# Bedrock Geology of the Lake Tapps Quadrangle Pierce County Washington

GEOLOGICAL SURVEY PROFESSIONAL PAPER 388-B

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*By* LEONARD M. GARD, JR.

GEOLOGIC STUDIES IN THE PUGET SOUND LOWLAND, WASHINGTON

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*A study of Tertiary sedimentary, volcanic, and intrusive rocks in the western foothills of the Cascade Range*

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1968

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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# BEDROCK GEOLOGY OF THE LAKE TAPPS QUADRANGLE, PIERCE COUNTY, WASHINGTON

By Leonard M. Gard, Jr.


## ABSTRACT

Bedrock crops out in an area of about 100 square miles in the south half of the Lake Tapps quadrangle, Washington, in the western foothills of the Cascade Range about 20 miles east of Tacoma. Bedrock consist of (a) more than 11,000 feet of Eocene and Oligocene sedimentary and volcanic rocks of the Puget Group and the lower part of the Ohanapecosh Formation, (b) intrusive rocks of probable Oligocene or Miocene age, and (c) thin semiconsolidated sedimentary deposits of Miocene age.

Rocks of the Puget Group are more than 9,000 feet thick and are divided, in ascending order, into the Carbonado, Northcraft, and Spiketon Formations. The Carbonado and Spiketon Formations consist of arkosic sandstone, siltstone, shale, and coal deposited in an environment of brackish-water streams and deltas adjacent to a marine embayment west of the quadrangle. These two formations had a common source to the east and are indistinguishable except where the Northcraft Formation is present between them. The Northcraft in the Lake Tapps quadrangle consists of a wedge of andesitic volcanic breccias derived from areas to the southwest.

The Ohanapecosh Formation conformably overlies the Puget Group and is composed of sedimentary rocks of volcanic detritus and interbedded pyroclastic rocks. This volcanic debris originated somewhere east of the quadrangle. Only 2,500 feet of Ohanapecosh rock crops out in the quadrangle, although more than 10,000 feet is presumably present in the Cascade Range to the east.

During Oligocene and Miocene time the Eocene and Oligocene rocks were folded into the Carbon River anticline, which trends and plunges north-northwest and can be traced from Burnett south to the Nisqually River. North of Burnett the anticline is concealed by surficial deposits. Along the core of the anticline are several smaller tightly folded anticlines and synclines whose trends parallel that of the major structure. All the folds have been broken by high-angle (chiefly reverse) faults that parallel the fold axes and that may have as much as 1,000 feet of displacement. Dips in the core of the Carbon River anticline range from 0° to 90° and average about 60°. On the west limb of the anticline the Northcraft Formation is more than 2,000 feet thick; on the east limb its maximum thickness is only 200 feet. Erosion may have removed the overlying Spiketon Formation from the west limb.

The Carbon River anticline is believed to have resulted from east-west lateral compression acting on Carbonado rocks between a buttress of thick downwarped Ohanapecosh Formation to the east and the competent Northcraft Formation to the west.

Following Oligocene or early Miocene uplift and erosion, hornblende-rich pumiceous alluvium and mudflows of late Miocene age were deposited on an uneven surface of Eocene rocks. The alluvium and mudflows were probably derived from an area in the Cascade Range where a granodiorite batholith may have broken through to the surface, causing explosive volcanism. The Miocene deposits probably are equivalent to part of the Ellensburg Formation on the east flank of the Cascades.

East-trending normal faults of small displacement have offset the Miocene and older rocks.

Small intrusions of igneous rock of probable Oligocene or Miocene age occur as dikes, sills, and plugs in rocks of Eocene and Oligocene age. The finer grained intrusive rocks are andesite and latite, and the coarser grained rocks are quartz diabase and hornblende dacite porphyry.

Bituminous coal has been mined from the Puget Group since 1874. Most of the higher grade coal was taken from the Carbonado Formation, which also provided the best coking coal on the west coast. Little mining is being done now, although resources estimated to be 362 million tons still remain. Other known resources in the bedrock of the quadrangle are clay, and stone for building construction, riprap, and road metal.


## INTRODUCTION

### LOCATION, CULTURE, AND ACCESSIBILITY

The Lake Tapps 15-minute quadrangle is in Pierce and King Counties southeast of Tacoma in western Washington (fig. 1). The quadrangle includes four 7½-minute quadrangles: (clockwise from the northwest corner) Sumner, Buckley, Wilkeson, and Orting. Bedrock crops out in the last three quadrangles; topographic maps of the Wilkeson and parts of the Buckley and Orting quadrangles served as the base for the geologic map (pl. 1).

The largest communities in these three quadrangles (and their populations as of 1960) are Buckley (3,538), Orting (2,697), Carbonado (424), Wilkeson (412), and Burnett (100). The last three towns, which owe their inception to the coal-mining industry, have slowly dwindled in population since the mid-thirties, when most of the mines shut down.

Sites of several abandoned coal-mining towns are now marked by a few buildings or, more commonly, by only foundations and ruins overgrown by brush. These old

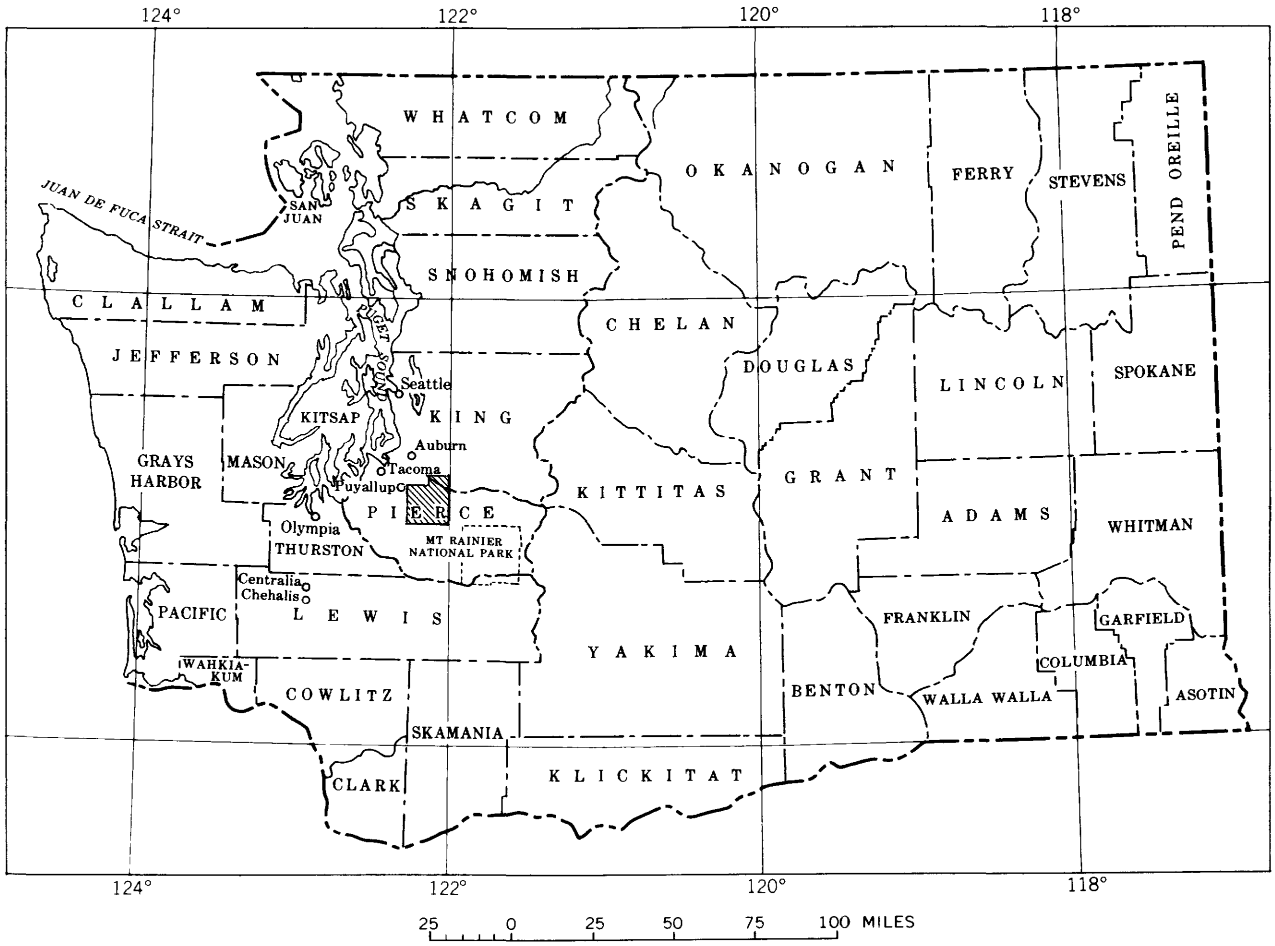


FIGURE 1.—Location of mapped area (patterned).

towns include: Spiketon, also known as Black Carbon and as Pittsburg, which was adjacent to South Prairie Creek in the SE¼ sec. 15, T. 19 N., R. 6 E., east of Burnett; South Willis, which was in the SE¼ sec. 22, T. 19 N., R. 6 E., northeast of Wilkeson; Melmont, which was about 3 miles south of Carbonado in the E½ sec. 21, T. 19 N., R. 6 E., along the abandoned railroad on the east side of the Carbon River; and Montezuma, now known as Upper Fairfax, which is in the southeast corner of the quadrangle.

Access to the area ranges from good to poor. Some parts of the area are accessible only by private logging roads and roads maintained for fire protection. Abandoned logging-railroad grades are useful as trails. Bedrock is exposed in some of the old roadcuts.

## PURPOSE

The Lake Tapps quadrangle was mapped as part of a geological study of the Puget Sound lowland, including the metropolitan area adjacent to Seattle and Tacoma. The purpose of the study is to provide basic geologic data useful in planning for future metropolitan and industrial growth and development of the area. Mapping of the bedrock of the Lake Tapps quadrangle was primarily undertaken to increase knowledge of the Tertiary stratigraphy and structure of the western foothills of the Cascade Range. The surficial deposits of the quadrangle were described by Crandell (1963).

## FIELDWORK AND ACKNOWLEDGMENTS

Geologic mapping was done during the summer months of 1953–56. The writer was assisted in the field at various times by L. A. Palmer, Leland Whitney, R. A. Fisher, D. C. Kapphahn, and R. A. Ferguson.

The writer appreciates the cooperation of the Northwestern Improvement Co. of the Northern Pacific Railroad in making available its collection of mine maps. The St. Regis Paper Co. was particularly helpful in allowing access to its tree-farm property and in making available its file of unpublished coal-mine maps. Discussions with Joseph Daniels and Simon Ash were invaluable in providing information about coal mining, history, and geologic structure of the area. The late Roland W. Brown identified the plant fossils and discussed their stratigraphic significance. Mr. Brown, during several field trips, aided the writer by sharing his considerable knowledge of the Tertiary floras of the Northwest.

The writer wishes to acknowledge the help and guidance of D. R. Crandell during the fieldwork and manuscript preparation.

### PREVIOUS WORK

The bedrock geology of this area was first examined in 1881–84 by Bailey Willis for the Northern Transcontinental Survey and was summarized by him (1886) in the Tenth Census Report of the United States and (1898) in the 18th Annual Report of the U.S. Geological Survey. Willis and G. O. Smith (1899) did further work on the geology and coal resources in 1896. Smith (1902) reviewed the structure and economic development of the coal fields.

In 1909–10, E. E. Smith (1911), of the U.S. Geological Survey, examined, sampled, and analyzed coals of the entire State of Washington in a cooperative program with the Washington State Geological Survey. Summary reports on the Wilkeson-Carbonado coal fields appear in the Washington Geological Survey Annual Reports for 1901 and 1902. Weaver (1937, p. 64–66) measured and published a stratigraphic section of the Puget Group in the Carbon Gorge.

The most comprehensive report on this area was by Joseph Daniels (1914), a mining engineer. Daniels' main contribution was a geologic-structure map of the Wilkeson-Carbonado area based on observations made in the coal mines that were operating at that time. His report included a tentative correlation of the coal seams that were then known. Later, Simon Ash (1931) compiled a correlation of the Burnett, Wilkeson, and Carbonado coal seams, on the basis of knowledge acquired through long association with this area both as a mining engineer and as State Mine Inspector.

## GENERAL SETTING

### DRAINAGE AND RELIEF

The master streams of the area are the Puyallup River and its two main tributaries, the Carbon and White Rivers; all these streams have their headwaters in the glaciers of Mount Rainier, a volcanic cone about 15 miles southeast of the quadrangle. The east-central part of the quadrangle is drained by South Prairie Creek and its tributary, Wilkeson Creek; both streams head in the Cascade Range. The south-central part of the quadrangle is drained by Voight and Frame Creeks, which originate on the north slope of the divide between the Carbon and Puyallup Rivers.

Waterfalls and rapids occur at several places where the streams cross resistant bedrock. Falls occur at four places on Voight Creek: in the NE¼ sec. 3, and in secs. 2, 12, and 13, T. 18 N., R. 5 E. At each place the stream has been superposed from glacial deposits onto resistant volcanic breccia. A waterfall occurs in sec. 5, T. 18 N., R. 5 E., where Lily Creek spills into the Carbon Gorge over outcrops of sandstone; and low falls and rapids occur at several places along Wilkeson Creek in secs. 27 and 34, T. 19 N., R. 6 E., upstream from Wilkeson, where the stream crosses resistant sandstone layers. The Carbon River forms rapids at many places in its gorge upstream from Carbonado.

The quadrangle is divided into two principal physiographic areas: (a) a broad rolling lowland at an altitude of 50–1,100 feet that is part of the Puget Sound lowland, and (b) and upland at an altitude of 1,100 to about 2,400 feet that is part of the foothills of the Cascade Range.

The total relief is about 2,400 feet; the highest point is 2,435 feet on the crest of Cowling Ridge (on which the Electron fire lookout is situated) in the south-central part of the quadrangle. The lowest point is where the Puyallup River flows from the quadrangle at an altitude of a little less than 40 feet. Total visible relief of bedrock is about 2,000 feet; the highest exposure is at an altitude of about 2,350 feet on the side of Cowling Ridge, and the lowest exposure is at an altitude of about 300 feet in sec. 8, T. 18 N., R. 5 E., where bedrock is exposed north of the narrows of the Puyallup River.

The Cascade foothills in the quadrangle are characterized by a rather flat, generally northwest-sloping surface that has been deeply dissected. The present topography and drainage are the result mainly of erosion and deposition during Pleistocene time, and Quaternary deposits mask an older topography carved on the bedrock surface. In a few places streams have eroded their valleys parallel to the strike of the bedrock. This is true of South Prairie Creek at two places east of Burnett, where the stream has cut northwest-trending strike valleys parallel to thick sandstone beds; and, to a lesser extent, it is true of Wilkeson Creek upstream from Wilkeson, where the stream flows parallel to the strike of resistant beds for short distances. Most streams, however, have been superposed randomly from glacial drift onto bedrock and are little influenced by the bedrock structures.

The deepest valley in the Cascade foothills is that of the Carbon River. Where the river enters the southeast corner of the quadrangle, the valley is about 1 mile wide and nearly 1,000 feet deep. A few miles downstream, the valley narrows, where the river cuts through more resistant bedrock, and forms the Carbon Gorge.

At Fairfax Bridge the gorge is nearly 900 feet deep and only a little more than 1,000 feet wide. The sides of this gorge form the most precipitous slopes in the area; in some places between Fairfax Bridge and Carbonado the walls are vertical to overhanging. About 3 miles downstream from Carbonado the river emerges from the bedrock gorge and occupies a broad steep-walled valley formed chiefly in surficial deposits. Farther downstream the Carbon is joined by South Prairie Creek and Voight Creek before it joins the Puyallup River 3 miles north of Orting.

Other principal valleys in the foothills are those of Gale and Voight Creeks. The valley of Gale Creek is V-shaped, narrow and cut in bedrock throughout the course of the stream. It joins Wilkeson Creek, which continues in a narrow bedrock valley to Wilkeson. The upper 4-mile segment of Voight Creek occupies a broad U-shaped valley, although the stream is about the same size as Gale Creek. After spilling over an outcrop of volcanic breccia, Voight Creek meanders across a drift surface, cascades over another rock outcrop, then becomes deeply entrenched in the drift about 3 miles upstream from its confluence with the Carbon River.

Melt water from the continental glaciers that occupied the Puget Sound lowland eroded a complex of large ice-marginal channels in the bedrock. Most channels trend southwest, transverse to the bedrock structure, and provide some of the best exposures of bedrock in the quadrangle. The largest channel is that of Fox Creek, which forms a narrow, steep-sided gorge between Spar Pole Hill and Cowling Ridge. A similar but smaller channel in bedrock lies in secs. 10 and 15, T. 18 N., R. 5 E., northwest of Spar Pole Hill; another large channel lies east of Wilkeson. The channels are generally swampy and poorly drained, and none are occupied by through-flowing streams.

## CLIMATE AND VEGETATION

The Puget Sound lowland has a marine climate, somewhat modified owing to distance from the Pacific Ocean and to the intervening Olympic Mountains. Summers are cool and dry, and winters are mild and wet. Prevailing winds blow from the Pacific Ocean, bringing moist air inland. Precipitation in the Lake Tapps quadrangle is principally rain and increases with an increase in altitude from the northwest to the southeast. At Buckley the average annual precipitation is about 49 inches whereas at the Carbon River entrance to Mount Rainier National Park it is about 67 inches. Rainfall is irregularly distributed through the year, about 65 percent falling at Buckley during the 6-month period from October through March.

The dense forests of fir, spruce, cedar, and hemlock that once covered this area were logged off early in this century. At the time of the mapping, only one small stand of virgin forest still remained, on the divide between Frame and Voight Creeks.

Much of the foothills area is now a tree farm and is covered with large stands of second-growth hemlock, fir, and spruce. Solitary giant Douglas-firs still tower above the second growth, as reminders of the virgin forests. Madrona grows in the better drained areas, and dense stands of red alder are found wherever there has not been artificial reforestation. Big-leaf maple, vine maple, and western redcedar are common in the lower, moister areas.

Fieldwork is hindered in the area by dense undergrowth along stream bottoms and in recently logged areas. In the logged areas, bracken interlaced with blackberry vines grows as much as 10 feet high, and devil's-club and nettles grow profusely in moister, shaded gullies. In stands of mature timber, undergrowth consists of salal, Oregon grape, sword fern, and maidenhair fern; here passage is easier.

## REGIONAL GEOLOGIC SETTING

Most of the Lake Tapps quadrangle lies within the Puget Sound lowland, a topographic and structural basin that extends from the Cascade Range on the east to the Olympic Mountains on the west. The southeastern part of the lowland is underlain by sedimentary and volcanic rocks of Eocene to Miocene age. These crop out in and adjacent to the cities of Seattle and Renton and in a belt 10–15 miles wide along the west flank of the Cascade Range. Rocks in this belt consist principally of folded and faulted rocks of the Tertiary Puget Group, overlain by the volcanic rocks that form most of this part of the Cascade Range. In the quadrangle, rocks of the Puget Group are exposed chiefly in the Carbon River anticline, a major northward-trending folded and faulted structure. The Wilkeson anticline is a part of this structure in the eastern part of the quadrangle.

Semiconsolidated deposits of late Miocene age crop out locally along the west margin of the Cascades. Miocene sediments probably continue westward and thicken beneath the unconsolidated Pleistocene deposits of the Puget Sound lowland.

## STRATIGRAPHY

More than 11,000 feet of sedimentary and volcanic rocks of Eocene to Miocene age crops out in the Lake Tapps quadrangle. The Eocene rocks were deposited in a fresh- and brackish-water environment, on flood plains and in deltas. These rocks form the Puget Group, which locally contains volcanic debris thought to be a tongue of the Northcraft Formation. The Puget Group is overlain by volcanic sedimentary rocks and pyroclastic rocks of the lower part of the Ohanapecosh Formation of Oligocene age. The Puget and Ohanapecosh rocks are folded and faulted and were intruded by dikes and sills of intermediate composition. After deformation and intrusion the rocks were uplifted and eroded. Semiconsolidated fluvial and lacustrine deposits of Miocene age were later deposited unconformably on the Puget and Ohanapecosh rocks in some places.

## EOCENE SERIES

### PUGET GROUP

The Puget Group consists of a thick sequence of middle (?) to upper (?) Eocene sedimentary rocks of nonmarine, fresh- and brackish-water origin that are locally interstratified with volcanic sedimentary rocks. The rocks of the Puget Group were first described by Willis (1886) and referred to as the "coal measures of the Puget Sound basin." These rocks subsequently were named Puget Group by White (1888, 1889), who described brackish- or fresh-water mollusks mostly collected in the vicinity of Wilkeson and Carbonado. White did not cite a specific type locality for the Puget Group, but he stated that the rocks were believed to crop out in many places along the east margin of the Puget Sound lowland and the west flank of the Cascade Range.

At first the Puget Group was considered to be correlative with the Laramie Formation of Late Cretaceous age in the Rocky Mountain region (Willis, 1886, p. 759; White, 1888, p. 446). Later, Willis and Smith (1899, p. 2) assigned an Eocene age to it. Fossil leaves collected during the present investigation indicate that the part of the group exposed in the Lake Tapps quadrangle was deposited during the later half of the Eocene and possibly into the Oligocene.

Willis (1898, p. 426) divided the Puget Group in the Wilkeson-Carbonado area into two coal-bearing sequences separated by massive sandstones that are virtually barren of coal. The massive sandstone unit was called the Wilkeson Formation or the Wilkeson Sandstone; the underlying coal-bearing rocks, the Carbonado Formation; and the overlying coal-bearing sequence, the Pittsburg Formation. However, the names South Prairie Formation and Burnett Formation were also used by Willis (1898, p. 426, 429, 430) for the upper coal-bearing rocks. Willis and Smith (1899, p. 2) referred to the Puget as a formation, and their columnar sections and structure map of the Wilkeson-Carbonado area indicate that the Carbonado, Wilkeson, and Burnett Formations were considered local divisions of the Puget.

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Willis (1898) described the Carbonado Formation as consisting of 1,100–2,000 feet of sandstone, siltstone, and shale containing coal seams of good quality. The Wilkeson Formation was described as consisting of about 1,000 feet of massive sandstone and minor amounts of shale. The Burnett Formation was described by Willis as consisting of 8,270 feet of sandstone, siltstone, and shale, and containing five workable seams of inferior coal. This thickness apparently included part of the Ohanapecosh Formation of this report.

During the present study, Willis' divisions could not be used, principally because the Wilkeson Formation is lenticular and its massive sandstones can be traced along the strike for only a short distance near Wilkeson. Elsewhere, such as in outcrops along the Carbon River, the stratigraphic interval of the typical thick sandstones of Willis' Wilkeson apparently is occupied by alternating thin beds of sandstone, siltstone, and mudstone. These beds can be correlated with the Wilkeson Formation only by their stratigraphic relation to the underlying coal seams (Willis, 1898, p. 425). The lithologic similarity of the strata in all three formations of Willis, as well as the scarcity of continuous exposures, renders these formations of limited use for mapping purposes and necessitates changes in nomenclature.

In this report, the following nomenclature is used for the pre-Ohanapecosh rocks in the Lake Tapps quadrangle. The Puget Group of White and of Willis is retained but is extended to include a thick wedge of volcanic rocks which are here correlated with the Northcraft Formation of Snavely and others (1951, 1958). The Carbonado Formation of Willis is redefined to include the coal-bearing rocks that underlie the Northcraft Formation. Thus, the Carbonado Formation of this report includes beds of Willis' Carbonado and Wilkeson Formations and the lower part of his Burnett Formation. The Spiketon Formation is here newly named to include the arkosic coal-bearing rocks that overlie the Northcraft Formation; the Spiketon includes the upper 3,600 feet of Willis' Burnett Formation. The Wilkeson, Pittsburg, South Prairie, and Burnett Formations of Willis are abandoned.

Local intertonguing of volcanic rocks of Eocene age with the coal-bearing rocks of the Puget Group has also been recognized in other parts of the Puget Sound lowland (Warren and others, 1945; Fisher, 1954; Mullineaux, 1961; Waldron, 1962; Vine, 1962). The presence of a tongue of volcanic sedimentary rocks within the coal-bearing rocks of the Puget Group in the Lake Tapps quadrangle was not recognized by Willis and Smith (1899), who assumed that these volcanic rocks were part of the overlying sequence of volcanic rocks now called the Ohanapecosh Formation. The rocks of the tongue in the Puget Group include volcanic conglomerate, volcanic sandstone, and volcanic siltstone[1] which can be traced southwestward to the Northcraft Formation of the Centralia area (Snavely and others, 1951; 1958, p. 22). The Northcraft Formation thickens toward the western part of the quadrangle. However, the Northcraft apparently is absent just south of the quadrangle on the east flank of the Carbon River anticline between the Carbon and Puyallup Rivers and is apparently also absent in the thick section of the Puget Group exposed along the Green River just north of the quadrangle (Warren and others, 1945; Vine, 1962).

### CARBONADO FORMATION

The Carbonado Formation consists of moderately indurated interbedded sandstone, siltstone, mudstone, and shale that contain carbonaceous shales and coal seams. The top is arbitrarily placed at the base of the volcanic sedimentary rocks of the Northcraft Formation. The total exposed thickness is more than 5,000 feet along the Carbon River west of Carbonado, here designated as a reference section; the base of the Carbonado was not seen.

#### DISTRIBUTION

The Carbonado Formation occupies a northward-trending belt about 3 miles wide in the eastern third of the quadrangle. The formation is best, though discontinuously, exposed on South Prairie Creek near Burnett, on Gale Creek near Wilkeson, and on the Carbon River from sec. 31, T. 19 N., R. 6 E., upstream to the quadrangle boundary. The formation is typically represented at the reference section in the walls of the Carbon River valley near Carbonado in secs. 4 and 5, T. 18 N., R. 6 E., and secs. 31 and 32, T. 19 N., R. 6. E. A detailed measured section of the rocks in this area was made by Weaver (1937, p. 64–66).

Outcrops are generally confined to valley walls of the main streams and to melt-water channels. In the vicinity of Wilkeson, ridges and knobs of resistant sandstone stand above valleys cut by melt water in less resistant beds. In a few places, steeply dipping resistant sandstone beds stand out as ribs or ridges in the valley walls.

#### DESCRIPTION

The Carbonado Formation is composed of light-gray to brown sandstone and gray to brown or black siltstone, mudstone, carbonaceous shale, and coal seams. The sandstone, though light gray on fresh surfaces, generally weathers to tan or light buff. It is commonly micaceous, and locally presents a "salt and pepper" appearance because it contains aggregates of iron oxides. Sandstone strata are locally very thick bedded but are commonly crossbedded, and they exhibit such sedimentary features as current ripple marks (fig. 2), intraformational conglomerates, scour-and-fill features, and, rarely, worm or pelecypod trails. Individual sandstone strata range greatly in thickness; some are only a few inches thick, others are as much as 100 feet thick.

The Carbonado Formation is characterized by lithologic variations and changes in thickness of bedding within short distances along the strike. Because of these variations and the vegetative cover, most strata cannot be traced for any great distance. Sandstone beds are commonly lenticular and many lenses are probably channel fillings. Such a lens is well exposed on the east bank of the Carbon River about 1,500 feet upstream from Fairfax Bridge.

Sandstone in the Carbonado is typically well sorted. Mechanical analyses of random samples show that clastic fragments of sand size constitute 76–92 percent of each sample; silt and clay compose the remainder (fig. 3). The sand-sized grains are subangular to subrounded; sparce well-rounded quartz grains may have been derived from older sedimentary rocks.

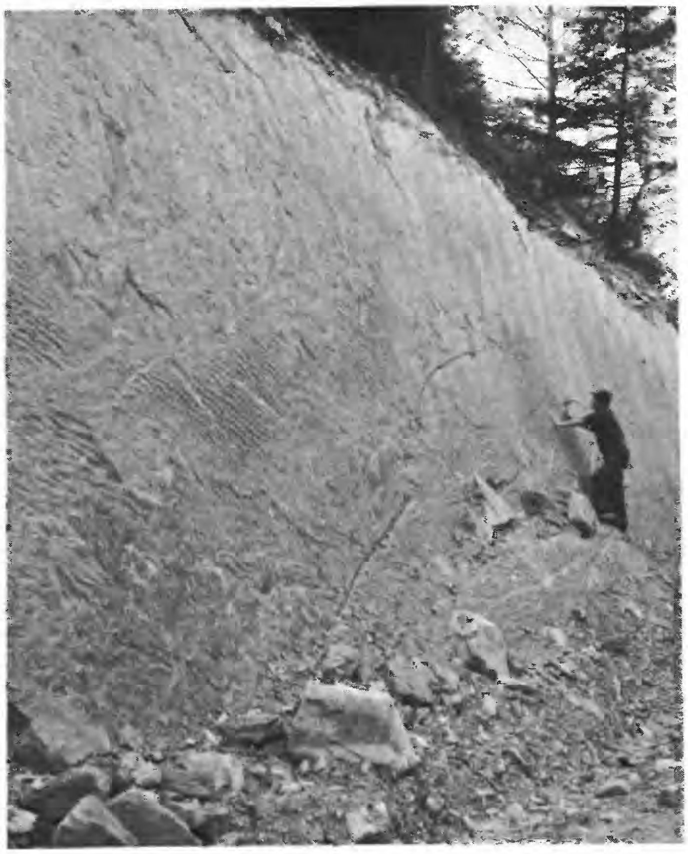

FIGURE 2.—Ripple-marked sandstone in the Carbonado Formation near the confluence of Wilkeson and Gale Creeks. Beds dip 70° E.

[1] The terms "volcanic conglomerate," "volcanic sandstone," and "volcanic siltstone" are used in this report to describe sedimentary rocks composed chiefly of water-transported volcanic-rock fragments, although some of these rock fragments may be of pyroclastic origin.

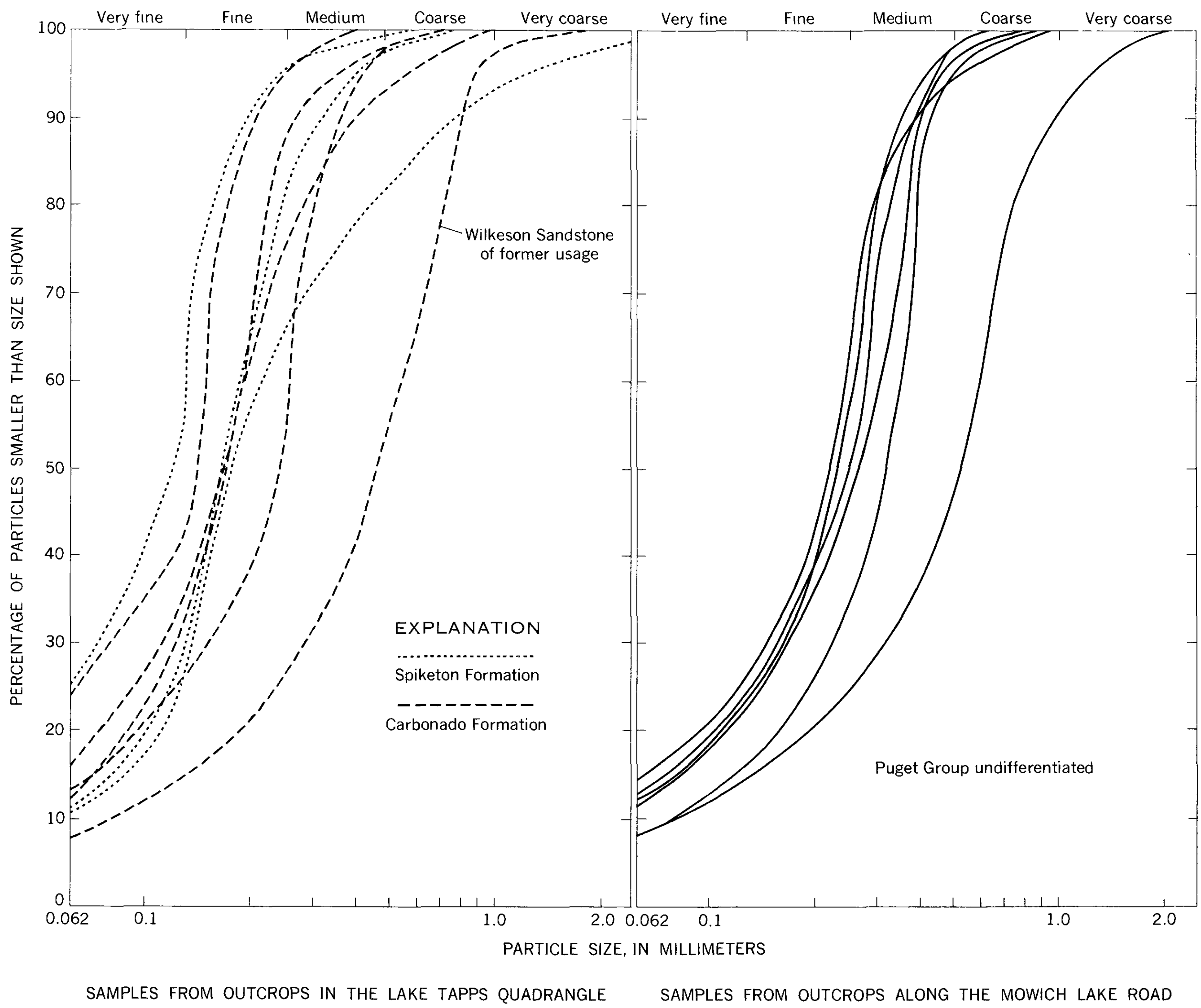


**Figure 3.**—Cumulative curves of sand-sized portions of eight samples of arkosic sandstone from the Carbonado and Spiketon Formations and six from the Puget Group undifferentiated.

Quartz and feldspar constitute the bulk of the sand-sized grains; black chert, quartzite, mica, and rock fragments are common minor constituents. The average composition of the rock is about 50 percent quartz and about 35 percent feldspar. Many of the quartz grains display undulatory extinction when viewed with a petrographic microscope. The feldspar is mainly plagioclase, although in some specimens as much as 20 percent is orthoclase. The plagioclase grains differ considerably in composition; most are albite or oligoclase, but some are sodic andesine. Both muscovite and biotite are present but seldom exceed 2 or 3 percent of the sample.

The silt- and clay-sized fractions of the sandstone consist of quartz and feldspar fragments, clay minerals, and chloritic material. An X-ray analysis of these combined fractions showed that roughly 55 percent is clay minerals, mainly illite, 35 percent is quartz, and 10 percent is plagioclase feldspar in the compositional range albite to andesine. The cementing material of the sandstone appears to be mainly secondary calcite, although the clay minerals probably also act as a binding agent.

Heavy minerals constitute a very small percentage of the sandstone, and it is necessary to disaggregate large samples to obtain a representative suite. Little variation is apparent in the kind of heavy minerals in the sandstone of either the Carbonado or the Spiketon Formations. Heavy minerals identified, in approximate order of decreasing abundance, are zircon, rutile, kyanite, tourmaline, staurolite, epidote, and hypersthene. Although garnet is scarce here, it is common in the upper part of the Puget Group that crops out along the Green River north of the quadrangle (Mullineaux, 1961). Most of the heavy-mineral grains are euhedral or broken euhedral crystals; the zircons are only slightly rounded at intersections or terminations of crystal faces.

Willis and Smith (1899, p. 2) described the Puget Group as being composed chiefly of sandstone. Although sandstone makes the most conspicuous outcrops because of its resistant nature, it probably forms less than half the total thickness of the Carbonado and Spiketon Formations. For example, sandstone constitutes only about 25 percent of the 8,500-foot-thick section of Puget along the Mowich Lake Road southeast of Fairfax, in the Mount Rainier quadrangle. The percentage of sandstone differs from place to place because of the lenticular nature of the beds, but the section along the Mowich Lake Road probably is fairly representative.

The siltstone and mudstone beds weather readily, so that outcrops are limited to artificial cuts or to recently eroded streambanks. Individual beds in these fine-grained strata range from laminations a fraction of an inch thick to beds 25 feet thick. Alternating thin beds of siltstone, mudstone, and fine-grained sandstone form sequences as much as 100 feet thick. Thin layers of oriented mica flakes are concentrated on certain bedding surfaces of many laminated siltstones. Because these beds tend to split along the layers of mica flakes, the amount of mica is easily overestimated.

The mudstones and siltstones are light brown to black, depending on the amount of incorporated organic matter, grain size, and state of oxidation.

Coal seams in the Carbonado Formation are as much as 15 feet thick, although most are 1–5 feet thick. Carbonaceous shales and beds of bony coal are common. The character of the coal seams was described in detail by Daniels (1914) and by Beikman, Gower, and Dana (1961).

#### FOSSILS AND AGE

Plant remains and a few poorly preserved fresh- and brackish-water mollusks are the only fossils found in the Carbonado Formation. Fossil leaves are more common in the fine-grained strata. Although carbonaceous beds generally contain many more leaves, the most perfectly preserved impressions occur in the less carbonaceous beds. Leaves in the carbonaceous beds locally occur in such profusion that identification of individual specimens is difficult or impossible.

Leaves were collected from the Carbonado Formation by the late Roland W. Brown, of the U.S. Geological Survey, and the writer and were identified by Brown. Fossil leaves common on coal-mine dumps at Wilkeson are: *Lastrea fischeri* Heer, *Anemia elongata*, *Ulmus* sp., *Metasequoia occidentalis* Chaney, and *Equisetum*. A siltstone block from the Carbonado Formation, which was engulfed in a mudflow breccia of the overlying Northcraft Formation, contained the following leaf assemblage: *Quercus* sp., *Cinnamomum dilleri* Knowlton, and *Persea pseudocarolinensis* Lesquereux. According to Brown, all these leaves date from the latter half of the Eocene. J. A. Wolfe (written commun., 1966) believes that the Carbonado Formation is probably no younger than middle Eocene.

The Wilkeson coal mines are in some of the lowest exposed strata of the Carbonado Formation, whereas the siltstone block incorporated into the Northcraft Formation must have come from near the top of the Carbonado.

Poorly preserved brackish- and fresh-water mollusks have been found at a few localities. "*Goniobasis*" cf. *G. drakei* (Arnold and Hanibal) and *Corbicula willisi* White were found by the writer in an isolated outcrop of the uppermost part of the Carbonado Formation in the NE¼NE¼ sec. 36, T. 19 N., R. 5 E. According to F. S. MacNeil, of the U.S. Geological Survey (written commun., 1958), the pelecypod *Corbicula willisi* lived in brackish to saline fluvial tidewater rather than under open-water marine conditions; the gastropod "*Goniobasis*" could indicate either fresh water or the fringe of a brackish-water environment. Thus, the environment represented here was probably a large shallow sound to which large quantities of fresh water were contributed by rivers.

Mollusks were also found in rocks of the Carbonado Formation that crop out along the Puyallup River 8 miles south of Carbonado in the NE cor. sec. 20, T. 17 N., R. 5 E. These rocks lie just below the base of the Northcraft Formation and therefore are in approximately the same stratigraphic position as the *Corbicula*-bearing rocks along the Carbon River. The outcrops along the Puyallup River also contain the pelecypod *Corbicula willisi* and a gastropod (*Acmaea* n. sp.), a shoreline limpet which has not been reported previously from the Puget Group; this collection indicates a near-shore environment of deposition.

### NORTHCRAFT FORMATION

#### DISTRIBUTION AND THICKNESS

The Northcraft Formation in the Lake Tapps quadrangle consists of volcanic breccia and tuff and lesser amounts of volcanic conglomerate and volcanic sandstone. It is well exposed in the western part of the mapped area on the south and east sides of Spar Pole Hill. Although only about 1,000 feet of the formation is exposed here, the Northcraft is more than 2,000 feet thick in the western part of the quadrangle. Its maximum thickness in the eastern part of the quadrangle is only about 200 feet.

The Northcraft lies at or near the surface in two northward-trending belts on both flanks of the Carbon River anticline, but it has been eroded from the crest. On the east flank of the anticline the formation occurs in a narrow belt of poorly exposed rocks. Outcrops are limited to the valley walls of South Prairie Creek, the sides of the melt-water channel east of Wilkeson, and the hillside in the NW¼ sec. 35, T. 19 N., R. 6 E., southeast of Wilkeson. On the west flank of the anticline, the belt of Northcraft outcrops is about 6 miles wide and can be traced for more than 20 miles from the Carbon River southward to the Nisqually River. In the southern part of the quadrangle these rocks are covered by Pleistocene deposits, and the location of the contact with the underlying Carbonado Formation is inferred from exposures along the Carbon River (fig. 4) and along the Puyallup River about 2 miles south of the quadrangle.

On the east limb of the anticline, the thin Northcraft is overlain by the Spiketon Formation; but on the west limb, where the Northcraft is considerably thicker, the Spiketon Formation is absent. Willis (1898) believed the volcanic breccia above arkosic strata of the Puget Group on the west limb to be correlative with the volcanic sedimentary rocks above arkosic beds on the east limb, which are now assigned to the Ohanapecosh Formation. Willis (1898, p. 425) accounted for the thicker section of Puget rocks on the east limb by assuming the presence of an unconformity between the Puget and his overlying "pyroxene andesite." In terms of the present stratigraphic nomenclature, Willis believed the Carbonado-Northcraft contact on the west limb of the Carbon River anticline to be equivalent to the Spiketon-Ohanapecosh contact on the east limb.

FIGURE 4.—Contact of westward-dipping mudflow breccia at base of the Northcraft Formation and underlying black shale of the Carbonado Formation. South valley wall of Carbon River in NW¼NE¼ sec. 31, T. 19 N., R. 6 E.

#### DESCRIPTION

The Northcraft Formation is composed mainly of somber-hued volcanic breccia [2] of andesitic composition. The breccia is composed predominantly of angular andesitic rock fragments, more than 2 mm in size, in a matrix of smaller andesitic rock fragments and euhedral and broken euhedral crystals of pyroxene and plagioclase. The rocks are generally brownish or yellowish black but on fresh surfaces may be brick red, dark gray, greenish gray, or black, depending upon the predominant color of the included fragments.

Unweathered cemented breccia commonly breaks across the larger rock fragments so that individual fragments can be distinguished by their color and outline on the fresh surface. Weathered or uncemented breccia erodes readily, and the larger fragments commonly protrude from the outcrop (fig. 5). The breccia appears mostly in massive beds, some of which are many tens of feet thick; the bases and tops of the beds are rarely exposed.

Most layers of breccia in the Northcraft Formation appear to have been emplaced as volcanic mudflows,

FIGURE 5.—Volcanic mudflow breccia in Northcraft Formation exposed in SW¼SE¼ sec. 24, T. 18 N., R. 5 E. Hammer (circled) at lower right shows scale.

[2] The term "volcanic breccia" is used here to denote pyroclastic breccias, flow breccias, and mudflow breccias regardless of a specific mode of origin.

but some may be breccias of pyroclastic origin or flow breccias. Where the entire thickness of a breccia unit can be seen (as in a gully on the east side of Spar Pole Hill near the center of sec. 13, T. 18 N., R. 5 E.) the individual layers show a crude gradation from coarser fragments at the base (fig. 6) to finer fragments at the top—a size distribution that suggests origin as mudflows (Crandell, 1957; Mullineaux and Crandell, 1962, p. 857–858). Silicified logs and wood fragments are abundant in some of the mudflow breccias, and some rock fragments are rounded and appear to be waterworn. Silicified wood fragments throughout a breccia suggest that the breccia moved along the ground, probably as a mudflow; some breccias that lack wood may have had a pyroclastic origin.

A mudflow breccia of the Northcraft Formation that crops out in the NW¼ sec. 35 T. 19 N., R. 6 E., southeast of Wilkeson consists of subangular to rounded pebbles and cobbles in a matrix of fine-grained volcanic debris. This breccia, which is more than 50 feet thick, conformably overlies an arkosic sandstone of the Carbonado Formation. The top of the breccia is not exposed. Many of the fragments in the lower part of the breccia are rounded, but no internal stratification can be seen. The fragments average about 2 inches in diameter, but some are as large as 2 feet. A few rock fragments are fine-grained volcanic sandstone and tuff, but most are types of porphyritic and nonporphyritic andesite. Rock fragments in the upper part of the breccia are smaller and more angular than those in the lower part. Irregular cavities are common in the upper part of the breccia, and silicified wood fragments and impressions of organic material are common throughout the breccia layer.

FIGURE 6.—Concentration of boulders in basal part of a volcanic mudflow breccia in Northcraft Formation in the NE¼SW¼ sec. 13, T. 18 N., R. 5 E.

Mudflow breccias in the lower part of the Northcraft Formation contain angular blocks of arkosic sandstone and siltstone, silicified wood, and irregular stringers of coal. Several large sandstone and siltstone blocks — some containing fossil leaves—occur in the lower part of the Northcraft Formation on both sides of the Carbon River below Carbonado. These blocks may have been dropped from streambanks into a volcanic mudflow as it moved along a channel in the Carbonado Formation. Such a block, exposed in a railroad cut about 50 yards west of the top of the Carbonado Formation, was interpreted by Willis and Smith (1899, p. 8) to be a pinnacle of carbonaceous shale and sandstone that had been buried by a Pleistocene mudflow.

The large blocks of sandstone have the following features in common: (a) The blocks appear to be surrounded by breccia, (b) contacts with the breccia are smooth and exhibit no evidence of faulting, and (c) bedding in the blocks is discordant with the breccia contacts and with the attitude of the breccia layers. The maximum exposed dimensions of the blocks range from 4 to 50 feet. All of the blocks are along the Carbon River except for an isolated exposure of sandstone well above the Carbonado-Northcraft contact on the steep hillside about 600 yards west of Waterhole Creek in sec. 7, T. 18 N., R. 6 E. Although no contacts are exposed here, this sandstone is also interpreted as being a block in a mudflow breccia of the Northcraft Formation.

Several coal prospects have been dug in breccia of the Northcraft in the valley walls of the lower Carbon River in the SW¼ sec. 30, T. 18 N., R. 6 E., and in the north-central part of sec. 36, T. 18 N., R. 5 E. A coal seam exposed in one of these prospects is thin, is irregular in shape and attitude, and lies nearly at right angles to the observed attitude of the enclosing mudflow breccia. These coal seams may have formed from peat incorporated by mudflows as they crossed swampy areas.

Beds of lithic tuff in the Northcraft crop out along the lower Carbon River. These beds contain angular fragments of andesite as well as some euhedral and broken crystals of pyroxene. The fragments are generally less than 1 mm in diameter and occur in a matrix of finer rock fragments, crystals, and devitrified glass. One tuff contains a few leaf impressions and organic fragments.

An outcrop along the Puyallup River in sec. 17, T. 18 N., R. 5 E., exposes about 20 feet of one of these lithic tuff beds. The tuff is gray to purplish red, strongly altered, highly fractured, and unstratified. Along the right bank of the river, just downstream from the highway bridge, the tuff is a lapilli tuff that contains scattered gray porphyritic and nonporphyritic vesicular bombs 2–4 inches in diameter. The bombs are well rounded, and some are almost spherical; a few are flattened on one side, and some appear to have been partially split open upon impact. A thin section of the very fine grained purplish-red phase of the tuff shows an opaque reddish-brown material thought to be devitrified glass. The top of the lithic tuff bed is not exposed, and the base is separated from an underlying coarse mudflow breccia by a sill of dense greenish-gray andesite 2 feet thick; near the highway bridge the tuff is intruded by a small dike.

This bed of lithic tuff lies only a few hundred feet from a quartz diabase intrusive that propylitized the adjacent rocks of the Northcraft Formation. The propylitized rocks are dull green to black. As seen in thin section, the plagioclase phenocrysts are almost completely replaced by calcite, and the pyroxenes are altered to bastite, chlorite, calcite, and magnetite. Secondary clay minerals, calcite, and pyrite are common. A narrow vein that contains pyrite and calcite was prospected in these altered volcanic rocks just west of the south abutment of the highway bridge.

No lava flows were identified in the Northcraft Formation within the quadrangle, but andesite flows occur in the formation along the Puyallup River south of the quadrangle, in T. 17 N., R. 5 E., and in T. 16 N., R. 5 E., near Lynch Creek. In a few places, such as at the waterfalls on Voight Creek in the east-central part of sec. 2, T. 18 N., R. 5 E., there are outcrops of what is probably a flow breccia. The breccia is monolithologic, and the fragments in it appear to be somewhat agglutinated.

Sandstone and conglomerate composed of volcanic rock fragments represent a minor part of the Northcraft Formation. These rock types are interbedded with mudflow breccias and are best exposed in gullies on the south and east sides of Spar Pole Hill. Interbedded pebble conglomerate and mudflow breccia crop out along Beane Creek, on the south side of Spar Pole Hill. Most pebbles in the conglomerate are about 1 inch in diameter, but some are as large as 4 inches; they are subrounded and are composed of red, gray, and black porphyritic andesite. A few subangular fragments of calcite are present. The matrix of the conglomerate consists of subangular silt- and sand-sized fragments of volcanic rock and minor quantities of feldspar and pyroxene.

#### FOSSILS AND AGE

Fossils other than wood are scarce in the Northcraft Formation within the quadrangle. Fossil leaves were collected from the formation, however, both south and east of the quadrangle. East of the quadrangle, fine-grained white tuff and lapilli tuff that crop out in the SE cor. sec. 25, T. 18 N., R. 6 E., east of Fairfax, contain the following fossil leaves: *Anemia* sp., *Cercidiphyllum* sp., and cf. *Glyptostrobus*. According to Roland W. Brown, this association is indicative of an Eocene age. The tuff containing these leaves is in the thin Northcraft Formation on the east limb of the Carbon River anticline.

Leaves from tuffaceous siltstones of the Northcraft Formation south of the Puyallup River in the SE¼ sec. 34, T. 16 N., R. 6 E., were identified as *Dryophyllum* sp., *Betula* sp., *Ulmus* sp., and *Alangium* sp.; leaf fragments of other dicotyledonous plants were also present. According to Brown, this collection is of Eocene age, apparently from the latter half.

Samples of silicified wood from a mudflow breccia at Spar Pole Hill were identified by Richard A. Scott, U.S. Geological Survey, as three species of dicotyledonous wood, of which two were recognized as *Platanus* sp., a species of sycamore, and *Cercidiphyllum* sp., the katsura-tree. These species are of limited paleontological significance, however, because they range from earliest Tertiary through the Miocene in west-coast floras.

Snavely, Brown, Roberts and Rau (1958) dated the Northcraft in the Centralia area as late Eocene on the basis of stratigraphic relation to other dated rocks, and by a faunal assemblage found in correlative rocks. The Northcraft Formation in the Lake Tapps quadrangle is also regarded as late Eocene in age.

### SPIKETON FORMATION

The Spiketon Formation, newly named in this report, is a series of alternating beds of light-gray arkosic sandstone, gray to brown or black siltstone, mudstone, shale, carbonaceous shale, and coal that overlies the Northcraft Formation in the eastern part of the quadrangle. It is typically exposed along the valley walls of South Prairie Creek near the abandoned coal-mining community of Spiketon in the SE¼ sec. 15, T. 19 N., R. 6 E., which is designated as the type locality. The formation is about 3,600 feet thick and includes the upper part of the Burnett Formation of Willis and Smith (1899, p. 8). It is overlain with apparent conformity by volcanic sedimentary and pyroclastic rocks of the Ohanapecosh Formation.

#### DISTRIBUTION

The Spiketon Formation lies at or near the surface in a northwestward-trending belt about three-quarters of a mile wide on the east flank of the Carbon River anticline but is absent on the crest and west flank. The Spiketon crops out in secs. 14, 15, 22, and 23, T. 19 N., R. 6 E., in the valley walls of South Prairie Creek east of Burnett, and along the walls of the melt-water channel east of Wilkeson. At these places it strikes slightly west of north and exhibits homoclinal eastward dips of 50°–75°. The sandstone beds stand out as ribs along the valley walls, but the more easily eroded mudstone, shale, and coal beds underlie steep-walled colluvium-filled draws and hence are seldom exposed except in artificial cuts. The most extensive outcrop of the formation is near the west edge of sec. 23, where South Prairie Creek flows parallel to the strike of a thick steeply dipping sandstone.

#### DESCRIPTION

The Spiketon Formation is lithologically indistinguishable from the Carbonado Formation, and the two can be separated only where the volcanic rocks of the Northcraft Formation are also present.

The sandstone is well sorted; mechanical analyses of three samples (fig. 3) show that sand constitutes 75–88 percent of each sample; silt and clay compose the remainder. These samples are comparable not only to the sandstone samples of the Carbonado Formation, but also to seven sandstone samples randomly collected from the 8,500-foot-thick section of the undifferentiated Puget Group that was measured along the Mowich Lake Road south of the quadrangle. The three Spiketon samples average 84 percent sand; the five Carbonado samples average 85 percent sand; and the seven samples from the Mowich Lake Road section average 89 percent sand.

The main known difference between the Carbonado and Spiketon Formations is in the quality of the coal occurring in them. Analyses of coal from this area (E. E. Smith, 1911) show that the coal of the Carbonado Formation generally cokes well and has an average Btu rating of 12,000–14,000, whereas the coal of the Spiketon Formation generally cokes poorly and has a Btu rating of 9,000–12,000. Some of this difference may be due to more intense folding of the Carbonado in the core of the Carbon River anticline. The coal seams of the Spiketon Formation were described by Beikman, Gower, and Dana (1961).

#### FOSSILS AND AGE

Only a few fossils have been found in the Spiketon Formation. The following collection of leaves was made by Willis in 1895 from the Spiketon Formation along South Prairie Creek in the SE¼ sec. 15, T. 19 N., R. 6 E., about 1½ miles east of Burnett. It was reexamined by Roland W. Brown (written commun., 1957) and identified as *Ficus* sp., *Cercidiphyllum elongatum* Brown, *Celastrus* sp., *Vitis* sp., *Chaetoptelea* sp., and *Myrica* sp. According to Brown, this assemblage is middle to late Eocene in age.

A few pelycypods that were found in a sandstone overlying the Winsor (Lady Wellington) coal seam in the SE¼ sec. 15 on South Prairie Creek were too poorly preserved to be identified.

The Spiketon Formation is here assigned an age of late(?) Eocene on the basis of its stratigraphic position and the fossil leaves found in it.

### ORIGIN OF THE PUGET GROUP

Downwarping in Eocene time formed a north-south depression at the approximate position of the present Puget Sound–Willamette trough, which was occupied by the Cowlitz-Arago Gulf from Vancouver Island south to the vicinity of Coos Bay, Oreg. (Weaver, 1945, p. 1407). To the west the gulf was separated from the ocean by a low peninsula of lower Eocene Metchosin Volcanics; to the east of the gulf lay a wide expanse of flood plains and deltas of westward-flowing streams (Weaver, 1945, p. 1408).

In the Lake Tapps quadrangle, deposits of these flood plains and deltas are represented by the Carbonado and Spiketon Formations. The mineralogy of the sandstone strata indicates that the sediments were derived principally from igneous and metamorphic rocks, the nearest known sources of which were the central and northern Cascades and the northern Rocky Mountains; even nearer possible source areas directly east of the quadrangle, for several hundred miles, are now covered by younger lavas.

The presence in the sandstone of large amounts of immature products of denudation suggests that the source area had either high relief or a rigorous climate (Pettijohn, 1949, p. 385). The most plausible assumption is that high relief of the source area was the dominant factor, because climatic conditions adjacent to the Cowlitz-Arago Gulf during the Eocene were moist and subtropical to temperate (F. H. Knowlton, in Willis and Smith, 1899, p. 3; R. W. Brown, oral commun., 1957).

The lithologic similarity of the Carbonado and Spiketon Formations suggests that both were derived from the same source and deposited under the same conditions. Hence, the arkosic beds of the Puget Group represent a prolonged period of delta and flood-plain deposition adjacent to a slowly subsiding marine trough.

The presence of a fresh- and brackish-water fauna in the Puget Group and the absence of marine fossils indicate that the depositional environment must have been at or above sea level during most of the deposition (White, 1888). Both Willis (1886) and White (1888) emphasized that because all the strata are nonmarine, subsidence must have kept pace with deposition; and because the strata are more than 8,500 feet thick, at least this much subsidence must have taken place.

Sedimentary structures in the sandstone beds indicate current deposition. Such structures are common to both offshore bars and stream deposits, but the angularity of the sand grains suggests that this material was deposited in stream channels (Pettijohn, 1949, p. 236). In addition, disconformities and intraformational conglomerates typical of fluvial sediments are common in these strata and indicate repeated local erosion and deposition.

The presence of many coal seams is evidence that parts of this area repeatedly were stable long enough to allow thick deposits of vegetal material to accumulate in swamps. As the area slowly sank, organic material was buried under thick deposits of mud and sand. The swamps probably formed in interfluves and, being bounded by natural levees, were of limited extent. For this reason the coal seams do not appear to be continuous over long distances, nor is their stratigraphic separation constant.

Some swamp deposits were preserved and became coal seams; others appear to have been eroded during lateral shifting of streams. Thus, some coal beds terminate at channels, whereas others are discontinuous lenses and streaks in the sandstone beds. Some lenses are thick, but they pinch out within short distances to form "bogus seams" (Daniels, 1914, p. 23).

Volcanism that occurred adjacent to the Cowlitz-Arago Gulf during deposition of the Puget Group is represented in the Lake Tapps quadrangle by volcanic breccia and tuff of the Northcraft Formation. The Northcraft was derived from a volcanic center that was producing lava flows, mudflows, and pyroclastics. Initial deposits of the formation in this area were volcanic mudflows that moved across the surface of the Carbonado Formation. Silicified wood fragments and irregular distorted bands of coal in mudflow deposits near the base of the Northcraft Formation indicate that at least some of the mudflows moved across forested and swampy areas. The presence of silicified wood in mudflow breccias more than 1,000 feet above the base of the formation probably indicates that sedimentation took place slowly enough to permit reforestation between times of mudflow deposition.

During deposition of the Northcraft Formation, the Lake Tapps quadrangle was probably near the outer edge of a northeastward-sloping fan of mudflows, alluvium, and pyroclastic deposits that originated at a volcanic center lying to the southwest. Such a direction of origin is suggested by the eastward thinning of the Northcraft, which is considered to be depositional in origin rather than erosional because evidence of diastrophism and beveling during the time of Puget deposition has not been recognized. The presence of interstratified breccias and lava flows southwest of the quadrangle, in contrast to the volcanic sedimentary rocks, mudflow breccias, and pyroclastic deposits that occur in the quadrangle, also suggests that the source of the volcanic rocks lay to the southwest. Snavely, Brown, Roberts, and Rau (1958, p. 23) suggested that the source of the Northcraft lay east of the Centralia area. The source of the Northcraft, thus, was probably between the Lake Tapps quadrangle and Centralia, possibly near Alder Reservoir.

The absence of the Spiketon Formation west of the Carbon River anticline may be the result of the broad fan of volcanic detritus, which probably diverted westward-flowing streams around its margins. However, continued subsidence of the area would have permitted arkosic sediments of the Spiketon Formation to overlap the slope of the Northcraft fan and become interbedded with tongues of volcanic debris. Whereas this onlap-and-intertonguing relation is not seen in the Lake Tapps quadrangle, two tongues of volcanic rock are interbedded with arkosic beds in the area between the Puyallup and Nisqually Rivers (fig. 7).

### CORRELATIONS

Rocks of the Puget Group in the Lake Tapps quadrangle can be correlated with similar sequences of Tertiary rocks to the south, east, and north (fig. 7). The Carbonado Formation is probably equivalent in age to at least the upper part of the McIntosh Formation of the Centralia area (Snavely and others, 1958), which consists chiefly of offshore marine siltstone but contains near-shore arkosic and basaltic sandstones in the upper and lower parts. This correlation is based on similarity of lithology, stratigraphic position, and fossil leaves in the two formations. Marine strata in the McIntosh grade eastward into nonmarine and brackish-water rocks that contain coal seams, but the absence of marine beds in the Carbonado suggests that the sea never advanced as far east as the Lake Tapps quadrangle.

The volcanic rocks of the Northcraft Formation in the quadrangle can be traced southward 30 miles to the Morton area, where they are part of a sequence of volcanic rocks that has been correlated with the Northcraft Formation in the Centralia area by Snavely, Brown, Roberts, and Rau (1958, p. 23) (fig. 8).

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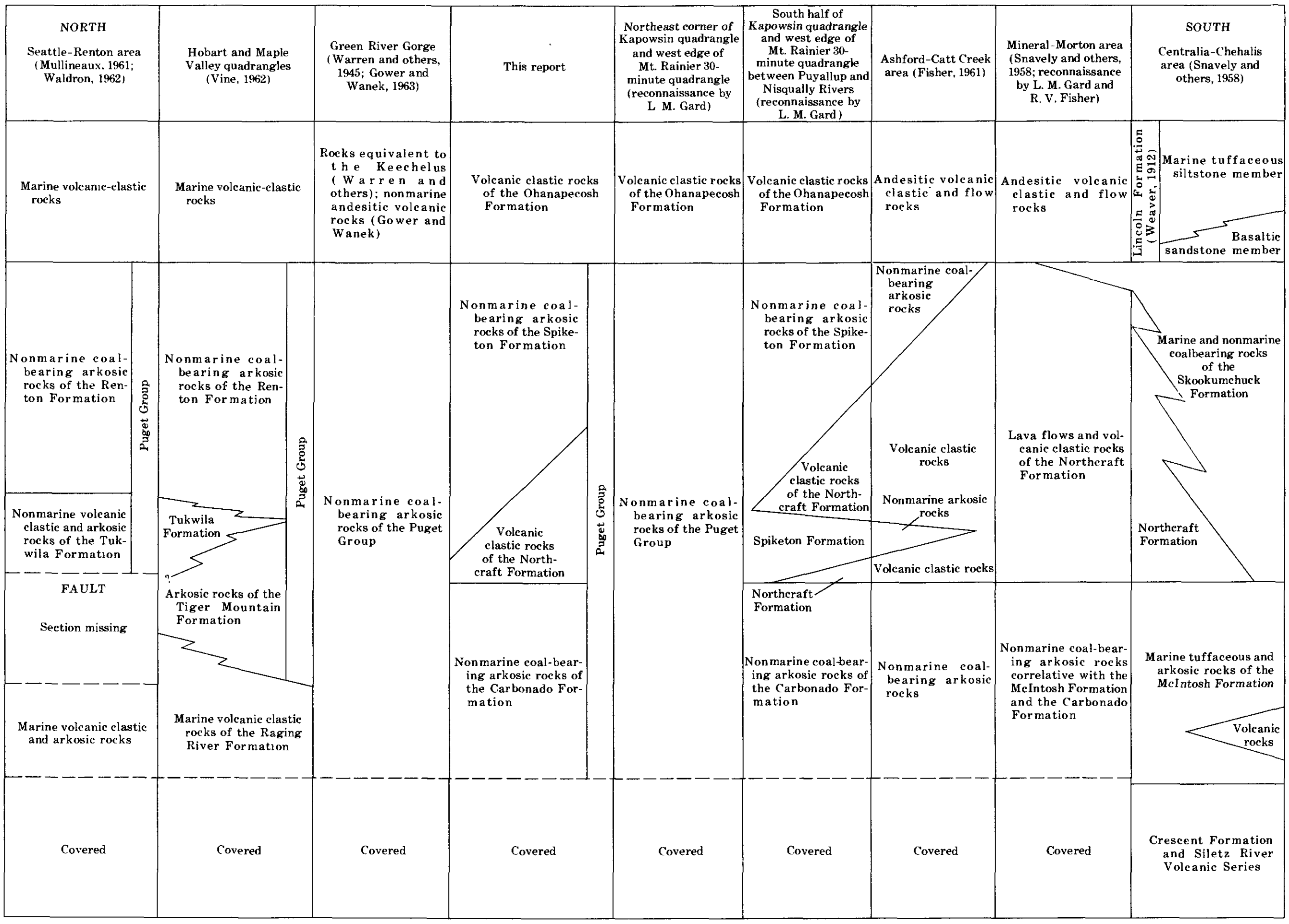


FIGURE 7.—Relation of Puget Group to other Tertiary rocks.

A wedge of volcanic sedimentary rocks similar to the Northcraft Formation, described as the Tukwila Formation of late Eocene age by Waldron (1962), also occurs in the Puget Group in the vicinity of Renton on the outskirts of Seattle. The Tukwila appears to attain its maximum thickness of about 7,000 feet near Issaquah, east of Seattle, and thins rapidly westward and southward (Warren and others, 1945; Vine, 1962). These volcanic sedimentary rocks are absent in a thick section of arkosic Puget Group rocks exposed along the Green River just north of the Lake Tapps quadrangle (Vine, 1962). Although apparently never coextensive with the Northcraft, the Tukwila Formation is probably in part correlative with the Northcraft Formation in the Lake Tapps quadrangle.

The Tukwila Formation near Issaquah is underlain by a sequence of nonmarine arkosic coal-bearing rocks, the Tiger Mountain Formation (Vine, 1962), of middle Eocene age. These nonmarine rocks conformably overlie marine sedimentary rocks of the Raging River Formation (Vine, 1962), which were regarded as middle and late(?) Eocene in age and now are considered as middle Eocene in age (Wolfe, 1968). Similarities in stratigraphic position, lithology, and age suggest that the rocks of the Tiger Mountain Formation are correlative with at least a part of the Carbonado Formation.

In the Lake Tapps quadrangle the Spiketon Formation overlies the Northcraft Formation, as does the lithologically similar Skookumchuck Formation in the Centralia area. The Spiketon is absent from the west flank of the Carbon River anticline; on the east flank it thins rapidly south of the Nisqually River and is absent in the Morton area (figs. 7, 8). In the Centralia area the Skookumchuck thins eastward (Snavely and others, 1958, pl. 2) and overlies the Northcraft in an onlap relation (Snavely and others, 1958, p. 27), similar to the inferred onlap relation between the Spiketon and Northcraft in the Lake Tapps quadrangle. Thus, arkosic sediments of the Puget Group locally may not have completely buried the volcanic rocks of the Northcraft Formation by the close of Puget deposition. Therefore, the Spiketon and Skookumchuck Formations were depos-

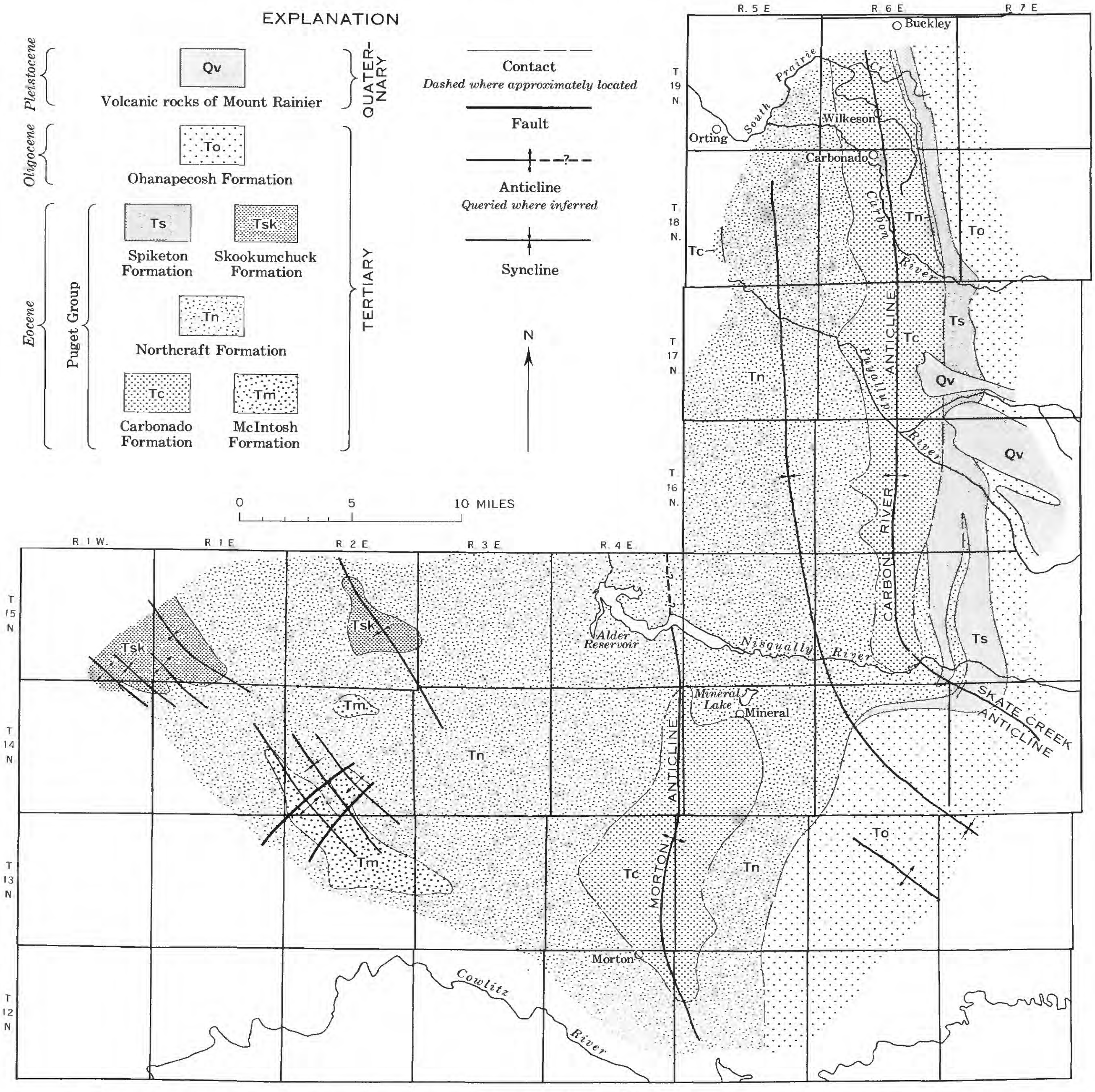


**FIGURE 8.—Relation of Puget Group to Ohanapecosh Formation, with special reference to the Northcraft Formation.**

ited at the same time in similar environments, but were not necessarily coextensive.

At Renton, marine volcanic sedimentary rocks equivalent in age to the Ohanapecosh Formation are underlain by coal-bearing arkosic strata of the Renton Formation (Mullineaux, 1961; Waldron, 1962). A similar relationship exists near Issaquah (Vine, 1962). Because the Spiketon and Renton Formations are lithologically similar and occupy similar stratigraphic positions they are considered to be correlative, although the Renton is considered by Wolfe (1968) to be of late Eocene and early Oligocene age.

## OLIGOCENE SERIES

### OHANAPECOSH FORMATION

Overlying the Spiketon Formation along the east edge of the quadrangle are well-indurated volcanic rocks thought to be the lower part of the Ohanapecosh Formation. In the Buckley quadrangle, these rocks were called the Keechelus Andesitic Series (Crandell and Gard, 1960).

In the geologic literature concerning rocks of the Cascade Range, the name Keechelus has been loosely applied to volcanic rocks that undoubtedly are not correlative with the rocks at the type locality of the Keechelus Andesitic Series (Smith and Calkins, 1906; Waters, 1961). Rocks described by Coombs (1936) as Keechelus in Mount Rainier National Park have recently been divided into three formations (Fiske, Hopson, and Waters, 1963). The oldest of these is the Ohanapecosh Formation, which consists of more than 10,000 feet of lavas and volcanic clastic rocks. These rocks are mainly andesitic and dacitic in composition and have been metamorphosed to the zeolite facies.

The rocks in the Lake Tapps quadrangle that are assigned to the Ohanapecosh Formation are the basal part, locally, of a succession of volcanic rocks that the writer has traced south along the strike to the interfluve between the Carbon and Mowich Rivers and thence eastward into rocks mapped as the Ohanapecosh Formation by Fiske, Hopson, and Waters (1963) in Mount Rainier National Park. More than 9,000 feet of eastward-dipping volcanic rocks is exposed along the west margin of the park.

Fiske, Hopson, and Waters (1963) included in the Ohanapecosh Formation tongues of volcanic clastic rocks near the southwest corner of Mount Rainier National Park. These rocks were described by Fisher (1957) as underlying several thousand feet of arkosic rocks of the Puget Group. If these volcanic clastic rocks are Ohanapecosh, this stratigraphic relation suggests that the base of the Ohanapecosh is older there than in the Lake Tapps quadrangle. The rock tongues described by Fisher are interpreted by the present writer to be tongues of volcanic clastic rocks of the Northcraft Formation derived from the west (fig. 7), rather than Ohanapecosh rocks derived from the position of the present Cascades. Fisher first called these tongues of volcanic rocks Keechelus, but he (1961, p. 1406) subsequently decided: "In view of the uncertainties of correlation, it seems best to await more detailed work before assigning formational names to the volcanic rocks described herein."

#### DISTRIBUTION

The Ohanapecosh crops out along the east flank of the Carbon River anticline in secs. 11, 14, and 23, T. 19 N., R. 6 E. It is best exposed in the steep valley walls of South Prairie Creek and in the south valley wall of the glacial melt-water channel now occupied by Page Creek in sec. 23, T. 19 N., R. 6 E., east of Wilkeson. Here Ohanapecosh strata strike slightly west of north and dip 45°–65° E. Just east of the quadrangle boundary, on South Prairie Creek, beds of Ohanapecosh strike east and dip 15° N. where they lie in the axis of a small northeast-plunging syncline.

#### DESCRIPTION

The Ohanapecosh exposed in the quadrangle consists of about 2,500 feet of sandstone, mudstone, conglomerate, and pyroclastic rocks. All strata are well indurated and of volcanic origin; they contain a few intercalated carbonaceous beds. Although no lava flows were recognized, several andesitic sills have intruded the volcanic sedimentary rocks. The Ohanapecosh rocks, though locally black, brown, red, and white, are mostly grayish green, which is the most characteristic color of these volcanic rocks throughout the Cascades. The distinctive green color is partly due to green, iron-rich montmorillonite.

Volcanic sandstone, siltstone, and conglomerate in the Ohanapecosh are all similar in composition. Volcanic sandstone in the lower part of the Ohanapecosh is poorly sorted and consists principally of subangular fragments of microlitic andesitic and basaltic rock, and plagioclase feldspar. Quartz was not seen in the sandstone. The matrix is composed of clay minerals, feldspar, small rock fragments, scattered pyroxene fragments, magnetite grains, calcite, and zeolites (fig. 9). Some of the

FIGURE 9.—Photomicrograph of volcanic sandstone from the Ohanapecosh Formation. Angular clasts are mostly fragments of volcanic rocks. Plane-polarized light. × 10.

sand-sized feldspar grains are partially altered to calcite. Other sand-sized grains are composed entirely of montmorillonite and occur with fresh-appearing feldspar grains, an association suggesting that these montmorillonite grains have not been formed in place from some other mineral. Brown and green montmorillonite are common constituents of all the volcanic sedimentary rocks. Some of the siltstone beds are platy and contain well-preserved leaf impressions and scattered organic material. The conglomerate commonly contains well-rounded pebbles of microlitic andesite that average about one-half inch in diameter but are as much as 2 inches in diameter.

A pale-greenish-gray altered tuff forms the ridge on the north side of South Prairie Creek in the center of sec. 23, T. 19 N., R. 6 E., at the east edge of the quadrangle. The tuff is composed of plagioclase fragments and minor amounts of small altered volcanic rock fragments set in a fine-grained matrix of devitrified shards (fig. 10). The rock is unusual because it yielded the only specimen collected in the quadrangle from the Ohanapecosh Formation in which shards were seen.

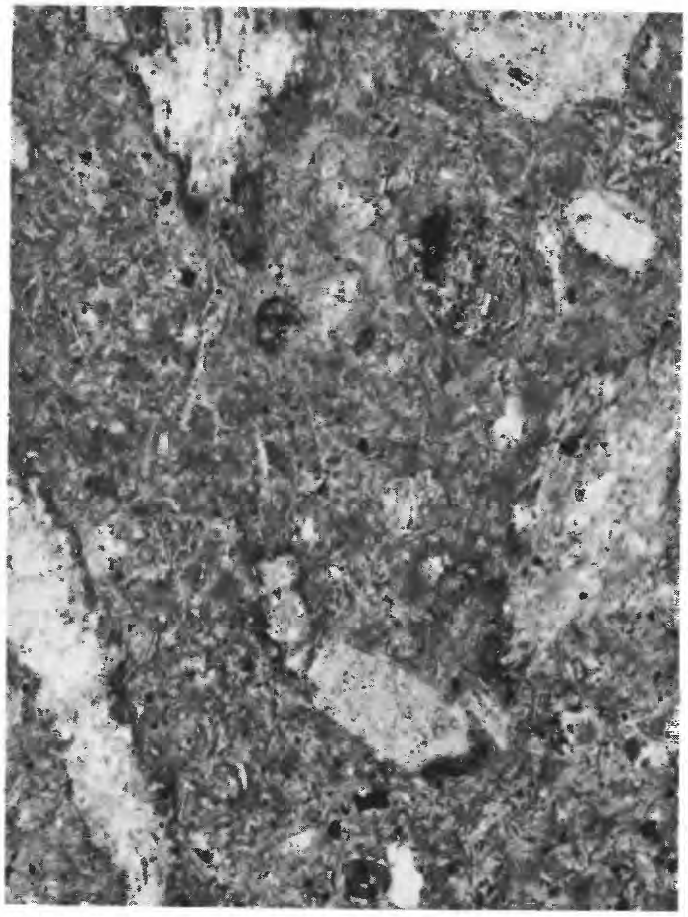

FIGURE 10.—Photomicrograph of tuff from the Ohanapecosh Formation. Matrix consists mainly of altered shards. Plane-polarized light. × 10.

The shards are altered to a zeolite mineral. Calcite and clay minerals are common in the matrix, and vesicular cavities in the rock are filled with a radially fibrous zeolite.

East of the quadrangle the Ohanapecosh is predominantly composed of breccia; elsewhere in the Cascades, volcanic mudflow breccias are common (Fisher, 1961), but none was recognized within the quadrangle.

The contact between Ohanapecosh rocks and the underlying Spiketon rocks on South Prairie Creek is obscured by talus, although the rocks both above and below the contact are well exposed. Some minor interfingering of Ohanapecosh strata with uppermost Spiketon beds was observed in roadcuts along a small private logging road on a hillside in the NW cor. sec. 11, T. 19 N., R. 6 E., northeast of Burnett. This relation suggests that the contact is conformable and that deposition of the Ohanapecosh began before deposition of the Puget Group ceased.

#### FOSSILS AND AGE

A fossil floral assemblage found in several siltstone beds in the lower few hundred feet of Ohanapecosh exposed on South Prairie Creek in the SW¼ sec. 23, T. 19 N., R. 6 E., was identified by Roland W. Brown as *Metasequoia occidentalis* (Newberry) Chaney, *Glyptostrobus dakotensis* Brown, *Populus* sp., *Chaetoptelea* sp., *Alnus* sp., *Lastrea fischeri* Heer, *Sparganum antiquum* (Newberry) Berry, *Quercus* sp., *Platanus raynoldsi* Newberry, *Carya* sp., and *Cercidiphyllum elongatum* Brown. According to Brown (written commun., 1955), this assemblage indicates that these rocks were deposited during the latter half of the Eocene. The Ohanapecosh was regarded as Eocene by Fiske, Hopson, and Waters (1963).

Another floral assemblage indicative of the same age was found about 1,000 feet higher in the section just east of the quadrangle boundary in the NE¼ sec. 23, T. 19 N., R. 6 E. This collection contained *Metasequoia occidentalis* (Newberry) Chaney, *Glyptostrobus dakotensis* Brown, *Populus* sp., *Chaetoptelea* sp., and *Alnus* sp. (R. W. Brown, written commun., 1955).

Although no fossils were found in the Ohanapecosh Formation in Mount Rainier National Park, Fiske, Hopson, and Waters (1963) described a small floral assemblage collected on the North Puyallup River just west of the park boundary. This assemblage is probably from about the same horizon as the ones just described and was assigned a late Eocene age by Brown. It contains some of the same species as do the assemblages found on South Prairie Creek.

On Catt Creek in the SE¼ sec. 13, T. 14 N., R. 6 E., south of the Nisqually River (about 30 miles south of the quadrangle), Brown and the author collected leaves—regarded as Eocene by Brown—from a volcanic siltstone in the Ohanapecosh. According to Fisher (1957), this siltstone lies at least 5,500 feet stratigraphically above the uppermost rocks of the Puget Group. Some 7,000 feet stratigraphically above the Catt Creek locality another collection of leaves was made that, according to Brown, are "suggestive of Oligocene age." These fossil leaves indicate that at least 5,500 feet of the lower part of the Ohanapecosh Formation here is of Eocene age, according to Brown.

On the basis of fossil plants, Wolfe (1961) considered the lower part of the "Keechelus" (Ohanapecosh Formation of this report) to be the equivalent of the Keasey and Lincoln "stages," which range in age from late Eocene to Oligocene. The rocks of the Ohanapecosh Formation in the Lake Tapps quadrangle are regarded as being of Oligocene age (Wolfe, written commun., 1966).

#### PROVENANCE

The presence of water-laid volcanic sedimentary rocks conformably overlying the Spiketon Formation suggests that when Ohanapecosh volcanism began, material derived from the volcanism entered the streams that had previously been depositing Puget sediments. The presence of some coarse volcanic conglomerate indicates that the source of the Ohanapecosh rocks was not far away.

Because the Puget streams were flowing westward, the volcanic source was probably somewhere east of the quadrangle. The following suggest that the volcanic activity started abruptly and that it must have been continuous and widespread and involved a large volume of material: (a) The apparent lack of mixing of arkosic Puget material with the volcanic debris, (b) the minor interfingering of Puget- and Ohanapecosh-type rocks, and (c) the upward gradation of the Ohanapecosh from water-laid sediments to mudflow breccias and lava flows. Eventually the products of this volcanism so completely disrupted the Puget drainage system that arkosic sediments were never again deposited in the area.

#### CORRELATION

The volcanic sedimentary and pyroclastic rocks of the Ohanapecosh Formation in the Lake Tapps quadrangle bear a marked resemblance to the basal member of the Lincoln Formation (of Weaver, 1912) in the Centralia area (Snavely and others, 1958). North of the quadrangle similar continental volcanic rocks have been described as conformably overlying the Puget Group in the Green River valley (Warren and others, 1945); similar rocks of marine origin near Renton have been tentatively correlated by Mullineaux (1961) with the Lincoln Formation of the Centralia area.

The basaltic sandstone member of the Lincoln Formation consists of more than 1,500 feet of deltaic, nearshore, and continental deposits composed of stream-worn fragments of volcanic rock of andesitic and basaltic composition and some pyroclastic material. The member contains a molluscan fauna reported to be of late Eocene age (Snavely and others, 1958, p. 51). Similarity of composition, stratigraphic position, and age suggest that at least part of the Ohanapecosh in the Lake Tapps quadrangle is equivalent to the basaltic sandstone member of the Lincoln Formation and, also, to similar rocks north of the quadrangle (fig. 7).

### INTRUSIVE ROCKS

Intrusive igneous rocks in the quadrangle form dikes, sills, and small plugs in rocks of Eocene and Oligocene age. The fine-grained intrusive rocks consist of andesite and latite; the medium-grained instrusive bodies are quartz diabase and hornblende dacite porphyry. Although some of the sills appear to be fairly extensive, lack of adequate exposures prevents tracing them more than a few hundred feet.

Precise dating of the instrusive rocks is not possible. They are certainly pre-Pleistocene and cannot be older than mid-Eocene. No evidence was found to suggest more than one time of intrusion. Also, no evidence was found that any of the dikes were sources of volcanic rocks in either the Northcraft Formation or the Ohanapecosh Formation; some dikes, however, could have been feeders for the deposits of Miocene age.

#### QUARTZ DIABASE

Quartz diabase crops out in the Carbon Gorge south of Carbonado and at localities along the Puyallup River valley. Quartz diabase in the Carbon Gorge is the most extensively exposed, and probably the largest, intrusive body in the quadrangle. It forms a sill at least 950 feet thick that can be traced along the gorge for nearly 3 miles and is intercalated between west-dipping beds of the Carbonado Formation. The sill is well exposed in sec. 16, south of Carbonado, where the Carbon Gorge crosses the sill diagonally from base to top for a distance of three-fourths of a mile. The north end of the sill is not exposed, but the sill was penetrated in the Carbonado coal mines, where mine maps indicate that it tapers to a blunt, rounded end in the NE¼ sec. 9, T. 18 N., R. 6 E., about a mile southeast of Carbonado. The southward extension of the sill is covered by glacial drift, but a few scattered outcrops of quartz diabase suggest that the sill extends at least as far south as sec. 28, T. 18 N., R. 6 E.

Contacts between the sill and the enclosing Carbonado Formation are sharp and mostly conformable with the bedding of the sedimentary rocks, which here generally strike almost due north and dip 55° W. A conformable lower contact is exposed in a roadcut on State Highway 5 about 400 yards south of Fairfax Bridge, where less than an inch of the underlying carbonaceous shale has been baked and hardened. The lower contact is poorly exposed on the east side of the river along an abandoned railroad grade south of the bridge. However, the lower contact is unconformable at river level about 350 feet south of Fairfax Bridge. There the sill cuts across bedding for about 200 feet; the contact strikes N. 65° E. and is vertical, whereas the adjacent sandstone strikes N. 25° W. and dips 55° W. Sandstone at the contact has been slightly baked, which suggests that this offset in the base of the sill took place during intrusion and was not the result of later faulting.

The upper contact of the sill is exposed in a gully just northwest of Fairfax Bridge. The sill appears to be conformable with an overlying siltstone that was only slightly affected by the heat of the intrusion. The upper contact crosses the Carbon River in the northern part of sec. 16, T. 18 N., R. 6 E., but is inaccessible.

The sill is a medium-grained dark-gray holocrystalline rock that weathers to a light greenish gray. The rock appears chalky where the feldspars have been strongly weathered. Feldspars and ferromagnesian minerals can easily be seen in hand specimen, but the quartz is easily overlooked. The interior of the sill is coarser in texture than either the base or the top, which suggests chilling of the margins. The sill is porphyritic along its margins and contains phenocrysts of white feldspar and pyroxene in a fine-grained dark-greenish-gray matrix. In thin section the matrix in these fine-grained margins consists of plagioclase, pyroxene, magnetite, and a few clusters of small anhedral quartz grains. The feldspars are partially altered to sericite and replaced by calcite; the pyroxenes are altered to hornblende and chlorite and partially replaced by calcite.

The coarser grained interior of the sill has a hypidiormorphic-granular texture and consists of phenocrysts of plagioclase, augite, and hypersthene in a matrix of smaller crystals. The interstitial minerals are amphibole, alkali feldspar, quartz, and magnetite. The plagioclase ranges in composition from intermediate labradorite to calcic andesine. The plagioclase crystals are zoned and show twinning according to both carlsbad and albite laws; in vein networks they have been altered to a more sodic plagioclase (albite?). The hypersthene has been altered to bastite, a variety of serpentine, which contains much secondary sphene. An average composition of the interior of the sill determined petrographically is as follows: 54 percent feldspar, 8 percent pyroxene, 15 percent quartz, 9 percent amphibole, 1 percent magnetite, and 13 percent other minerals, including alteration products. A chemical analysis of the rock is given in table 1 (No. 154656).

A quartz-diabase intrusive of unknown shape and dimension crops out in the Puyallup River valley wall in sec. 32, T. 18 N., R. 5 E., at the south edge of the quadrangle. It is best exposed in a small quarry at the community of Electron, just south of the quadrangle boundary. Although the rock is poorly exposed, it is believed to intrude volcanic rocks of the Northcraft Formation.

The rock is grayish white in fresh exposures in the quarry but has weathered to a pinkish cast at other outcrops, evidently as a result of staining and partial alteration of the feldspars. Many joints in the quartz diabase contain epidote. This intrusive is somewhat more coarsely crystalline than the interior of the sill exposed in the Carbon Gorge.

The quartz diabase exposed in the quarry contains xenoliths of basalt. In thin section the contact between quartz diabase and a large basalt xenolith is sharp; the xenolith has a thin rim, which appears to have resulted from slight remelting and chilling; and the quartz diabase is granulated for about one-fourth of an inch away from the contact.

The texture of the rock is hypidiomorphic-granular. The primary minerals are plagioclase, pyroxene, and hornblende. The plagioclase is labradorite ($An_{55-60}$) which is zoned and twinned. The interstitial minerals are plagioclase, pyroxene, amphibole, quartz, and micropegmatitic intergrowths of quartz and alkali feldspar. The alkali feldspar in the interstices is partially altered to clay minerals, and the amphibole is partially altered to undetermined minerals of low birefringence and low relief. A few zircon crystals were observed in one thin section. An average composition of this quartz diabase is as follows: 53 percent plagioclase, 12 percent ferromagnesian minerals, 20 percent quartz, 7 percent alkali feldspar, 3 percent iron minerals, and 5 percent alteration products. A chemical analysis of the rock is given in table 1 (No. 154657).

Another body of intrusive quartz diabase crops out in the Puyallup River valley about 4 miles south of Orting, where it intruded volcanic rocks of the Northcraft Formation. The quartz diabase crops out on both sides of the river, but the size and shape of the body are not known.

This intrusive rock is a medium- to fine-grained gray quartz diabase in which plagioclase and augite are the most prominent minerals. In thin section the rock has a hypidiomorphic-granular texture, with primary plagioclase and pyroxene set in a matrix of smaller crystals.

The plagioclase is calcic labradorite ($An_{60-65}$) which is zoned and twinned. The interstitial minerals are plagioclase, augite, hornblende, quartz, apatite, and magnetite. Many of the minerals are partially or completely altered. Pyroxene grains in one thin section are rimmed with amphibole, and the amphibole grains are partially altered to bastite. Other alteration products in the rock are calcite, pyrite, clay minerals, chlorite, and chalcedony.

### HORNBLENDE DACITE PORPHYRY

Light-gray hornblende dacite porphyry, conspicuously different from other intrusive rocks in the quadrangle, is exposed in a quarry south of Orting. Quarrying in the SE¼ sec. 6, T. 18 N., R. 4 E., has revealed a large mass of porphyry at least 100 feet thick; depth of the base is unknown. Outcrops of the intrusive rock are bordered by Pleistocene deposits, so the relation of the intrusion to the country rocks is not known. Columnar jointing at the periphery of the quarry and massive jointing in the center of the exposure suggest that the rock was emplaced at shallow depth, possibly as a lacolithic body. At the north end of the quarry the rock is cut by joint columns more than 50 feet long and about 4 feet across; at the south end the rock is massive and has widely spaced rectangular jointing. Deeply weathered zones, as much as 30 feet wide and extending the full height of the quarry face, occur in the columnar dacite. In these zones the rock is weathered to grus that consists of weathered feldspar, amphibole, and clay. Many cavities of irregular shape occur in the massive part of the porphyry. The smaller ones are filled with zeolites and green montmorillonite; the larger ones are generally empty or thinly lined with montmorillonite.

Rounded and angular andesite xenoliths as large as 14 inches in diameter are common (fig. 11). Other xenoliths are composed of black tuff similar to the propylitized tuff in the Northcraft Formation (p. B11) that crops out at the highway bridge across the Puyallup River about 2 miles south of the quarry.

FIGURE 11.—Xenoliths of andesite in hornblende dacite porphyry exposed in quarry 2 miles south of Orting.

In thin section the porphyry consists of fresh-appearing subhedral to euhedral plagioclase phenocrysts (average 4 mm in length but may be as long as 8 mm) and euhedral to subhedral green hornblende crystals (as long as 10 mm but averaging 4 mm in length) in an aphanitic groundmass of stubby plagioclase crystals, hornblende, magnetite, montmorillonite, and glass (fig. 12). The plagioclase phenocrysts, which are zoned and exhibit both carlsbad and albite twinning, range in composition from sodic labradorite cores ($An_{50-55}$) to sodic andesine rims ($An_{35-40}$). The hornblende phenocrysts are pleochronic from pale green to dark green; although they appear fresh in hand specimen, in thin section they have alteration rims composed mainly of magnetite and chlorite(?). A chemical analysis of this rock is given in table 1 (No. 154654).

Amygdules seen in one thin section are lined with tiny green hemispheroids of radially fibrous montmoril-

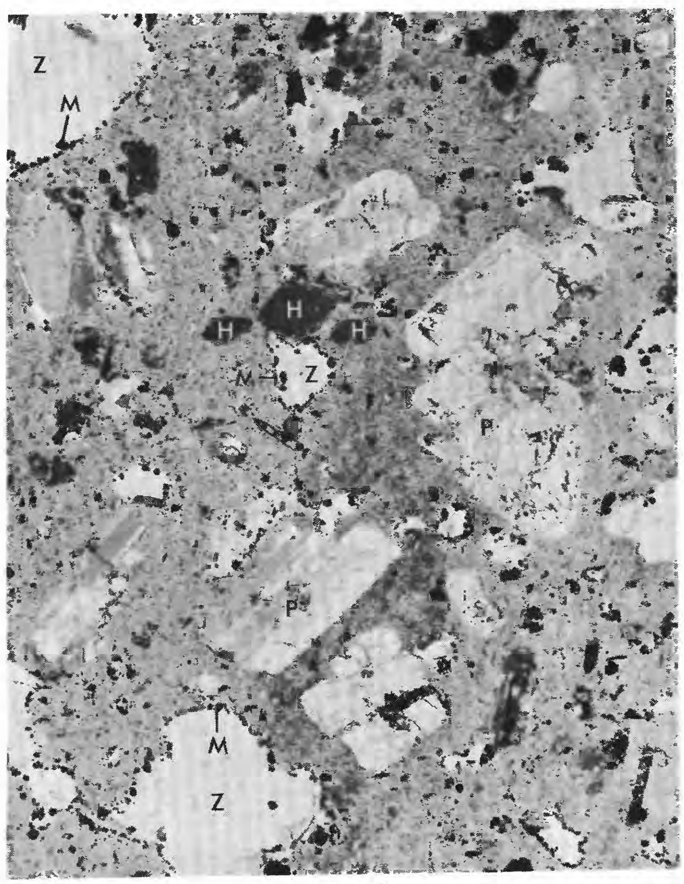


FIGURE 12.—Photomicrograph of hornblende dacite porphyry exposed in quarry 2 miles south of Orting. Note hornblende crystals with altered rims (H); twinned and zoned plagioclase feldspar (P) and cavities containing zeolites (Z) rimmed with montmorillonite (M). × 10; nicols at 45°.

lonite and filled with at least two zeolites, stilbite and chabazite (fig. 12). Zeolites and montmorillonite also occur in the aphanitic groundmass. The montmorillonite appears to have formed first, followed by stilbite, then chabazite. In another thin section the cavities contain only a lining of hemispheroids of green montmorillonite. This montmorillonite, according to E. J. Young, of the U.S. Geological Survey (oral commun., 1958), is mostly nontronite, the iron-rich variety. One of the cavities contained several tabular crystals of calcite which apparently had formed much later than the other minerals.

### PYROXENE ANDESITE

Sills and dikes of pyroxene andesite have intruded all Eocene and Oligocene formations in the quadrangle. Sills are more common than dikes in the Carbonado and Spiketon Formations, undoubtedly because the bedding planes offered lines of least resistance to the invading magma. Although the Tacoma folio (Willis and Smith, 1899) shows an intrusive body in sec. 23, T. 18 N., R. 6 E., east of the Carbon River, no outcrops of this body were found during the present mapping. Angular blocks of igneous rock in the Wingate Hill Drift of late(?) Pleistocene age (Crandell, 1963) may have led Willis and Smith to postulate the presence of such an intrusive.

With few exceptions these dikes and sills are dark-gray, black, or greenish-gray rocks that vary in texture from a fine- to medium-grained porphyry and have prominent feldspar and pyroxene phenocrysts. Thin sections of the rocks generally show plagioclase and pyroxene phenocrysts in a matrix of feldspar microlites and a few small pyroxene and magnetite crystals. The texture of the rocks is commonly hyalopilitic, trachytic, or felted. The plagioclase phenocrysts are zoned and twinned, and their composition ranges from calcic andesine to calcic labradorite. The pyroxene phenocrysts are commonly augite and hypersthene. A chemical analysis of pyroxene andesite from a sill that crops out in sec. 14, T. 19 N., R. 6 E., east of Burnett is given in table 1 (No. 154655).

Most of these rocks appear to fit the description of an andesite as defined by Williams, Turner, and Gilbert (1954, p. 43, 94): they contain plagioclase phenocrysts that are commonly more calcic than $Ab_1An_1$, the average composition of the plagioclase is more sodic than $Ab_1An_1$, and the silica content is between 52 and 66 percent. Although the chemical composition of the different sills and dikes undoubtedly varies and some bodies may more properly be classified as basalt, the term "andesite" is probably more applicable to this suite of intrusive rocks.

Only a few of the many dikes and sills in the Lake Tapps quadrangle have been shown on the geologic map in this report. The andesite sills and dikes appear to have had little effect upon their host rocks except where they intruded coal seams. Many small igneous intrusive bodies where found in the mines at South Willis, Wilkeson, Carbonado, Melmont, and Fairfax, mostly in the southern mines (Daniels, 1914, p. 29). According to Daniels, the instrusion of these bodies markedly altered the characteristics as well as the structure of the coal beds. Ash (1925, p. 833, 843) reported that a seam of coal mined at Carbonado was converted to semianthracite, owing to the heat given off by a large sill, and that one seam was completely burned out adjacent to small dikes and sills. In the bottom of the Carbon Gorge in the SW¼ sec. 4, T. 18 N., R. 6 E., an andesite sill 20 feet thick intruded a coal seam and converted it to dense natural coke. The coke shows miniature polygonal columns about one-half of an inch thick and 2–4 inches long. The sill has irregular boundaries, and many small apophyses of it extend into the coke.

### LATITE

Three latite bodies in T. 18 N., R. 5 E., are intruded into the Northcraft Formation. The largest of these is an oval-shaped mass of light-gray to creamy-tan latite about 800 feet wide and 3,000 feet long that crops out in the SE¼ sec. 22, and the SW¼ sec. 23, in the melt-water channel occupied by Fox Creek. The long axis of the intrusion trends eastward almost parallel to the channel. This intrusive is also exposed in cuts along a logging road in the Fox Creek channel and in a small pit adjacent to the road where it has been quarried for road metal. The rock is well jointed and breaks into platy fragments. This latite displays flow banding, much of which is contorted (fig. 13). The rock contains many xenoliths of gray and tan igneous rock unlike any other rocks known in the area. One such inclusion is an angular fragment of devitrified perlitic glass. In some places the latite is so crowded with these angular inclusions that even in thin sections the rock is easily mistaken for a breccia.

In thin section the plagioclase phenocrysts are oligoclase ($An_{15-20}$); some are faintly zoned and show albite twinning. The only other primary mineral is a pyroxene (augite?), which occurs as small scattered phenocrysts altered to clay minerals and magnetite. The flow banding that is so conspicuous in the rock can also be seen in thin section (fig. 13); the gray bands are cryptofelsitic and the tan bands are microfelsitic. A chemical analysis of this rock is given in table 1 (No. 154658).

The presence of oligoclase feldspar, the absence of recognizable quartz, and the high percentage of silica

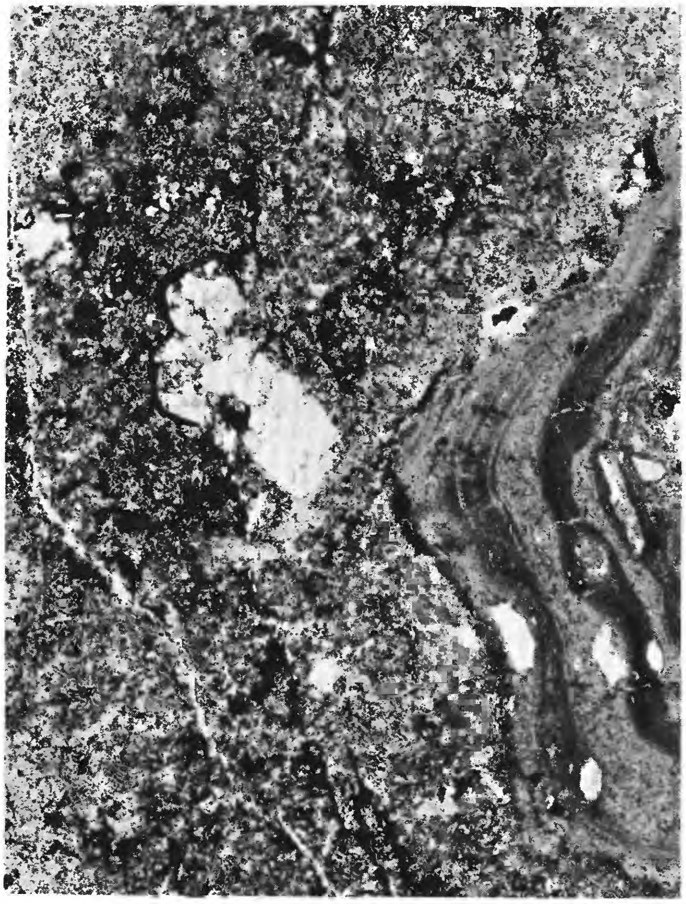

FIGURE 13.—Photomicrograph of latite that crops out in a roadcut in the SE. cor. sec. 22, T. 18 N., R. 5 E. × 10.

indicate that this intrusive is a latite or trachyandesite (Williams and others, 1954, p. 97).

The latite must have been extremely viscous at the time it was emplaced. Contortion of the flow banding is common, and in one thin section cryptofelsitic latite appears to have been broken and the fragments recemented by microfelsitic latite. Many of the phenocrysts are crushed and broken and occur in small clusters of discrete granules; some of these granules appear to have been rolled and are no longer in optical continuity with each other.

The second latite body, a dike that intrudes pyroxene-bearing breccias of the Northcraft Formation, crops out in the east wall of the Fox Creek channel in the center of sec. 13. The dike is more than 100 feet thick and can be traced for 200 feet up the hillside. It strikes N. 20° W. and dips 60° E. The latite is megascopically and microscopically similar to that of the latite body just described, except that it contains fewer inclusions. The rock consists of oligoclase and pyroxene phenocrysts in a microfelsitic groundmass. Flow banding is more pronounced on the west side of the dike; near the contact, the flow banding exhibits drag folding. This drag folding suggests that the latite was very viscous when intruded.

A third latite body crops out on the north side of Spar Pole Hill in the NW. cor. sec. 11, but its extent is not known. A thin section of this rock reveals that it is composed of clots of gray crytofelsitic latite in tan microfelsitic latite. Shapes of the clots of gray latite suggest that it was pulled apart while it was very viscous. Some of the oligoclase phenocrysts are crushed. No mafic minerals were seen, but the presence of large masses of magnetite suggest that original phenocrysts of pyroxene were altered and were replaced by magnetite.

## MIOCENE DEPOSITS

Sediments of Miocene age have been recognized at several localities in the Puget Sound lowland (Mullineaux and others, 1959); three of these localities are in the Lake Tapps quadrangle. Exposures are generally small and of limited extent. At one of the three localities these sediments consist of fluvial sand and gravel, lacustrine sand, silt, and clay, and volcanic ash layers. At another locality the sediments include three volcanic mudflow deposits, several ash layers, and pumice gravel.

The extent of covered Miocene deposits shown on plate 1 is based on the pattern of outcrops and the position of the deposits with respect to the surface on the older Tertiary rocks. The distribution shown represents an inferred minimum extent of these deposits but is not based on borings or other physical evidence.

### DESCRIPTION

Miocene deposits along lower Voight Creek probably have a maximum thickness of about 125 feet, although the total thickness exposed at any one outcrop is 86 feet. (See the following measured section.) These deposits are semiconsolidated lacustrine sand, silt, and clay, and alluvial sand and gravel that consist chiefly of detritus from the Ohanapecosh Formation. However, pebbles of fresh white hornblende-bearing pumice are widely scattered in the alluvium, and volcanic ash layers have been recognized at two horizons. Carbonized or partially carbonized wood fragments ranging from tiny specks to large logs are common. The outer few inches of one large log is carbonized, whereas the central part is fresh and burns readily.

A complete section is not available in any single exposure, and owing to the absence of marker beds, individual outcrops along the valley walls cannot be correlated. Though a complete section could not be measured, the following measured section is probably representative of the beds in the Voight Creek area.

*Miocene deposits, NW¼NW¼ sec. 2, T. 18 N., R. 5 E., on Voight Creek, 3.2 miles southeast of Orting, Pierce County, Wash.*

[Beds strike N. 70° E. and dip 35° N.]

| | *Thickness (ft.)* |
|---|---|
| Pleistocene deposits | |
| 22. Orting Drift. | |
| Miocene deposits | |
| 21. Clay, greenish-gray | 0.5 |
| 20. Sand, very fine grained, clayey, gray | 1.8 |
| 19. Sand, pebbly, coarse; grades upward to fine-grained bluish-gray sand | 2.3 |
| 18. Sand, silty, bluish-gray | 1.4 |
| 17. Silt, clayey, thin-bedded, bluish-gray | 2.4 |
| 16. Covered | 10.3 |
| 15. Silt, tuffaceous, light-greenish-gray | 4.5 |
| 14. Ash, thin-bedded, white; locally stained by iron oxides; pinches and swells, locally absent; maximum observed thickness | 1.3 |
| 13. Silt, sandy, pebbly, gray; upper part has many wood fragments | 2.0 |
| 12. Covered | 13.8 |
| 11. Sand, pebbly; some pumice pebbles | 2.0 |
| 10. Sand, medium-grained, buff | 3.5 |
| 9. Sand, pebbly; some pumice pebbles | 3.0 |
| 8. Sand, medium-grained, thin-bedded; wood fragments | 5.0 |
| 7. Silt, clayey, blue | 2.0 |
| 6. Sand and silt in alternating thin layers | 4.5 |
| 5. Clay, silty, tuffaceous, light-buff; wood fragments, sparse leaves | 6.0 |
| 4. Sand, pebbly; grades upward into unit 5; some pumice pebbles | 4.0 |
| 3. Clay, silty, blue | 9.0 |
| 2. Sand, medium-grained, brown; grains mainly quartz | 1.5 |
| 1. Sand, medium-grained, pebbly; rich in quartz; some pumice pebbles; contains much wood including a log 6 ft long by 2 ft in diameter | 6.0 |
| 0. Slope wash | |
| Total | 86.8 |

At least 70 feet of pumice gravel, mudflow deposits, and volcanic ash occurs in the Miocene deposits in the valley walls of South Prairie Creek and Gale (or Wilkeson) Creek in secs. 16 and 17, T. 19 N., R. 6 E., near Burnett. The lowest exposed sediments consist of a lacustrine silt and clay more than 6 feet thick that is overlain by pumice gravel and three volcanic mudflows; these deposits are overlain, in turn, by more lacustrine silt and sand (Mullineaux and others, 1959, p. 689). The basal mudflow is the thickest, the coarsest, and apparently the most widespread unit of these Miocene deposits; it is at least 20 feet thick and is probably as much as 40 feet. Stones in the mudflow consist mostly of rocks derived from the Ohanapecosh Formation but also include white hornblende-bearing pumice and light-gray prophyritic dacite. A pumice-bearing mudflow that crops out in the north wall of the Carbon River valley in sec. 30, T. 19 N., R. 6 E., is lithologically similar to the basal mudflow of the section near Burnett.

Gravel in the Miocene deposits near Burnett consists almost entirely of white pumice (analysis 154659, table 1) that was probably transported by streams from areas near a volcanic vent. Mudflows that occur immediately above and below this pumice gravel consist almost wholly of light-gray prophyritic dacite (analysis 154660, table 1).

### FOSSILS AND AGE

Fossil leaves were collected from the Miocene deposits at both the Voight Creek and the Burnett localities. Leaves from a siltstone cropping out on Voight Creek in NE¼NW¼ sec. 2, T. 18 N., R. 5 E., were identified by Roland W. Brown as *Picea* sp., *Fagus washoensis* LaMotte, *Platanus dissecta* Lesquereux, *Cercidiphyllum crenatum* (Unger) Brown, *Crataegus* sp., and *Rubus* sp. Leaves from outcrops along Voight Creek in the SE¼NW¼ sec. 3, T. 18 N., R. 5 E., were identified by Brown as *Abies* sp., *Chamaecyparis* sp., ?*Sequoia affinis* Lesquereux, and *Quercus browni* Brooks. Fossil leaves at the Burnett locality were found only in the volcanic ash that directly underlies the basal mudflow deposit. Brown identified these as *Fagus washoensis* LaMotte and *Quercus* sp.

The fossil leaves in these deposits include *Fagus washoensis*, which did not survive the Miocene in this area (R. W. Brown, written commun., 1956). *Cercidiphyllum crenatum* is not known in the late Miocene according to J. A. Wolfe (written commun., 1966); therefore, these deposits are regarded as middle or late(?) Miocene in age. The leaves indicate a temperate climate, and their similarity to leaves in deposits of the same age east of the present Cascade Range supports other evidence that no range existed at that time comparable in height to the present range (Chaney, 1938, p. 641), although a highland probably did exist in this area as a remnant of post-Ohanapecosh diastrophism.

Deposits of Miocene age have also been recognized in adjacent areas along the west flank of the Cascade Range (Mullineaux and others, 1959). To the north, the Hammer Bluff Formation crops out along the Green River in T. 21 N., R. 6 E.; to the south semiconsolidated deposits of the Mashel Formation (Walters, 1965) occur near Eatonville. Sedimentary deposits of Miocene age nearly 800 feet thick were mapped and described by Roberts (1958) near Castle Rock in southwestern Washington and have been named the Wilkes Formation.

### ORIGIN

By late Miocene time an erosion surface of moderate relief had been formed on the bedrock of the Lake Tapps quadrangle. At least part of the area was occupied by lakes and streams in which silt, clay, sand,

TABLE 1.—*Rapid chemical analyses of rocks in the Lake Tapps quadrangle*

[Samples were analyzed by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, under the supervision of W. W. Brannock, by methods similar to those described by Shapiro and Brannock (1956). NA, not analyzed]

| | Laboratory number, rock type, and sample locality | | | | | | |
|---|---|---|---|---|---|---|---|
| | 154654 | 154655 | 154656 | 154657 | 154658 | 154659 | 154660 |
| | Hornblende dacite porphyry | Pyroxene andesite | Quartz diabase | Quartz diabase | Latite | Hornblende-bearing pumice (Miocene) | Hornblende dacite (Miocene) |
| | Orting Quarry | South Prairie Creek | Carbon River Gorge | Electron Quarry | Fox Creek | Burnett | Burnett |
| $SiO_2$ | 67. 4 | 61. 6 | 59. 9 | 60. 4 | 71. 4 | 60. 0 | 66. 4 |
| $Al_2O_3$ | 16. 3 | 16. 9 | 16. 2 | 17. 5 | 15. 1 | 18. 6 | 16. 1 |
| $Fe_2O_3$ | 1. 6 | 3. 2 | 2. 0 | 2. 3 | 1. 8 | 2. 6 | 1. 1 |
| FeO | 1. 7 | 2. 4 | 3. 4 | 3. 3 | . 42 | 2. 6 | 1. 6 |
| MgO | 1. 4 | 2. 6 | 3. 4 | 3. 2 | . 28 | 2. 6 | 1. 4 |
| CaO | 4. 1 | 5. 4 | 5. 8 | 5. 4 | . 52 | 5. 6 | 4. 3 |
| $Na_2O$ | 4. 2 | 4. 5 | 3. 2 | 4. 0 | 5. 8 | 4. 2 | 4. 0 |
| $K_2O$ | 1. 9 | 1. 1 | 1. 8 | 1. 7 | 2. 9 | 1. 1 | 2. 0 |
| $H_2O$ | . 40 | 1. 4 | 2. 8 | 1. 4 | 1. 2 | 1. 3 | 2. 2 |
| $TiO_2$ | . 42 | . 71 | . 63 | . 82 | . 34 | . 76 | . 45 |
| $P_2O_5$ | . 16 | . 18 | . 13 | NA | NA | NA | NA |
| MnO | . 06 | . 06 | . 08 | . 09 | . 03 | . 09 | . 06 |
| $CO_2$ | <. 05 | <. 05 | . 40 | <. 05 | . 06 | <. 05 | . 07 |
| Sum | 99. 69 | 100. 10 | 99. 74 | 100. 16 | 99. 85 | 99. 50 | 99. 68 |

and gravel were being deposited. Leaves and wood fragments in the lacustrine and alluvial deposits indicate that forests flourished in a warm temperate climate. Deposition of these sediments was interrupted by volcanism, recorded here first by a layer of volcanic ash, and subsequently by volcanic mudflows and alluvium rich in newly erupted volcanic debris. Ash and pumice represent contemporaneous volcanic activity, and the presence of the mudflow deposits suggests that this activity was taking place in or adjacent to the drainage basins of the Miocene streams. However, the distance of the volcanic vent or vents from the Lake Tapps quadrangle is not known. The presence of fluvial sand and gravel suggests that the mudflows followed stream valleys. The location of the Miocene mudflows and alluvium near the north end of an ancient Pleistocene valley—that of the ancestral Mowich River (Crandell, 1963)—suggests that this valley may have existed in Miocene time.

### SOURCE

The lithology of the Miocene deposits indicates that they were derived in part from the Ohanapecosh Formation that lies east of this area. A highland probably existed at that time, but the Cascade Range had not yet attained its present height (Mullineaux and others, 1959). The most significant units in the Miocene deposits are the volcanic mudflows and pumice gravel in the Burnett area, because the rock types in them are unusual and distinctive. The glassy gray hornblende dacite differs from rocks in the Ohanapecosh and other pre-Miocene rocks, which are generally altered and darker gray or green, and from andesitic rocks of Mount Rainier volcano, which are mostly less glassy hypersthene andesite. Comparable fresh white pumice is not common in either the Ohanapecosh, Stevens Ridge, or Fifes Peak Formations. In the sand-sized fraction of the volcanic debris the characteristic heavy-mineral suite is green hornblende, magnetite, and ilmenite and is easily distinguished both from the epidote- and pyroxene-rich suite in sediments derived from the Ohanapecosh and from hypersthene-rich sand derived from Mount Rainier.

This distinctive hornblende-rich volcanic debris has been compared and in part correlated with the Ellensburg Formation of central Washington (Mullineaux and others, 1959). The Ellensburg consists chiefly of volcanic detritus, at least 1,600 feet thick, that was transported by streams eastward into central Washington from the position of the present Cascade Range (G. O. Smith, 1903, p. 2). The detritus was derived from a growing chain of explosive andesitic volcanoes west of the Yakima-Ellensburg area (Waters, 1955, p. 664). The volcanic detritus on the west flank of the Cascade Range undoubtedly had the same source.

Although the general source area of the volcanic debris can be inferred, few remnants of late Miocene volcanoes have been found. Hornblende-bearing andesite flows have been described at a few places; one is the Howson Andesite in the Snoqualmie quadrangle that Smith and Calkins (1906, p. 10) suggested might be related to the Ellensburg Formation, and another is an andesite found by Abbott (1953) at Deep Creek near Bumping Lake southeast of Mount Rainier.

The hornblende-bearing volcanic detritus in the Miocene deposits in the Lake Tapps quadrangle and in the Ellensburg Formation may be products of an eruptive phase of the Snoqualmie batholith and similar plutons in the Cascade Range (Fiske, 1960; Gard, 1960; Fiske and others, 1963). The Snoqualmie Granodiorite was intruded in Miocene and early Pliocene time (Fiske and others, 1963) into rocks that now form much of the central part of the Cascade Range. Green hornblende and biotite are the predominant ferromagnesian minerals in the granodiorite (Smith and Calkins, 1906; Coombs, 1936, p. 167), and green hornblende is the dominant ferromagnesian mineral in the Ellensburg Formation (Coombs, 1941).

Fuller (1925) presented a strong case for the Snoqualmie batholith's having deroofed itself during intrusion and having provided much of the debris which forms the upper part of the "Keechelus Andesitic Series." He argued that loss of a large amount of volatile constituents caused premature solidification of the batholith and curtailed differentiation. He believed that these factors were largely responsible for the scarcity of ore deposits and late-stage differentiates associated with the batholith.

Further evidence for the batholith's having been emplaced under shallow cover and having caused explosive volcanism is suggested by the "granite breccias" found near Bumping Lake by Abbott (1953), and the "explosion breccias" found by Thomas L. Wright (written commun., 1959; Fiske and others, 1963) in Mount Rainier National Park. Wright concluded that contemporaneous volcanism was a distinct possibility and that the resulting rocks should be rich in amphibole rather than pyroxene. This conclusion is substantiated by the presence, in Mount Rainier National Park, of welded tuff and a flow of hypersthene-oxyhornblende andesite thought to be products of a volcanic phase of a late Miocene or early Pliocene granodiorite pluton (Fiske and others, 1963).

## STRUCTURE

The bedrock of this area has been deformed by folding and faulting. Because of the widespread distribution of Quaternary deposits and the cover of dense vegetation, outcrops are sparse and small, and marker horizons generally cannot be recognized or traced. For these reasons, fold axes and fault traces shown on the geologic map (pl. 1) are only approximately located. Details of the geologic structure are inferred chiefly from subsurface information obtained from coal mines in the Carbonado and Spiketon Formations. At the time of the investigation the mines were inaccessible; thus, most of the structure shown on plate 1 was interpreted from published and unpublished coal-mine maps (Daniels, 1914; Bird and Marshall, 1931).

### MAJOR FOLDS

The dominant structural features of the area are the major northerly trending folded and faulted Carbon River anticline (of which Wilkeson anticline is a part), and the broad gentle synclines on either side of it. The Carbonado Formation is exposed in the axis of the anticline; the Northcraft, Spiketon, and Ohanapecosh Formations crop out on the east limb; but only the Northcraft is exposed on the west limb.

The Carbon River anticline plunges northward and disappears beneath Quaternary deposits near South Prairie Creek (Crandell and Gard, 1960), but the structure extends southward beyond the edge of the quadrangle for more than 30 miles to the Nisqually River (fig. 8). South of the Nisqually it veers and plunges southeastward and becomes the Skate Creek anticline of Fisher (1961).

The broad syncline west of the Carbon River anticline is characterized by dips of generally 35° or less, and the few reliable attitudes obtained west of Voight Creek suggest that the axis of the syncline nearly coincides with Cowling Ridge and Spar Pole Hill. On the west limb of the syncline the Carbonado Formation is represented by a small outcrop of east-dipping arkosic sandstone on the west bank of the Puyallup River in sec. 20, T. 18 N., R. 5 E. Evidently the sandstone here was uplifted along a small east-trending normal fault. West of the Puyallup River, bedrock is covered by unconsolidated Pleistocene deposits of the Puget Sound lowland.

East of the Carbon River anticline, rocks of the Puget Group are covered by the thick Ohanapecosh Formation. The Ohanapecosh and younger formations lie in the Unicorn syncline (east of the quadrangle), which trends north-northwest for at least 30 miles roughly parallel to the Carbon River anticline and crosses Mount Rainier National Park (Fiske and others, 1963).

### MINOR FOLDS

The Carbonado Formation has been deformed into a series of small tight synclines and anticlines (pl. 1), mostly in the core of the Carbon River anticline. The largest of these is the Wilkeson anticline, which trends N. 30° W. and plunges at a low angle northward. Average dips on the flanks of this anticline are generally about 60°; and although overturned beds are rare, nearly vertical dips are common. The Wilkeson anticline has been delineated by the attitudes of beds exposed in coal mines from Burnett southward for a distance of about 5 miles.

A small tightly folded syncline and anticline lie on the east flank of the Carbon River anticline in sec. 2 east of Carbonado. The folds trend northeastward and plunge in the same direction. Their northward extensions are exposed in the valley walls of South Prairie Creek just east of the quadrangle in secs. 23, 24, and 25, T. 19 N., R. 6 E., and the syncline continues 6 miles to the northeast into sec. 6, T. 19 N., R. 7 E.

Two other anticlines and an intervening syncline within the Carbon River anticline occur east of Carbonado in secs. 3 and 10, T. 18 N., R. 6 E. (pl. 1). These structures do not crop out, but were identified during exploration for coal.

Maps of mine workings at Melmont (abandoned) reveal complexities of structure in secs. 9, 10, 15, and 16, T. 18 N., R. 6 E., that were unsuspected prior to mining. In the NE cor. sec. 21, T. 18 N., R. 6 E., the Melmont tunnel (originally known as the Blossberg tunnel) (pl. 2) was driven 1,600 feet eastward from the tracks of the now-abandoned Northern Pacific Railroad on the east side of the Carbon River. The tunnel, driven normal to the strike of the beds, intersected a high-angle reverse fault about 275 feet from the portal and then crossed steeply dipping beds that exhibit small tightly folded and faulted anticlines and synclines.

South of the Willis fault at Carbonado (pl. 1), most coal seams strike southward. In secs. 16 and 17, T. 18 N., R. 6 E., however, the seams are folded into a small northwest-trending syncline and anticline. Maps of mines north of the Carbon River near Fairfax depict similar small north-plunging folds in the Carbonado Formation. Mine workings in sec. 34 T 18 N., R. 6 E., south of Fairfax revealed a series of small south-plunging folds that continue southward at least as far as the Montezuma mine, which is on Evans Creek about a mile south of the quadrangle boundary.

### FAULTS

The bedrock of the mapped area is cut by many high-angle faults which generally are not seen at the surface; most were discovered during coal mining. Although the pattern of faults shown on the geologic map is considerably generalized, there appears to be two distinct sets: high-angle reverse and normal strike faults that parallel fold axes (such as the Burnett, Wilkeson, Menzies, and Devereaux faults), and normal faults (such as the Willis and Miller faults) that transsect and postdate the strike faults. (See sections, pl. 1.)

The strike faults trend north-northwestward, have relatively large displacements, and are commonly upthrown on their west sides. These faults occur at or near the axes of minor folds and probably formed during late stages of folding of the Carbon River anticline. One, known as the Burnett fault, was described by Daniels (1914, p. 43) as a hinge fault. At the north end, near Burnett, the west side of this fault is downthrown as much as 1,000 feet, whereas at the south end the same side is upthrown an unknown amount. At section *B–B′* (pl. 1), the east side is downthrown about 900 feet, as calculated from the position of the Northcraft Formation and from the stratigraphic separation between the base of this formation and the Wingate coal seam. The throw must increase southward, because the Northcraft crops out close to the approximate trace of the fault in the NW. cor., sec. 35, T 19 N., R. 6 E., southeast of Wilkeson.

Most normal cross faults trend east-southeast, east, or northeast, cut folds and strike faults, and offset coal seams. According to Daniels (1914, p. 43), coal miners could often locate faulted coal seams merely by following coal streaks in gouge along the fault until the seam was found on the opposite side.

The cross fault with the largest known displacement is the Willis fault, which offsets the coal seams mined at Carbonado. The south side of the fault moved downward possibly as much as 1,800 feet, displacing the west-dipping coal seams eastward on the south side of the fault. The Miller fault lies 300 feet southwest of the Willis fault, is parallel to it, and also has the south side downthrown. Maps of the coal mines under Wingate Hill suggest that other cross faults may lie farther south, but because of lack of specific information, these faults have not been shown on the geologic map.

Faults offset sediments of Miocene and Pleistocene age in several places. In a Northern Pacific Railroad cut on South Prairie Creek west of Burnett, a mudflow of Miocene age is displaced at least 40 feet by a normal fault that strikes east and dips 80° N. At several places along Voight Creek in the N½ sec. 2, T. 18 N., R 5 E., Miocene deposits, which elsewhere are nearly horizontal, dip steeply north along the north side of an east-trending normal fault. Strikes here are N. 30°–70° E., and dips 3°–80° N. In the valley of Kings Creek in sec. 34, T. 18 N., R. 5 E., at the south edge of the quadrangle, small east-trending normal faults have cut not only breccias of the Northcraft Formation but also mudflows of the Lily Creek Formation of Pleistocene age (Crandell, 1963). One fault in the Northcraft brought unweathered volcanic rocks against deeply weathered volcanic rocks.

### ORIGIN OF INTENSE DEFORMATION IN THE CARBON RIVER ANTICLINE

The most impressive structural feature of the Lake Tapps quadrangle is the tight folding and high-angle faulting of the rocks in the Carbon River anticline. Deformation of the lower Tertiary rocks of western Washington is generally characterized by broad open folds, such as those that flank this anticline. The more intense deformation in the anticline itself was probably localized by the presence of a weak north-trending linear zone in the rock sequence. The stratigraphy and geologic history of the area suggest at least two reasons why a weak zone might have been present.

First, the sequence of sedimentary rocks might have been thin at the site of the present anticline. To the east, the thick Ohanapecosh Formation apparently never formed a great highland; instead, much of the formation was deposited under water, indicating subsidence of the basin of deposition as the rocks accumulated (Fiske and others, 1963). The writer suggests that subsidence in this basin was greater than subsidence at the site of the Carbon River anticline, and that earlier subsidence in the Puget basin to the west was also greater. If so, the sedimentary rocks under the present anticline would be relatively thin and, consequently, weak. When the region was subjected to east-west lateral compression, the rocks in the present anticline were more intensely folded and faulted than those in adjacent areas, where the rocks were thicker.

Second, differences of strength between the Northcraft Formation and the rest of the Puget Group might also have influenced the type of deformation. As mentioned previously, the Northcraft thins rapidly eastward, not only in the Lake Tapps quadrangle, but also in the area between the Puyallup and Nisqually Rivers. The Northcraft is regarded as more competent than the Carbonado and Spiketon Formations mainly because it is composed chiefly of well-indurated volcanic breccia. DeSitter (1956, p. 240) stated that a fold often forms on the thin wedge of a competent member when a lateral force is applied. He inferred that a detachment plane forms somewhere below the competent member, and he visualized (fig. 183, p. 240) that the beds lying immediately below the competent member, but above the detachment plane, are subject to tight folding or crumpling. If a fold formed in the thin wedge of Northcraft Formation in the manner described by deSitter, the underlying, weaker Carbonado Formation then might have easily crumpled into tight folds as shown in figure 14. If this explanation is correct, a detachment plane probably lies under or within the Carbonado Formation.

### AGE OF DEFORMATION

At least three episodes of deformation are recorded in the rocks exposed in the quadrangle. The earliest occurred during Eocene time, when the area subsided more than 8,000 feet while the Puget Group was being deposited. Deformation probably of Oligocene or Miocene age then formed the major structures, including the Carbon River anticline. Post-Miocene deformation produced cross faults and gentle folding in rocks as young as Pleistocene.

Little evidence exists in the quadrangle to closely date the formation of the major structures. The youngest rocks involved locally are Ohanapecosh strata that are probably of Oligocene age. The oldest rocks that postdate the intense deformation are the deposits of late Miocene age, which lie unconformably on strongly folded and eroded rocks of the Puget Group.

Evidence in nearby areas suggests that the major deformation may have occurred during parts of Oligocene and Miocene time. The Ohanapecosh Formation in Mount Rainier National Park was folded, uplifted, eroded, and locally weathered to saprolite before deposition of the Stevens Ridge Formation (Fiske and others, 1963). The Stevens Ridge and the overlying Fifes Peak Formation were subsequently folded along the same axes, although to a lesser extent (Fiske and others, 1963). The Stevens Ridge and Fifes Peak Formations probably range in age from late Oligocene to early Miocene; thus, this deformation started in early or middle Oligocene time, after deposition of the Ohanapecosh, and continued, at least sporadically, until at least early Miocene time.

A light-colored felsite porphyry that is probably an ash flow of the Stevens Ridge Formation lies unconformably on volcanic sandstones of the lower part of the Ohanapecosh Formation just east of the quadrangle in the SE¼ sec. 23, T. 19 N., R. 6 E. The proximity of this apparently unfolded flow to the top of the Puget Group suggests that post-Ohanapecosh erosion must have been extremely deep and that most, if not all, of

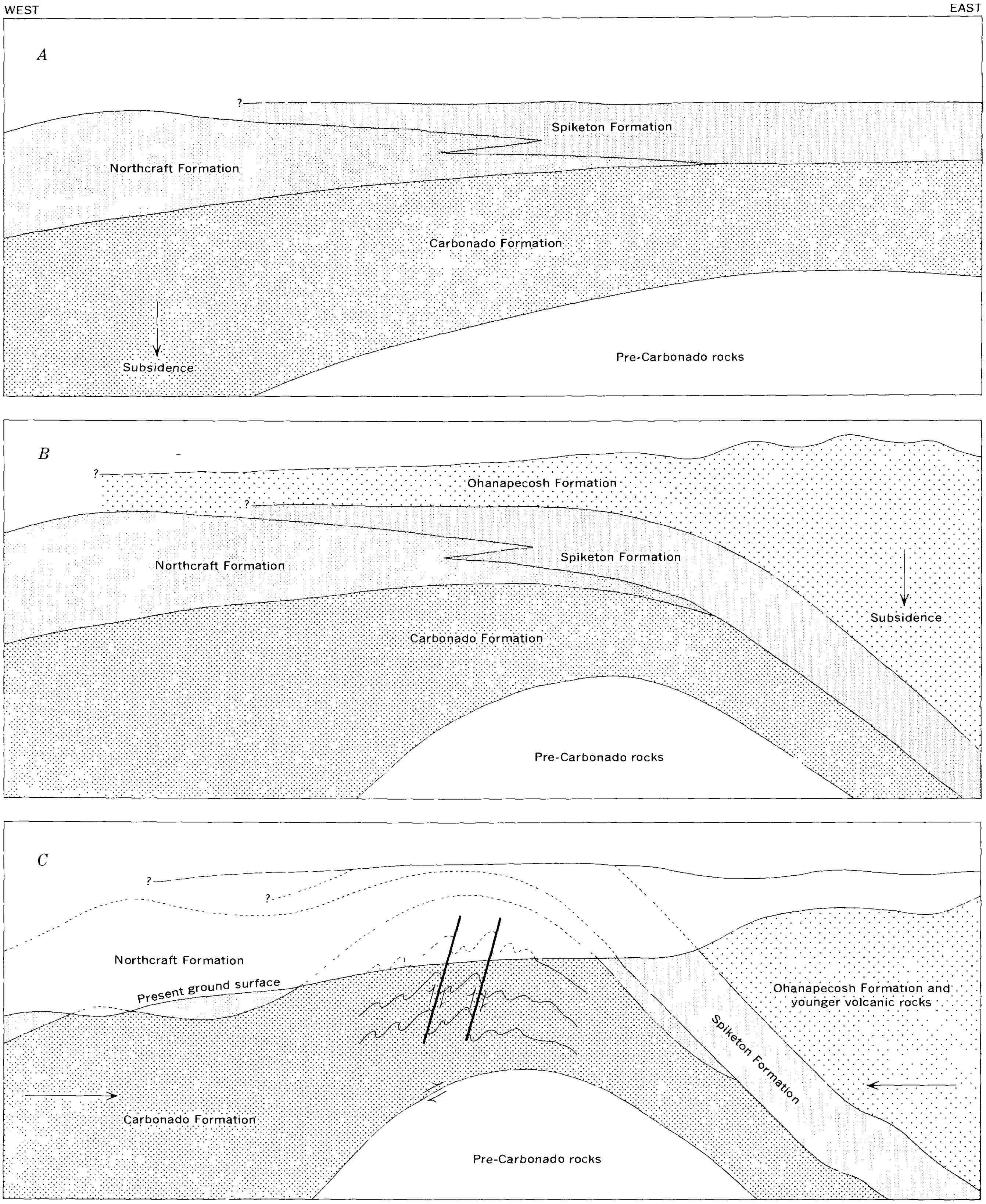


FIGURE 14.—Hypothetical sequence of structural development in the Carbon River anticline. *A*, late Eocene time. *B*, Oligocene time. *C*, late Oligocene to Miocene time.

the folding of the Carbon River anticline must have been completed by Stevens Ridge time.

## ECONOMIC GEOLOGY

Known mineral resources in the bedrock of the quadrangle are limited to nonmetallic deposits. Coal has been the most important economic natural resource, although the bedrock also has value for construction stone and possibly clay. The large quantities of sand and gravel available were described by Crandell (1963).

### COAL

Bituminous coal was discovered about 1863 in outcrops of the Carbonado Formation in the Carbon Gorge, and mining began before 1874. Coal from this district, particularly that from the Carbonado Formation, proved to be the most satisfactory coking coal on the west coast, and large quantities of coke were produced. Coal production reached its peak in 1913 when 856,425 tons was mined. Except for a slight rise during World War II, production has dwindled since 1913; in 1960 a few hundred tons was mined for local consumption.

Coal reserves in Pierce County were recently estimated to be 362 million tons (Beikman and others, 1961, p. 63). Of this total, about 13 million tons is estimated to be in the Ashford area, 17 miles south of the quadrangle. Including the Fairfax-Montezuma area, which lies just south of the quadrangle boundary, the total estimated reserves for the Lake Tapps area are 347.8 million tons. Of this figure, about 39 percent is measured and indicated reserves, and about 61 percent is inferred reserves. The Wilkeson-Carbonado area contains 222 million tons of coal reserves, the Spiketon-South Willis area 88.8 million tons, the Melmont area 16 million tons, and the Fairfax-Montezuma area in Tps. 17 and 18 N., R. 6 E., both north and south of the Carbon River, 21 million tons.

Most of the easily accessible coal has been taken out, and because the cost of mining the remaining coal would be high, the coal will probably not be mined extensively under present economic conditions.

### CONSTRUCTION STONE

Several thick sandstone beds are potential sources of building and ornamental stone in the Lake Tapps quadrangle. Only the "Wilkeson" sandstone of the Carbonado Formation, however, is currently being commercially exploited for these uses. This sandstone has been quarried at Wilkeson, on the east flank of the Carbon River anticline, and used in building construction for more than 50 years. The rock is gray to buff, is low in iron and other discoloring agents, wears well, and is of moderate strength; but it lacks the three-dimensional splitting qualities of an ideal building stone (Currier, 1960, p. 51). Shedd (1903, p. 68–70) described the Wilkeson and gave the results of physical and chemical tests made on it. In the Wilkeson quarry, the stone is massive, and bedding planes are obscure, but both bedding planes and joints are utilized in quarrying. Large blocks outlined by drill holes are loosened by explosives and then lowered to cutting sheds at the foot of the quarry face. In the cutting sheds the blocks are cut to required size with wire saws.

Other sandstone beds of the Puget Group have been quarried on South Prairie Creek near Burnett and near Melmont in sec. 22, T. 18 N., R. 6 E. Rock from these quarries was used locally as foundation stone for mine buildings and coke ovens. A small quarry was intermittently operated in a cross-stratified sandstone of the Carbonado Formation; the quarry is in the Puyallup River valley in sec. 20, T. 18 N., R. 5 E.

Bedrock has been intermittently quarried in several places in the Lake Tapps quadrangle for road metal, fill, and riprap. Bodies of intrusive rock provide the best source of broken stone. Massive sandstone beds of the Carbonado and Spiketon Formations have been used locally for riprap and fill, but they lack the durability necessary for crushed stone and riprap of good quality. In the foothills of the Cascade Range, where deposits of unweathered gravel are scarce and long haulage of gravel from the lowland impractical, unweathered igneous rock has been crushed and used for road metal. Lava flows are not found in the Northcraft Formation in the quadrangle, and the volcanic breccia is generally not suitable for broken stone because of alteration and weathering.

A quarry in sec. 6, T. 18 N., R. 5 E., about 2 miles south of Orting has been intermittently operated by Pierce County chiefly for riprap to be used locally for channel control and abutment protection along rivers. The stone is quarried from the massively jointed central part of a mass of dacite, where the rock is unaltered up to the contact with the overlying drift. On the north side of the quarry a columnar phase of the rock is weathered along joints down to a depth of more than 20 feet and was not being worked at the time of the investigation.

Most of the larger bodies of intrusive rock in the quadrangle should be suitable for crushed stone and some may be usable for riprap. The most promising rock is the quartz-diabase sill in the Carbon Gorge; the rock is massively jointed and should produce large blocks suitable for riprap. A massively jointed quartz-diabase intrusive in sec. 32, T. 18 N., R. 5 E., at Electron, just south of the quadrangle, is another potential source for riprap and crushed stone. The latite intrusive that crops out along Fox Creek in secs. 22 and 23, T. 18 N., R. 5 E., appears to be a possible source of crushed stone, but platy jointing of the latite precludes its use as riprap. Only a few cubic yards of this rock have been quarried, probably because a large deposit of gravel about a mile to the west provides sufficient stone for local road-building needs.

## CLAY DEPOSITS

Clay has never been produced commercially in the Lake Tapps quadrangle although there are several potential sources. The largest and most widespread is in the claystone beds of the Carbonado and Spiketon Formations. Other sources are the Miocene deposits that crop out on Voight and Wilkeson Creeks and the deeply weathered volcanic breccia in the Northcraft Formation.

A program of sampling and testing the claystone beds of the Puget Group that crop out along the Mowich Lake road was conducted by the U.S. Bureau of Mines. J. G. Schlagel, mining engineer with the Bureau of Mines, Division of Mineral Technology, reported (written commun. to H. J. Kelly, Bureau of Mines, 1959) that, of the samples tested, one was high refractory (pyrometric cone equivalent, PCE, of 29 or higher), four were low refractory (PCE 19–26), and one was nonrefractory (PCE $<19$). Two samples bloated, indicating that some shale or claystone might be used for expanded aggregate. Owing to the steep dip of the beds and to the large amounts of overburden, this source of clay would presumably have to be developed by underground mining methods.

Weathered volcanic breccia of the Northcraft Formation crops out on the south and west sides of Spar Pole Hill and on the west side of Cowling Ridge. Breccia in roadcuts along Beane Creek on Spar Pole Hill is weathered to clay but still retains the outlines of individual clasts. These weathered deposits resemble those at Clay City, about 8 miles to the south, where deeply weathered rocks of the Northcraft are being mined and used in the manufacture of brick and tile.

## OIL AND GAS

Several test wells in which traces of gas and oil were found have been drilled just north of the Lake Tapps quadrangle on the extension of an anticline exposed in the Green River Gorge. Only minor exploration for oil and gas has taken place within the quadrangle because of inadequate geologic knowledge and apparent lack of potential source beds. In 1915 an oil-exploration well was drilled at Orting to a depth of about 2,600 feet (Glover, 1947); although gas was reported, details are not known. In 1961 a well (the Blessing-Siler 1) drilled west of Buckley in sec. 31, T. 20 N., R. 6 E., penetrated sedimentary rocks of the Carbonado Formation. No oil was found, but "gas-cut" mud was found in the lower part of the hole. The hole was drilled to a depth of 6,924 feet below sea level and penetrated bedrock at a depth of about 125 feet below sea level (V. E. Livingston, Jr., written commun., 1963).

Oil may be present in the Lake Tapps quadrangle in rocks of the Carbon River anticline. The McIntosh Formation of the Centralia area is regarded as a potential source rock for oil (Snavely and others, 1958, p. 93); nonmarine arkosic rocks of the Puget Group were inferred (see p. B13, this report) to pass westward into marine rocks correlative with the McIntosh. Oil from such source rocks west of the Lake Tapps quadrangle could have migrated eastward into the area now occupied by the Carbon River anticline. This anticline plunges northward and, although no structural closures have been established in it, some stratigraphic traps may exist at depth along its west flank.

## GEOLOGY OF A POTENTIAL DAMSITE IN THE CARBON GORGE

The Carbon River has long been considered a potential source of water power. Two potential damsites have been considered. One, the Fairfax Bridge site, is in the Carbon Gorge and will be discussed here; the second, in sec. 31, T. 19 N., R. 6 E., was mapped geologically by J. T. Pardee, of the U.S. Geological Survey (unpub. data, 1939).

The Fairfax Bridge damsite is in the Carbon Gorge in secs. 16, 21, and 22, T. 18 N., R. 6 E., about 3 miles south of Carbonado. The site was examined in detail and the geology mapped by the writer in 1955 (pl. 2).

*Physiography.*—In the vicinity of Fairfax Bridge the sides of the Carbon Gorge are rugged and steep and are nearly vertical in many places. A few hundred feet upstream, where the river has cut through less resistant sedimentary rocks of the Carbonado Formation, the canyon walls are less steep and there is a terrace at an altitude of about 1,200 feet on the east side of the river. This terrace is represented in the gorge only by an inconspicuous shoulder on the canyon wall. Below the terrace or shoulder there is a steep-walled inner gorge about 50 feet deep that is accessible in many places only by use of a rope.

*Bedrock geology.*—The bedrock of the damsite area consists of steeply dipping sedimentary rocks of the Carbonado Formation and a sill of quartz diabase that intruded the Carbonado. The sedimentary rocks consist of alternating sandstone, siltstone, and shale that contain coal seams as much as 11 feet thick. These rocks are mostly quartz and feldspar grains cemented by calcite and contain small amounts of muscovite and biotite.

The sill of quartz diabase is at least 950 feet thick. Its contacts are conformable in most places; however, where the base of the sill is exposed in the bottom of the gorge about 350 feet upstream from Fairfax Bridge, the contact trends at a right angle to the bedding of the sedimentary rocks for about 200 feet and then becomes conformable again. Contacts are sharp, and the sedimentary rocks were little altered or disturbed by intrusion of the sill. The contacts are generally tight, although small seeps were observed on the west canyon wall at the lower contact.

The Carbon Gorge trends diagonally across the westward-dipping sill for about three-fourths of a mile. The diabase that crops out in the inner gorge is fresh and hard, but higher on the canyon walls it is more weathered, particularly along joints. This contrast probably resulted from weathering rather than hydrothermal alteration, and below the weathered zone, rocks along the joints are probably fresh and the joints tight.

*Surficial deposits.*—The only glacial deposit recognized in the damsite area is a layer of outwash gravel, generally less than 20 feet thick, on the terrace at an altitude of 1,200 feet. Alluvial sand and gravel along the valley floor is generally thin and of small areal extent. Where the gorge cuts across the diabase sill, the alluvium consists mainly of a few boulders too large for the river to move except at flood stage.

A mantle of colluvium generally less than 10 feet thick overlies most of the bedrock; it is commonly thinner on the sill. The colluvium was mapped only where it is more than 5 feet thick. It consists of weathered and fresh fragments of bedrock mixed with detritus derived from glacial deposits higher on the slopes.

*Structure.*—The bedrock in the damsite area has been compressed into tight steep-sided folds, and faulted. The sedimentary rocks here are on the west limb of a faulted anticline; they strike north and dip about 55° W. The diabase sill was probably intruded prior to folding and thus was folded with the sedimentary rocks. In many places the rocks were compressed so strongly that reverse faulting occurred, particularly along and adjacent to fold axes. The nature of these folds and faults is shown in section *C–C′* of plate 2, which has been constructed along the axis of the abandoned Melmont coal-mine tunnel[3].

The sill has three prominent sets of joints. Along two of the sets weathering of the diabase has occurred; one of these strikes N. 60° E. and dips 65° S., and the other strikes due east and dips 80° N. The third joint set strikes N. 10° W., approximately parallel to the trend of the sill, and dips about 55° W.

[3] Subsurface information taken from unpublished geologic maps and coal-mine maps in the George W. Evans collection in the University of Washington library.

#### SUITABILITY AS A DAMSITE

This location is in many ways well suited as a damsite; however, certain limiting factors must be considered if a dam were to be designed and constructed.

*Foundation conditions.*—The diabase sill provides an excellent foundation for a masonry or earth dam. The sill is strong and relatively unweathered; however, weathering along joints should be explored, and if necessary, the joints should be excavated or grouted to seal them. Drilling should be done to locate the sill contacts precisely.

*Tunneling conditions.*—The diabase sill should provide good tunneling conditions, but some overbreakage may be expected because of jointing of the rock. The shale and siltstone of the Carbonado Formation are relatively incompetent, and tunnels in this formation, except where massive sandstone occurs, will have to be supported and lined.

*Foundation leakage.*—Some leakage can be expected in the more permeable sandstone beds and along joints and fractures in both the sedimentary and igneous rocks. The sill contacts appear to be fairly tight and passage of water along them should be minor.

A possible disadvantage to this site, and perhaps a factor limiting the height of a dam here, is the presence in the reservoir area of the abandoned Melmont coal mine. The portal of the mine is on the right bank about 850 feet upstream from the east abutment of the Fairfax Bridge, at an altitude of 1,278 feet along the abandoned Northern Pacific Railroad track. The portal is now collapsed, and entry to the mine is impossible. Mine maps indicate that a tunnel extended eastward from the portal at least 1,600 feet. Gangways were driven both north and south along coal seams crossed by the tunnel, and much coal was removed. From a point higher on the hillside somewhere east of the tunnel portal, an additional separate inclined shaft or slope was sunk which provided entry to coal seams that were mined below river level.

The principal disadvantage of a dam located here is the possible leakage of the reservoir:

1. Water impounded behind a dam with a crest altitude of more than 1,278 feet will undoubtedly flow into the old Melmont tunnel. From the tunnel it will find its way into the gangways that were driven at least 5,750 feet north from the tunnel. Whether tunnels connect these workings with the Carbonado and Wilkeson mines to the north is not known; no connecting tunnels are shown on old mine maps. The possibility of such a connection must be considered, however, as it would provide an easy route for leakage of reservoir water. Therefore reopening and sealing off of the Melmont tunnel is recommended. In addition, although mined-out areas in

the coal beds commonly were allowed to collapse after the coal was withdrawn, it is not safe to assume that collapse occurred at all places in this mine, nor that collapse would effectively seal off all the existing workings.

2. Water might also enter the slope mine whose gangway lies below river level. This slope extends down to a gangway that passes about 625 feet below and 100 feet west of the Melmont tunnel portal. The gangway trends slightly west of north along the strike and extends at least 700 feet north of the point under the Melmont tunnel portal. If these workings are connected to the main tunnel, they would also be subject to flooding and possible leakage.

*Landslides.*—No large landslides were observed within the mapped area. Detailed geologic mapping of the entire reservoir area, however, should be undertaken prior to any construction to determine the existence of any old slides or of potential slide areas.

*Silting of the reservoir.*—Melt water from the Carbon and Russell glaciers contributes much rock flour (finely ground rock particles, chiefly silt and clay size, resulting from glacial abrasion) to the Carbon River. Ponding of the river by a dam would cause much of the coarser rock flour to settle out. Consequently, before a dam is constructed the rate of expected silting of the reservoir should be studied, and possible means of flushing of the reservoir should be considered. Rock flour that remains in suspension may cause excessive abrasion on valves, pipes, tunnel linings, turbines, and other equipment.

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U.S. GOVERNMENT PRINTING OFFICE : 1968 O—277-594

# Geologic Studies in the Puget Sound Lowland Washington

GEOLOGICAL SURVEY PROFESSIONAL PAPER 388

*This volume was published as separate chapters A and B*

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

**William T. Pecora,** ***Director***

Library of Congress catalog-card No. GS 67-319.

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