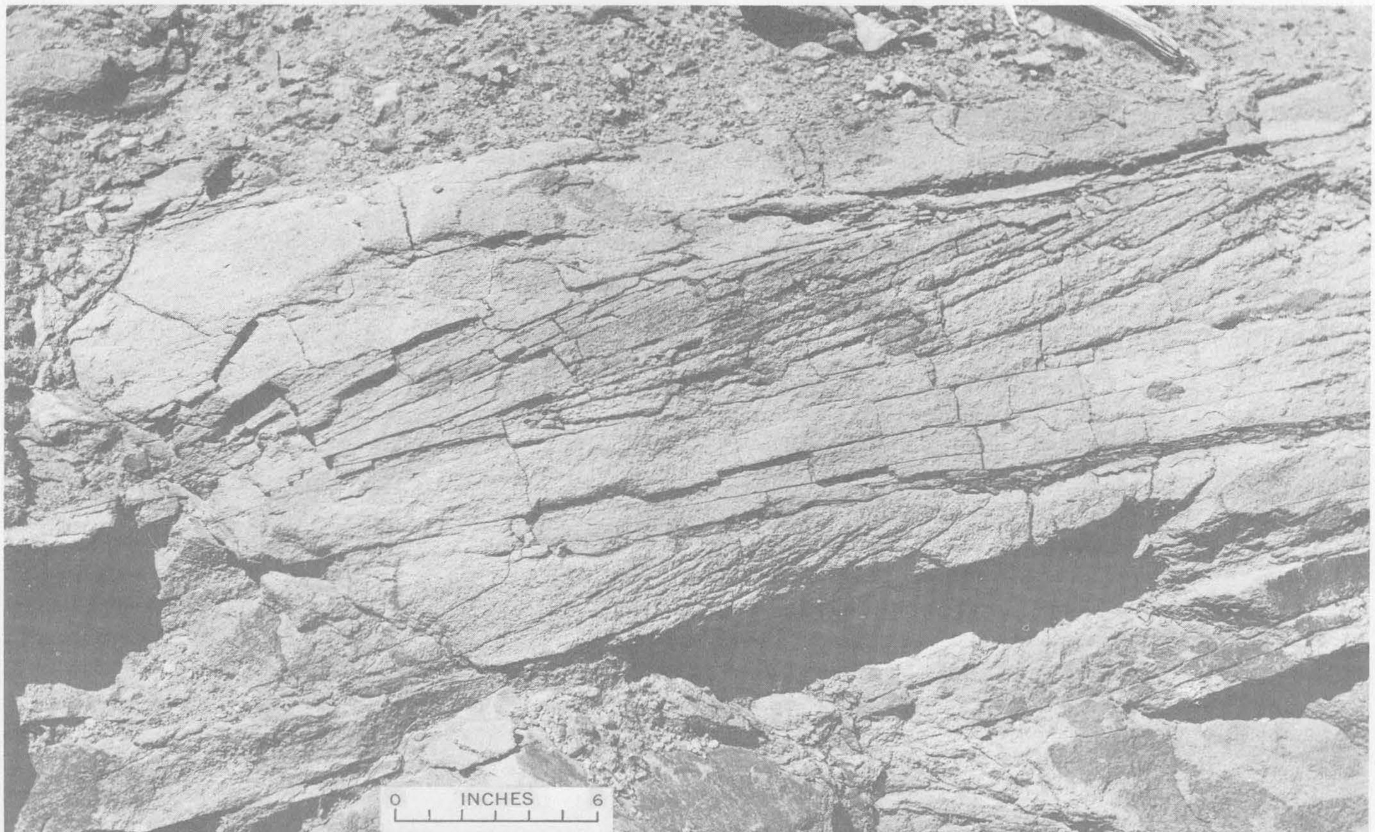

FIGURE 4.—Cross-stratified sandstone in the Tiger Mountain Formation exposed on the south side of Tiger Mountain, NW¼ sec. 17, T. 23 N., R. 7 E.

FIGURE 5.—Interstratified sandstone and siltstone in the Tiger Mountain Formation exposed on the south side of Tiger Mountain, NW¼ sec. 17, T. 23 N., R. 7 E.

excellent leaves preserved as thin films of carbonaceous material. The leaves may occur in the same bed, but the bed could not be traced across the intervening distance. The leaf collections were described by J. A. Wolfe (1968); he indicated that they are probably equivalent in age to the upper part of the Fultonian Stage.

The upper tongues of the Tiger Mountain Formation are interstratified with rocks of the Tukwila Formation that contain plant fossils from the lower part of the Ravenian Stage. Thus, the known range of the Tiger Mountain Formation is from the late Fultonian Stage through the early Ravenian Stage. Therefore, the base of the Puget Group in the Tiger Mountain–Taylor Mountain area, as defined by the base of the Tiger Mountain Formation, is younger than the lower part of the Puget Group in the Green River area, where Wolfe (1968) recognized the Franklinian Stage. Although direct correlation between stages defined in terms of marine fauna and those defined in terms of plant fossils is imprudent, the Raging River Formation likely includes the northern equivalents of the Franklinian Stage of the Green River area. Restricting the Puget Group to the nonmarine strata in the Tiger Mountain–Taylor Mountain area thus shortens the age range of the Puget Group to younger rocks. The definitions of the informal terms early, middle, and late Eocene are slightly different, depending on whether they are defined in terms of marine megafossils, Foraminifera, or plant fossils. Thus, it seems best not to define the age of the Tiger Mountain Formation in these terms.

TUKWILA FORMATION

Volcanic rocks exposed near the town of Tukwila in secs. 11 and 14, T. 23 N., R. 4 E., south of Seattle were named the Tukwila Formation by Waldron (1962). He described the Tukwila Formation in the type area as consisting mostly of volcanic sandstone, siltstone, and shale, but including some volcanic conglomerate, tuff, tuffaceous sandstone and siltstone, and a few beds of carbonaceous shale. He estimated the Tukwila Formation to be more than 2,500 feet thick. About 500–750 feet below the top of the formation, Waldron distinguished an arkosic unit similar to the overlying Renton Formation. Although the base is not exposed, the contact of the Tukwila Formation with underlying marine and nonmarine sedimentary rocks of middle Eocene age is thought to be a fault. The Tukwila Formation is interstratified with, and conformably underlies, the Renton Formation near Seattle, and Waldron included both formations in the Puget Group. This interstratified relationship between the volcanic and nonvolcanic rocks had previously been mapped by Warren, Norbisrath, Grivetti, and Brown (1945), who designated the volcanic rocks as a volcanic series of Eocene age.

The principal belt of outcrops of the Tukwila Formation lies along a series of low mountains and hills that extend intermittently west-northwest from the Cascade Range to Lake Washington and include Taylor Mountain, Tiger Mountain, West Tiger Mountain, Squak Mountain, and Newcastle Hills. The Tukwila Formation also crops out northeast of Issaquah, in the vicinity of Grand Ridge, and in the area south of Seattle, near Renton and Tukwila (Waldron, 1962; Mullineaux, 1965a). The Tukwila Formation is known to occur only in part of the area underlain by the Puget Group and is not continuous with volcanic rocks known elsewhere in strata of equivalent age. For example, in the Buckley quadrangle about 25 miles south of Tiger Mountain, Crandell and Gard (1959) mapped a bed 100 feet thick of brown andesite pebble-and-cobble conglomerate within the Puget Group. They believed that the andesitic material came from a local source west of the Buckley quadrangle. The source may have been the same as that of the Northcraft Formation of late Eocene age in the Centralia-Chehalis area (Snavely and others, 1951b, 1958), which, though derived from a separate volcanic center, may be partly equivalent in age and similar in lithology to the Tukwila Formation.

The Tukwila Formation is as much as 6,800 feet thick in the Tiger Mountain–Taylor Mountain upland area but abruptly thins to the southwest. To the north the Tukwila Formation dips under a thick cover of younger rocks and glacial drift. The relation between the Tukwila Formation and the younger volcanic rocks to the east has not been determined.

In the Tiger Mountain–Taylor Mountain upland area, many of the highest hills and most resistant ledges are underlain by the Tukwila Formation. This is largely due to the resistance of these rocks to erosion and to a lesser extent to the presence of igneous rocks that have intruded the Tukwila. Thick massive beds of tuff-breccia are especially hard when fresh, and they form many ledges along the southeast side of the canyon of Issaquah Creek, on West Tiger Mountain, on the west flank of South Tiger Mountain, and in the canyon of Holder Creek.

The Tukwila Formation in the Tiger Mountain–Taylor Mountain upland area consists chiefly of volcanic sandstone and siltstone, tuff, lapilli tuff, tuff-breccia, and volcanic conglomerate. In this area the Tukwila also includes at least four lenticular beds about 25 to 200 feet thick consisting of arkosic sandstone, carbonaceous claystone, and impure coal. Volcanic flow rocks are present but not so abundant. The thickness from the base to the top of the Tukwila Formation can be estimated with any degree of reliability only on Taylor Mountain. In estimating the thickness of the formation, no allowance was made for the possibility that the observed dip could be primary. If the observed dip is primary, the true thickness at a specific locality would be less. In the area between Tiger Mountain and Issaquah, the thickness of the Tukwila Formation may be greater than estimated, but the lower part of the sequence is faulted out.

The sequence of rocks in the Taylor Mountain area is described in stratigraphic section 6 (p. 60), which is a composite section of smaller intervals measured between the principal marker beds (designated beds C, D, E, and F) and the upper and lower contacts. In general, the upper strata are characterized by medium- to coarse-textured rocks such as tuff-breccia, lapilli tuff, and volcanic conglomerate (figs. 8, 10), whereas the lower strata are characterized by volcanic sandstone, tuffaceous siltstone (fig. 6), and local lenses of coarse-textured rocks. The coarse-textured rocks are generally thicker and more continuous west and northwest of Taylor Mountain, and they compose a fairly large part of the exposed sequence on West Tiger Mountain.

Primary sedimentary structural features, including lamination, cross-lamination, convolute bedding, and slump structures, are readily apparent in tuffaceous siltstone where partly silicified, as shown in figure 6. A thin section perpendicular to the lamination of the specimen illustrated in figure 6 shows that the average grain size is about 0.01 mm and that concentrations of dark minerals only a few grains thick form some of the laminae. Some beds of volcanic sandstone have a mottled appearance owing to irregularities in grain size, sorting, or cementation. Stratification is inconspicuous in most of the volcanic rocks in the Tukwila Formation, but the arkosic micaceous sandstone marker beds are locally well bedded, particularly where concentrations of mica parallel the bedding. Beds of lapilli tuff and tuff-

FIGURE 6.—Polished section of tuffaceous siltstone from the Tukwila Formation, NE¼ sec. 4, T. 22 N., R. 7 E., showing primary structures.

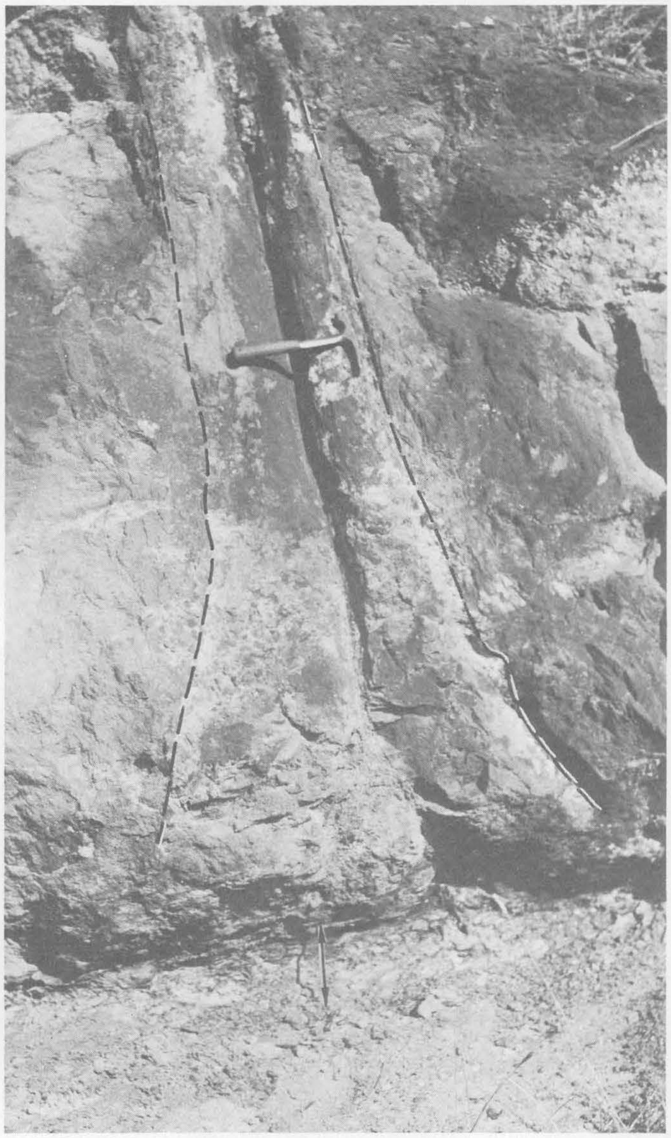

FIGURE 7.—Upright fossil tree trunk in lapilli tuff in the Tukwila Formation, exposed in roadcut of U.S. Highway 10, SW¼ sec. 25, T. 24 N., R. 6 E. Dashed lines indicate approximate position of tree trunk. Fossil-soil profile is indicated by arrow.

breccia commonly appear to be massive but may show a local bedding-plane concentration of rock fragments or a friable zone between adjacent units. An upright fossil tree trunk visible in a roadcut on U.S. Highway 10 about 3 miles east of the intersection with the main street of Issaquah (fig. 7) appears to be rooted in a friable zone. This suggests that the friable zone may represent a fossil-soil horizon. Similar carbonaceous and siliceous fossil tree trunks, as well as twigs, stems, and leaves, are relatively common in the tuff-breccia.

In many places the beds of tuff-breccia are so well indurated that they will break across rock fragments and matrix alike (fig. 8). The individual rock fragments and the matrix are generally similar in composition, which gives the rock a nearly uniform texture and makes recognition of rock fragments difficult. A polished or thin section of the tuff-breccia generally facilitates the identification of rock fragments and matrix, as shown in figure 9. Distinctly sharp contacts between rock fragments and matrix indicate no welding or fusion of the rocks fragments and the matrix. Beds of volcanic conglomerate are distinguished from beds of tuff-breccia

FIGURE 8.—Tuff-breccia in the Tukwila Formation in new highway cut NW¼ sec. 31, T. 23 N., R. 7 E.

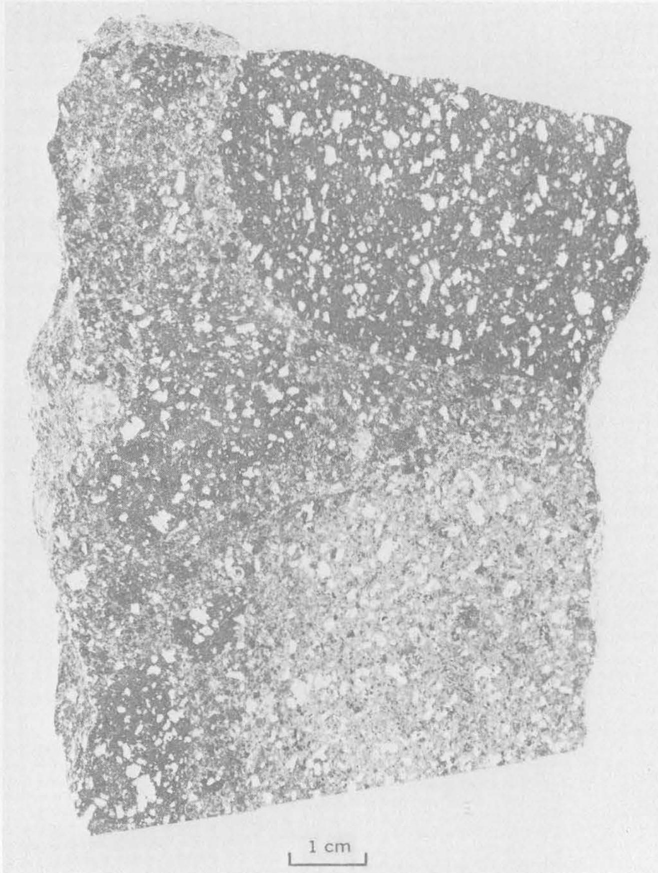

FIGURE 9.—Polished section of tuff-breccia from the Tukwila Formation exposed in quarry, SE¼ sec. 6, T. 23 N., R. 6 E., showing the distinct boundaries of the rock fragments and the lithologic similarity of boulders and matrix.

by the fact that the boulders in the conglomerate tend to weather out in their original shape (fig. 10). The matrix of the volcanic conglomerate is generally more friable and less resistant to weathering.

Plagioclase feldspar is the most common mineral in the Tukwila Formation and is characteristic of almost all rock types from tuffaceous siltstone to tuff-breccia, it constitutes more than 50 percent of many volvanic rock types. Zoned plagioclase phenocrysts in tuff-breccia and lapilli tuff generally range in composition from An_{20} to An_{30}. Hornblende is the most common mafic mineral identified, but in many rocks the mafic minerals have been altered beyond recognition and are replaced by chlorite, opaque minerals (including magnetite), and, locally, calcite. The fine-grained groundmass of most of the volcanic rocks consists of a microcrystalline intergrowth of altered plagioclase laths, quartz, chlorite, calcite, and opaque minerals. In contrast to the more abundant volcanic rocks, the micaceous sandstone marker beds and their associated carbonaceous rocks are like the rocks in the Tiger Mountain Formation. The mica in them is commonly brown, green, or black and is chloritic. The sandstone is generally arkosic.

Dark-gray hypocrystalline rocks 1–6 feet thick are locally interstratified with sedimentary and volcanic rocks in the middle and upper parts of the Tukwila Formation. These rocks, probably basaltic in composition, are commonly vesicular and contain needles of plagioclase 1–3 mm long in a microcrystalline groundmass. Although these rocks form locally conspicuous ledges, it is not known whether they are flows or sills.

A tuff-breccia exposed in a new roadcut about 1 mile north of Hobart afforded an unusual opportunity to study a fresh exposure of the Tukwila Formation. Table 4 gives the chemical analysis of a rock sample from this exposure.

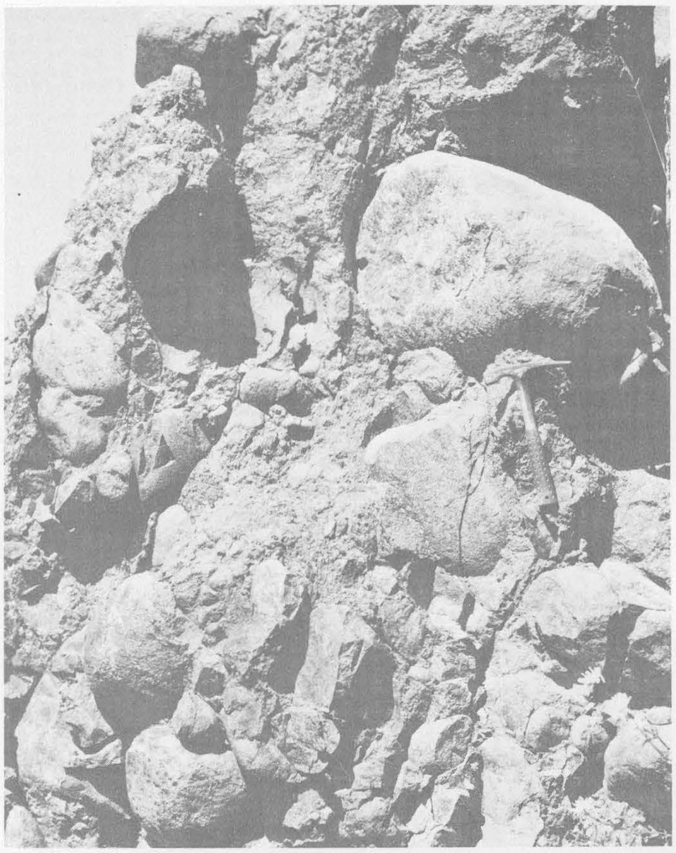

FIGURE 10.—Volcanic conglomerate in the Tukwila Formation on the west ridge of West Tiger Mountain, sec. 1, T. 23 N., R. 6 E.

All exposures of the Tukwila Formation in the mapped area are at least partly chloritized, and in many areas surface weathering has further modified the original rock to massive saprolite. Also, most rocks in the Tukwila Formation near the hydrothermally altered area—between Tiger Mountain and South Tiger Mountain— show some alteration to kaolinite and silica. Tiger Mountain, for example, is underlain by tuffaceous siltstone that has been silicified to form a porcellanite in some areas, and elsewhere, chiefly kaolinite. Locally, volcanic sandstone beds have been altered almost completely to chlorite but have retained the original porous texture of a sandstone.

TABLE 4.—*Chemical analysis of tuff-breccia from the Tukwila Formation*

[NW¼ sec. 31, T. 23 N., R. 7 E.; USGS lab. No. 160540; field No. SR62-132. Analysis by Paul Elmore, Samuel Botts, Gillison Chloe, Lowell Artis, and H. Smith, U.S. Geol. Survey. Rapid method of analysis similar to that described by Shapiro and Brannock (1962)]

Compound	*Percent*
SiO_2	58.4
Al_2O_3	17.5
Fe_2O_3	2.3
FeO	2.3
MgO	3.3
CaO	5.6
Na_2O	4.1
K_2O	.68
H_2O-	3.4
H_2O+	1.3
TiO_2	.55
P_2O_5	.14
MnO	.08
CO_2	.24
Sum	100

Fossil-leaf impressions, both flat and curled, and casts of *Equisetum* nodes are locally abundant in tuffaceous siltstone and fine-grained volcanic sandstone of the Tukwila Formation. J. A. Wolfe studied the fossil leaves from the following four localities in the Tukwila Formation of this area:

USGS paleobotany loc. 9685, NE¼NE¼ sec. 17, T. 23 N., R. 7 E.
9686, SW¼SW¼ sec. 8, T. 23 N., R. 7 E.
9687, SE¼NW¼ sec. 27, T. 23 N., R. 7 E.
9815, SW¼NW¼ sec. 31, T. 23 N., R. 7 E.

The strata at localities 9685, 9686, and 9687 probably are assignable to the lower Ravenian Stage (pl. 2), whereas the strata at locality 9815 may be as young as the late Ravenian Stage. In the Fall City quadrangle, leaf fossils were collected from the Tukwila Formation exposed in a roadcut along the south side of U.S. Highway 10 in the NE¼SW¼ sec. 30, T. 24 N., R. 7 E. (USGS paleobotany loc. 9738). Wolfe (1968) included this collection in the late Ravenian Stage. Previous collections of fossils from the Tukwila Formation include the so-called "Steels Crossing" locality 8640, near the city of Renton, which Wolfe included in the early Ravenian Stage. Thus, the Tukwila Formation is mostly of late Eocene age in the areas mapped. However, fossil plants collected by W. C. Warren from locality 9035, in the NW¼SE¼ sec. 2, T. 23 N., R. 5. E., along the side of the May Creek road, have been assigned by Wolfe to the early Kummerian Stage. If these rocks are continuous with the Tukwila Formation, then an earliest Oligocene age may be possible for the top of the Tukwila Formation.

RENTON FORMATION

Waldron (1962) named the coal-bearing rocks exposed in the city of Renton, about 4 miles west of the Maple Valley quadrangle, the Renton Formation. D. R. Mullineaux (written commun., 1962) estimated that in the type area the Renton Formation is about 2,500 feet thick. It conformably overlies the Tukwila Formation and consists of fine- to medium-grained arkosic and and feldspathic sandstone and lesser amounts of siltstone, sandy shale, coal, and carbonaceous shale. No fossils were reported from the type area. Warren, Norbisrath, Grivetti, and Brown (1945) mapped these coal-bearing rocks overlying their Eocene volcanic series as the Puget Group. Structure section *A–A′* on their map shows about 2,500 feet of strata of the Puget Group in the Newcastle area, where the rocks dip northward beneath unnamed Oligocene and Miocene marine sedimentary rocks.

South of Taylor Mountain the Tukwila Formation is conformably overlain by at least 2,185 feet of coal-bearing strata similar to those of the Renton Formation at Renton. Rocks in a similar stratigraphic position are designated as the Renton Formation near Cedar Mountain and in the Fifteenmile Creek area, although the contacts with overlying and underlying rocks are concealed in these areas. Thus, the areal distribution of the Renton Formation is similar to that of the Tukwila Formation. The Renton crops out intermittently from the type area south of Seattle to the Cascade Range. The north limit of the Renton Formation is uncertain because the formation dips beneath younger rocks and Quaternary deposits west of Issaquah. The Renton Formation cannot be recognized with certainty south of the Hobart quadrangle, although rocks in the upper part of the Green River section of the Puget Group in the Cumberland quadrangle are lithologically similar and largely equivalent in age.

The contact of the Renton Formation on the underlying Tukwila Formation is probably everywhere conformable. Where exposed north of Taylor, near the N¼ corner of sec. 3, T. 22 N., R. 7 E., the contact is sharp, but at an outcrop along Webster Creek, half a mile to the west, it is transitional. The contact of the Renton Formation with younger unnamed volcanic rocks is not exposed anywhere in the mapped area. Mullineaux (1965a) showed it as disconformable elsewhere. In the Fifteenmile Creek area no angular discordance is evident between the Renton Formation and the isolated outcrop of unnamed volcanic rocks about three-quarters of a mile to the west.

The Renton Formation is characterized in the mapped area by fresh- and brackish-water sedimentary rocks that are generally more friable than the older strata in the Puget Group. The Renton Formation is readily distinguished from the enclosing formations by its lack of volcanic debris. Fine- to coarse-grained or granular feldspathic and arkosic micaceous sandstone is interstratified with siltstone, carbonaceous claystone, and coal beds in the Renton.

Compared with older sandstone beds of the Puget Group, those of the Renton Formation contain more quartz, potash feldspar, white mica, and kaolinite, but less plagioclase, colored mica, carbonate cement, and hydrous clay minerals. Quartz and feldspar are the principal mineral grains in the formation. Feldspar constitutes 15–40 percent of the sand-size grains and consists of nearly equal proportions of plagioclase and potash feldspar. The matrix in nine out of 11 samples of sandstone, siltstone, and claystone from the Renton Formation was found to contain abundant kaolinite and minor amounts of mica (illite), montmorillonite, and other clay minerals. Of the other two samples, one contained abundant mica (illite), and the other, more montmorillonite than kaolinite. Carbonate cement is mainly concentrated in concretions that are locally as much as 5–10 feet long and 0.5–2 feet thick.

Horizontal lamination (fig. 11) is characteristic of the siltstone and claystone beds, whereas cross-lamination and ripple marks, though locally inconspicuous, are common in the sandstone beds. Conglomerate, which contains pebbles composed principally of siltstone, is fairly abundant. The strata are light gray to gray when fresh but weather pale yellowish gray to brown.

The Renton Formation in the Taylor area is described in stratigraphic section 7 (p. 60), was compiled from previously published data, mine records, and measurements of scattered outcrops. Most of the conspicuous ridges of the Renton Formation in the Taylor syncline are formed by ledges of sandstone and igneous sills, as described in the stratigraphic section. The valleys are underlain by fine-grained clastic rocks and coal beds. Very sparse surface data in this area make correlation with subsurface data uncertain. For example, Weaver (1916, p. 121–122) described a detailed section of rocks 1,414 feet thick in the main crosscut tunnel of the Taylor mine. The only coal bed he identified was the number 7, but this is probably not the same bed as the coal bed identified as the No. 7 in this report.

Near Cedar Mountain, the canyon eroded by the Cedar River provides one of the few exposures of the Renton Formation in the Maple Valley quadrangle. Evans (1912) stated that the rocks exposed in this area are about 2,000 feet thick. However, summation of the stratigraphic intervals given by Evans supplemented with mine data and new data from scattered outcrops indicates a thickness of about 1,550 feet for strata exposed in the canyon area and penetrated in the adjacent mine workings, as shown in stratigraphic section 8 (p. 61). Weaver (1916, p. 119) described 1,492 feet of strata from the same area, but the one coal bed included in his section is not identifiable and cannot be correlated with section 8.

West of the older mine workings at Cedar Mountain is another stratigraphic sequence about 2,900 feet thick

FIGURE 11.—Horizontally laminated siltstone in the Renton Formation exposed in a clay pit, NW¼ sec. 30, T. 24 N., R. 6 E.

that includes at least six coal beds. The total thickness may be 4,000 feet, if the approximately 1,100 feet of strata exposed near the south end of Lake Desire is a continuous stratigraphic sequence above the youngest coal bed. Coal beds have not been correlated across the faults that separate the two parts of the Cedar Mountain district. The approximate stratigraphic intervals separating the bases of coal beds in the western part of the Cedar Mountain area, as calculated from the mine maps, are as follows: New Lake Young coal bed to Ryan No. 1 coal bed, 850 feet; Ryan No. 1 coal bed to Ryan No. 2 coal bed, 280 feet; Ryan No. 2 coal bed to Discovery coal bed, 680 feet; Discovery coal bed to Jones (Slope) coal bed, 130 feet; and Jones (Slope) coal bed to Cavanaugh No. 2 coal bed, 975 feet. Description of the strata between coal beds were not found among the mine data, and the workings are no longer accessible.

In the Fifteenmile Creek area, about 1½ miles west of Tiger Mountain, rocks tentatively correlated with the Renton Formation consist of at least 700 feet of friable arkosic micaceous sandstone, siltstone, carbonaceous claystone, and coal. These rocks are separated from the Tukwila Formation to the north by an east-trending fault. Three coal beds—the Tiger Mountain Nos. 1, 2, and 3, from youngest to oldest—are about 400, 515, and 600 feet, respectively, below the top of the exposed sequence. The Tiger Mountain No. 3 coal bed is about 100–700 feet above a thick sill. According to the old mine records, this interval contains two or more additional coal beds; one, described as anthracitic, may have been increased in rank by the heat of intrusion. The existence of these lower coal beds could not be verified because of the cover of glacial drift. At least two other small sills have been intruded into the coal-bearing part of the sequence, but they seem to be much more limited in extent than the lower sill, which may be more than 400 feet thick. The lower sill is underlain by sandstone.

Leaf fossils from the Renton Formation were collected from three localities as follows:

USGS paleobotany loc. 9729, SE¼NW¼ sec. 3, T. 22 N., R. 7 E.
9730, SW¼NW¼ sec. 29, T. 23 N., R. 6 E.
9688, SW¼NE¼ sec. 32, T. 24 N., R. 6 E.

Strata of locality 9729, in the Taylor coal field, were assigned by Wolfe (1968) to the upper Ravenian Stage. Strata at locality 9730, a roadcut near Cedar Mountain, and locality 9688, a roadcut about 1½ miles west of Issaquah, contain leaf fossils that Wolfe assigned to the late Kummerian Stage. Thus, in the Hobart, Maple Valley, and Issaquah areas, the Renton Formation ranges from late Eocene to early Oligocene in age. In addition to leaf fossils, the rocks in the Renton Formation locally contain several species of fresh- or brackish-water mollusks. Fossil mollusks were collected from two localities, as given in table 5. In reference to the fossil collections, F. Stearns MacNeil stated (written commun., 1959) that the association of *Potamides lewisiana* and *Corbicula olequahensis* was reported by C. E. Weaver from beds he referred to as the Cowlitz Formation of late Eocene age. They are probably of brackish-water origin. The two forms of *Batissa* may be variants of one species. They have been described from the Puget Group, but elsewhere the genus is known chiefly from East Asia and Oceania. These two species probably inhabited fresh water.

TABLE 5.—*Fossil mollusks from the Renton Formation*

[Identifications by F. Stearns MacNeil (written commun., 1959), U.S. Geol. Survey

	Locality	
	[1] 651	[2] 650
PELECYPODA		
Batissa newberryi White	×	------
Batissa dubia White	×	------
Corbicula cf. *C. willisi* White and *C. olequahensis* (Weaver)	------	×
GASTROPODA		
Potamides lewisiana Weaver	------	×

[1] Specimens supplied by Ralph Clark, geologist, International Pipe and Ceramics Corp., from a clay pit near the center of the S½ sec. 32, T. 24 N., R. 6 E., Issaquah quadrangle, Washington.
[2] Abandoned clay pit near Taylor, in the SW¼NE¼ sec. 9, T. 23 N., R. 7 E., Hobart quadrangle.

SUMMARY INTERPRETATION OF THE RAGING RIVER FORMATION AND PUGET GROUP

The stratigraphic relation between the undifferentiated Puget Group in the Green River area to the south and the much thicker sequence of Raging River, Tiger Mountain, Tukwila, and Renton Formations on the north is concealed beneath glacial drift on either side of the Cedar River. Similar floral stages in both areas indicate, however, that most of the 6,000 feet of strata in the Green River area correlates with most of the 14,000 feet of strata in the Tiger Mountain–Taylor Mountain upland area (fig. 12; pl. 2), although some minor exceptions may exist. The oldest rocks in the Green River area are assigned to the Franklinian Stage, which probably is older than any of the fossil-bearing rocks to the north, but the fossil-bearing rocks in the north are underlain by several hundred feet of altered strata in which no fossils were found. The youngest rocks in the undifferentiated Puget Group in the Green River area are assigned to the early Kummerian Stage of earliest Oligocene age, whereas rocks as late as the late Kummerian Stage of early Oligocene age are found in the Renton Formation. Despite these slight differences in age, the rate of accumulation of sediment apparently was nearly twice as fast in the north as in the south.

Fresh- or brackish-water pelecypods, such as *Batissa*, occur in the Renton Formation, as well as in the undifferentiated Puget Group to the south. The pelecypod occurrence indicates that, except for the Raging River Formation, deposition took place close to sea level in both areas and that subsidence kept pace with deposition of the sediment, as noted by Willis (1886, p. 759). The change in thickness and lithology of the Puget Group and the Raging River Formation from the Green River area to the Tiger Mountain–Taylor Mountain upland area apparently takes place across some sort of hinge line that is now buried under glacial deposits. Subsidence occurred at different rates on each side of the hinge line. The greater subsidence on the north is probably related to collapse coincident with the extrusion of large quantities of volcanic material. The relative volumes of sedimentary and volcanic material in the two areas is indicated on plate 2, which shows a composite lithologic section of each area and the probable correlation, as based on floral stages.

The clay-mineral suites in the sections are also shown on plate 2. In view of the relative constancy of the nonmarine coastal environment of deposition in the Green River area, the progressive change in the clay-mineral suite in the Puget Group probably indicates a progressive change in the source area. The periods of volcanic activity, represented by abundant volcanic material in the Raging River, Tiger Mountain, and Tukwila Formations to the north, are not characterized by any distinct clay-mineral suites in the undifferentiated Puget Group in the Green River area. The upper part of the undifferentiated Puget Group on the south, which cor-

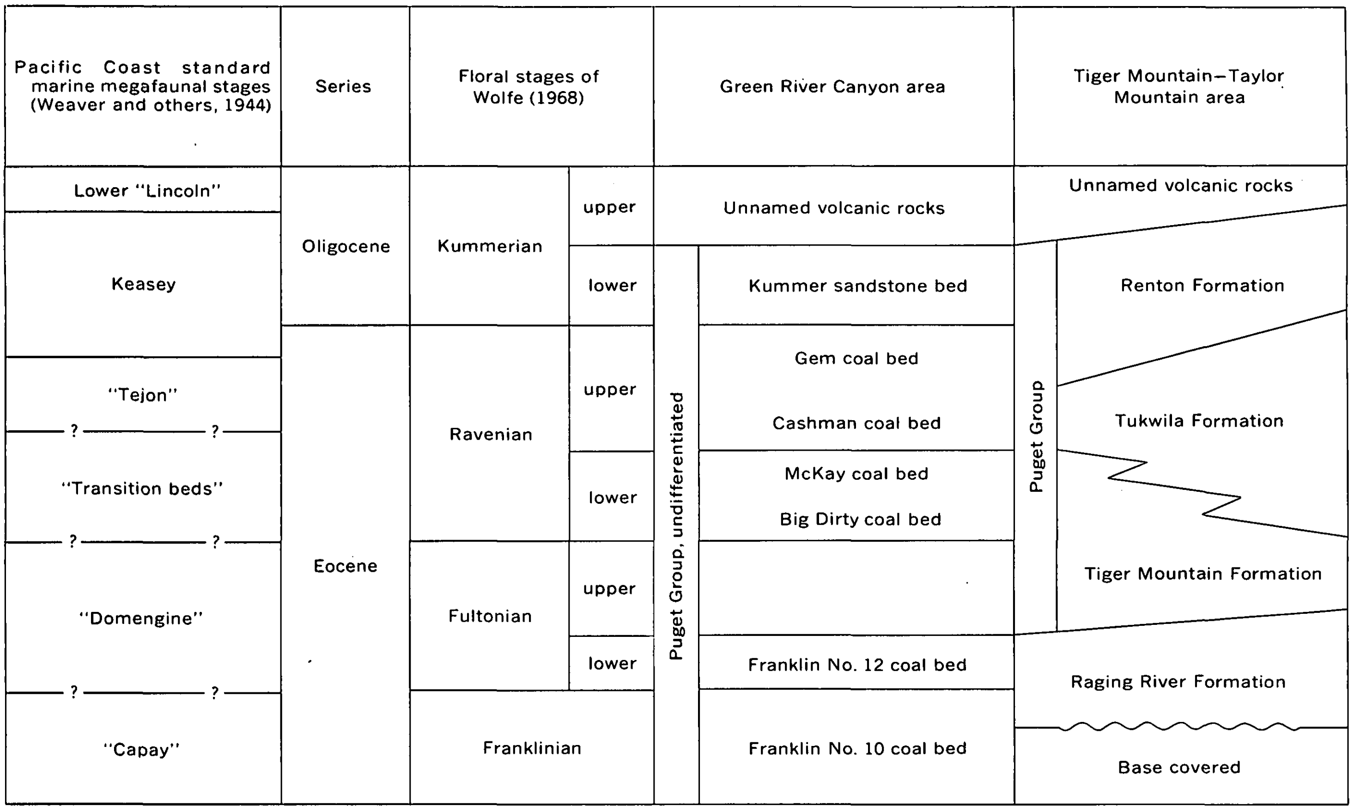

FIGURE 12.—Correlation of the Puget Group in the Green River Canyon area and equivalent rocks in the Tiger Mountain–Taylor Mountain area. Queries indicate uncertain position of megafaunal stage boundaries relative to position of floral stage boundaries.

relates with the Renton Formation, contains montmorillonite as a common minor constituent. Montmorillonite is far less common in the Renton Formation; therefore, the probable source for it was to the south and east, where unnamed volcanic rocks intertongue with the upper part of the Puget Group. Because the northern and southern facies are so dissimilar, it can be inferred that the hinge line between the two facies also represents a barrier across which very little sediment was transported.

Bressler (1957) presented evidence that sedimentary rocks equivalent in age to the Puget Group that occur east of the Cascade Range were formed of sediments largely derived from a lower Tertiary crystalline highland whose center was near the Wenatchee Mountains. There, the Mount Stuart Granodiorite of pre-Tertiary age was uplifted in Late Cretaceous or early Tertiary time and provided the source for most of the arkosic detritus in the Swauk and Roslyn Formations. The Cascade Range was not formed until later, so the streams draining this highland flowed westward across a broad flood plain before reaching the sea. Deposits on this flood plain form the Puget Group. Local volcanic centers like the Tiger Mountain–Taylor Mountain upland area interrupted the otherwise uniform flood plain. The eastward embayment of marine rocks in the Raging River Formation seems to coincide with the somewhat later accumulation of volcanic material in the Tukwila Formation. Both were probably deposited during the same rapid subsidence that was accompanied by outpourings of volcanic material.

A northwest-trending fault zone with large lateral displacement could be proposed as an alternative to the hinge-line hypothesis, and the lateral displacement would explain the apparent lack of mixing between the northern and southern facies. Evidence of faulting is abundant on the south sides of Squak and Tiger Mountains, but there is no field evidence other than the marked difference in lithologic facies to suggest that these faults have large lateral displacement.

UNNAMED VOLCANIC ROCKS

Interstratified with, and conformably overlying, the Puget Group in the Cumberland, Hobart, and Maple Valley quadrangles is a thick sequence of volcanic rocks informally referred to as unnamed volcanic rocks. These rocks range from andesitic tuff-breccia, tuff, and flow rocks near the southeast corner of the Cumberland quadrangle to fluvial volcanic sandstone, conglomerate, and tuff near Black Diamond. Similar rocks along the west margin of the Cascade Range were named the Enumclaw Volcanic Series by Weaver (1916, p. 84, 232–235), but this name was not precisely defined, and, so far as is known, the name has not been used by other workers. Smith and Calkins (1906, p. 8) gave the name Keechelus Andesitic Series to upper Tertiary volcanic rocks that they mapped along the crest of the Cascade Range. Warren Norbisrath, Grivetti, and Brown (1945) extended the name Keechelus Andesitic Series to the intrusive and volcanic rocks of post-Puget age in the area of this report. Several other workers (Coombs, 1936; Fisher, 1954; and Crandell and Gard, 1959) also extended the name to volcanic rocks that interfinger with and overlie the Puget Group on the west side of the Cascade Range. Waters (1961) showed that the rocks originally included in the Keechelus Andesitic Series are younger than those subsequently assigned this name and that extension of the name to include older rocks is unwarranted. Therefore, the older volcanic rocks formerly assigned to the Keechelus Andesitic Series by Warren, Norbisrath, Grivetti, and Brown (1945) are included in the unnamed volcanic rocks of this report.

Where exposed near the southeast corner of the Cumberland quadrangle, the unnamed volcanic rocks are about 5,000 feet thick and consist of stratified tuff, lapilli tuff, tuff-breccia, flow breccia, platy to massive flow rock, and lesser quantities of volcanic sandstone and siltstone. These rocks form the conspicuous escarpment more than 1,200 feet high east of Walker Lake. Small isolated exposures of unnamed volcanic rocks occur (1) in the southwest corner of the Cumberland quadrangle, (2) half a mile northwest of Bayne, (3) north of Sugarloaf Mountain in secs. 28, 29, and 34, T. 22 N., R. 7 E., (4) west of Landsburg in the NE¼ sec. 23, T. 22 N., R. 6 E., and (5) along Fifteenmile Creek in the S½ sec. 14, T. 23 N., R. 6 E. In addition, these rocks probably underlie much of the drift plain in parts of the Maple Valley and Hobart quadrangles.

In the southwest corner of the Cumberland quadrangle, north and east of Bass Lake, the unnamed volcanic rocks consist chiefly of volcanic sandstone and conglomerate and locally contain abundant fossil plant remains. The outcrop west of Bayne is lapilli tuff and tuff-breccia. The outcrops north of Sugarloaf Mountain are principally tuff-breccia but also include some volcanic flows. The outcrop in the canyon of the Cedar River west of Landsburg consists of volcanic sandstone interbedded with basaltic flow breccia and a platy flow that is exposed during periods of low water. The outcrop in Fifteenmile Creek near the northeast corner of the Maple Valley quadrangle consists of deeply weathered volcanic pebble conglomerate and tuff. These sedimentary volcanic rocks are composed of relatively unstable minerals and readily weather to a soft, brown saprolite.

The clastic volcanic rocks are generally composed of plagioclase grains of about the composition of andesine, volcanic rock fragments, and subordinate grains of augite and hornblende in a chloritized matrix. Many of the larger grains have also been chloritized. This alteration is reflected in the color of the rocks, which are grayish yellow green, dusky yellow green, or pale olive. The flow rocks are generally medium-dark-gray to dark-gray porphyritic andesite with pilotaxitic textures. Phenocrysts 5–20 mm long, consisting of euhedral to subhedral zoned plagioclase (chiefly andesine) and accessory augite, are scattered in a microcrystalline groundmass of plagioclase and dark minerals.

Warren, Norbisrath, Grivetti, and Brown (1945) mapped unnamed marine rocks of Oligocene and Miocene age west of Issaquah that consist of volcanic sandstone and tuff beds and are similar, except for the presence of marine fossils, to the unnamed volcanic rocks in the western part of this area. Similar rocks in the Renton quadrangle were regarded by Mullineaux (1965a) as the Lincoln(?) Formation of Weaver (1912, p. 10–22). Thus, within about 16 miles, these rocks grade from tuff-breccia and flow rocks near the Cascade Range into volcanic sandstone and tuff beds containing fossil plant remains, and then into marine sedimentary rocks composed almost entirely of detritus from the volcanic center.

Fossil plant remains were collected from several localities in the unnamed volcanic rocks, both in the mapped area and in adjacent areas (Wolfe, 1961). The flora from locality 9681, next to the Walker Lake road, occurs in the part of the Puget Group that lies above a tongue of unnamed volcanic rocks. This part contains a flora assigned to the early Kummerian Stage of earliest Oligocene age. The flora from volcanic rocks at localities 9689 and 9690 in the southwest corner of he Cumberland quadrangle and that at 9693 on the Green River, half a mile east of the Cumberland quadrangle, are assigned to the late Kummerian Stage of early Oligocene age. Elsewhere this same flora occurs in beds of the Renton Formation of the Puget Group (USGS palebotany loc. 9730) at Cedar Mountain and at locality 9688, 1½ miles north of the Maple Valley quadrangle west of Issaquah. Therefore, the fossil evidence suggests that the lower part of the unnamed volcanic rocks in the Green River area is nearly equivalent in age to the Renton Formation a few miles to the north, as noted by Wolfe (1961, p. C229). The upper age limit for the unnamed volcanic rocks as mapped in this area is unknown.

Based on stratigraphic position and age, the unnamed volcanic rocks are at least in part equivalent to the Ohanapecosh Formation of the Mount Rainier area (Fiske and others, 1963; Waters, 1961) and the Lincoln Formation of Weaver (1912, p. 10–22) in the Centralia-Chehalis area of southwest Washington (Snavely and others, 1958, p. 35–53). Possibly the upper part of the unnamed volcanic rocks is also correlative with the Stevens Ridge and Fifes Peak Formations of the Mount Rainier area (Fiske and others, 1963; Waters, 1961).

UPPER TERTIARY SEDIMENTARY DEPOSITS

Partly consolidated sedimentary deposits are exposed in several small outcrops in and adjacent to the Green River in two areas in the Cumberland quadrangle. One area is west of Kanaskat, and the other, southeast of Palmer. These flat-lying to gently dipping beds unconformably overlie the Puget Group and are unconformably overlain by glacial outwash. Glover (1941, p. 150) included the deposits east of Palmer in the Hammer Bluff Formation, a sequence of gently dipping sedimentary deposits that he named (Glover, 1936) for its occurrence at Hammer Bluff, about 8 miles southwest of the Palmer locality. Both deposits were derived chiefly from rocks in the Puget Group, but they were probably never coextensive.

The sedimentary deposits southeast of Palmer, which crop out on the south side of the Green River in the NW¼ sec. 14, T. 21 N., R. 7 E., are about 20 feet thick where exposed in cuts along the Northern Pacific Railway, but they were deposited on an irregular surface and may be thicker elsewhere. They are composed of locally derived gravel, sand, silt, and sandy clay. A woody lignite bed about 1½ feet thick occurs in the upper part. The gravel is componsed of angular to subangular cobbles and pebbles of friable to semifriable arkosic and feldspathic sandstone. The sand beds are poorly sorted and grade into sandy clay beds. Sand and clay beds are yellowish gray to light olive gray and locally contain abundant carbonaceous fragments. The clay becomes plastic when wet and was once mined on a small scale to be used for baked clay products.

The sedimentary deposits west of Kanaskat in the SW¼NE¼ sec. 10, T. 21 N., R. 7 E., are about 25 feet thick and are mostly breccia and gravel almost entirely composed of mafic igneous rocks. A bed 4 feet thick of friable fine to medium sand occurs in the lower part of the unit. These deposits rest on the irregular surface of a porphyritic andesite intrusive and the steeply dipping sandstone beds of the Puget Group. Many rock fragments in the breccia and the gravel seem to have been locally derived from the underlying intrusive.

Glover (1941, p. 150) and Warren, Norbisrath, Grivetti, and Brown (1945) included the deposits southeast of Palmer in the Hammer Bluff Formation and considered them to be of Pliocene or Pleistocene age. More recent work by Mullineaux, Gard, and Crandell (1959, p. 693), however, indicated a probable late Miocene age for the Hammer Bluff Formation at its type locality. Because the deposits near Palmer and Kanaskat occupy the same stratigraphic position as the Hammer Bluff Formation, they were tentatively assigned a late Miocene(?) age by Gower and Wanek (1963).

QUATERNARY DEPOSITS

Quaternary deposits blanket most of the three quadrangles mapped. The Pleistocene deposits were derived from material transported by continental glaciers from the north and by outwash streams carrying melt water from both the retreating continental ice sheets and the Cascade glaciers to the east. Crandell, Mullineaux, and Waldron (1958) recognized four drift sheets in the Puget Sound lowland, but only the last—the Vashon Drift—is widely exposed in the mapped area. Pre-Vashon drift is exposed locally along the Cedar River valley west of Landsburg, but no attempt was made to map this older drift in the field. The pre-Vashon deposits shown on the geologic map (pl. 1) are sketched from notes and observations by D. R. Mullineaux (oral commun., 1961), who studied these deposits in connection with regional studies of the Pleistocene and detailed mapping in the adjacent quadrangles to the west.

VASHON DRIFT

Willis (1898b, p. 111) gave the name Vashon Drift to deposits laid down on Vashon Island in Puget Sound by the last continental ice sheet that occupied the entire Puget Sound lowland. This ice sheet, like those that preceded it, was confined between the Olympic Mountains on the west and the Cascade Range on the east as the ice advanced southward to a position about halfway between Olympia and Centralia (Bretz, 1913, p. 22). The ice was thick enough to override all but the highest peak of Tiger Mountain, whose northern slopes are thickly mantled with drift. Where not differentiated, these latest glacial deposits are mapped as glacial drift. Locally, the Vashon Drift is subdivided into ground moraine (till), deposits of silt and sand, and terrace gravel and stratified drift.

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TILL

Till, in the form of ground moraine, was deposited over nearly the entire area during the advance of the ice. Till is widely exposed, especially in the lowland area of the Maple Valley quadrangle, where it consists of as much as 50 feet of a compact mixture of cobbles, sand, and clay. There, the drift plain is mantled by till which has formed distinctive drumlinlike parallel ridges and depressions and low, rounded hills that are elongated in the direction of the ice advance. Because the till is relatively compact and impermeable, the ground moraine is poorly drained, and many areas of undrained depressions on this surface contain lakes, swamps, and peat bogs. In many such areas the till is overlain locally by a veneer of stratified drift, lake, and swamp deposits. However, south of the Cedar River, the ground moraine in the lowland areas is almost completely obscured by younger deposits of stratified drift, but till is preserved on the hills, such as those near Black Diamond and Ravensdale, where it forms a mantle that conforms closely to the shape of the preglacial topography.

Compact till also forms a mantle 5–15 feet thick over the bedrock in most of the upland areas, especially on the north slopes in the Tiger Mountain and Taylor Mountain areas. Although Tiger Mountain is relatively free of drift above an altitude of about 2,700 feet, nearly all the other peaks in the area, including Squak Mountain, West Tiger Mountain, South Tiger Mountain, Taylor Mountain, and the unnamed 2,607-foot peak about a mile west of Tiger Mountain, are covered by a thick mantle of till. Slopes along the canyon of Issaquah Creek between Squak Mountain and West Tiger Mountain are relatively free of drift, which indicates that the advancing ice tended to scour the sides of the canyon. Drift was found at a depth below sea level in underground workings adjacent to this canyon and suggests that the advancing ice cut deeply into the canyon and that the canyon was subsequently filled to a depth of about 150 feet. A rather large quantity of till was deposited in the saddle between Tiger Mountain and West Tiger Mountain and was spread over the hummocky slopes to the south, including South Tiger Mountain. The west face of Tiger Mountain was probably scoured by the ice that moved through the saddle. Till on the crest of Taylor Mountain includes boulders of sandstone with marine fossils that could only have come from the Raging River Formation in the valley of the Raging River, to the north.

SAND AND SILT

A deposit of horizontally laminated, but massive weathering fine sand and silt of principally lacustrine origin lies on the Vashon Drift in the Issaquah Creek area. It extends south from the canyon of Issaquah Creek to the vicinity of Hobart. West of Hobart the deposit is found as far as Francis Lake, where medium to coarse fluvial sand is interstratified with the fine sand and silt. These deposits probably accumulated in or along a lake formed when drainage to the north and west was blocked by ice during the recession of the Vashon ice sheet. Eventually, an outlet for the lake was established along the south side of Squak Mountain, but when the ice block in the canyon of Issaquah Creek melted, the lake drained north through the canyon.

TERRACE GRAVEL AND STRATIFIED DRIFT

The repeated advance and recession of the continental ice sheet in the Puget Sound lowland disrupted the preglacial pattern of streams that flowed westward from the Cascade Range. In general, streams were displaced southward during the periods of maximum glacial advance. The latest changes are well illustrated by the gravel deposits and abandoned stream channels that are readily recognizable on topographic maps of the region. The diversion of various tributaries of the Snoqualmie River when its lower valley was blocked by the continental ice sheet was thoroughly discussed by Mackin (1941). He showed that the mountain valleys of the Middle and South Forks of the Snoqualmie River and the Cedar River were all blocked by the advancing continental ice at a time when the Cascade glaciers were retreating. At the maximum stand of the ice, morainal embankments were built up; the upper valleys were partly filled by deltaic sediment; and lakes were formed that extended well back into the Cascade Range. He also showed how the combined discharge from these lakes and melt water from the continental ice sheet and the Cascade glaciers found a new outlet to the southwest through the Cedar spillway and the modern Cedar Valley, whose lower course is the ancestral valley of the Green River. The Green River was also diverted to the south, as described by Campbell and others (1915, p. 186–187). Discharge from the Cedar spillway backed up in the old channel of the Green River and flowed down a smaller valley, which is the present valley of the Green River. The lower course of the smaller valley was also blocked at the mountain front, so that the combined flow from lakes, the Green River, and glacial melt water was diverted across a line of low hills in what is now the abandoned Walker Lake channel. This is a gravel-filled channel ½–1 mile wide at an altitude of 1,100–1,300 feet that contains Walker Lake and part of the drainage of Deep Creek and Coal Creek. The abandoned Walker Lake channel has a steep gradient (500 ft in about 4 miles) and shows evidence of the powerful erosion that steepened the slope of the mountain east of Walker Lake.

As the ice retreated from its maximum stand, the Green River established its present course as far as Palmer and for a time occupied a channel through the saddle where the town of Bayne is now situated. This change in the channel caused the hill west of Bayne to be separated from the main part of the Cascade Range front. Further retreat of the ice opened the ancestral Green River channel north of Kanaskat, but by that time the Green River was entrenched in its new course and did not return to its former channel. Part of this former channel then carried the flow from the Cedar spillway to the lowland. For a time the Cedar River occupied a channel through a saddle where the town of Durham is now. The channel separated the hill west of Durham from the main part of the Cascade Range, so that the situation here is identical with that at Bayne. Continued retreat of the ice across the gentle northwest slope of the preglacial lowland caused the Cedar and Green Rivers to occupy successively lower positions marginal to the toe of the glacier until the rivers had spread a mantle of outwash gravel across the broad lowland areas of the Cumberland quadrangle and the southern parts of the Hobart and Maple Valley quadrangles. Finally, the Green River entrenched the valley west of Cumberland and eventually cut a gorge into bedrock as much as 200 feet below the level of the outwash gravels. The Cedar River occupied a temporary channel through the lowland where the towns of Georgetown and Ravensdale are now situated. Later, it shifted to the northwest but continued farther to join the Green River west of Black Diamond. For a while the Cedar River flowed southwest from the site of Maple Valley and joined the Green River about 8 miles west of the Mable Valley quadrangle. Eventually, the Cedar River flowed to the north, past the site of Maple Valley; but the present course was not established until after the river had flowed for a time northeast of Cedar Grove into the Issaquah valley and then northwest along the south side of Squak Mountain. The Issaquah Creek canyon east of Squak Mountain probably remained blocked until after the Cedar River established its present course.

Stratified gravel and sand were deposited along the floor of the now-abandoned melt-water channels. The upper surfaces of these deposits form terraces whose successive levels have recorded the described sequence of events. These deposits are generally well sorted and permeable. As a result, the land in the channels is generally well drained, but some lakes and swamps occur in these melt-water channels where large ice blocks were buried by ice, then melted to form kettle holes. The thickness and character of the gravelly deposits differ locally, and they were not studied in detail. These deposits are the source of gravel for several commercial quarries.

The valley of Deep Creek, between Taylor Mountain and Tiger Mountain, contains a rather thick deposit of stratified drift up to an altitude of about 1,400 feet, as shown in figure 13. The stratified drift probably was deposited in melt water impounded between the lobe of ice in the valley of the Raging River on the east and the lobe of ice in the valley of Issaquah Creek on the west.

LANDSLIDE DEBRIS

Recent soil creep, talus, and colluvial deposits are rather common on many of the steeper slopes in the area, but outcrops are generally too poor to allow mapping of most such deposits separately. However, three large landslides, recognized by breakaway scarps, slump blocks, distorted bedding, and hummocky topography were mapped and are described.

A landslide on the south side of the Green River, about 2–3 miles south of Black Diamond, has formed in glacial drift and deeply weathered unnamed volcanic rocks along the axis of the Kummer syncline. Continued movement on this slide in recent years is indicated by repeated breaks in the highway where it crosses the slide. The main scarp of this slide is formed in the unnamed volcanic rocks, and the toe has been eroded away by the Green River. The position of this slide along the axis of the Kummer syncline may indicate that it is structurally controlled.

A landslide at the west end of Taylor Mountain is composed of glacial drift and underlying bedrock from the Tukwila Formation. Although movement within the bedrock is chiefly parallel to the strike, the hummocky topography and fan-shaped toe suggest that the slide moves as a slow earthflow.

On the south side of Taylor Mountain, near Brew Hill, a landslide is composed of glacial drift and rocks of the Tukwila Formation. Although its shape cannot be definitely determined because exposures are poor, this landslide is thought to be an earthflow with some rather large coherent blocks of sandstone within it. Movement within the bedrock part of this slide is chiefly downdip.

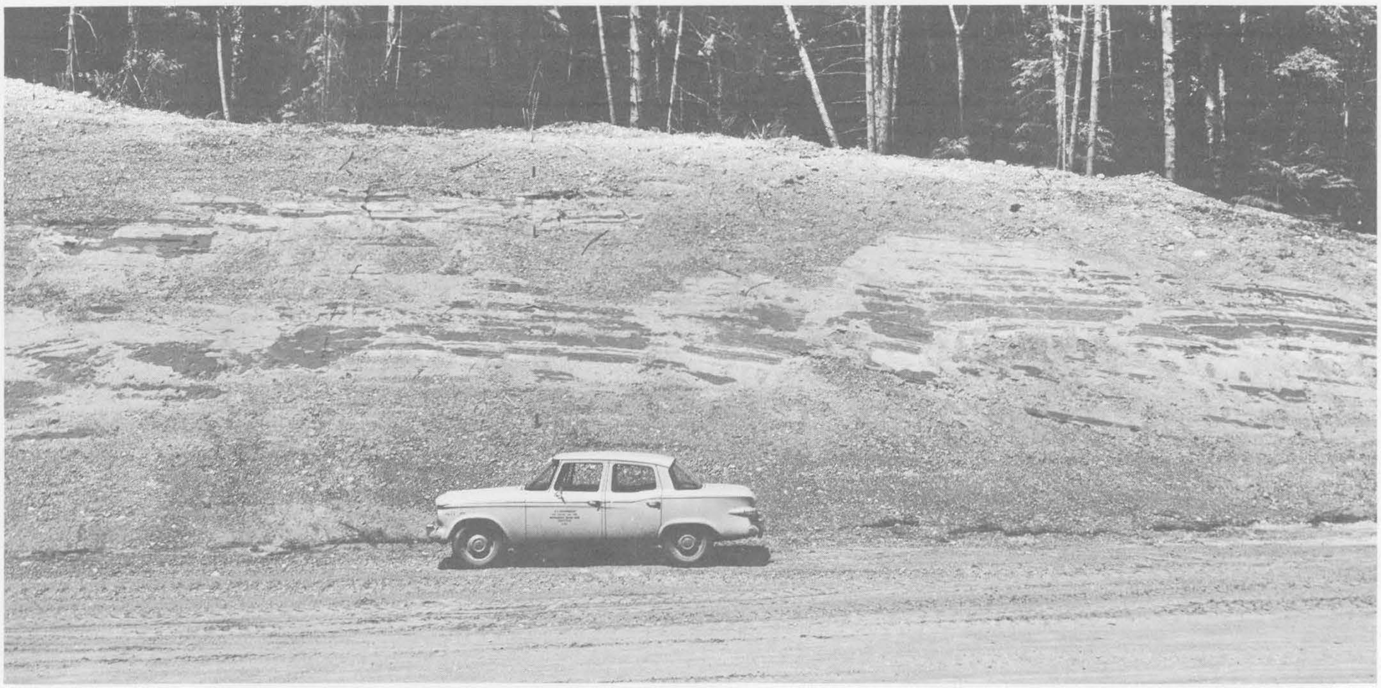

FIGURE 13.—Stratified sandy drift at an altitude of about 1,400 feet in the valley of Deep Creek, between Taylor Mountain and Tiger Mountain. The stratification is apparent in this fresh roadcut because of the variation in surface moisture between the sandy and clayey strata.

PEAT AND SWAMP DEPOSITS

Peat and swamp deposits are scattered throughout the drift plain. These deposits occur adjacent to present lakes of glacial origin or mark the sites of former glacial lakes. Some lakes, such as Otter Lake and Shadow Lake in the western part of the Maple Valley quadrangle, formed in depressions in the ground moraine and are probably underlain by till; other lakes, including Walsh Lake, Retreat Lake, and Walker Lake, probably formed in kettle holes in stratified drift and may be underlain by porous gravel. Vegetation has filled the shallow margins of many of these lakes, and elsewhere peat bogs fill depressions that formerly contained lakes. Rigg (1958, p. 69–95) studied the peat deposits in this area and found chiefly sedimentary and fibrous varieties of peat mixed with local concentrations of sphagnum, woody peat, and inorganic detritus. Most of the peat and swamp deposits shown on the geologic map (pl. 1) are at least 4 feet thick, and some are locally much thicker. Peat and organic soil deposits, including many that are less than 4 feet thick, are further classified on the soil map of King County by Poulson, Miller, Fowler, and Flannery (1952). Peat is locally used as a soil conditioner.

ALLUVIUM

Holocene alluvium consisting of gravel and sand was mapped along the modern flood plain of the Cedar River, especially below Landsburg, and locally on the Green River, as near Kanaskat and Palmer Junction. Alluvium was also mapped along Issaquah Creek and Coal Greek. These deposits are similar in most respects to the older terrace gravels, but they are closer to the modern stream profile and have undergone relatively little erosion. The alluvium deposits are nearly flat and include humus in the soil profile; they are commonly utilized for grazing land and dwellings and are subject to the potential hazard of flooding.

INTRUSIVE IGNEOUS ROCKS

Igneous rocks intrude the Raging River Formation and the Puget Group at many places in the Cumberland, Hobart, and Maple Valley quadrangles. Locally, the unnamed volcanic rocks are also intruded. Most of the intrusions are sills or sill-like bodies less than 40 feet thick. A few are as much as 150 feet thick, and one on Fifteenmile Creek is about 400 feet thick. The intrusive rocks commonly form massive outcrops or steep slopes because they are more resistant to weathering and erosion than the enclosing sedimentary rocks. All have a porphyritic texture and are generally medium dark gray to dark greenish gray. Most are probably calcic andesites, though some may be basaltic and others dacitic in composition. Phenocrysts of plagioclase feldspar 2–4 mm long commonly make up 5–20 percent of the rock; augite phenocrysts locally make up as much as 10 percent. Most of the phenocrysts are euhedral to subhedral, and many are zoned. The groundmass is generally composed of fine to very fine laths of plagioclase feldspar, pyroxene (augite?), chlorite, clay minerals, and magnetite. Secondary calcite occurs in the groundmass and as a replacement of plagioclase phenocrysts. The feldspar, both in the groundmass and as phenocrysts, is chiefly andesine, and most is somewhat altered. A sill, about 100 feet thick, which may be fairly representative of these intrusive bodies, occurs in sec. 26, T. 21 N., R. 7 E. Table 6 gives the chemical composition of this sill.

The 400-foot sill on Fifteenmile Creek is exposed on a prominent unnamed hill in the NE¼ sec. 13, T. 23 N., R. 6 E., and adjacent sections. It is medium-dark-gray porphyritic rock composed of about 15 percent plagioclase phenocrysts and 85 percent groundmass. The phenocrysts average about 1 by 3 mm; the groundmass consists mainly of smaller plagioclase blades that average about 0.5 by 1 mm and a less abundant mafic mineral, probably augite, as well as calcite, chlorite, and opaque minerals. Adjacent to the overlying sandstone the intrusion is highly altered, and calcite forms as much as 30 percent of the rock. A smaller sill occurs in the NW¼ sec. 13 but probably is related to the main mass. It is nearly holocrystalline and contains fewer large phenocrysts. It consists of about 50 percent plagioclase with a composition of about An_{45}, 30 percent augite(?), and 20 percent fine-grained groundmass, which includes calcite and other alteration products plus opaque minerals. The intrusive rocks exposed on nearby hills as far south as South Tiger Mountain in sec. 30, T. 23 N., R. 7 E., are probably related to the intrusion at Fifteenmile Creek. They differ chiefly by being finer grained and by having more chloritic alteration. A porphyritic intrusive rock is exposed about 1¼ miles west of the main mass at Fifteenmile Creek near the center of the S½ sec. 14, T. 23 N., R. 6 E. This sill is overlain by the unnamed volcanic rocks and is assumed to cut these rocks, although the contact is covered. The sill is similar in most respects to the main mass at Fifteenmile Creek, but is considerably altered and contains green chalcedony, native copper, and an isotropic zeolite among alteration products.

TABLE 6.—*Chemical analysis of igneous sill*

[Analyses by Paul Elmore, I. H. Barlow, Samuel Botts, and Gillison Chloe, U.S. Geol. Survey. Rapid method of analysis similar to that described by Shapiro and Brannock (1956)]

Compound	*Percent*
SiO_2	54.4
Al_2O_3	18.1
Fe_2O_3	2.1
FeO	4.7
MgO	3.1
CaO	5.8
Na_2O	3.9
K_2O	.79
H_2O-	.66
H_2O+	2.8
TiO_2	1.1
P_2O_5	.25
MnO	.09
CO_2	2
Sum	100

East of Lake Desire a medium-dark-gray to dark-gray porphyritic intrusive rock crops out on the hilltops in NW¼ sec. 31, T. 23 N., R. 6 E. The contact of this intrusion with the sedimentary rocks is not exposed, but the intrusion is probably a sill. The rock contains about 60 percent plagioclase phenocrysts 0.5–10 mm long; 20 percent mafic mineral, probably augite; and 20 percent groundmass, including fine-grained plagioclase, chlorite, and opaque minerals. Another porphyritic intrusive rock crops out along the axis of Sherwood anticline on Webster Creek in the NE¼SE¼ sec. 4, T. 22 N., R. 7 E. It is medium dark gray and similar in texture and general appearance to those previously described but has been intensely altered. The plagioclase grains are extremely clouded, and chlorite and opaque minerals are abundant.

An intrusive rock in the canyon of Issaquah Creek is distinctively different from most in the area and was mapped separately (porphyritic intrusive, pl. 1). It is a greenish-gray porphyritic hornblende andesite or dacite and is exposed chiefly in the canyon walls in sec. 10, T. 23 N., R. 6 E. This intrusive body apparently cuts across beds of the Tukwila Formation, is lenticular in shape, and may be a small stock. Inasmuch as the rock resembles fragments in the conglomerate and tuff-breccia in the upper part of the Tukwila Formation, it possibly represents a vent of a volcano that supplied extrusive material. The rock is composed of phenocrysts of zoned and altered plagioclase and hornblende as much as 5 mm long in a fine-grained groundmass. Subhedral plagioclase phenocrysts (fig. 14) make up about 40 percent of the rock. In thin section the plagioclase is seen to be clouded, strained, and partly replaced by zeolite(?) along cleavage planes. On an X-ray diffractometer pattern of the plagioclase, the specific peaks, used in the method of Smith and Yoder (1956), are broad, and their spacing indicates a probable range in composition from about An_{25} to An_{35}. Euhedral horn-

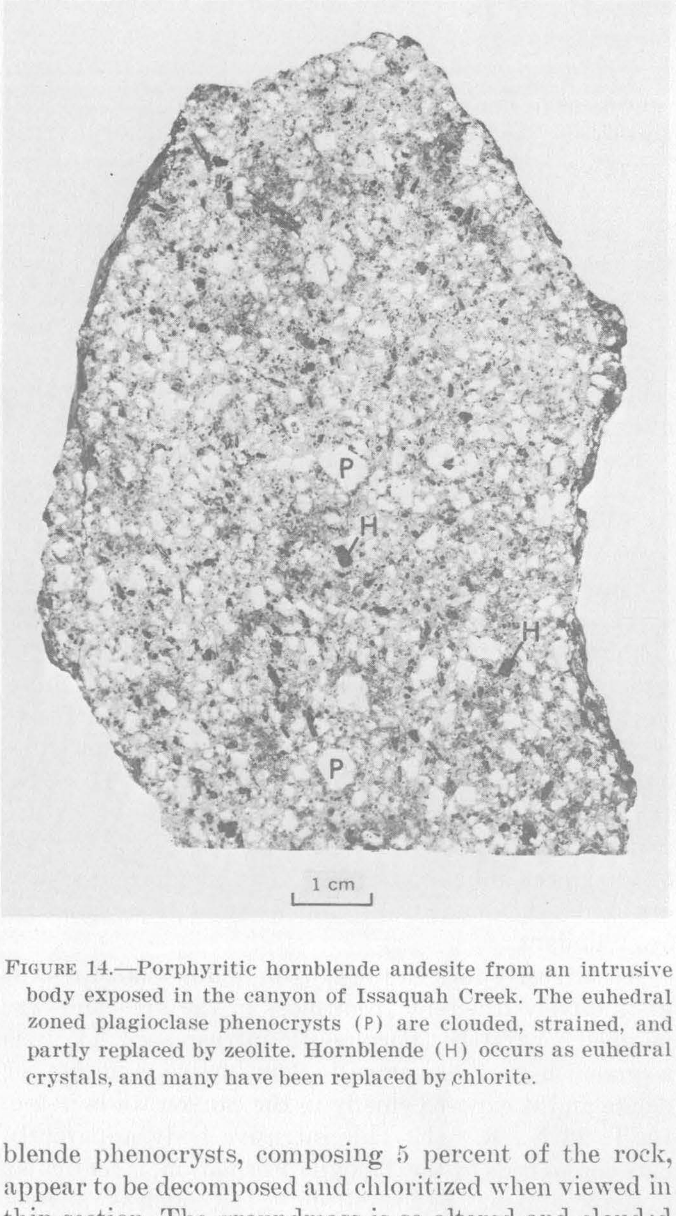

FIGURE 14.—Porphyritic hornblende andesite from an intrusive body exposed in the canyon of Issaquah Creek. The euhedral zoned plagioclase phenocrysts (P) are clouded, strained, and partly replaced by zeolite. Hornblende (H) occurs as euhedral crystals, and many have been replaced by chlorite.

blende phenocrysts, composing 5 percent of the rock, appear to be decomposed and chloritized when viewed in thin section. The groundmass is so altered and clouded that its composition was not determined, but opaque minerals probably make up 1–2 percent of the rock. An X-ray diffractometer analysis of the whole rock indicates that quartz is a major constituent, but individual grains are sparse. Probably much of the clouded appearance of the groundmass is due to a microscopic intergrowth of quartz, plagioclase, and chlorite.

The igneous sills that intrude the lower part of the Raging River Formation in secs. 9, 10, and 15, T. 23 N., R. 7 E., are dark gray to light gray, depending on the degree of alteration. In the dark-gray sills some of the mafic minerals and groundmass are partly replaced by calcite and chlorite. Where light gray the sills are generally more intensely altered and contain quartz and pyrite in addition to the calcite and chlorite. In some of the more intensely altered rocks, the original igneous texture is almost completely obscured; the rock is a hornfels and is almost impossible to distinguish in the field from rocks of sedimentary origin. Intensely altered sills are also associated with some of the coal beds at Sugarloaf Mountain, but they are not shown on the geologic map. They are discussed in the section "Hydrothermally Altered Rocks."

Probably the igneous rocks in the area represent more than one age of intrusion. The hornblende andesite intrusion in the canyon of Issaquah Creek is apparently associated with and about the same age as the hornblende-bearing volcanic rocks of the Tukwila Formation—that is, Eocene. The dark augite-bearing rocks, which probably include all other sills, are similar in composition to the unnamed volcanic rocks. These dark augite-bearing rocks are probably genetically related to the younger volcanic rocks and are tentatively assigned an Oligocene age, though they may be younger.

HYDROTHERMALLY ALTERED ROCKS

In the northern part of the Hobart quadrangle, some of the sedimentary and volcanic rocks have been so completely altered by hydrothermal solutions that the characteristics of the original rock are indeterminable. These rocks are composed of clay, quartz, and iron oxide minerals and were mapped separately as hydrothermally altered rocks (pl. 1) in three areas between the north peak of South Tiger Mountain and the north boundary of the Hobart quadrangle. The rocks consist chiefly of microcrystalline silica intergrown with clay (generally kaolinite) and impregnated with limonitic and hematitic iron. The iron oxides cement the quartz and clay along a network of intersecting veinlets. Between the veinlets, the rock is white to shades of red, yellow, and brown. Concentric bands of color are common. The dip of the strata is usually obliterated, and outcrops are commonly brecciated. A broad transition zone generally occurs between hydrothermally altered rock and unaltered rock.

Where rocks of different compositions lie next to each other, hydrothermal alteration was locally very selective. An example of this can be seen on the south slope of Tiger Mountain, where molds and casts of marine mollusks in the Raging River Formation are well preserved in a moderate-red fine-grained rock that is otherwise highly altered. Seemingly fresh unaltered sandstone and siltstone of the Tiger Mountain Formation lie directly above the altered rock in the Raging River Formation; west of the unaltered Tiger Mountain rocks, the strata are completely altered to siliceous, argillaceous, and ferric minerals. The clay matrix of the sandstone beds in the Tiger Mountain Formation contains kaolinite rather than montmorillonite or chlorite, which are common elsewhere; thus, the effects of hydrothermal alteration may be present although not megascopically apparent. The Tukwila Formation in the Tiger Mountain area has been altered to an unusually fine textured yellow to brownish-gray rock that resembles porcellanite. Fossil leaf impressions are locally well preserved in the porcellanitelike rock, but stratification and minor lithologic differences are obscure.

Another example of selective alteration is seen in the excellent exposure in the SW¼SE¼ sec. 34, T. 22 N., R. 7 E., where an altered sill intrudes the Big Elk coal bed. The sill, 5–8 feet thick, generally follows the bedding of the coal but locally cuts across the bedding (fig. 15). It is very light gray to yellowish gray and has been completely altered to a mass of kaolinite, quartz, brown veinlets of limonite, dispersed crystal pods of calcite, and radiating fibrous crystal aggregates of dawsonite. (Dawsonite was identified by A. J. Gude, 3d, written commun., 1963). The original crystal texture of the sill has been obliterated. The coal, on the other hand, is fresh and unaltered, except in a zone 1–3 inches thick bordering the sill where the coal is altered to ash and coke. Baking of the coal next to the sill probably resulted in production of volatile organic compounds that reacted chemically with the sill and caused its alteration before it could crystallize. The altered igneous intrusion in the Taylor coal field that was mined as a source of clay (Glover, 1941, p. 122) was probably similar to the sill at the Bik Elk coal bed.

Igneous-rock alteration similar to that at Sugarloaf Mountain was observed on a prominent high ridge a short distance east of the axis of the Taylor syncline, near the center of sec. 3, T. 22 N., R. 7 E. This may be the "intrusive dike" mentioned by Evans (1912, p. 136–138) which closely follows the No. 1 coal bed and at times seems to have destroyed the coal. Evans (1912, p. 141) stated:

> Some of the intrusive dikes and sills have decomposed in place, and the resulting material is used extensively in the factory for manufacturing various wares.

FIGURE 15.—Igneous sill intruded into the Big Elk coal bed, SW¼SE¼ sec. 34, T. 22 N., R. 7 E. The sill overlies the Big Elk coal bed beside which the man is standing. Arrow points to the coal ash and coke that forms the light-colored band below and parallel to the sill.

The dikes and sills are further described by Glover (1941, p. 122), who stated:

> A 22-foot rhyolite sill, completely altered, was formerly mined on the west side of the syncline. This clay was called "Taylor White," and was mined from two drifts for 2,600 feet on one level and for 6,800 feet on a lower level. A large amount of this clay probably still lies along the strike of the sill, so that a demand for material to be used with ball clay for common whiteware could be met.

In describing a sample of the altered rock, Glover continued:

> Kaolinization has not progressed to the colloidal, unctuous state found in some of the eastern Washington residual clays, and so the material is mealy, crumbles easily, and is very hard feeling. It is composed of partly altered feldspar, quartz, some white mica, and a small amount of calcite. Extensive leaching has removed the femic minerals and their alteration products. Some samples are so homogeneous that component minerals are recognized with difficulty.

STRUCTURE

Although the major physiographic regions of western Washington—the Olympic Mountains, the Puget Sound lowland, and the Cascade Range—are distinctive and easily recognized (Fenneman, 1931, p. 422–458), the regional structure is somewhat obscure. The Olympic Mountains on the west represent the structurally high Olympic uplift (Cohee, 1961) in which pre-Tertiary (?) rocks are flanked on the north, east, and south by a thick sequence of Tertiary volcanic and sedimentary rocks. The Puget Sound lowland is a region of folded Tertiary rocks overlain by Pleistocene drift that was labelled the Puget downwarp by Cohee (1961). However, such a classification depends upon the part of the adjacent mountain areas with which it is compared. The northern section of the Cascade Range consists of northwest-trending pre-Cenozoic metamorphic rocks and Cenozoic plutonic rocks (Huntting and others, 1961). A few miles south of U.S. Highway 10, across Snoqualmie Pass, the Cascade Range consists chiefly of a thick pile of folded Cenozoic volcanic rocks and small areas of Cenozoic sedimentary and plutonic rocks. The area described in this report is adjacent to the western margin of the Cascade Range, opposite the zone in which the character of the range changes (fig. 16).

The Puget Sound lowland includes three gravity lows alined along a north-south trend, the middle one of which centers near Seattle (fig. 16). An area of higher gravity lies southwest of Seattle between the middle and southernmost gravity lows, approximately due west of the area of this report. The gravity contours in this area trend in a west-northwest direction and correspond, in general, to the trend of the upland area which extends west from Tiger Mountain to the Newcastle Hills. Weaver (1916, p. 150–108) described the structure of the upland area and referred to it as the Newcastle Hills anticline. He speculated that the south side may be bounded by a fault, a possibility that seems to be strengthened by the northwest dip which is visible in a rock quarry in the Tukwila Formation on Squak Mountain, about half a mile north of the Maple Valley quadrangle. The trends of the gravity contours and the speculative fault correspond in a general way to the trend of the hinge line that separates the two areas of different subsidence rates. North of this hinge line rocks of middle and late Eocene age may be more than twice as thick as to the south. When projected east-southeast, the hinge line seems to correspond approximately to the boundary between the northern and southern parts of the Cascade Range. If these speculations are meaningful, the west-northwest trend may reflect a major structure dating back at least to Eocene time.

Small folds and faults are common in the Cumberland, Hobart, and Maple Valley quadrangles and tend to obscure the regional pattern as outlined above. The rocks are deformed into a series of anticlinal and synclinal folds whose flanks generally dip 30°–60° and are locally vertical to overturned. The map distance between the axes of adjacent anticlines and synclines generally ranges from ¼ to 2 miles. Most of the folds trend approximately north, and many of the faults trend northwest.

Taylor Mountain area.—The northwest-trending Taylor syncline, on the south side of Taylor Mountain, plunges to the southeast before being concealed beneath Quaternary deposits. The northeast flank of the syncline is relatively gentle and can be mapped continously across Taylor Mountain, as shown by the trace of the sandstone marker beds in the Tukwila Formation; the southwest flank is steep and is locally overturned. About half a mile southwest of the axial trace of the Taylor syncline is the axial trace of the Sherwood anticline, exposed in the banks of Webster Creek. The approximate position of both the Taylor syncline and the Sherwood anticline can be identified nearly 2 miles northwest of Taylor by the strike and dip of beds in the Tukwila Formation.

Tiger Mountain area.—A synclinal structure on the south side of Tiger Mountain plunges to the southwest and may be a continuation of the Taylor syncline. An anticlinal axis about half a mile to the west, near the crest of Tiger Mountain, may be a northward continuation of the Sherwood anticline, although the axial trace was mapped for only a few thousand feet. The Tiger Mountain fault is inferred to be west of the crest of Tiger Mountain in order to account for the apparent

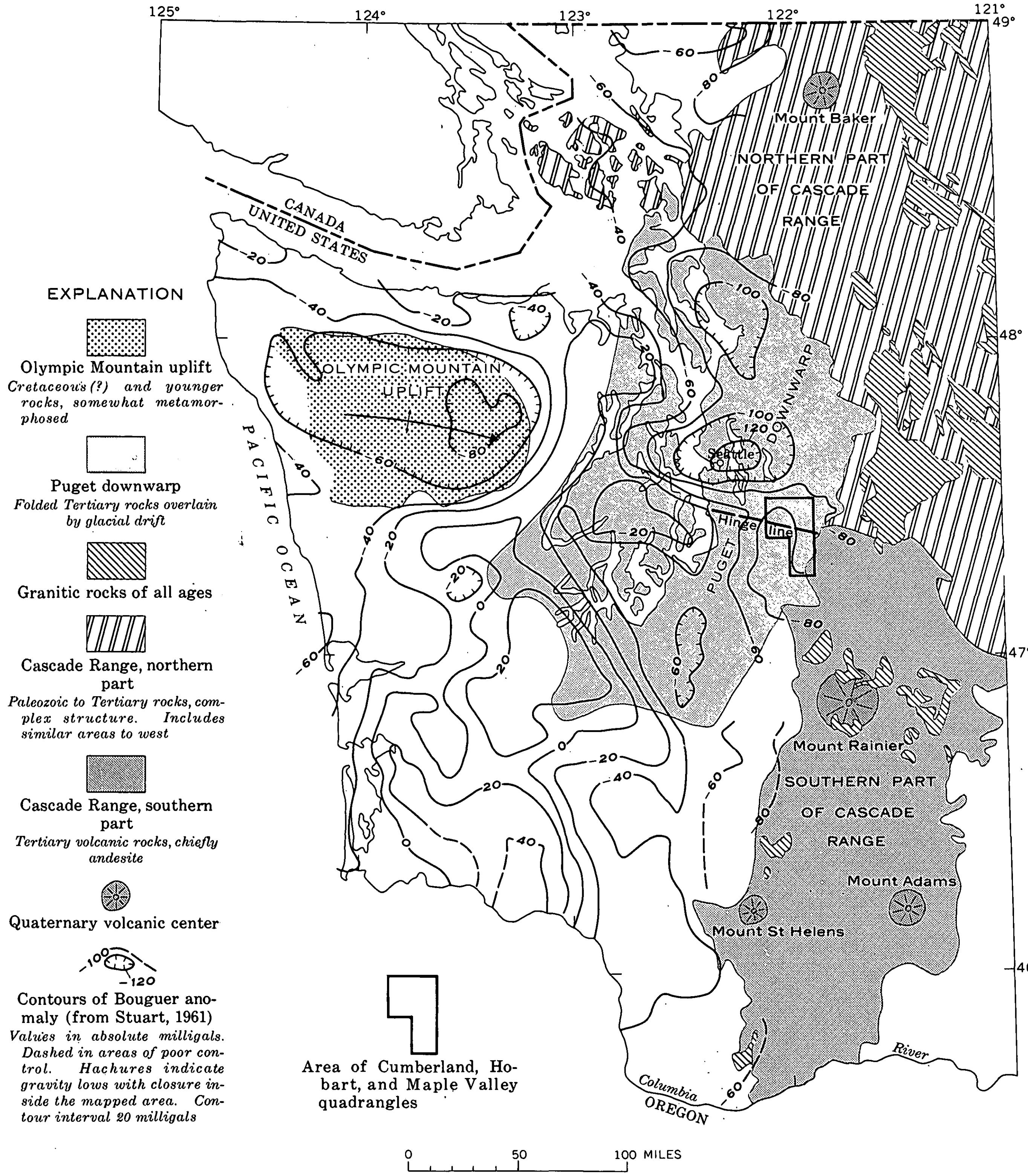

FIGURE 16.—Major tectonic provinces and gravity in western Washington. Geology modified from Huntting, Bennett, and Livingston (1961).

4,000 feet of stratigraphic displacement between the Raging River Formation in the NW¼ sec. 17, T. 23 N., R. 7 E., and the Renton Formation, less than a mile to the west. A faulted anticline is inferred to underlie the Quaternary deposits in the Raging River area, and the trend of the structure is inferred to be parallel with the valley, although only one outcrop on the east side of the valley shows a reversal in dip. The anticline is assumed to be faulted because of the structurally low position of the outcrop on the east side of the valley.

Holder Creek area.—The Hobart fault is inferred to account for (1) the lack of continuity of the coal bed exposed in a prospect on the south side of Holder Creek, (2) the possible duplication of tuff-breccia beds exposed on Holder Creek below the coal prospect and those along the west flank of South Tiger Mountain, and (3) the absence of the Renton Formation in outcrops on the southwest side of the Sherwood anticline. The fault on South Tiger Mountain is inferred to explain the abrupt change from unaltered intrusive and volcanic rock on the south to hydrothermally altered rock on the north.

Fifteenmile Creek area.—Mine maps of the abandoned coal workings on Fifteenmile Creek indicate a number of east-trending faults of a few feet displacement. At least one fault is clearly visible in the canyon walls. The abrupt termination of the Renton Formation to the north is apparently due to a major east-west fault that has dropped the Renton Formation into juxtaposition with the Tukwila Formation, but the displacement is unknown.

West Tiger Mountain–Squak Mountain area.—Although only one bedding attitude was recorded on the south slope of West Tiger Mountain, the Tukwila Formation dips uniformly about 35° NW. A major fault probably separates the West Tiger Mountain area from the exposures in Fifteenmile Creek to the south. This fault probably joins with, or is a continuation of, the major structural feature that is the south boundary of Squak Mountain, as previously mentioned.

Cedar Mountain area.—Because of the mantle of Quaternary deposits, the bedrock structure of the lowland area west of the Tiger Mountain–Taylor Mountain upland is mostly unknown, except in the Cedar Mountain coal field, where both outcrops and underground mine workings have provided detailed information. Outcrops along the Cedar River show erratic strike and dip, especially near collapsed strata overlying coal beds. Strata in the main haulage way of the Cedar Mountain mine show a fairly uniform dip of about 22° SE., but the strike swings from about east, under the river, to south, east of the river, indicating the plunging nose of an anticline. Workings in the New Black Diamond mine and nearby mines north of Lake Desire show a range in dip from about 25° to 45° SE. and a large number of northwest-trending faults of small displacement. The mine area north of Lake Desire is probably separated from the area near the Cedar River by a major northwest-trending fault or a series of faults, although the displacement cannot be determined because of the uncertainty in correlating coal beds from one side of the fault to the other. The area between Cedar Mountain and Squak Mountain is possibly underlain by a large syncline.

Green River area.—In the canyon of the Green River is a continuous sequence of north-trending folds, some of which can be traced for several miles. The Lawson anticline, near the center of the Cumberland quadrangle in sec. 8, T. 21 N., R. 7 E., is structurally the highest point in the area; yet the fold itself is a rather narrow one. Strata are exposed that are probably as much as 1,850 feet below the Franklin No. 9 coal bed. The east flank dips about 30°–40°, and the west flank dips about 80°, indicating that the axial plane dips to the east. The thickness of Eocene strata underlying those exposed in the canyon is unknown. A minor syncline and anticline separate the Lawson anticline from the Kummer syncline, which lies about 2 miles to the west. These minor folds plunge southward and have east-dipping axial planes. The Kummer syncline is a large downwarp whose axis plunges to the south and is offset south of Black Diamond by the northwest-trending Franklin fault, a strike-slip fault with about 1,000 feet of right-lateral displacement. The location and displacement on this fault are well documented from exposures in the coal-mine workings on both sides of the fault and on both flanks of the syncline. To the north the Kummer syncline is cut off near Lake No. 12 by two northwest-trending normal faults; the rocks on the south side of each fault are downdropped. The southern fault is vertical and has a throw of about 750 feet; the northern fault dips about 65° S. and has about 500 feet of throw.

Ravensdale-Georgetown area.—A series of anticlinal and synclinal folds plunges northwest near the Ravensdale fault, which trends generally westward. North of the fault the folds plunge northwest beneath Quaternary deposits. At Georgetown a northwest-trending fault was found in mining the Ravensdale No. 5 coal bed. This fault is inferred to extend northwest, thus explaining the apparent large left-lateral displacement between the Ravensdale coal beds and approximately equivalent beds in the Georgetown and Landsburg area. Neither the magnitude nor the direction of displacement along this fault could be determined, however. North of Georgetown the strata are steeply dipping to overturned toward the northwest. None of the coal beds have been traced north of the Cedar River. The beds in the single outcrop of unnamed volcanic rocks exposed along the Cedar River about a 1½ miles northwest of Landsburg have a northwest strike and a northeast dip, suggesting that a large syncline may lie north of the river.

Sugarloaf Mountain area.—The folds in the Sugarloaf Mountain area northwest of Kanaskat trend generally northwest and are broken by several faults which also trend north or northwest, but neither folds nor faults can be traced into adjacent areas.

Durham area.—The upland east of Sugarloaf Mountain, in the Durham area, forms the west margin of the Cascade Range, where the rocks in the Puget Group are last exposed before dipping beneath the unnamed volcanic rocks to the east. Overturned strata near Durham are probably in limbs of drag folds on the east side of a reverse fault which strikes north and dips east. South of Durham the Green River fault is inferred to explain an apparent right-lateral offset of the contact across the canyon between the Puget Group and the overlying unnamed volcanic rocks about 1 mile east of the Cumberland quadrangle. If the movement on this fault has been horizontal, the south side has moved nearly 3,000 feet to the west. If the movement has been vertical, the south side has been downdropped about 1,400 feet. The northwestward continuation of the Green River fault is uncertain, but this fault may be continuous with the large fault at Georgetown. If the movement has been horizontal, the thick section of overturned Puget near Landsburg may have resulted from drag along the south side of the fault.

Cumberland-Bayne area.—A series of rather small asymmetric folds plunges southward east of the Lawson anticline and south of the Green River. Many of these folds are broken by northwest-trending faults on which the exact displacements are not known. The apparent large lateral offset of the contact along the northwest-trending fault west of Walker Lake may be real, or it may in part reflect a miscorrelation of beds on opposite sides of the fault. As mapped, this fault has an apparent throw of about 750 feet.

Although ultimately related to such regional tectonic features as the Olympic uplift, the Puget downwarp, and the Cascade Range, individual structural features in the Cumberland, Hobart, and Maple Valley quadrangles present a rather bewildering structure pattern. This is partly because extensive Quaternary deposits conceal many critical areas and also because the folding is superimposed on a complexly interstratified sequence of volcanic and sedimentary rocks. Although the local offsetting of folds by faults suggests that the faults are younger, both features probably developed during one major period of orogeny, during which both Eocene and younger rocks were deformed. The age of this orogeny can be bracketed from evidence in adjacent areas. Warren, Norbisrath, Grivetti, and Brown (1945) followed C. E. Weaver in assigning an early Miocene age to the upper part of the marine rocks exposed in a roadcut of U.S. Highway 10 in sec. 13, T. 24 N., R. 5 E., near the south end of Sammamish Lake. These marine rocks dip northward and are apparently parallel with the underlying Puget Group rocks; so it may be assumed that these marine rocks are involved in the principal folding. The gently tilted unconsolidated sediments that unconformably overlie the Puget Group at Hammer Bluff, along the Green River about 1½ miles west of the Cumberland quadrangle, were described by Mullineaux, Gard, and Crandell (1959) as being of probable late Miocene age. Although the ages of these deposits were not verified during the present study, they seem to indicate an early or middle Miocene age for the major folding in the area.

ECONOMIC GEOLOGY

CLAY DEPOSITS

A variety of rocks from this area, ranging from altered igneous rock to glacial clay, have been used in the manufacture of different kinds of brick, sewer pipe, and refractory ware. The largest sources of clay are the Renton Formation and the upper part of the undifferentiated Puget Group. A few miles west and northwest of the mapped area, at Renton and Newcastle, International Pipe & Ceramics Corp. and Builders' Brick Co. were operating plants in 1962, utilizing source materials from the Renton Formation. The fine-grained rocks in the Renton Formation commonly contain kaolinite as the principal clay mineral; the older rocks in the Puget Group contain a variety of other clay minerals, many of which are not satisfactory for the manufacture of baked clay products because of low fusion temperatures, undesirable swelling characteristics, poor color, or other properties.

Many of the commercial clay deposits in this area are described in a comprehensive report by Glover (1941). Much additional information on high-alumina clay deposits is available in a report by Nichols (1946). Table 7 presents a summary of information on the clay deposits in this and adjoining areas and includes much data obtained from these two sources. Though the report by Nichols (1946) is concerned with the potential of high-alumina clay deposits as ore for metallic aluminum, these same deposits may be valuable as a source of refractory clay. Kaolinite, boehmite, and gibbsite, which are the principal "ore" minerals, are also the principal ingredients of refractory clay. Most of these deposits also contain variable amounts of siderite grains 1–2 mm long imbedded in the clay. The siderite detracts from the value of these deposits but can be easily removed from the clay in a laboratory magnetic separator, which suggests the possibility of beneficiating the clay on a commercial scale. Nichols (1946, table 12) estimated the clay resources to be about 20 million tons.

Perhaps the most abundant and most suitable sources of clay for nonrefractory wares are the siltstone, claystone, and carbonaceous shale that are interbedded with coal in the Puget Group, especially in the upper part. Kaolinite is a waste product of the glass-sand industry in this area. Sandstone mined in sec. 30, T. 21 N., R. 7 E., is washed to remove the silt and clay; tailings from this process might be suitable for clay products. Another deposit of friable sandstone with a kaolinite clay matrix similar to that used for making glass occurs adjacent to an igneous sill in the Fifteenmile Creek area, NW¼ sec. 13, T. 23 N., R. 6 E.

Kaolinite is one of the principal products of the hydrothermal alteration in the Tiger Mountain area, and many of the volcanic and sedimentary rocks adjacent to the mapped area of hydrothermally altered rock have also been kaolinized. For example, the matrix of the rocks in the Tiger Mountain Formation in the NW¼ sec. 17, T. 23 N., R. 7 E., has a much higher proportion of kaolinite to other clay minerals than do equivalent rocks elsewhere, but the Tiger Mountain Formation does not have the altered appearance of adjacent rocks in the Raging River and Tukwila Formations. Locally, as on the north side of South Tiger Mountain, the hydrothermally altered rocks are bleache, which suggests that much of the iron and other soluble

TABLE 7.—*Clay deposits in the Cumberland, Hobart, and Maple Valley quadrangles and adjacent areas.*

Deposit or area	Location	Stratigraphic position	Type	Reference, resource data, and notes
Harris mine	SE sec. 32, T. 24 N., R. 6 E	Base of Renton Formation below Jones coal bed.	Claystone, carbonaceous, gray, semiflint, partly refractory; slacks readily; contains kaolinite and siderite.	Deposit described as variable in thickness and composition (Nichols, 1945; Glover, 1941, p. 120) (International Pipe. & Ceramics Corp. mine).
Tiger Mountain area	SW sec. 9, T. 23 N., R. 7 E	Top of Raging River Formation	Claystone, silty, dark-gray, semiflint; slacks readily; contains mixed-layer clay minerals.	International Pipe & Ceramic Corp. prospect.
Cedar Mountain area	NW sec. 29, T. 23 N., R. 6 E	Upper part of Renton Formation above the A coal bed.	Claystone, silty, dark-gray, semiflint, slacks readily; contains kaolinite; has bloating characteristics.	Exploration work by Hecla Mining Co.
Cedar Mountain area	NE sec. 30, T. 23 N., R. 6 E	Renton Formation above No. 2 coal bed.	Foundry sand consisting of a mixture of clayey sandstone, siltstone and claystone.	Cavanaugh Molding Sand Co.
Taylor area	Sec. 3, T. 22 N., R. 7 E	Renton Formation, clay beds overlying the No. 1, 2, and 6 coal beds.	Claystone, carbonaceous, dark-gray, semiflint; slacks readily; probably contains kaolinite.	Described by Glover (1941, p. 122–128). Mines abandoned.
Taylor area	Sec. 3, T. 22 N., R. 7 E	"Taylor white" or "Taylor purple" intrusive igneous rocks.	Hydrothermally altered igneous sills; probably contains kaolinite.	Described by Glover (1941, p. 122–124). Mines abandoned.
Durham area	Secs. 35, 36, T. 22 N., R. 7 E., secs. 1, 2, T. 21 N., R. 7 E.	250 to 900 feet below top of Puget Group undifferentiated.	High-alumina flint clay; contains kaolinite and boehmite; in part refractory.	2,450,000 tons (dry) [1] (Nichols, 1945).
Kanaskat area	Sec. 12, T. 22 N., R. 7 E	350 ft below top of Puget Group undifferentiated.	High-alumina flint clay; contains kaolinite; in part refractory.	301,000 tons (dry) [1] (Nichols, 1945).
Kangley area	Sec. 26, T. 22 N., R. 7 E	500 ft below Kangley coal	High-alumina flint clay	Nichols (1945).
Kummer area	E½ sec. 26, T. 21, N., R. 6 E	About 1,200 ft below top of Puget Group undifferentiated below the Kummer 0 coal bed.	High-alumina flint clay; contains kaolinite, gibbsite, and siderite; in part refractory.	Described by Glover (1941, p. 128–133) and Nichols (1945).
Blum deposit	W½ sec. 31, T. 21 N., R. 7 E., NE sec. 36, T. 21 N., R. 6 E.	About 1,200 ft below top of Puget Group undifferentiated below Kummer 0 coal bed.	High-alumina flint clay; contains kaolinite and gibbsite; slacking; in part refractory.	1,044,000 tons (dry) [1] (Nichols, 1945).
Stanridge Hill	W½ sec. 6, T. 20 N., R. 7 E	Top of Puget Group undifferentiated.	Flint clay, dark-gray, contains kaolinite and montmorillonite, but is low refractory.[2]	Exposed in road cut of SE 392d Street.
Palmer Junction area	NW sec. 14, T. 21 N., R. 7 E	Unnamed upper Tertiary deposit.	Clay, carbonaceous, contains woody lignite fragments.	Described by Glover (1941, p. 150–151).
Palmer Junction area	W½ sec. 14, T. 21 N., R. 7 E	Upper part of Puget Group undifferentiated.	Flint clay, dark-gray; contains kaolinite and siderite.	
Bayne area	SE sec. 15, T. 21 N., R. 7 E	Puget Group undifferentiated	Shale, carbonaceous, sandy, dark-gray.	Described by Glover (1941, p. 134).
Ravensdale	SW sec. 36, T. 22 N., R. 6 E	do	Burned waste from abandoned coal tipple.	Used by International Pipe & Ceramics Corp., probably for grog.
Sugarloaf Mountain area	SE sec. 34, T. 22 N., R. 7 E	Puget Group undifferentiated at the Big Elk coal bed.	Waste from abandoned coal tipple	Used by International Pipe & Ceramics Corp.
Franklin mine area	NE sec. 18, T. 21 N., R. 7 E	Puget Group undifferentiated directly below No. 12 coal bed.	Siltstone; tests show possible use as a bloating clay.	
Unnamed prospect	NW sec. 30, T. 21 N., R. 7 E	Puget Group undifferentiated 500 ft above Gem coal.	Friable sandstone containing kaolinite clay matrix.	Possible source of clay by washing the sandstone. Palmer Coking Coal Co., Inc.

[1] Measured and indicated resources calculated on the basis of 25.5 percent or more available Al_2O_3, but less than 20.3 percent available Fe_2O_3, and making conservative assumptions regarding continuity of the deposit downdip.

[2] A sample (field No. V-23C) was tested by the U.S. Bur. Mines and was rated as low refractory on the basis of a cone test (PCE 23).

minerals have been removed. The resulting kaolinite-rich rock may well be suited for some kinds of ceramic ware.

In recent years interest in using the so-called bloating clays for the manufacture of lightweight or "expanded" aggregate has been increasing. These clays swell or become frothy during the baking process as a result of the emission of gases from carbonaceous matter or from certain minerals. Unfortunately, the desirable physical properties cannot be judged by the external appearance or by the clay mineralogy of the material because the critical factors include the rate of gas emission, the fusion temperature, and the viscosity of the partly fused rock. These properties can be best determined by appropriate testing in a laboratory furnace. Harris, Strandberg, and Kelly (1962) described the results of such tests on samples from western Washington and indicated that material from the Renton Formation in the Cedar Mountain area is suitable for the manufacture of lightweight aggregate. However, the material from the Cedar Mountain area cannot be processed to the extremely low bulk densities necessary to make it competitive with other sources.

Most of the clay deposits that have been used locally for the manufacture of baked-clay products are nonmarine and nonvolcanic in origin. The marine rocks and volcanic rocks are generally low in kaolinite, but some may have qualities useful in the clay industry. The mineral composition of a sample of marine claystone from a prospect pit of the International Pipe & Ceramics Corp. (table 1, sample 63) suggests that although it may not be suitable for many special products, this claystone is probably satisfactory for some products and has the advantage of uniformity and accessibility. The presence of sufficient carbonaceous matter and fine-grained pyrite suggests that this claystone has some potential as a bloating clay.

A sample of light-yellowish-gray siliceous claystone that resembles diatomite but probably is an altered tuff from the Tukwila Formation in the SE¼NW¼ sec. 27, T. 23 N., R. 7 E., was submitted to the U.S. Bureau of Mines in 1959 for routine clay testing. The cone test on the sample (No. AW–1) showed a light fired color (tan) and a low refractory rating (PCE 23–26). A differential thermal analysis of the clay indicates a medium kaolinite or halloysite content. A duplicate sample (H–70A) collected in 1960 for X-ray diffractometer analysis contained mostly quartz. Only a small proportion of the duplicate sample was in the $< 2\ \mu$ size range, and the X-ray pattern showed an unusually broad weak peak with a gradual rise from about 6 A to a point at 15 A. On the glycolated sample, a separate peak occurred at 17 A, which indicated the presence of montmorillonite; and a broad secondary peak occurred between 7 and 8 A, which may explain the earlier Bureau of Mines analysis for halloysite or poorly crystallized kaolinite. Although the duplicate sample only represents a 2-foot-thick bed, similar results were obtained from other samples of altered tuff and fine-grained tuffaceous siltstone beds in the Tukwila Formation in both the Tiger Mountain and the Taylor Mountain areas. More testing is needed on this type of rock to determine its suitability for the manufacture of clay products.

SAND AND GRAVEL DEPOSITS

The mantle of glacial drift that covers most of the Cumberland, Hobart, and Maple Valley quadrangles provides a large supply of sand and gravel. The materials range widely in size and degree of sorting. Till, especially in ground moraines, tends to be well indurated because it was compacted under a heavy load of ice and contains silt and clay. The till would be difficult to excavate with light power equipment because it contains many large boulders imbedded in a compact clay matrix. Till is commonly used as fill in road construction and in other places where the size of the boulders is relatively unimportant. Deposits of glacial outwash or terrace gravel are generally used when washed and graded sand or gravel is desired. However, some of the terrace gravel deposits mapped in this area are composed chiefly of well-sorted cobbles and boulders too large for concrete mix and similar uses, unless the boulders are crushed. If sand and pebble-size material is required, exploratory excavations should be made to assure an adequate supply of the desirable sizes. Gravel deposits composed of outwash glacial drift generally have many different layers and lenses that range in composition from mostly sand to mostly cobbles. The principal gravel quarries in this area that were being actively mined in 1961 are listed in table 8.

Drift deposits of pre-Vashon age along the lower slopes of the valley of the Cedar River downstream from Maple Valley provide a source of relatively clean medium-grained sand. These deposits are overlain by younger till and outwash; hence, only limited quantities

TABLE 8.—*Sand and gravel quarries in the Cumberland, Hobart, and Maple Valley quadrangles*

Name	*Location*
1. Western Sand & Gravel Co	NE¼SE¼ sec. 16, T. 22 N., R. 6 E.
2. .....do	NE¼ sec. 32, T. 23 N., R. 6 E.
3. King County Highway Department	SE¼NE¼ sec. 17, and SW¼NW¼ sec. 16, T. 23 N., R. 6 E.
4. Seattle Cedar River watershed	SW¼ sec. 14, T. 23 N., R. 7 E.
5. Smith Brothers Silica Sand Co., Inc	SE¼NW¼ sec. 30, T. 21 N., R. 7 E.
6. Stoneway Sand & Gravel Co	NE¼SE¼ sec. 23, T. 23 N., R. 5 E.

of the clean sand are obtainable without removing overburden. Deposits of sandy stratified glacial drift are also exposed at many places along the new highway that follows the valleys of Holder Creek and Deep Creek (fig. 13). Fine sand and silt is abundant in lacustrine deposits in the valley of Issaquah Creek near Hobart. Except for local concentrations of coarser grained sand, most of these deposits are too fine grained for commercial-grade sand.

Sand suitable for the manufacture of amber glass is mined from an open pit in the SE¼NW¼ Sec. 30, T. 21 N., R. 7 E., by the Smith Brothers Silica Sand Co. In 1962 the company opened a pit in a friable massive sandstone zone in the upper part of the undifferentiated Puget Group. The rock is a very light gray medium- to coarse-grained arkose comprising about two-thirds quartz, one-third potash-feldspar, and minor lithic fragments. The matrix makes up about 10 percent of the rock and is chiefly silt-size quartz grains and kaolinite.

CONSTRUCTION STONE

The nearness of the mapped area to metropolitan Seattle makes it economical to quarry stone for a variety of construction purposes. A good local market exists for stone ranging from fine aggregate for use in road construction to riprap for use in retaining walls, erosion-abatement fill, and fill for dams and other engineering works. Relatively fresh intrusive or volcanic rocks, especially lava flows and tuff-breccias, have been used for decorative garden stone. In 1961, garden stone and broken rock were quarried from a greenish-gray tuff-breccia bed in the Tukwila Formation in the SE¼ sec. 6, T. 23 N., R. 6 E., about half a mile north of the Maple Valley quadrangle. The greenish-gray porphyritic hornblende andesite in the canyon of Issaquah Creek might also be suitable for garden stone. Rock in other igneous sills in the mapped area may have value as construction stone, but its darker color may detract from its decorative value. These include the massive sill near the head of Fifteenmile Creek, the sill near Cedar Mountain, the sills that intrude the Raging River Formation, a grayish sill that weathers red near Palmer Junction, several sills in the canyon of the Green River, and the sill at Sugarloaf Mountain.

Sedimentary rock, especially sandstone, is usually preferred for dimension stone because of the greater ease with which it can be split parallel to the stratification and cut in other directions. Large slabs of feldspathic micaceous sandstone were formerly quarried from bed F of the Tukwila Formation in the NE¼ sec. 4, T. 22 N., R. 7 E., adjacent to the abandoned railroad to Taylor. Other suitable sandstone can probably be obtained from the Raging River Formation and the lower part of the Puget Group. Many sandstone beds in the Renton Formation and the upper part of the undifferentiated Puget Group are poorly indurated and too soft for use as dimension stone.

COAL

MINING HISTORY

Coal was first discovered and mined in King County in 1853 near the present site of Renton (Green, 1947, p. 8). This coal was of poor quality, and only a small amount was produced for local use. Coal mining began near Issaquah in 1862 and in Newcastle the following year (Evans, 1912, p. 239). By about 1880 coal was mined in the Cedar Mountain area, and in 1930 a peak production of 349,000 tons of coal was reached. Between 1880 and 1944, the last year of recorded production, the Cedar Mountain area produced about 4 million tons of coal. Production in the Tiger Mountain area began in 1891 (Evans, 1912, p. 134), and from 1905 to 1940, the last year of recorded production, about 640,000 tons of coal was mined. Production figures are not available for the years before 1905.

The first recorded mining in the Green River district was at Black Diamond in about 1883. The Green River district has produced about 25 million tons of coal—more than half the total King County production. Although most of the Green River district lies in the Cumberland quadrangle, a significant amount of this production has come from mines in the McKay coal bed directly west of the mapped area. Annual production in the Green River district reached a high of 925,000 tons in 1903. Production has declined almost continuously since that date, and current annual production is only about 50,000 tons.

Most of the coal produced in the area of this report has been mined underground. Both drift, or "water-level" and slope mines have been used. Drift mines are self-draining mines in which the lowest point in the mine is the portal. Many mines were started as drift mines and later, when all coal above the level of the portal had been extracted, were converted to slope mines. In slope mines, gangways along the strike of the coal bed are driven off the main slope at different levels. These mines are troubled by water seepage and require continuous pumping to remove excess water. Evans (1912, p. 201–216) described in detail the methods used in specific mines. Table 9 lists the coal mines and prospects in the report area.

TABLE 9.—*Coal mines and prospects in the Cumberland, Hobart, and Maple Valley quadrangles*

[Compiled from published references, unpublished mine maps, and field investigations]

No. (pls. 1, 3)	Mine or prospect	Location of portal				Coal bed
		T. (N.)	R. (E.)	Sec.	Fraction sec.	
1	Abandoned slope mine	21	7	8	NW¼	Franklin No. 10.
2	Anderson mine	21	6	1	NE¼	Sunshine (Dale No. 7).
3	Black Beauty and Okay mines.	21	7	8	NW¼	Franklin No. 10 and Black Beauty.
4	Black Diamond mine	21	7	7	SE¼	McKay.
5	Black Knight mine	22	6	36	SE¼	Black Knight.
6	Blue Blaze mine	21	6	36	NE¼	Kummer No. 1(?).
7	Boldes Carbon mine	21	7	22	NE¼	Carbon.
8	Boldes No. 3½ mine	21	7	22	SW¼	Unknown.
9	Cannon mine	21	7	19	SW¼	McKay and Gem.
10	Carbon mine	21	7	15	SW¼	Little Carbon and Big Carbon (Carbon).
11	Carbon No. 3 mine	21	7	22	SW¼	Eureka No. 3.
12	Cashman prospect	22	7	33	NE¼	Cashman.
13	Cedar Mountain mine	23	6	29	NW¼	Cedar Mountain No. 1 and Bed A.
14	Dale mine	22	6	36	SW¼	Dale Nos. 4 and 7.
15	Daly mine (Bayne mine)	21	7	22	NW¼	Bayne Nos. 1, 3, and 5.
16	Danville No. 1 mine	22	6	24	SW¼	Frazier.
17	Danville No. 2 mine	22	6	24	SE¼	Eight-foot, Six-foot, and Landsburg No. 1.
18	Davis prospect	21	7	14	NW¼	Davis.
19	Durham mines	21	7	2	NW¼	Durham Nos. 1 and 2.
20	Elk mines	22	7	34	SE¼	Big Elk, New Elk, and Little Elk.
21	Elk prospects	22	7	34	SW¼	Big Elk(?) and Lower Elk.
22	Eureka mine	21	7	21	SE¼	Eureka Nos. 1, 2, and 3.
23	Eureka-Navy mine	21	7	21	SE¼	Unknown bed.
24	Franklin-Gem mines	21	7	18	NE¼	Gem.
25	Franklin mines	21	7	18	SE¼	Franklin Nos. 9, 10, 11, and 12, McKay, and Gem.
26	Gem prospect	21	6	13	SW¼	Gem.
27	Ginder Lake mine	21	6	12	NW¼	McKay.
28	Green River mine	21	6	36	SE¼	Kummer No. 4(?).
29	Hiawatha tunnel	22	7	35	SW¼	Long Rock tunnel, Upper Mammoth, Hiawatha, and several other beds.
30	Hi Heat mine	21	7	8	SW¼	Franklin No. 10.
31	Hudson prospects	21	7	14	NE¼	Pocahontas and Hudson No. 1 beds.
32	Independent mine	21	7	33	NW¼	Independent No. 6.
33	Kummer mine	21	6	26	NE¼	Kummer Nos. 1, 2, 3½, and 4.
34	Kummer No. 4 prospect	21	6	25	NW¼	Kummer No. 4.
35	Lawson mine	21	6	13	NW¼	McKay.
36	Lizzard Mountain prospect.	21	7	21	NW¼	Unnamed bed.
37	Markus prospects	21	7	4	NW¼	Several bony coal beds.
38	McIntyre prospect	22	7	28	SE¼	McIntyre.
39	McKay mine	21	6	1	NE¼	McKay.
40	National Development Co. mine.	22	7	10	NW¼	Unnamed bed.
41	Navy mine	21	7	28	NW¼	Navy Nos. 4 and 6.
42	New Black Diamond mine.	23	5	25	NE¼	Ryan No. 1, Ryan No. 2, Discovery and Jones (Slope).
43	New Hi Heat mine	21	7	19	NE¼	Franklin No. 10.
44	New Hyde mine	21	7	29	SW¼	Franklin No. 12 and McKay.
45	New Lake Young mine	23	5	36	SW¼	New Lake Young.
46	Niblock prospect	23	7	8	NE¼	Unnamed bed (probably same bed as at the Ruffner prospects).
47	No. 2 mine	21	6	14	NE¼	Franklin No. 12.
48	No. 7 mine	21	7	7	NW¼	McKay.
49	No. 12 mine	21	6	12	SW¼	McKay.
50	No. 14 mine	21	6	14	SE¼	McKay.
51	Northwest Improvement Co. prospect.	23	7	31	NE¼	Unnamed bed (possible equivalent to bed C of Tukwila Formation).
52	Oakdale prospects	22	7	28	S½	Unnamed bed.
53	Occidental mines	21	7	16	SE¼	Occidental Nos. 1, 2, 3, 4, 5, 6, 8, and 14.
54	Occidental No. 14 slope	21	7	16	NE¼	Occidental No. 14.
55	Old Carbon mine	21	7	21	NE¼	Unnamed bed.
56	Old Hyde mine (Rose-Marshall mine).	21	7	29	NW¼	Franklin No. 12 and McKay.
57	Old No. 12 mine	21	6	12	SE¼	McKay.
58	Rainier prospects (sec. 8 prospects).	21	7	8	SW¼	Franklin Nos. 9(?) and 10.
59	Ravensdale mines	22	6	36	SE¼	Ravensdale Nos. 3, 3½, 4, 5, and 9.
60	Raven mines	22	6	36	NE¼	Ryan Nos. 4 and 5.
61	Red Devil mine (Cavanaugh mine).	23	5	26	NE¼	Cavanaugh No. 2.
62	Rogers mine	22	6	24	SE¼	Rogers.
63	Ruffner prospects	23	7	16		Unnamed bed.
64	Section 6 mine	21	7	6	SE¼	McKay.
65	Strain New Franklin mine.	21	7	7	SE¼	McKay.
66	Sunset mine	21	7	33	NE¼	Sunset Nos. 1 and 2.
67	Taylor No. 1 mine (Denny-Renton mine).	22	7	3	SE¼	Taylor Nos. 1, 2, 3, 3½, 4, 6, 7, and 8.
68	Taylor No. 2 mine	22	7	3	SW¼	Taylor Nos. 1, 2, 3½, 4, 5, and 6.
69	Taylor No. 3 mine	22	7	3	NW¼	Taylor No. 0.
70	Tiger Mountain Coal Co. mine.	23	6	13	NW¼	Tiger Mountain Nos. 1, 2, and 3.
71	Tobacco prospect	22	6	25	SW¼	Tobacco.
72	Unnamed mine	23	6	19	SW¼	Discovery.
73	Unnamed mine	21	7	26	NW¼	Unnamed.
74	Unnamed mine	23	6	30	NE¼	Cedar Mountain No. 2.
75	Unnamed prospect	23	7	28	NW¼	Unnamed coal bed (possibly equivalent to bed C of the Tukwila Formation)
76	Upper Diamond mine	21	6	11	SE¼	McKay.
77	Wonder mines	22	7	33	SW¼	Two unnamed beds.

During and shortly after World War II, many of the thicker coal beds in the Cumberland quadrangle were strip mined. One of the largest strip pits was on the Franklin No. 12 coal bed on the east limb of the Kummer syncline (fig. 17). Locally, the McKay coal bed south of the Ravensdale fault and several of the Ravensdale coal beds north of the fault were also strip mined. Other beds strip mined were the Cumberland, Carbon, several of the Occidental coal beds west of Bayne, several beds in the Sugarloaf Mountain area, the Durham No. 1 coal bed, and the Navy Nos. 4 and 6 coal beds. In general, however, coal beds in King County dip steeply, and strip mining is difficult and expensive.

PHYSICAL AND CHEMICAL PROPERTIES

The coal in the Cumberland, Hobart, and Maple Valley quadrangles ranges in rank from subbituminous B to high-volatile A bituminous, according to the classification established by the American Society for Testing and Materials (1966, p. 73). Most of the coal is of high-volatile B bituminous rank. Coal beds that are borderline between the subbituminous and bituminous categories are here included in the bituminous category. An average of the available analyses is given for the coal beds that are bituminous in some localities and subbi-

FIGURE 17.—Strip mine in the Franklin No. 12 coal bed, E½ sec. 18, T. 21 N., R. 7 E. Coal zone is nearly 40 feet thick at arrow.

tuminous in others. Generally, the higher the coal bed stratigraphically, the lower its rank. Thus, all coal beds of the Kummer coal zone in the Green River area are subbituminous, as are those in the Renton Formation except the bituminous coal in the New Lake Young coal bed in the Cedar Mountain area and the coal beds of the Taylor area. All coals for which analyses were not available are assumed to be of bituminous rank.

Averages of analyses of the coal beds are given in table 10. The average ash content of all the coal beds analyzed is about 15 percent. The McKay coal bed has the lowest average ash content, about 4.5 percent; and the Sunset No. 7 coal bed has the highest ash content, 38.5 percent, which is unusually high. Most of the coals analyzed have less than 19 percent ash. The sulfur content is low, ranging from 0.2 to 1.9 percent in individual samples. The average for the coal beds is 0.6 to 0.7 percent sulfur. The moisture content in individual samples ranges from 2.1 to 19.2 percent and averages 8 percent. Volatile matter ranges from 26.4 to 40.3 percent and averages about 35 percent. Fixed carbon in the coal beds ranges from 30.2 to 51.4 percent and averages

TABLE 10.—*Averages of analyses (as-received basis) of coal samples from the Cumberland, Hotart, and Maple Valley quadrangles*

[M, moisture; VM, volatile matter; FC, fixed carbon; Btu, British thermal units. Sources of analyses: U.S. Bur. Mines, 1931, 1941, and 1958]

Coal beds	Proximate (percent)				Sulfur (percent)	Btu	Number of analyses averaged
	M	VM	FC	Ash			
"A" bed o' Elk mine	7.2	34.4	38.4	19.9	0.8	10,420	2
Alta (Big Seam)	4.7	38.0	45.2	12.1	.9	12,420	1
Bayne No. 1	8.7	30.2	41.2	19.0	.5	10,380	1
Bayne No. 3	4.9	33.0	41.0	21.1	.5	10,730	1
Bayne No. 5	5.1	33.8	42.7	18.4	.6	11,060	1
Big Elk	5.7	35.9	42.6	15.6	.6	11,550	1
Carbon	4.6	32.3	51.4	11.7	.7	12,452	3
Cavanaugh No. 2	9.7	40.1	43.7	6.5	.9	11,800	1
Dale No. 4	16.0	32.6	41.8	9.4	.5	9,855	6
Dale No. 7	14.9	32.8	43.0	9.4	.6	10,117	3
Discovery	10.1	34.4	37.1	18.3	.5	9,755	2
Durham No. 2	3.4	31.4	47.8	17.4	.9	11,590	1
Dutch	5.8	31.8	32.9	29.5	.8	9,270	2
Eight-Foot	8.9	38.1	40.3	7.6	.9	12,555	2
Franklin No. 10 (upper bench)	6.4	38.8	40.0	18.5	.6	10,990	2
Franklin No. 10 (lower bench)	5.7	37.2	41.5	15.8	.7	11,355	2
Frazier	15.6	32.5	43.0	8.8	.5	10,860	3
Gem	11.6	34.7	40.8	12.7	.5	11,438	4
Jones	10.8	35.1	40.9	13.3	.4	10,344	9
Kummer No. 1	13.6	31.5	40.3	14.6	.4	9,563	3
Kummer No. 4	18.7	32.7	32.9	15.7	.6	10,360	1
Landsburg No. 1	11.1	37.4	41.3	10.0	.3	10,820	2
Little Elk	5.6	33.7	45.0	15.6	.7	11,285	2
McIntyre	10.5	35.2	42.4	11.9	.4	10,700	1
McKay	11.3	39.6	46.0	4.5	.6	12,070	25
Navy No. 4	5.5	32.5	41.2	21.0	.7	10,820	2
Navy No. 6	5.5	32.7	42.4	19.2	.6	10,905	2
Occidental No. 1	5.2	34.6	47.4	12.6	.6	12,075	2
Occidental No. 2	5.4	33.0	47.1	14.5	.7	11,590	1
Occidental No. 3	4.2	36.6	47.5	11.7	.8	12,335	4
Occidental No. 6	5.3	33.0	40.9	20.7	.5	10,660	2
Occidental No. 14	4.1	34.9	49.1	11.9	.5	----------	2
Ravensdale No. 3	9.4	36.3	45.0	9.2	.6	11,455	2
Ravensdale No. 4	7.4	37.4	44.0	11.2	.5	11,500	1
Ravensdale No. 5	9.1	36.5	41.4	13.0	.6	10,856	5
Ravensdale No. 9	7.3	40.3	46.6	5.8	.6	12,370	1
Six-Foot	9.0	39.9	41.2	9.9	.5	11,250	1
Sunset No. 1	12.7	31.1	43.7	12.5	.9	9,890	1
Sunset No. 2	5.0	34.2	42.3	18.4	1.6	11,205	2
Sunset No. 7	4.9	26.4	30.2	38.5	.4	7,990	1
Taylor No. 2	6.4	36.7	41.4	15.5	1.3	11,140	1
Taylor No. 3	4.9	36.1	34.1	24.9	1.9	10,000	1
Taylor No. 4	4.8	36.5	48.6	10.1	.8	12,410	1
Taylor No. 5	4.3	35.6	45.2	14.9	.7	11,870	1
Taylor No. 6	5.6	36.0	44.0	14.4	.9	11,550	1
Taylor-unnamed	6.0	34.2	42.9	16.9	.4	11,000	1
Tiger Mountain No. 1	19.2	32.5	35.9	12.4	.2	8,810	1
Unknown bed of Eureka mine	5.9	31.3	43.9	18.9	.5	10,940	1

about 42 percent. Most of the coals analyzed have heating values of greater than 10,000 Btu, ranging from 7,990 Btu for the high-ash Sunset No. 7 coal bed to 13,230 Btu for one sample of the McKay coal bed. The average of 25 analyses of the McKay coal bed is 12,070 Btu.

CLASSIFICATION OF RESOURCES

The known resources of coal as determined by mapping and exploration in the Cumberland, Hobart, and Maple Valley quadrangles are estimated to be about 630 million tons. Of these resources, about 22 percent, or 140 million tons, is classified as subbituminous, and 78 percent, or 490 million tons, is classified as bituminous. Resources are estimated for bituminous coal beds 14 or more inches thick and for subbituminous coal beds 2½ or more feet thick, all within 3,000 feet of the surface. These resources are classified according to rank of coal, thickness of bed, thickness of overburden, and reliability of data. Table 11 lists the resources by individual bed and township. Only parts of some townships are present in the mapped area; therefore, the resource figures shown in table 11 do not represent the total coal resources for these townships and should not be compared directly with the resource estimates made by Beikman, Gower, and Dana (1961).

TABLE 11.—*Estimated remaining resources of coal in the Cumberland, Hobart, and Maple Valley quadrangles, January 1, 1962*

Rank: B, bituminous; S, subbituminous.
Overburden: I, 0–1,000 ft; II, 1,000–2,000 ft; III, 2,000–3,000 ft.
Resources, thickness:
Thin: Subbituminous coal 2½–5 ft thick; bituminous coal 14–28 in. thick.
Intermediate: Subbituminous coal 5–10 ft thick; bituminous coal 28–42 in. thick.
Thick: Subbituminous coal more than 10 ft thick; bituminous coal more than 42 in. thick.

Coal bed	Rank	Overburden	Resources, in millions of short tons, in beds of thickness shown: Measured and indicated: Thin	Measured and indicated: Intermediate	Measured and indicated: Thick	Measured and indicated: Total	Inferred: Thin	Inferred: Intermediate	Inferred: Thick	Inferred: Total	All categories: Thin	All categories: Intermediate	All categories: Thick	All categories: Total
T. 20 N., R. 6 E. (part)														
Gem	B	II							0.72	0.72			0.72	0.72
Kummer No. 0	S	I					0.44			.44	0.44			.44
		II					1.45			1.45	1.45			1.45
		III					.39			.39	.39			.39
Kummer No. 4	S	I		0.54		0.54		1.41		1.41		1.95		1.95
		II						1.22		1.22		1.22		1.22
Township total				0.54		0.54	2.28	2.63	0.72	5.63	2.28	3.17	0.72	6.17
T. 20 N., R. 7 E. (part)														
Gem	B	II							0.68	0.68			0.68	0.68
Kummer No. 0	S	I					0.57			.57	0.57			.57
		II					.69			.69	.69			.69
		III					.30			.30	.30			.30
Kummer No. 4	S	I						0.90		.90		0.90		.90
		II						1.08		1.08		1.08		1.08
		III						.26		.26		.26		.26
Township total							1.56	2.24	0.68	4.48	1.56	2.24	0.68	4.48
T. 21 N., R. 6 E. (part)														
Dale No. 4	S	I		0.65		0.65		0.58		0.58		1.23		1.23
Dale No. 7	S	I	0.67			.67	1.22			1.22	1.89			1.89
		II					.24			.24	.24			.24
Franklin No. 10	B	I							6.49	6.49			6.49	6.49
		II							5.86	5.86			5.86	5.86
		III							5.87	5.87			5.87	5.87
Franklin No. 12	B	I			0.49	.49			3.44	3.44			3.93	3.93
		II			.86	.86			3.45	3.45			4.31	4.31
		III			2.32	2.32			3.49	3.49			5.81	5.81
Gem	B	I		.88		.88		.12	.53	.65		1.00	.53	1.53
		II		.86	1.68	2.54		.13	1.15	1.28		.99	2.83	3.82
		III		.57		.57		.55	12.21	12.76		1.12	12.21	13.33
Harris	B	I					.20			.20	.20			.20
		II					1.17			1.17	1.17			1.17
		III					1.21			1.21	1.21			1.21
Kummer No. 0	S	I	2.76			2.76	3.53			3.53	6.29			6.29
		II	2.71			2.71	3.53			3.53	6.24			6.24
		III					.54			.54	.54			.54
Kummer No. 1	S	I		2.44		2.44		5.63		5.63		8.07		8.07
		II		2.50		2.50		4.68		4.68		7.18		7.18
		III						.28		.28		.28		.28
Kummer No. 4	S	I		7.14		7.14		3.87		3.87		11.01		11.01
		II						2.22		2.22		2.22		2.22
McKay	B	I			2.49	2.49			1.36	1.36			3.85	3.85
		II			3.50	3.50			12.48	12.48			15.98	15.98
		III			3.53	3.53		1.41	3.44	4.85		1.41	6.97	8.38
Unnamed Kummer	S	I					1.51			1.51	1.51			1.51
Township total			6.14	15.04	14.87	36.05	13.15	19.47	59.77	92.39	19.29	34.51	74.64	128.44

TABLE 11.—*Estimated remaining resources of coal in the Cumberland, Hobart, and Maple Valley quadrangles, Jan. 1, 1962*—Con.

Coal bed	Rank	Overburden	Resources, in millions of short tons, in beds of thickness shown											
			Measured and indicated				Inferred				All categories			
			Thin	Intermediate	Thick	Total	Thin	Intermediate	Thick	Total	Thin	Intermediate	Thick	Total
T. 21 N., R. 7 E. (part)														
Bayne No. 1	B	I			0.58	0.58			0.16	0.16			0.74	0.74
		II							.40	.40			.40	.40
Bayne No. 3	B	I			.31	.31			.18	.18			.49	.49
		II							.16	.16			.16	.16
Bayne No. 5	B	I			.43	.43			.21	.21			.64	.64
		II							.13	.13			.13	.13
Black Beauty	B	I						1.23		1.23		1.23		1.23
		II						1.47		1.47		1.47		1.47
Carbon	B	I			2.00	2.00							2.00	2.00
Durham No. 1	B	I			1.95	1.95			2.02	2.02			3.97	3.97
		II							4.03	4.03			4.03	4.03
Durham No. 2	B	I			.45	.45			.65	.65			1.10	1.10
Eureka No. 1	B	I			.94	.94			.28	.28			1.22	1.22
		II							.91	.91			.91	.91
		III							.38	.38			.38	.38
Eureka No. 2	B	I			.92	.92			.20	.20			1.12	1.12
		II							.51	.51			.51	.51
		III							.26	.26			.26	.26
Eureka No. 3	B	I		0.61		.61						.61		.61
		II						.36		.36		.36		.36
		III						.16		.16		.16		.16
Franklin No. 9	B	I						1.37		1.37		1.37		1.37
		II						1.12		1.12		1.12		1.12
		III						.25		.25		.25		.25
Franklin No. 10	B	I			6.34	6.34			8.35	8.35			14.69	14.69
		II			7.41	7.41			14.28	14.28			21.69	21.69
		III			2.60	2.60			13.95	13.95			16.55	16.55
Franklin No. 11	B	I	.62			.62	.88			.88	1.50			1.50
		II	.70			.70	.93			.93	1.63			1.63
		III	.53			.53	.79			.79	1.32			1.32
Franklin No. 12	B	I			7.97	7.97			6.86	6.86			14.83	14.83
		II			11.81	11.81			6.95	6.95			18.76	18.76
		III			3.77	3.77			11.06	11.06			14.83	14.83
Gem	B	I		.58	3.78	4.36						.58	3.78	4.36
		II		.62	1.98	2.60			2.21	2.21		.62	4.19	4.81
		III		.59		.59			1.01	1.01		.59	1.01	1.60
Harris	B	I	.60			.60	1.80			1.80	2.40			2.40
		II	.56			.56	.59			.59	1.15			1.15
		III	.32			.32	.02			.02	.34			.34
Hudson No. 1	B	I						.28		.28		.28		.28
Kummer No. 0	S	I	.16			.16	2.72			2.72	2.88			2.88
		II					.51			.51	.51			.51
Kummer No. 4	S	I						.81		.81		.81		.81
Lower Mammoth	B	I							.17	.17			.17	.17
		II							.08	.08			.08	.08
McKay	B	I		.40	3.88	4.28		.94	5.56	6.50		1.34	9.44	10.78
		II		1.05	4.97	6 02		2.79	.90	3.69		3.84	5.87	9.71
		III			3.33	3.33		.46		.46		.46	3.33	3.79
Navy Nos. 4 and 6	B	I			2.07	2.07			1.27	1.27			3.34	3.34
		II			3.86	3.86			.16	.16			4.02	4.02
		III							5.69	5.69			5.69	5.69
Occidental No. 1	B	I		.19		.19		.57		.57		.76		.76
		II						.30		.30		.30		.30
Occidental No. 3	B	I			.52	.52			1.84	1.84			2.36	2.36
		II							.49	.49			.49	.49
Occidental No. 6	B	I			.41	.41			.74	.74			1.15	1.15
		II							.30	.30			.30	.30
Occidental No. 14	B	I			.77	.77			.78	.78			1.55	1.55
		II							.85	.85			.85	.85
		III							.14	.14			.14	.14
Old Carbon	B	I			.36	.36			2.42	2.42			2.78	2.78
		II			.57	.57			1.88	1.88			2.45	2.45
		III							.76	.76			.76	.76
Sunset No. 1	S	I	2.17			2.17	1.88			1.88	4.05			4.05
		II	1.54			1.54	1.67			1.67	3.21			3.21
		III					2.58			2.58	2.58			2.58
Sunset No. 2	B	I			2.41	2.41			1.58	1.58			3.99	3.99
		II			1.63	1.63			1.67	1.67			3.30	3.30
		III							2.66	2.66			2.66	2.66
Deep Creek	B	I							.99	.99			.99	.99
Palmer "B"	B	I						.65		.65		.65		.65
Palmer "A"	B	I							4.74	4.74			4.74	4.74
South Elk Bed	B	I							.62	.62			.62	.62
Cumberland	B	I			.90	.90			4.21	4.21			5.11	5.11
		II							1.57	1.57			1.57	1.57
		III							.43	.43			.43	.43
Upper Mammoth	B	I							.27	.27			.27	.27
		II							.15	.15			.15	.15
Yellow Jacket	B	I			2.39	2.39			.14	.14			2.53	2.53
		II			2.36	2.36			2.30	2.30			4.66	4.66
		III							2.76	2.76			2.76	2.76
Township total			7.20	4.04	83.67	94.91	14.37	12.76	123.27	150.40	21.57	16.80	206.94	245.31

TABLE 11.—*Estimated remaining resources of coal in the Cumberland, Hobart, and Maple Valley quadrangles, Jan. 1, 1962*—Con.

Coal bed	Rank	Overburden	Resources, in millions of short tons, in beds of thickness shown											
			Measured and indicated				Inferred				All categories			
			Thin	Intermediate	Thick	Total	Thin	Intermediate	Thick	Total	Thin	Intermediate	Thick	Total
T. 22 N., R. 5 E. (part)														
New Lake Young	B	III							0.56	0.56			0.56	0.56
Township total									0.56	0.56			0.56	0.56
T. 22 N., R. 6 E. (part)														
Black Knight	B	I						0.39		0.39		0.39		0.39
Dale No. 4	S	I						.36		.36		.36		.36
Eight-foot	B	I			2.10	2.10							2.10	2.10
		II							2.54	2.54			2.54	2.54
		III							4.90	4.90			4.90	4.90
Frazier	B	I			1.08	1.08			4.58	4.58			5.66	5.66
		II							3.21	3.21			3.21	3.21
		III							1.76	1.76			1.76	1.76
Landsburg No. 1	B	I			5.93	5.93							5.93	5.93
		II							9.40	9.40			9.40	9.40
		III							13.68	13.68			13.68	13.68
McKay	B	I			.43	.43							.43	.43
		II							1.02	1.02			1.02	1.02
Ravensdale No. 3	B	I			2.50	2.50			2.32	2.32			4.82	4.82
Ravensdale No. 4	B	I			1.97	1.97			1.83	1.83			3.80	3.80
Ravensdale No. 5	B	I			1.75	1.75			2.72	2.72			4.47	4.47
Ravensdale No. 9	B	I		1.04		1.04		.88		.88		1.92		1.92
Rogers	B	I			3.65	3.65							3.65	3.65
		II							6.87	6.87			6.87	6.87
		III							8.22	8.22			8.22	8.22
Six-foot	B	I			1.59	1.59							1.59	1.59
		II							3.67	3.67			3.67	3.67
		III							3.91	3.91			3.91	3.91
Township total				1.04	21.00	22.04		1.63	70.63	72.26		2.67	91.63	94.30
T. 22 N., R. 7 E. (part)														
Alta	B	I			0.38	0.38			0.26	0.26			0.64	0.64
		II							.27	.27			.27	.27
Big Elk	B	I			1.22	1.22			4.40	4.40			5.62	5.62
		II							.49	.49			.49	.49
Cashman	B	I			1.26	1.26			3.10	3.10			4.36	4.36
Durham No. 1	B	I			.02	.02			1.02	1.02			1.04	1.04
		II							1.26	1.26			1.26	1.26
Durham No. 2	B	I			.13	.13			.32	.32			.45	.45
Durham No. 3	B	I							.36	.36			.36	.36
New Elk	B	I			.64	.64			1.64	1.64			2.28	2.28
Lower Elk	B	I			.88	.88			1.36	1.36			2.24	2.24
		II							.44	.44			.44	.44
Lower Mammoth	B	I							.94	.94			.94	.94
		II							.47	.47			.47	.47
Soft Coal	B	I					.25			.25	.25			.25
Taylor No. 1	B	I			2.68	2.68							2.68	2.68
		II							1.95	1.95			1.95	1.95
		III							1.59	1.59			1.59	1.59
Taylor No. 2	B	I			1.61	1.61							1.61	1.61
		II							.96	.96			.96	.96
		III							.67	.67			.67	.67
Taylor No. 3	B	I		1.58		1.58						1.58		1.58
		II						.88		.88		.88		.88
		III						.61		.61		.61		.61
Taylor No. 4	B	I		1.53		1.53						1.53		1.53
		II						1.24		1.24		1.24		1.24
		III						.79		.79		.79		.79
Taylor No. 5	B	I			1.62	1.62							1.62	1.62
		II							1.74	1.74			1.74	1.74
		III							1.17	1.17			1.17	1.17
Taylor No. 6	B	I			2.04	2.04							2.04	2.04
		II							2.19	2.19			2.19	2.19
		III							1.33	1.33			1.33	1.33
Taylor No. 8	B	I			.89	.89							.89	.89
		II							1.56	1.56			1.56	1.56
		III							1.09	1.09			1.09	1.09
South Elk	B	I							1.42	1.42			1.42	1.42
		II							1.65	1.65			1.65	1.65
		III							.14	.14			.14	.14
McIntyre	B	I							1.83	1.83			1.83	1.83
		II							.34	.34			.34	.34
Taylor No. 0	B	I			.51	.51			.16	.16			.67	.67
		II							.58	.58			.58	.58
Upper Mammoth	B	I							1.31	1.31			1.31	1.31
		II							.69	.69			.69	.69
Township total				3.11	13.88	16.99	0.25	3.52	38.70	42.47	0.25	6.63	52.58	59.46

TABLE 11.—*Estimated remaining resources of coal in the Cumberland, Hobart, and Maple Valley quadrangles, Jan. 1, 1962*—Con.

Coal bed	Rank	Overburden	Resources, in millions of short tons, in beds of thickness shown: Measured and indicated				Inferred				All categories			
			Thin	Intermediate	Thick	Total	Thin	Intermediate	Thick	Total	Thin	Intermediate	Thick	Total
T. 23 N., R. 5 E. (part)														
Cavanaugh No. 2	S	I	1.01			1.01					1.01			1.01
		II					0.88			0.88	.88			.88
Discovery	S	I		1.54		1.54		1.10		1.10		2.64		2.64
		II		.92		.92		1.53		1.53		2.45		2.45
		III		.13		.13		1.90		1.90		2.03		2.03
Jones	S	I		1.19		1.19		.10		.10		1.29		1.29
		II		3.99		3.99						3.99		3.99
		III		1.10		1.10						1.10		1.10
New Lake Young	B	I			1.29	1.29							1.29	1.29
		II							1.30	1.30			1.30	1.30
		III							.59	.59			.59	.59
Ryan No. 1	S	I		1.19		1.19		3.89		3.89		5.08		5.08
		II		.20		.20		2.09		2.09		2.29		2.29
Ryan No. 2	S	I	.82			.82	1.97			1.97	2.79			2.79
		II	.15			.15	.92			.92	1.07			1.07
Township total			1.98	10.26	1.29	13.53	3.77	10.61	1.89	16.27	5.75	20.87	3.18	29.80
T. 23 N., R. 6 E. (part)														
Cedar Mountain No. 1	S	I			5.51	5.51							5.51	5.51
		II							10.43	10.43			10.43	10.43
		III							1.19	1.19			1.19	1.19
Cedar Mountain No. 2	S	I	2.29			2.29					2.29			2.29
		II					0.55			.55	.55			.55
Discovery	S	I		1.91		1.91						1.91		1.91
		II		.63		.63		1.11		1.11		1.74		1.74
		III		1.20		1.20		0.82		.82		2.02		2.02
Jones	S	I		.20		.20		.94		.94		1.14		1.14
		II		1.65		1.65		.09		.09		1.74		1.74
		III		.74		.74						.74		.74
Ryan No. 1	S	I		.96		.96						.96		.96
		II		2.45		2.45						2.45		2.45
Ryan No. 2	S	I	.47			.47					.47			.47
		II	.95			.95					.95			.95
Tiger Mountain No. 1	S	I	1.52			1.52					1.52			1.52
		II					1.62			1.62	1.62			1.62
		III					.80			.80	.80			.80
Tiger Mountain No. 3	S	I		1.86		1.86						1.86		1.86
		II						1.96		1.96		1.96		1.96
		III						1.04		1.04		1.04		1.04
Township total			5.23	11.60	5.51	22.34	2.97	5.96	11.62	20.55	8.20	17.56	17.13	42.89
T. 23 N., R. 7E. (part)														
Taylor No. 4	B	I		0.25		0.25						0.25		0.25
Taylor No. 5	B	I			0.35	.35							0.35	.35
Taylor No. 6	B	I			.62	.62							.62	.62
		II							0.03	0.03			.03	.03
Taylor No. 8	B	I			.38	.38							.38	.38
		II							.21	.21			.21	.21
Township total				0.25	1.35	1.60			0.24	0.24		0.25	1.59	1.84
Grand total			20.55	45.88	141.57	208.00	38.35	58.82	308.08	405.25	58.90	104.70	449.65	613.25

In calculating resources, a standard weight of 1,800 tons per acre-foot was used for bituminous coal, and one of 1,770 tons per acre-foot was used for subbituminous coal. The coal-resource estimates are divided into three bed-thickness categories as given in table 11: thin, intermediate, and thick. All partings were excluded from the estimates given. At the time of this investigation, only a few coal beds were well enough exposed that the coal sections could be measured; therefore, U.S. Bureau of Mines measurements, chiefly from exposures in mines, are the principal sources of thickness data used in the resources estimates (U.S. Bureau Mines, 1931, 1941, 1958). Some thickness data were also obtained from Evans (1912) and from Warren, Norbisrath, Grivetti, and Brown (1945). Coal resources are also classified by thickness of overburden (table 11).

Estimates of coal resources are divided according to the abundance and reliability of the data into three categories: measured, indicated, and inferred. Measured resources are computed from dimensions of coal beds revealed in outcrops, trenches, mine workings, and drill holes. The points of observation are no more than half a mile apart, and the thickness and extent of the coal bed is so well known that the computed resource tonnage is judged to be accurate within 20 percent of the true tonnage. Indicated resources are those that are computed partly from specific measurements and partly from the projection of data for a reasonable distance on the basic geologic evidence. In most areas the points of observation are about 1 mile apart. Because of extensive glacial cover and complex structure, most indicated resources in this report are less than half a mile from the points of observation. Inferred resources are those based on a broad knowledge of the geologic character of individual coal beds and on an assumed continuity of the coal. In general, inferred resources in this report lie within 2 miles of the points of observation. To avoid disclosing measured resources of coal on an individually owned property, measured and indicated resources were combined.

DESCRIPTIONS OF COAL BEDS

To facilitate discussion the coal beds have been grouped by areas as follows: Green River, Ravensdale-Georgetown, Sugarloaf Mountain-Durham, Palmer-Bayne, Walker Lake-Cumberland, Cedar Mountain, Taylor, and Tiger Mountain areas. Figure 18 shows generalized columnar sections of most of the principal coal beds in the Cumberland, Hobart, and Maple Valley quadrangles. Although individual coal beds in the Cedar Mountain and Taylor areas cannot be directly correlated with coal beds in the Green River area, they are probably equivalent to beds in the Kummer coal zone and possibly the upper part of the Franklin zone.

Graphic sections of coal beds are shown on plate 3. Descriptions of areas and individual coal beds follow. Plate 4 shows the mapped areas of the described resources.

GREEN RIVER AREA

The coal beds of the Franklin coal zone (fig. 18) have been the most economically important beds in the

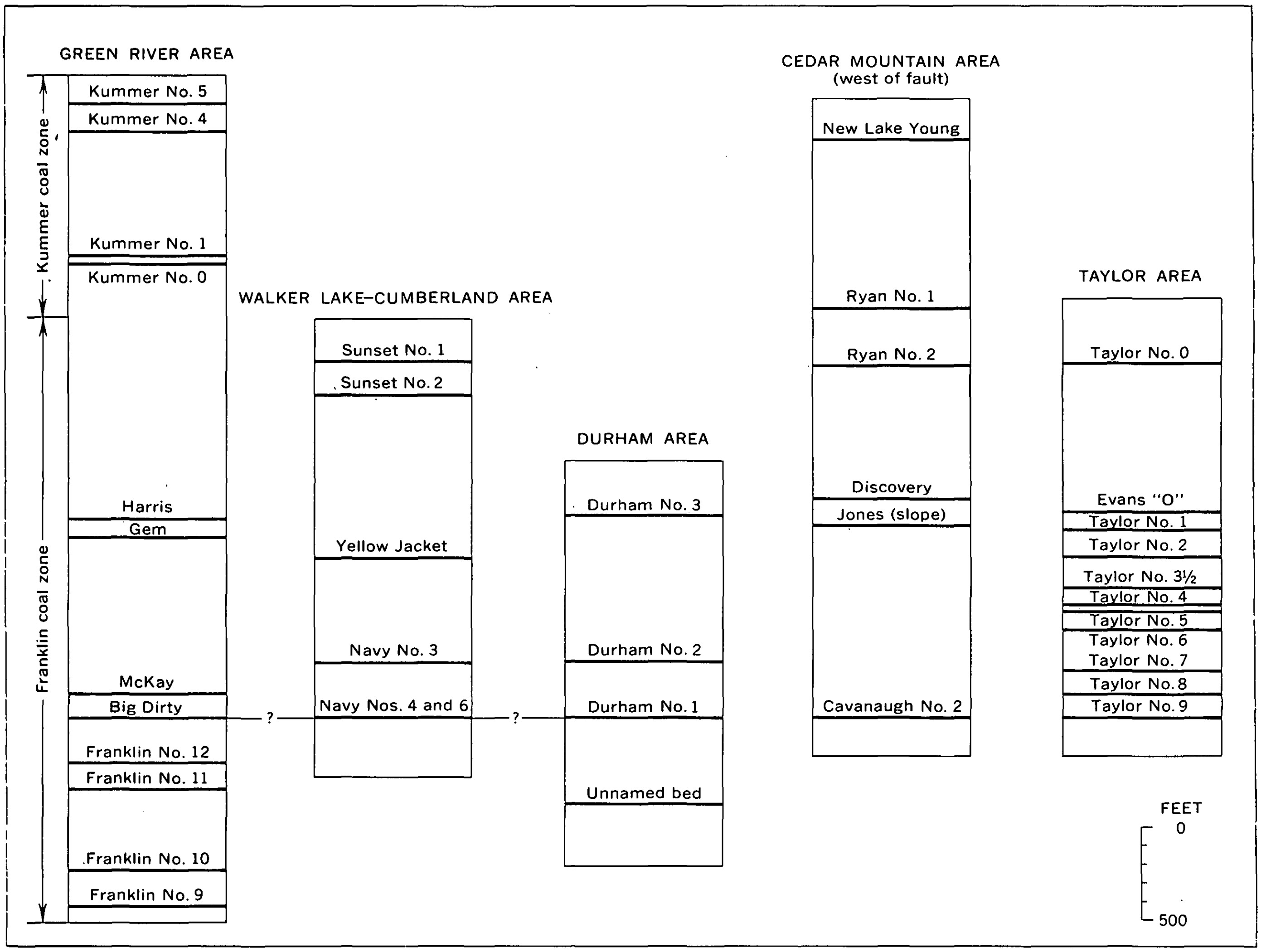

FIGURE 18.—Principal coal beds in the Cumberland, Hobart, and Maple Valley quadrangles. Queried lines indicate tentative correlation between the Big Dirty, Navy Nos. 4 and 6, and Durham No. 1 coal beds, as suggested by a study of fossil leaves.

report area. The principal beds in this coal zone are, from oldest to youngest, the Franklin Nos, 9, 10, 11, and 12, Big Dirty, McKay, Gem, and Harris coal beds. Data were sufficient to allow estimation of resources for all the above-mentioned beds except the poorly exposed Big Dirty coal bed. West of the Cumberland quadrangle, in mine "B," a coal bed that has not been recognized in the Cumberland quadrangle was mined between the McKay and Gem coal beds (Evans, 1912). This coal bed and perhaps several others may also be present in the Franklin coal zone.

Franklin No. 9 coal bed.—The Franklin No. 9 coal bed and its possible correlative, the Old Carbon coal bed, are probably the oldest coal beds included in the resource estimates. Older beds exposed in the Green River Canyon are too impure to be classed as resources. Very little coal has been mined from the Franklin No. 9 coal bed. No analyses are available for this bed, but because of its stratigraphic position the bed is assumed to be of bituminous rank. Evans' (1912, fig. 30) measurement of 5 feet 3 inches of coal was used in estimating resources for the Franklin No. 9 bed. Plate 4, map *A*, shows the distribution of coal resources for this bed.

Franklin No. 10 coal bed.—The Franklin No. 10 coal bed has been extensively mined north of the Green River on the east limb of the Kummer syncline. It has also been mined at two localities in the W½ sec. 8, T. 21 N., R. 7 E. Reliable measurements of the thickness of coal in this bed range from 5 feet 4 inches to 11 feet 4 inches (pl. 3, map locs. 25, 30). The distribution of coal resources for this bed is shown on plate 4, map *B*.

Franklin No. 11 coal bed.—The Franklin No. 11 coal bed was not observed during the course of the current fieldwork. According to Evans (1912, fig. 30, p. 163) it is 1 foot 10 inches thick. It has been mined north of the Green River in the SE¼ sec. 18, T. 21 N., R. 7 E. The distribution of coal resources for this bed is shown on plate 4, map *C*.

Black Beauty coal bed.—The Black Beauty coal bed is between the Franklin Nos. 10 and 12 coal beds in the W½ sec. 8, T. 21 N., R. 7 E. Possibly the Black Beauty bed is equivalent to the Franklin No. 11 coal bed. The Black Beauty is reported to contain about 2½ feet of clean coal (Ernest Seliger, oral commun., 1961), and this figure is used in the resources estimate. The distribution of these resources is shown on plate 4, map *D*.

Franklin No. 12 coal bed.—The Franklin No. 12 coal bed, also called the Fulton coal bed, is a 40-foot-thick zone of coal, impure coal, and partings. Only part of this bed is now exposed. Warren, Norbisrath, Grivetti, and Brown's (1945) measurement of 7 feet 5 inches of clean coal in an outcrop along the Green River was used in calculating the resource estimates of this bed (pl. 3, map loc. 78). The Franklin No. 12 bed was only partly exposed and probably contains additional coal of adequate quality to appreciably increase its resources. This bed has been extensively mined underground east of the axis of the Kummer syncline, both north and south of the Green River, and has been extensively strip mined along its outcrops on the east limb of the Kummer syncline north of the Green River. The distribution of resources of the Franklin No. 12 coal bed is shown on plate 4, map *E*.

McKay coal bed.—In the report area the McKay coal bed has been the coal bed most extensively mined, owing to its low ash content and high heating value (table 9). The McKay coal bed consists of an upper bench that ranges in thickness from 2 feet to 8 feet 1½ inches and a lower bench 4–6 feet thick (pl. 3, map locs. 39, 50, 64). South of the Green River in the SW¼ sec. 29, T. 21 N., R. 7 E., the bed apparently thins to less than 3½ feet (pl. 3, map loc. 44); it has been recognized to extend from Deep Lake on the south to the Ravensdale fault on the north. The coal bed exposed in a strip pit on the east limb of a north-plunging anticline directly south of the Ravensdale fault in the SE¼ sec. 36, T. 22 N., R. 6 E., is tentatively assigned to the McKay bed for purposes of calculating resources (pl. 3, map loc. 80). This assignment is questionable, however, for fossil leaves collected above this bed (USGS paleobotany loc. 9732) are assigned to the late Fultonian Stage; the coal bed occurs between the Franklin No. 12 and Big Dirty coal beds in the Green River section. Plate 4, map *F*, shows the distribution of resources of the McKay coal bed.

Gem coal bed.—The Gem coal bed ranges in thickness from 3 feet 10 inches south of the Franklin fault to 2 feet 4½ inches in the N½ sec. 18, T. 21 N., R. 7 E., north of the fault. This bed has been extensively mined on the east limb of the Kummer syncline on both sides of the Franklin fault. Plate 4, map *D*, shows the distribution of coal resources for the Gem bed. Plate 3 shows a graphic section of this bed (map loc. 24).

Harris coal bed.—The Harris coal bed was not observed during the course of the current work. According to Evans (1912, fig. 32, p. 167), this coal bed is 2 feet 3 inches thick. The Harris coal bed has been mined in secs. 18 and 19, T. 21 N., R. 7 E. The distribution of resources for this bed is shown on plate 4, map *G*.

Kummer coal beds.—Data were sufficient to estimate resources for only four coal beds in the Kummer coal zone—the Kummer Nos. 0, 1, and 4 and an unnamed bed exposed on the south side of the Green River in the NE¼ sec. 25, T. 21 N., R. 6 E. Additional data on thicknesses of other beds in the Kummer coal zone would increase the resource estimates of this zone. The Kummer Nos. 0, 1, and 4 have been mined on the west limb of the Kümmer syncline. The bed mined in the Green River mine in the SE¼ sec. 36, T. 21 N., R. 6 E., is here tentatively considered to be the Kummer No. 4 bed. The bed mined at the Blue Blaze mine in the NE¼ sec. 36, T. 21 N., R. 6 E., may be the Kummer No. 1 bed, but its thickness is unknown; so it could not be included in the resource estimates. The Kummer No. 3 bed was mined north of the Green River on the west limb of the Kummer syncline, but the thickness of this bed is unknown; so it also could not be included in the resource estimate. The distribution of coal resources for the Kummer Nos. 0, 1, and 4, and the unnamed coal beds is shown on plate 4, maps *H*, *I*, *J*, and *K*, respectively; also, the graphic sections are shown on plate 3 for the Kummer Nos. 1 (map loc. 33) and 4 (map locs. 28, 33) and the unnamed Kummer coal beds (map loc. 84).

Dale Nos. 4 and 7 coal beds.—The Dale Nos. 4 and 7 coal beds are exposed in strip pits in the N½ sec. 1, T. 21 N., R. 6 E. The Dale No. 4 bed occurs in two benches. The upper bench is 1 foot 10 inches to 2 feet 5½ inches thick, and the lower bench is 2 feet 5 inches to 3 feet thick. The Dale No. 7 coal bed ranges from 2 feet 8½ inches to 3 feet 9 inches thick. Analyses of these beds indicate that they are of subbituminous rank. Both beds have been mined by underground and strip-mining methods in sec. 1, T. 21 N., R. 6 E. The Dale No. 7 bed is tentatively considered to be correlative with the Gem coal bed of the Franklin coal zone. The distribution of coal resources for the Dale No. 4 and the Dale No. 7 coal beds is shown on plate 4, maps *G* and *D*, respectively. Graphic sections of these beds are shown on plate 3 (map loc. 14).

Black Knight coal bed.—The Black Knight coal bed was being mined in 1962 in the S½ sec. 36, T. 22 N., R. 6 E. It is apparently the same as the bed that was strip mined along the section line between sec. 36 T. 22 N., R. 6 E., and sec. 1, T. 21 N., R. 6 E. A south-dipping reverse fault separates the Black Knight coal bed from the Dale No. 7 coal bed to the south, with which the Black Knight bed may correlate. The Black Knight coal bed is arbitrarily classed as bituminous rank in the resource estimates, although no analyses are available. Plate 4, map *D*, shows the distribution of resources for the Black Knight coal bed.

RAVENSDALE-GEORGETOWN AREA

Ravensdale coal beds.—Coal resources have been estimated for four coal beds at Ravensdale: the Ravensdale Nos. 3, 4, 5, and 9. All four beds have been mined by underground and strip-mining methods. The interval between Nos. 3 and 4 is so small that they are considered as one bed in the resource table. The Ravensdale No. 3 bed is 7 feet 1 inch thick; the No. 4 bed is 5 feet 7 inches thick; the No. 5 bed is 8 feet 10 inches thick; and the No. 9 bed is 2 feet 2½ inches thick. Unpublished mine maps show two coal beds, the Ryan Nos. 4 and 5, beneath the Ravensdale beds, but no thicknesses are given for these beds, and they are not included in the resource estimates. Correlation of the individual Ravensdale beds with individual beds in the Franklin coal zone is uncertain. Fossil leaves collected between the Ravensdale Nos. 3 and 4 coal beds (USGS paleobotany loc. 9694) were assigned to the early Ravenian Stage by Wolfe (1968). This would place these beds in an interval containing the McKay coal bed of the Franklin coal zone. Fossil leaves from the Ravensdale No. 5 coal bed (USGS paleobotany loc. 9728) were assigned to the late Ravenian Stage, the lower part of which lies between the McKay and Gem coal beds of the Franklin coal zone. Coal resources of the Ravensdale Nos. 5 and 9 coal beds are shown on plate 4, maps *L* and *F*, respectively. Resources for the Ravensdale Nos. 3 and 4 are shown together on plate 4, map *E*. Graphic sections of the Ravensdale coal beds are shown on plate 3 (map loc. 59).

Coal beds north of Georgetown.—Resources are estimated for the Eight-foot, Six-foot, Landsburg No. 1, Rogers, and Frazier coal beds in the area north of Georgetown. These beds are vertical or steeply dipping. They are separated from the beds at Ravensdale by a northwest-trending fault of unknown displacement. The Eight-foot bed ranges from 6 feet 5 inches to 8 feet 1¼ inches in thickness (pl. 3, map loc. 17); the Six-foot bed is 5 feet 6 inches thick; the Landsburg No. 1 bed is 20 feet 5 inches thick; the Rogers bed is 11 feet 6 inches thick (pl. 3, map loc. 79); and the Frazier bed ranges from 8 feet 1 inch to 9 feet 3 inches in thickness (pl. 3, map loc. 16). These beds have all been mined, but most of the production has come from the Landsburg No. 1 coal bed. Mines were active in 1962 on both the Landsburg No. 1 and the Rogers beds. Fossil leaves collected from strata between the Rogers and Landsburg No. 1 beds (USGS paleobotany loc. 9695) were assigned to the late Fultonian Stage, the strata are between the Franklin No. 12 and the top of the Big Dirty beds in the Franklin coal zone. Thus, the Rogers and Landsburg No. 1 coal beds may be correlative to the McKay and Franklin No. 12 beds, respectively. Plate 4, maps *G*, *F*, *E*, *C*, and *B*, shows the distribution of resources of the Frazier, Rogers, Landsburg No. 1, Six-foot, and Eight-foot coal beds, respectively.

SUGARLOAF MOUNTAIN–DURHAM AREA

Elk coal beds.—Resources are estimated for the South Elk, Lower Elk, Big Elk, New Elk, and Cashman coal beds. The distribution of their resources is shown on plate 4, maps *A*, *E*, *L*, *F*, and *D*, respectively. The South Elk coal bed was strip mined in the NW¼ sec. 3, T. 21 N., R. 7 E. Plate 3 (map loc. 81) shows a graphic section of this bed. The Lower Elk coal bed, which has also been called Elk No. 2 bed, is 5 feet 7 inches thick. The unnamed bed of Elk prospect No. 2 is here considered to be the Lower Elk coal bed. The Big Elk coal bed, 11½ feet thick, is tentatively correlated with the Durham No. 1 coal bed. The New Elk coal bed, also known as the Dutch coal bed, is 4 feet 5 inches thick (pl. 3, map loc. 20). The Cashman coal bed is tentatively correlated with the Victory, or Bed A, coal bed. The Cashman was mined in the NE¼ sec. 33, T. 22 N., R. 7 E., and the Victory, or Bed A, was mined in the S½ sec. 34, T. 22 N., R. 7 E. The Cashman coal bed (Victory, or Bed A) is 9 feet 1 inch thick (pl. 3, map loc. 20). Fossil leaves collected from the Cashman horizon (USGS paleobotany loc. 9731) were assigned by Wolfe (1968) to the late Ravenian Stage which occupies the interval between the McKay coal bed and the Kummer sandstone of Evans (1912, p. 46) in the Franklin coal zone.

McIntyre coal bed.—The previously unnamed bed of the McIntyre prospect north of Sugarloaf Mountain in the NW¼SE¼ sec. 28, T. 22 N., R. 7 E. (U.S. Bureau Mines, 1931, p. 128), is here called the McIntyre coal bed. This bed contains 4 feet 5 inches of coal (pl. 3, map loc. 38). Plate 4, map *J*, shows the distribution of resources of this bed.

Alta coal bed.—The Alta coal bed, or Big Seam, is the bed mined in the Alta and Kangley mines east of the Cumberland quadrangle in secs. 28 and 35, T. 22 N., R. 7 E. This bed is 5½ feet thick. Plate 4, map *F*, shows the distribution of resources of this bed.

Beds in Hiawatha tunnel.—The Hiawatha tunnel, an east-west tunnel perpendicular to the strike of the beds in the S½ sec. 35, T. 22 N., R. 7 E., cuts several coal beds. Resources are estimated for three beds cut by this tunnel: the Lower Mammoth, the Upper Mammoth, and the Soft Coal beds. The thicknesses used in these resource calculations are from unpublished mine maps. Of the three beds, only the Upper Mammoth was mined in the area of this report. Analyses are not available for any of these beds, but the beds are here assumed to be of bituminous rank. The distribution of resources for the Lower Mammoth, Upper Mammoth, and Soft Coal beds is shown on plate 4, maps *E*, *L*, and *G*, respectively.

Durham coal beds.—Resources are estimated for the Durham Nos. 1, 2, and 3 coal beds. An unnamed underlying bed was mined in the NW¼ sec. 2, T. 21 N., R. 7 E., but its thickness is not known; therefore it was not included in the resource estimates. The Durham No. 1 coal bed—a thick zone of coal, impure coal, and carbonaceous siltstone—contains 13½ feet of coal. The Durham No. 2 coal bed is 4 feet 6¼ inches thick (pl. 3, may loc. 19), and the Durham No. 3 coal bed is 4 feet 4 inches thick. Fossil leaves collected from the Durham No. 1 coal bed (USGS paleobotany loc. 9832) were assigned to the late Fultonian Stage by Wolfe (1968). On the basis of this assignment the Durham No. 1 coal bed is considered to be approximately equivalent to the Big Dirty coal bed. The Durham No. 1 is also thought to be correlative with the Big Elk bed to the west. Maps *D*, *F*, and *L* on plate 4 show the distribution of resources for the Durham Nos. 3, 2, and 1 coal beds, respectively.

PALMER-BAYNE AREA

Palmer coal beds.—The Palmer A and Palmer B coal beds crop out in roadcuts on the west limb of a south-plunging syncline east of Palmer. The Palmer A coal bed crops out in the NW¼NW¼ sec. 14, T. 21 N., R. 7 E.; the Palmer B coal bed crops out in the NE¼NE¼ sec. 15, T. 21 N., R. 7 E. The Palmer A coal bed is 2 feet 5 inches thick, and the Palmer B coal bed is 3 feet 7 inches thick. Maps *H* and *I* on plate 4 show the distribution of resources for the Palmer A and Palmer B coal beds, respectively. Graphic sections of these beds are shown on plate 3 (map loc. 82).

Carbon coal bed.—The Carbon coal bed has been extensively mined along a south-plunging syncline east of Bayne. On the west limb of the syncline this bed occurs as two beds, separated by an interval of about 27 feet, which Evans (1912, p. 189) called the No. 1 and No. 2 beds. The beds were called the Big and Little Carbon beds by Warren, Norbisrath, Grivetti, and Brown (1945). The two beds merge on the east limb of the syncline. The Carbon bed averages about 9 feet thick. Plate 4, map *L*, shows the distribution of resources of the Carbon coal bed, and plate 3 (map loc. 10) shows a graphic section.

Bayne coal beds.—The Bayne coal beds are separated from the Carbon coal bed by a southeast-trending fault. The Bayne beds are, from oldest to youngest, the Bayne Nos. 1, 3, and 5 coal beds. The Bayne No. 1 coal bed is about 5 feet 10 inches thick; the No. 3 bed is 3 feet 11 inches thick; and the No. 5 bed is 4 feet 9½ inches thick. Graphic sections of the Bayne coal beds are shown on plate 3 (map loc. 15). Maps *C*, *B*, and *A* on plate 4 show the distribution of the coal resources for the Bayne Nos. 1, 3, and 5 coal beds, respectively.

Occidental coal beds.—Unpublished mine maps indicate that there are at least 10 coal beds in the Occidental coal zone west of Bayne. However, data are sufficient to allow estimation of resources for only five of these Occidental beds—the Occidental Nos. 14, 6, 3, 2, and 1 coal beds (pl. 3, map loc. 53). The Occidental No. 14 bed is 5 feet thick; the No. 6 bed is about 3 feet thick; the No. 3 bed is 9 feet 8 inches thick; the No. 2 bed is 3 feet 4 inches thick, and the No. 1 bed is 5 feet 6 inches thick. Fossil leaves collected from the Occidental No. 6 coal bed (USGS paleobotany loc. 9733) were assigned to the late Fultonian Stage by Wolfe (1968). This bed is therefore considered to be approximately equivalent to the Big Dirty bed of the Franklin coal zone. Maps *E*, *L*, *D*, *F*, and *H* on plate 4 show the distribution of resources for the Occidental Nos. 14, 6, 3, 2 and 1 coal beds, respectively.

Old Carbon coal bed.—The Old Carbon coal bed is a thick zone of coal, impure coal, and partings. The bed is estimated to have 5 feet 4 inches of coal resources. A small amount of the Old Carbon bed was strip mined west of Bayne. Plate 4, map *A*, shows the distribution of resources of the Old Carbon coal bed.

Cumberland coal bed.—The Cumberland coal bed is about 350 feet stratigraphically above the Old Carbon coal bed west of Bayne. The Cumberland bed, which was previously unnamed, is 7 feet 4 inches thick where exposed in a strip pit in the NE¼ sec. 21, T. 21 N., R. 7 E. This bed is tentatively considered to be approximately stratigraphically equivalent to the Franklin No. 10 coal bed. Plate 4, map *B*, shows the distribution of resources of the Cumberland coal bed.

Hudson No. 1 coal bed.—The Hudson No. 1 coal bed east of Palmer contains, according to Evans (1912, fig. 38), 3 feet 4½ inches of coal (pl. 3, map loc. 1). Plate 4, map *J*, shows the distribution of resources of this bed.

Deep Creek coal bed.—The Deep Creek coal bed (here named) crops out in a roadcut in the SE¼NW¼ sec. 23, T. 21 N., R. 7 E. It is 6 feet thick. Plate 4 map *K*., shows the distribution of resources for this bed.

WALKER LAKE-CUMBERLAND AREA

Eureka coal beds.—The Eureka coal beds are, from oldest to youngest, the Eureka Nos. 1, 2, and 3. They are 4 feet 4 inches, 4 feet 2 inches, and 2 feet 7 inches thick, respectively. A graphic section of the Eureka No. 3, coal bed is shown on plate 3 (map loc. 22). The Coal Creek fault probably separates these beds from the Navy coal beds on the south. On the basis of fossil leaves (USGS paleobotany loc. 1025), Wolfe (1968) assigned the Eureka beds to the upper Ravenian Stage. Therefore, these beds are considered to be approximately equivalent to the Gem and Harris coal beds of the Franklin coal zone. Maps *H*, *G*, and *D* on plate 4 show the distribution of coal resources of the Eureka Nos. 1, 2, and 3 coal beds respectively.

Navy coal beds.—The Navy Nos. 4 and 6 coal beds are considered as one bed in the resource estimates. These two beds contain an average total thickness of 6 feet 3 inches of good coal. No thickness data are available for the overlying Navy No. 3 coal bed, and the bed is not included in the resource estimates. Fossil leaves collected from strata directly overlying the Navy Nos. 4 and 6 coal beds (USGS paleobotany loc. 9734) were assigned to the early Fultonian Stage by Wolfe (1968). These beds are therefore approximately equivalent to the Franklin No. 12 coal bed. The distribution of resources of the Navy Nos. 4 and 6 coal beds is shown on map E of plate 4.

Yellow Jacket coal bed.—The Yellow Jacket coal bed overlies the Navy No. 3 coal bed (fig. 18). The Yellow Jacket bed is 4 feet thick. Plate 4, map *G*, shows the distribution of resources for this bed. A graphic section is shown on plate 3 (map loc. 85).

Independent No. 6 coal bed.—The Independent No. 6 coal bed is a thick zone of coal, impure coal, and shale. The thickness of coal was interpreted as 7 feet from the graphic section by Evans (1912, fig. 49, p. 197). The distribution of resources for the Independent No. 6 coal bed is shown on map *I* of plate 4.

Sunset coal beds.—Resources are estimated for two Sunset coal beds, the Sunset Nos. 1 and 2. Several other Sunset coal beds have been reported, but data on their thicknesses and locations are lacking, so these beds could not be included in the resource estimates. The Sunset No. 1 coal bed, about 4 feet 8 inches thick (pl. 3, map loc. 66), is of subbituminous rank, whereas the Sunset No. 2 coal bed is of bituminous rank. In the resource calculation, the U.S. Bureau of Mines (1931, p. 112) reported thickness of 3 feet was used. This measurement evidently included only part of the bed; Evans (1912, fig. 46) showed about 11 feet of coal and shaly coal. Elsewhere, Evans (1912, p. 195) indicated about 6½ feet of coal for the Sunset No. 2 bed. Maps *K* and *I* on plate 4 show the distribution of resources for the Sunset Nos. 1 and 2, respectively.

CEDAR MOUNTAIN AREA

A major northwest-trending fault cuts through the Cedar Mountain area, and coal beds could not be correlated across this fault. East of the fault are the Cedar Mountain A, No. 1, and No. 2 coal beds. Data are insufficient to allow estimation of resources for the

Cedar Mountain A coal bed. The Cedar Mountain No. 1 coal bed is 11 feet 11 inches thick (Evans, 1912, p. 115). The Cedar Mountain No. 2 coal bed is about 3½ feet thick. West of the fault, resources are estimated for the New Lake Young, Ryan No. 1, Ryan No. 2, Discovery, Jones, and Cavanaugh No. 2 coal beds. The New Lake Young bed is 4 feet 5 inches thick. The Ryan Nos. 1 and 2 coal beds are 9 feet and 4 feet 9 inches thick, respectively. The Discovery coal bed is 5 feet 3 inches thick. The Jones coal bed averages about 6 feet 3 inches in thickness. The Cavanaugh No. 2 coal bed is about 3½ feet thick. Thickness data from the U.S. Bureau of Mines (1931, 1941) were used for the beds west of the fault. Graphic sections of the New Lake Young, Ryan No. 2, Jones, and Cavanaugh No. 2 coal beds are shown on plate 3 (map locs. 42, 45, 61). The New Lake Young coal bed is of bituminous rank. All other coal beds in the Cedar Mountain area are of subbituminous rank. The distribution of resources in the Cedar Mountain area is shown on plate 4, maps *D*, *F*, and *G–L*.

TAYLOR AREA

The coal beds of the Taylor area are all of bituminous rank. Ten coal beds have been mined in this area. They are, from oldest to youngest, the Taylor Nos. 8, 7, 6, 5, 4, 3½, 3, 2, 1, and 0. The Taylor No. 7 coal bed is not thick enough to be included in the resource estimates, and no thickness data are available for the Nos. 3½ and No. 9 beds or for the Evans "0" bed. The stratigraphic position of bed No. 3 is not known and so was not shown on the columnar section for the Taylor area (fig. 18), but the position of No. 9 and the Evans "0" beds are shown, even though there is no record of their having been mined. The thicknesses of the Taylor coal beds included in the resource estimates are: No. 8 bed, 3 feet 10 inches; No. 6 bed, 4 feet 7½ inches; No. 5 bed, 3 feet 10 inches; No. 4 bed, 2 feet 8½ inches; No. 3 bed, 3 feet 5 inches; No. 2 bed, 3 feet 8½ inches; No. 1 bed, 6½ feet; and No. 0 bed (unnamed bed of U.S. Bureau Mines, 1941), 6 feet 7½ inches. Data for the Taylor No. 0 coal bed are from the U.S. Bureau of Mines (1941, p. 60–61), and for the Taylor Nos. 1 and 8 coal beds, from Evans (1912, p. 137–139). Thicknesses of all the other beds are from the U.S. Bureau of Mines (1931, p. 136–137). Graphic sections of the Taylor Nos. 2, 3, 4, 5, and 6 coal beds are shown on plate 3 (map loc. 67). The distribution of resources of the Taylor coal beds are shown on plate 4, maps *D*, *F*, and *G–L*.

TIGER MOUNTAIN AREA

Resources are estimated for two beds in the Tiger Mountain area, the Tiger Mountain Nos. 1 and 3 coal beds. Both beds are of subbituminous rank. The Tiger Mountain No. 1 coal bed averages about 4 feet 2 inches in thickness (U.S. Bureau Mines, 1931, 1941). The Tiger Mountain No. 3 coal bed is 6 feet thick, according to a company report (G. W. Evans, written comun., 1940). The Tiger Mountain No. 2 coal bed is between the Tiger Mountain Nos. 1 and 3 beds, but it is too thin to be included in the resource estimate (U.S. Bureau Mines, 1931, p. 123). G. W. Evans (written commun., 1940) reported two coal beds 4 feet thick underlying the Tiger Mountain No. 3 coal bed, but data on the extent and quality of these beds were insufficient to include them in the resource estimates. Maps *J* and *K* on plate 4 show the distribution of resources for the Tiger Mountain No. 1 and No. 3 coal beds, respectively. A graphic section of the Tiger Mountain No. 3 coal bed is shown on plate 3 (map loc. 70).

ESTIMATE OF TOTAL POTENTIAL RESOURCES

The estimate of 613 million tons of coal for the area of this report (p. 48) is based on data available on thickness and extent of individual coal beds and does not represent the total amount of coal present. Additional data on thickness and extent of coal beds through core drilling, mining, and trenching would greatly increase the above estimate. Much coal is present in beds of unknown thickness and in beds that have yet to be discovered, especially in the eastern part of the Cumberland quadrangle. In addition, the Tiger Mountain Formation probably contains coal, and much of the area covered by glacial drift for several miles on either side of the Cedar River is probably underlain by a thick sequence of coal-bearing rocks. The writer estimates a total potential resource of about 5 billion tons of coal within 6,000 feet of the surface in the Cumberland, Hobart, and Maple Valley quadrangles. The extension of this coal estimate to a depth of 6,000 feet was necessitated by the poor stratigraphic and structural control in the Cedar River Valley area.

OIL AND GAS POSSIBILITIES

Petroleum exploration in western Washington has been slow and sporadic, but interest is expected to continue for many years because of the occurrence of marine rocks—a likely source for petroleum. Marine rocks are present in the Raging River Formation and may underlie most of the Hobart and Maple Valley quadrangles. A possible indication of the former presence of petroleum in the rocks of this area is a black deposit containing organic carbon that coats grains of sand in the Tiger Mountain Formation in the S½SW¼ sec. 17, T. 23 N., R. 7 E. This deposit may represent a hardened residue of petroleum from which the more volatile constituents have been lost.

Assuming that suitable source beds for petroleum exist at depth, exploration should be directed toward finding a favorable structural or stratigraphic trap where fluid hydrocarbons have accumulated. The rocks in the mapped areas are folded into a number of easily recognized anticlines that are favorable for oil accumulation, but where the rocks are sufficiently porous and permeable to serve as reservoirs at depth is unpredictable. In a sequence of marine and nonmarine strata, permeable rocks may occur as elongate lenses of well-sorted sand deposited as offshore bars parallel to the strand line. Sandstone lenses of this type may exist in the subsurface rocks of this area, particularly along the ancient shoreline that probably lay parallel to the west-trending hinge line that existed near the common boundary of the Hobart and Cumberland quadrangles.

QUICKSILVER DEPOSITS

Deposits of cinnabar occur at two places in the canyon of the Green River in rocks of the Puget Group: (1) along the crestline of the Lawson anticline at the site of the Royal Reward mine, and (2) along the northwest-trending fault in the NE¼ sec. 17, T. 21 N., R. 7 E., at the site of the Cardinal Reward mine. Only a few flasks of mercury have been produced from these two deposits, and the mines were not operating in 1961. The cinnabar is closely associated with realgar and orpiment, both of which are more conspicuous than cinnabar. The rocks at both localities have been fractured and brecciated, and the cinnabar occurs in small lenses and veins in the brecciated zone. At the Royal Reward mine the mineralized zone is in sandstone and carbonaceous shale below an igneous sill along the crestline of the Lawson anticline. Near the Cardinal Reward mine the mineralized zone is confined chiefly to the zone of brecciated rock next to the northwest-tending fault.

STRATIGRAPHIC SECTIONS

SECTION 1.—*Composite section of the Puget Group exposed in the Green River Canyon between the NE¼ sec. 26, T. 21 N., R. 6 E., and the axis of the Lawson anticline*

[Measured by A. A. Wanek, J. D. Vine, and H. D. Gower, 1959, 1960, and 1961. Thickness of units based on field estimates adjusted to fit geologic profiles. *, sill, not included in thickness totals]

	Thickness (feet)
Unnamed volcanic rocks (thickness not measured).	
Concealed	200
Puget Group, undifferentiated:	
Sandstone, poorly exposed	25
Coal, impure, and carbonaceous siltstone	7
Sandstone, poorly exposed	140

SECTION 1.—*Composite section of the Puget Group exposed in the Green River Canyon between the NE¼ sec. 26, T. 21 N., R. 6 E., and the axis of the Lawson anticline*—Continued

	Thickness (feet)
Puget Group, undifferentiated—Continued	
Coal, impure, and carbonaceous siltstone (Kummer No. 5 coal bed)	15
Sandstone and siltstone, poorly exposed	210
Siltstone; in part sandy and fine-grained sandstone; poorly exposed	160
Sandstone, fine-grained, and siltstone; poorly exposed; Kummer No. 4 coal bed at top of unit	180
Sandstone, light-gray to light-brownish-gray, fine- to medium-grained; medium-gray partly sandy siltstone; and carbonaceous zones composed of coal, impure coal, and carbonaceous siltstone	480
Siltstone, carbonaceous, and coal (Kummer No. 0 coal bed)	6
Claystone, dark-gray to medium-gray, hard, brittle; in part carbonaceous (Kummer fire clay bed)	10
Siltstone, carbonaceous, and impure coal	2
Sandstone, light-yellowish-gray to gray, cross-stratified; forms massive cliffs; contains large brownish-gray concretions (Kummer sandstone bed)	225
Siltstone, medium-gray, faintly bedded; in part sandy. Contains a few concretionary lenses as much as 2½ ft thick and 5 ft long; poorly exposed	90
Coal and impure coal	10
Siltstone; in part carbonaceous; impure coal and silty very fine grained to fine-grained sandstone; poorly exposed	260
Coal and impure coal	11
Sandstone, fine- to medium-grained; very fine grained in upper 15 ft; cross stratified, resistant. Contains fragments of coal and small pebbles of sedimentary rocks at the base	160
Siltstone, carbonaceous, and impure coal	10
Sandstone, very fine grained; siltstone, carbonaceous siltstone, and carbonaceous shale; thin bedded. Contains abundant fossil leaves	29
Sandstone, light-gray to brownish-gray, very fine grained to fine-grained, thin-bedded	90
Sandstone, light-gray to brownish-gray, medium- to coarse-grained, cross-stratified, resistant	160
Concealed	170
Sandstone, light-gray to brownish-gray, medium- to coarse-grained, cross-stratified	50
Carbonaceous zone containing Harris and Gem coal beds. Most of this section is covered by glacial drift	100
Sandstone, light-gray to brownish-gray, medium- to coarse-grained, partly friable, cross-stratified, massive-weathering	90
Siltstone, carbonaceous siltstone, and impure coal	20
Sandstone, brownish-gray, fine- to medium-grained	70
Concealed	40
Siltstone, interbedded with carbonaceous siltstone, impure coal, and sandstone	85
Sandstone, brownish-gray, medium-grained, resistant	120
Andesite(?) sill	*3
Siltstone and sandstone, thin-bedded; some coal and impure coal; poorly exposed	255

SECTION 1.—*Composite section of the Puget Group exposed in the Green River Canyon between the NE¼ sec. 26, T. 21 N., R. 6 E., and the axis of the Lawson anticline*—Continued

	Thickness (feet)
Puget Group, undifferentiated—Continued	
Sandstone, coarse- to fine-grained, partly cross-stratified, resistant	30
Siltstone, interbedded with fine-grained to very fine grained sandstone	80
Siltstone, poorly exposed; includes McKay coal bed at top of unit	80
Coal, impure, and carbonaceous siltstone; Big Dirty coal bed	40
Sandstone, siltstone, impure coal, and carbonaceous siltstone; thin bedded	30
Sandstone, massive, resistant	20
Sandstone, and siltstone; thin bedded	5
Sandstone; coarse grained at base; well sorted; resistant	50
Coal and impure coal	4
Sandstone, fine-grained, and sandy siltstone; thin bedded	100
Coal, impure coal, and carbonaceous siltstone. Contains several thin tuff partings and Franklin No. 12 coal bed. Concealed in Green River canyon but well exposed in strip pit north of the river	45
Siltstone, sandy, and sandstone, coal, and impure coal; Franklin No. 11 coal bed in upper part of unit; poorly exposed	245
Andesite, porphyritic, sill	*120
Sandstone, light-brown to bluish-gray fine-grained to very fine grained, and light-gray to light-bluish-gray siltstone. About 70 percent of this interval is concealed	45
Sandstone, light-gray, fine-grained; in part cross-stratified. Contains intraformational breccia composed of dark-gray siltstone fragments	55
Siltstone, medium-gray. Contains several fine-grained sandstone and carbonaceous siltstone beds	40
Coal, impure coal, and carbonaceous siltstone; Franklin No. 10 coal bed	30
Sandstone, thin- to thick-bedded; locally very hard. Some beds show small-scale cross lamination	60
Siltstone, sandy, and silty sandstone; medium gray; thin bedded. Contains small calcareous concretions and several thin impure coal beds	60
Sandstone, light-gray, fine-grained, cross-stratified	45
Concealed. Franklin No. 9 coal bed	15
Sandstone, light-gray to brownish-gray, very fine-grained to medium-grained; cross-stratified in upper half; very thin horizontally bedded in lower half. Contains some convolute bedding and intraformational breccia. A section of siltstone and carbonaceous siltstone about 10 ft. thick occurs near the center of unit	120

SECTION 1.—*Composite section of the Puget Group exposed in the Green River Canyon between the NE¼ sec. 26, T. 21 N., R. 6 E., and the axis of the Lawson anticline*—Continued

	Thickness (feet)
Puget Group, undifferentiated—Continued	
Siltstone, carbonaceous; claystone and impure coal; thin bedded. Contains several tuff beds as much as 2 ft. thick	36
Sandstone, light-gray to brownish-gray, fine- to coarse-grained, fairly well sorted, cross-stratified, resistant	110
Siltstone, carbonaceous siltstone, shale, and impure coal; thin bedded	80
Sandstone, light-gray, fine-grained, poorly sorted; locally very micaceous; cross stratified, ripple marked; thin horizontal bedding in lower 15 ft	40
Siltstone, carbonaceous, and carbonaceous claystone; thin bedded	100
Sandstone, light-gray to brownish-gray, fine- to medium-grained, cross-stratified, resistant. Contains two carbonaceous zones, 1 and 8 ft. thick, in upper part	200
Siltstone, sandy, grayish-brown; in part carbonaceous	30
Sandstone, fine- to medium-grained, brownish-gray; thin horizontal bedding to cross stratified. Resistant in lower half	200
Sandstone, very fine grained, and sandy siltstone; thin horizontal bedding	40
Sandstone, fine- to medium-grained, massive-weathering, resistant	125
Siltstone and sandstone; interbedded with carbonaceous siltstone, claystone, and impure coal	480
Sandstone, medium-grained, cross-stratified, resistant	45
Siltstone and very fine grained sandstone; thin bedded. Contains some carbonaceous claystone and impure coal beds	120
Concealed	40
Sandstone, fine- to coarse-grained; thick horizonal bedding to cross stratified; very hard in lower half	45
Andesite, porphyritic, sill	*12
Sandstone, fine- to medium-grained; cross stratified in part; in upper part sand grains are coated with black bituminous(?) material	30
Total exposed thickness of the Puget Group	6,200

Base not exposed.

SECTION 2.—*Raging River Formation exposed in the tributary to Raging River, W½ sec. 9, T. 23 N., R. 7 E.*

[Measured by J. D. Vine, 1961. Thickness of units based on field estimates adjusted to fit a geologic profile. Sample numbers are listed in table 1; locality numbers are shown on plate 1.*, sill, not included in thickness total]

	Thickness (feet)
Tiger Mountain Formation of Puget Group:	
Sandstone, micaceous, arkosic; thickness not measured (sample H–95).	
Raging River Formation:	
Claystone, silty, dark-gray to black; more silty and sandy in the upper part; contains calcareous concreations 1–5 cm in diameter; contains marine fossils including Foraminifera (sample H–18)	160
Sandstone, volcanic, medium- to coarse-grained, gray to greenish-gray; cemented with a green mineral (celadonite or glauconite); contains impressions of root tubes and a number of marine organisms including *Turritella uvasana* cf. subsp. *hendoni* Merriam (loc. 649; sample H–96). (Altitude of bed at creek level, about 1,775 ft.)	5
Sandstone, volcanic, fine-grained; weathers brown; poorly exposed	10
Covered; section offset	10
Sandstone, volcanic, fine- to medium-grained, gray; speckled with black mineral grains; weathers flaggy to slabby owing to carbonaceous laminae. (Altitude at base of sandstone, about 1,750 ft.)	30
Siltstone, dark-gray, massive; exposed partly along creek and partly in steep moss-covered banks	60
Sandstone, volcanic, fine grained, silty. (Altitude, about 1,720 ft.)	2
Covered	8
Sandstone, volcanic, very fine grained, silty, dark-gray; exposed in steep moss-covered banks	40
Covered	10
Sandstone, volcanic, very fine grained, dark-gray, poorly exposed	40
Sandstone, volcanic, very fine grained, dark-gray; contains abundant pelecypods, some with calcareous shell fragments preserved (sample H–323). (Altitude at base of sandstone, about 1,680 ft.)	25
Covered	10
Sandstone, volcanic, very fine grained, dark-gray; contains small pelecypods; weathers to blackish-brown irregular fragments	25
Siltstone, dark-gray; weathers to irregular fragments as much as 2 cm long	30
Sandstone, volcanic, very fine grained, medium- to dark-gray, hard; bedding obscure; weathers irregularly; contains marine fossils, including a small *Turritella*, a 1-cm-long pelecypod with concentric striae, and a small echinoid	80
Covered	30
Sandstone, volcanic, medium-grained, light-yellowish-gray, moderately well consolidated (sample H–311)	35
Covered	90
Sandstone, volcanic, medium-grained, gray to brownish-gray, friable; laminated with gray siltstone	20

SECTION 2.—*Raging River Formation exposed in the tributary to Raging River, W½ sec. 9, T. 23 N., R. 7 E.*—Continued

	Thickness (feet)
Raging River Formation—Continued	
Sandstone, volcanic, granular, gray, friable; contains fragments of reworked siltstone near base	25
Siltstone, sandy, dark-gray, soft; contains calcareous concretions 1–2 feet long near the top	15
Sandstone, volcanic, fine-grained, friable; interlaminated with siltstone; bedding somewhat wavy or lenticular	7
Siltstone, dark-gray, irregular fracture, soft; bedding obscure	5
Sandstone, volcanic, medium- to coarse-grained, gray; speckled with black grains; friable; sparse laminae of dark-gray siltstone; otherwise thick bedded and massive weathering; dark-brown iron-oxide stain abundant along weathered joints	30
Siltstone, gray, soft; weathers to irregular fragments as much as 5 cm long	20
Sandstone, volcanic, coarse-grained to granular, friable; weathers brown	5
Sandstone, volcanic, coarse-grained, brown, friable; laminated with dark-gray siltstone	7
Conglomerate, volcanic; grading upward into a friable coarse-grained brown volcanic sandstone; conglomerate pebbles average 1 cm long	8
Sandstone, volcanic, coarse-grained, friable; weathers dark brown or dark gray; forms massive ledge	28
Siltstone, dark-gray; irregular fracture; soft; bedding obscure	5
Covered	40
Siltstone, dark-bluish-gray; irregular fracture; soft; bedding obscure; weathers with a dark-reddish-brown iron-oxide stain along joints. (Altitude at base of outcrop, about 1,570 ft.)	25
Covered	700
Siltstone, clayey, hard, medium-gray, massive (sample H–310). (Altitude at top of outcrop, about 1,300 ft.)	35
Claystone, black and brown, soft; somewhat laminated; contains pyrite	25
Siltstone, dark-gray; medium-gray and brown mottling	5
Sandstone, medium-grained, medium-dark-gray, hard	5
Siltstone, medium-gray, massive, hard; bedding obscure	25
Sandstone, gray, medium-grained; recrystallized to a hard rock by intrusion	1
Igneous sill, dark-gray; 0.5-mm average grain size in upper half; light-gray 2- to 3-mm-long phenocrysts in lower half	24*
Sandstone, gray, medium-grained, hard; altered by intrusion. (Altitude at base of outcrop, about 1,170 ft.)	100
Covered (interval probably conceals a fault)	
Total exposed thickness of the Raging River Formation above fault	1,836

SECTION 3.—*Raging River Formation exposed in the tributary to Raging River, secs. 10, 15, and 16, T. 23 N., R. 7 E.*

[Measured by J. D. Vine, 1961. Thickness of units based on field estimates adjusted to fit a geologic profile. Locality numbers are shown on plate 1.*, sill, not included in thickness total]

	Thickness (feet)
Tiger Mountain Formation of the Puget Group:	
Sandstone, micaceous, arkosic (thickness not measured).	
Raging River Formation:	
Covered (this interval may conceal a fault. (Altitude at base of covered interval, about 1,420 ft.)	100
Siltstone, dark-gray; weathers to small irregular fragments	40
Sandstone, very fine grained, gray; forms ledge	3
Siltstone, sandy, dark-gray; contains euhedral plagioclase grains, especially near fossil molds; contains *Turritella* and a small pelecypod; bedding completely obscured. (Altitude at base of siltstone, about 1,375 ft.)	65
Sandstone, volcanic, very fine grained, medium-gray; sparse silty laminae; bedding faintly visible; contains marine fossils (loc. 647)	40
Covered	200
Siltstone, weathers dark gray to dark brownish gray; partly exposed	15
Sandstone, volcanic, very fine grained, silty; partly exposed	25
Sandstone, volcanic, very fine grained; weathers dark yellowish brown to dark brownish gray; forms ledge; contains worm trails on bedding planes. (Altitude at base of sandstone, about 1,190 ft.)	7
Covered	40
Sandstone, volcanic, very fine grained; weathers dark yellowish brown; contains echinoderm	8
Sandstone, volcanic, very fine grained, silty; weathers dark grayish brown; massive to slabby; forms ledge	40
Siltstone, dark-brownish-gray; contains small marine pelecypods. (Altitude at base of siltstone, about 1,130 ft.)	90
Covered	20
Sandstone, volcanic, medium-grained, gray, hard; weathers yellowish brown; speckled with altered plagioclase grains; a crab leg and a *Cristispira pugetensis* Allison (sample H–312) were found	7
Covered. (Altitude at base of covered interval, about 1,080 ft.)	80
Siltstone, dark-gray and medium-dark-gray, laminated; forms ledge	40
Covered	10
Sandstone, volcanic and cherty; upper part is medium grained and moderately friable; lower part is hard and siliceous (sample H–313)	10
Covered	50
Siltstone, dark-gray and medium-dark-gray, laminated; also massive siltstone and sandy siltstone	30
Igneous sill, dark-gray, aphanitic; plagioclase phenocrysts as much as 2 mm long; mafic mineral not identified; forms ledge. (Altitude at base of igneous ledge, about 1,030 ft.)	50*

SECTION 3.—*Raging River Formation exposed in the tributary to Raging River, secs. 10, 15 and 16, T. 23 N., R. 7 E.*—Con.

	Thickness (feet)
Raging River Formation—Continued	
Covered. (Altitude at base of covered interval, about 940 ft.)	230
Sandstone, volcanic, medium- to coarse-grained, conglomeratic; sandstone is medium light gray; well-rounded conglomerate pebbles commonly 1–2 cm long, composed of chert and volcanic rock. (Altitude at base of conglomerate, about 890 ft.)	130
Sandstone, volcanic, medium-grained; weathers bluish gray; contains light-gray chert concretions	7
Sandstone, conglomeratic; similar to 130-ft-thick unit above	30
Siltstone, yellowish-gray, massive	28
Total exposed thickness of the Raging River Formation	1,345

SECTION 4.—*Tiger Mountain Formation and lower members of the Tukwila Formation exposed on the north side of Deep Creek in secs. 16 and 21, T. 23 N., R. 7 E.*

[Measured by J. D. Vine, 1961. Thickness of units based on field estimates adjusted to fit a geologic profile]

	Thickness (feet)
Tukwila Formation, main body:	
Tuff, fine-grained, and tuffaceous siltstone; mostly covered	Not measured
Tiger Mountain Formation:	
Member B:	
Sandstone, medium- to coarse-grained, micaceous; locally granule and pebble conglomerate; crossbedded, friable; characteristically contains abundant dark-colored chert grains	525
Tukwila Formation:	
Member B:	
Volcanic sandstone and tuff, very fine grained to medium-grained, greenish-gray to gray; thin lenses of lapilli tuff and tuff-breccia; contains leaf impressions locally	475
Tiger Mountain Formation:	
Member A:	
Sandstone, fine- to medium-grained, micaceous, feldspathic, crossbedded	375
Tukwila Formation:	
Member A:	
Tuff, locally altered to a porcellanite, and volcanic siltstone and sandstone; weathers to a soft slope that is mostly covered	350
Tiger Mountain Formation, main body:	
Covered, dump of abandoned coal prospect at the top	250
Sandstone, gray, medium-grained, arkosic; weathers massive (partly covered)	50
Covered	20
Sandstone, gray, medium-grained, arkosic; weathers massive; forms highest ledge of waterfalls	30

SECTION 4.—*Tiger Mountain Formation and lower members of the Tukwila Formation exposed on the north side of Deep Creek in secs. 16 and 21, T. 23 N., R. 7 E.*—Continued

	Thickness (feet)
Tiger Mountain Formation, main body—Continued	
Coal and clay	1
Covered	1
Siltstone, carbonaceous, dark-gray; coaly streaks near top	2
Sandstone, gray, medium-grained, arkosic, micaceous	12
Siltstone, medium-gray; streaked with dark gray; thick bedded; weathers massive to slabby	5
Sandstone, gray, fine-grained; interbedded with gray siltstone; weathers into conspicuous units ½–5 ft thick	35
Siltstone, gray; interbedded with gray fine- to medium-grained arkosic micaceous sandstone	4
Covered	2
Siltstone, dark-gray, carbonaceous; grades to a lighter, yellowish gray at the top. Forms lowest exposure at base of waterfalls	8
Covered	340
Siltstone, dark-gray, poorly exposed	100
Sandstone, volcanic, medium-gray to greenish-gray, very fine grained: weathers yellowish brown; contains carbonaceous laminae (sample H–84, table 1)	20
Covered	60
Sandstone, arkosic, micaceous, gray, fine- to medium-grained	8
Covered	9
Sandstone, arkosic, micaceous, gray, fine- to medium-grained	5
Covered	10
Sandstone, arkosic, micaceous, gray, fine- to medium-grained	8
Covered	15
Sandstone, arkosic, micaceous, gray, fine- to medium-grained; forms massive ledge; contains claystone fragments as much as 3 in. long; sparse leaf impressions	15
Covered	55
Sandstone, arkosic, micaceous, light-olive-gray, fine- to medium-grained; forms massive-weathering ledge; abundant chloritic alteration of mica and other minerals; contains abundant leaf impressions of land plants; claystone fragments sparsely scattered in sandstone. A dark-brown to black substance, possibly an organic material, forms a coating on the sand grains in the middle of the outcrop in a 2-ft-wide zone discordant to bedding (sample H–77, table 1)	15
Siltstone, dark-gray; interlaminated with medium-gray fine-grained sandstone; carbonaceous material occurs along some laminae	20

SECTION 4.—*Tiger Mountain Formation and lower members of the Tukwila Formation exposed on the north side of Deep Creek in secs. 16 and 21, T. 23 N., R. 7 E.*—Continued

	Thickness (feet)
Tiger Mountain Formation, main body—Continued	
Total thickness, main body, Tiger Mountain Formation	1,100
Total thickness, Tukwila Formation, members A and B	825
Total thickness, all measured parts, Tiger Mountain Formation	2,000
Raging River (?) Formation:	
Siltstone, dark-gray, massive	35

SECTION 5.—*Zone of interstratified Tiger Mountain Formation and Tukwila Formation exposed in a small canyon in the E½ sec 21, T. 23 N., R. 7 E.*

[Measured by J. D. Vine, 1961. Thickness of units based on field estimate adjusted to fit a geologic profile]

	Thickness (feet)
Tukwila Formation, main body:	
Tuff and volcanic sandstone, mostly covered	Not measured
Tiger Mountain Formation:	
Member B:	
Sandstone, gray, fine- to medium-grained, micaceous, arkosic; chloritic alteration of mica and other minerals; contains local concentrations of coaly laminae and coalified wood fragments; interbedded with impure coal and brown carbonaceous claystone beds as much as 1 ft thick	250
Tukwila Formation:	
Member B:	
Tuff, greenish-gray, fine-grained, silty, and volcanic sandstone	150
Tiger Mountain Formation:	
Member A:	
Sandstone, gray, medium-grained, micaceous; speckled with black grains; friable; weathers massive	100
Tukwila Formation:	
Member A:	
Tuff, greenish-gray, fine-grained, laminated; forms hard ledge with a 50-ft waterfall in the lower part	200
Tiger Mountain Formation:	
Main body:	
Sandstone, gray, medium-grained, micaceous, friable; contains numerous coaly laminae and coalified wood fragments	10
Claystone, dark gray	6
Siltstone, clayey; contains well-preserved fossil leaf remains (USGS paleobotany loc. 9813)	4
Covered, interval not measured.	
Total thickness of interval measured	720

SECTION 6.—*Composite section of the Tukwila Formation and upper members of the Tiger Mountain Formation in the Taylor Mountain area, measured along a series of lines in secs. 22, 27, and 34, T. 23 N., R. 7 E., and the NE¼ sec. 4, T. 22 N., R. 7 E.*

[Measured by J. D. Vine and C. L. Rice, 1960. Thickness of units based on field estimates adjusted to fit a geologic profile]

	Thickness (feet)
Puget Group:	
Tukwila Formation:	
Main body:	
Volcanic sandstone, medium- to coarse-grained, clastic texture; thin beds of fine-grained tuffaceous rock containing locally abundant *Equisetum.* Tuff-breccia composed of volcanic boulders as much as 3 ft in diameter in a volcanic matrix locally abundant. A 6-ft-thick vesicular basalt sill or flow with plagioclase needles in microcrystalline groundmass occurs locally at the top	300
Tuff-breccia and volcanic conglomerate contains rounded volcanic boulders as much as 3 ft in diameter in a porphyritic matrix of zoned plagioclase and microcrystalline material	100
Volcanic sandstone, medium- to coarse-grain, greenish-gray, and lapilli tuff	755
Sandstone, gray, fine- to medium-grained, crossbedded; characteristically contains brown to black mica flakes; as much as 200 ft thick 1 mile northeast of Taylor (Bed F)	50
Volcanic sandstone, very fine grained, tuffaceous, and thin basalt sills similar to that at the top of the upper unit	1,000
Sandstone, very fine grained; contains brown mica flakes (Bed E)	25
Volcanic sandstone and siltstone, tuffaceous, thin basalt sills similar to that at the top of the upper unit	375
Sandstone, fine- to medium-grained; contains brown mica flakes; includes a 2-ft-thick basalt sill similar to that at the top of the upper unit (Bed D)	100
Volcanic sandstone, tuff, and tuffaceous siltstone; locally includes tuff-breccia and basalt sills similar to that at the top of the upper unit. A bed of pale-yellowish-gray clay at the base contains well-preserved fossil leaf impressions (USGS paleobotany loc. 9687) on Taylor Mountain	1,000
Sandstone, carbonaceous shale, and impure coal. The sandstone is fine- to medium-grained and characterized by brown mica flakes and a chlorite matrix (Bed C)	100
Volcanic sandstone, tuff, and volcanic flow rocks characterized by a glassy matrix with numerous spherulites	2,350
Total thickness of main body of the Tukwila Formation	6,175

SECTION 6.—*Composite section of the Tukwila Formation and upper members of the Tiger Mountain Formation in the Taylor Mountain area, measured along a series of lines in secs. 22, 27, and 34, T. 23, N., R. 7 E., and the NE¼ sec. 4. T. 22 N., R. 7 E.*—Continued

	Thickness (feet)
Puget Group—Continued	
Tiger Mountain Formation:	
Member B:	
Sandstone, greenish-gray, medium to coarse-grain, and scattered laminae containing chert granules and pebbles; micaceous, friable; weathers to a massive vertical cliff that exfoliates parallel to face of cliff. Extensive chloritic alteration of mica and other minerals	120
Tukwila Formation:	
Member B:	
Lapilli tuff and tuffaceous sandstone; forms massive cliff with a 100-ft waterfall	320
Tiger Mountain Formation:	
Member A:	
Sandstone, gray, fine- to coarse-grained, micaceous, mostly covered	220
Tukwila Formation:	
Member A:	
Tuff, volcanic sandstone, and locally coarse-grained lapilli tuff; mostly covered	340
Tiger Mountain Formation, main body:	
Sandstone, gray medium-grained; interbedded with siltstone	Not measured
Total thickness, Tukwila Formation	6,835
Total thickness, Tiger Mountain Formation, members A and B	340

SECTION 7.—*Part of the Renton Formation at Taylor*

[Compiled from observations in the mine workings by Evans (1912, p. 66–68, 134–141), notes on coal analyses by U.S. Bur. Mines (1931, p. 74–75, 136–137; 1941, p. 40–41, 60–61), mine map data, and field notes by J. D. Vine, 1960–61. Thickness of major units adjusted to fit a geologic profile. *, sill, not included in thickness total]

	Thickness (ft)	Thickness (in)
Renton Formation:		
Covered (interval to top unknown).		
No. 0 coal bed, U.S. Bur. Mines sample B39391	6	1¾
Sandstone and laminated siltstone containing leaf fossils at locality 9729; includes a kaolinized igneous sill. Upper part covered	650	------
Shale, massive, and sandy shale (includes No. "0" coal bed of Evans, 3 ft)	170	------
No. 1 coal bed (includes 6 ft 6 in coal)	8	4
Sandstone, shaly	20	------
Intrusive sill, altered	*23	------
Coal bed, impure	No data	
Sandstone, massive	90	------
No. 2 coal bed (includes U.S. Bur. Mines sample 9173, 3 ft 8½ in)	21	6

SECTION 7.—*Part of the Renton Formation at Taylor*—Con.

	Thickness (ft)	(in)
Renton Formation—Continued		
Shale	13	------
No. 3 coal bed, U.S. Bur. Mines sample 9175	3	5
Sandstone, massive	125	------
Intrusive sill	No data	
No. 3½ coal bed, impure	No data	
Sandstone and shale	75	------
No. 4 coal bed (includes U.S. Bur. Mines sample 9172, 2 ft 8½ in)	11	5
Shale	25	------
No. 5 coal bed (includes U.S. Bur. Mines sample 9174, 3 ft 10 in)	11	11
Shale	80	------
No. 6 coal bed (includes U.S.B.M. sample 9175, 4 ft 7½ in)	19	8
Sandstone, massive, and shale at the top and bottom	180	------
No. 7 coal bed (includes 1 ft 2 in coal)	33	3
Sandstone, and shale (includes bony bed 6 ft below No. 7 coal bed)	90	------
No. 8 coal bed (includes 4 ft coal)	6	1
Sandstone, massive	80	------
No. 9 coal bed (includes no clean coal)	12	6
Sandstone, yellowish-gray, fine- to medium-grained, micaceous, arkosic, laminated, friable; weathers massive; locally contains imperfectly preserved leaf fossils	450	------
Total of approximate thickness of sedimentary rocks	2,180	
Tukwila Formation.		

SECTION 8.—*Part of the Renton Formation in the Cedar Mountain area, W½ sec. 29 and NE¼ sec. 30, T. 23 N., R. 6 E.*

[Compiled from observations in the mine workings and roadcuts by Evans (1912, p. 64–65, 115–116), mine-map data, and field notes by J. D. Vine, 1961. Thickness of major units adjusted to fit a geologic profile; USGS paleobotany localities shown on plate 1]

	Thickness (feet)
Renton Formation:	
Covered (interval to top unknown).	
Siltstone, gray; weathers hackly to slightly fissile; micaceous; thin beds of calcareous siltstone; exposed in roadcut	150
Covered	400
Siltstone, gray; carbonaceous material emphasizes small-scale low-angle cross lamination; contains calcareous concretionary lenses 2–18 in. thick, 1–5 ft long	100
Covered	10
Coal, impure; McQuade seam (?); no outcrop	9
Shale; no outcrop	9
Covered	92
Sandstone; contains shale fragments; marked by collapse area at surface	38
Coal bed A; outcrop slumped and largely covered	6
Shale, carbonaceous; exposed in roadcut	2
Claystone, gray; exposed in roadcut	3

SECTION 8.—*Part of the Renton Formation in the Cedar Mountain area, W½ sec. 29 and NE¼ sec. 30, T. 23 N., R. 6 E.*—Con.

	Thickness (feet)
Renton Formation—Continued	
Siltstone, gray; sandy calcareous ledges that contain fossil leaf impressions locally (USGS paleobotany loc. 9730); exposed in roadcut	70
Siltstone, gray; locally red where baked; contains leaf fossils; slumped where exposed in roadcut	5
Coal bed No. 1; upper part burned and slumped; lower 3 ft exposed in roadcut; included as much as 11 ft 11 in. of coal before mining	13
Sandstone, friable, fine- to medium-grained, micaceous; exposed in roadcut	20
Covered	50
Sandstone, medium-gray, cross-laminated; contains light-gray concretions as much as 3 ft long; exposed in riverbank	8
Covered	10
Sandstone, micaceous; interstratified with laminated carbonaceous siltstone; contains calcareous concretions 1–3 ft long; exposed in railroad cut	12
Siltstone, laminated, carbonaceous; base obscured by slumping; exposed in railroad cut	10
Covered	65
Siltstone, clayey and sandy (Cavanaugh foundry sand)	40
Sandstone, gray, fine-grained, friable, micaceous; laminated in upper part with carbonaceous silt	50
Covered. Interval is marked by a depression that is probably the result of caving of abandoned workings on coal bed No. 2	100
Coal bed No. 2	No data
Covered. Interval calculated from mine data	275
Coal, discovery seam (?)	No data
Base not exposed.	
Total of approximate thickness of sedimentary rocks, Renton Formation	1,550

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