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Reprint No. 3

# Tertiary Stratigraphic Papers, Southwestern Washington

**McIntosh formation, Centralia-Chehalis coal district, Washington**

By
P. D. SNAVELY, JR., WELDON W. RAU, LINN HOOVER, JR., and ALBERT E. ROBERTS

**Lyre formation (redefinition), Northern Olympic Peninsula, Washington**

By
R. D. BROWN, JR., P. D. SNAVELY, JR., and H. D. GOWER

**Twin River formation (redefinition), northern Olympic Peninsula, Washington**

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Reprinted from
The Bulletin of the American Association of Petroleum Geologists
vol. 35, no. 5, May 1951, p. 1052-1061
vol. 40, no. 1, January 1956, p. 94-107
vol. 42, no. 10, October 1958, p. 2492-2512

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STATE PRINTING PLANT, OLYMPIA, WASHINGTON
1959

# McINTOSH FORMATION, CENTRALIA-CHEHALIS COAL DISTRICT, WASHINGTON

BY

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Reprinted for private circulation from
THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Vol. 35, No. 5, May, 1951

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 35, NO. 5 (MAY, 1951), PP. 1052-1061, 6 FIGS.

# McINTOSH FORMATION, CENTRALIA-CHEHALIS COAL DISTRICT, WASHINGTON[1]

PARKE D. SNAVELY, JR., WELDON W. RAU, LINN HOOVER, JR., AND ALBERT E. ROBERTS[2]

## ABSTRACT

The name McIntosh formation is proposed for more than 4,000–4,500 feet of dark gray marine siltstone and claystone, and interbedded arkosic and basaltic sandstone which crops out in the Centralia-Chehalis coal district, Lewis and Thurston counties, Washington. The siltstone and claystone beds contain a fauna correlative with the Laiming's B-1A foraminiferal zone of upper Domengine age of California. The McIntosh formation is correlated with the Mill Creek and Sacchi Beach beds of local usage and perhaps with the Burpee formation of Oregon.

## INTRODUCTION

In the Centralia-Chehalis coal district of western Lewis and southern Thurston counties, Washington, the coal-bearing rocks rest with angular discordance on a succession of andesite and basalt flows, and sedimentary and pyroclastic rocks, which has a thickness of about 1,000 feet. Beneath this succession of flows and associated rocks lies more than 4,000 feet of dark gray marine siltstone and claystone with interbedded arkosic and basaltic sandstone. This siltstone and claystone sequence has previously been included with the younger coal-bearing rocks in the Puget group of Eocene age or in some areas mapped as undifferentiated Oligocene and Eocene (Culver, 1919). On the geologic map of western Washington (Weaver, 1937) the area underlain by the siltstone and claystone sequence was shown as Cowlitz formation of Eocene age, which also included the younger coal-bearing rocks. The base of the siltstone and claystone sequence is not exposed in the Centralia-Chehalis coal district, but the sequence is a distinctive lithologic unit, the exposed part of which is mappable. The name McIntosh formation is here proposed for these sedimentary rocks.

## TYPE LOCALITY AND GENERAL FIELD RELATIONS

The type area of exposure of the McIntosh formation is in the central and southeastern parts of T. 16 N., R. 1 W., extending into the northern parts of Secs. 2 and 3, T. 15 N., R. 1 W. The formation is particularly well exposed in road cuts along the south side of McIntosh Lake in Secs. 14 and 23, T. 16 N., R. 1 W., from which the formation is named, and in road cuts along the CCC road in Secs. 27, 34, and 35, T. 16 N., R. 1 W., and in the NE. ¼, NW. ¼ of Sec. 2, T. 15 N., R. 1 W. Several hundred feet of the beds of the formation are exposed on the south side of McIntosh Lake, where an exceptional opportunity to observe the lithologic character of the formation in fresh exposures was afforded by road cuts, and where the beds contain well preserved Foraminifera. Good sections

[1] Published by permission of the director of the United States Geological Survey. Manuscript received, December 15, 1950.

[2] Geologists, United States Geological Survey.

across a part of the formation are elsewhere exposed along the South Fork of the Newaukum River in Sec. 6, T. 13 N., R. 2 E., and along the Skookumchuck River in Sec. 2, T. 14 N., R. 2 E.

The beds of the upper part of the McIntosh formation are poorly exposed in weathered outcrops in the vicinity of Tenino, Washington (Fig. 1), where they form a low undulating topography. A few miles northeast of Tenino, a test well for oil drilled by the Ohio Oil Company in Sec. 10, T. 16 N., R. 1 W., indicated that volcanic rocks underlie the McIntosh formation. Minimum thickness of 4,000 feet has been computed by the writers for the formation in the vicinity of Tenino (Fig. 2), but data secured from other test wells in this region suggest that the formation may reach maximum thickness of more than 5,000 feet.

The McIntosh formation in the Centralia-Chehalis district crops out chiefly along the axial parts of broad plunging anticlines. Faults of moderate to small displacement and shear zones are common throughout the district, and many are apparent by zones of slickensides and brecciation within the beds of the formation. The formation is overlain with apparent disconformity by strata that consist of andesite and basalt flows, with associated sedimentary and pyroclastic rocks. This relationship is evident along the west side of Crawford Mountain in Secs. 26 and 35, T. 16 N., R. 1 W.

### LITHOLOGIC COMPOSITION

The McIntosh formation consists chiefly of dark gray well indurated tuffaceous siltstone and claystone with thin interbedded tuff zones (Fig. 3). Some beds are massive, although stratification may be made apparent by tuffaceous zones or interbedded sandstone. Irregularly located calcareous nodules and lenses are common. The siltstone and claystone are fissile in part and are commonly finely micaceous. Carbonaceous material and pyrite are present in most places. Most beds are laminated, consisting of fine layers of siltstone and fine-grained tuff or sandstone. The sedimentary rocks weather into an iron-stained shaly and crumbly soil, the color of which, in most places, is a mottled light gray and light yellowish orange.

The upper part of the McIntosh formation consists of 250 feet of massive arkosic sandstone which has been quarried for building stone near Tenino, Washington (Fig. 4). Dark gray basaltic and light gray arkosic sandstone is interbedded throughout the formation, but it is increasingly more abundant toward the eastern part of the area (Fig. 5). The predominance of sandy beds with interbedded carbonaceous layers in exposures of the formation east of the Centralia-Chehalis coal district indicates that the shore line of the basin of deposition was at the east.

Microscopic studies show that the basaltic sandstone is composed of 70–75 per cent clastic grains and 25–30 per cent calcite, glass, chlorite, chalcedony, and zeolitic minerals, all of which form the matrix. Most of the grains are subrounded, although rounded and angular grains are present. Basalt grains make up an aver-

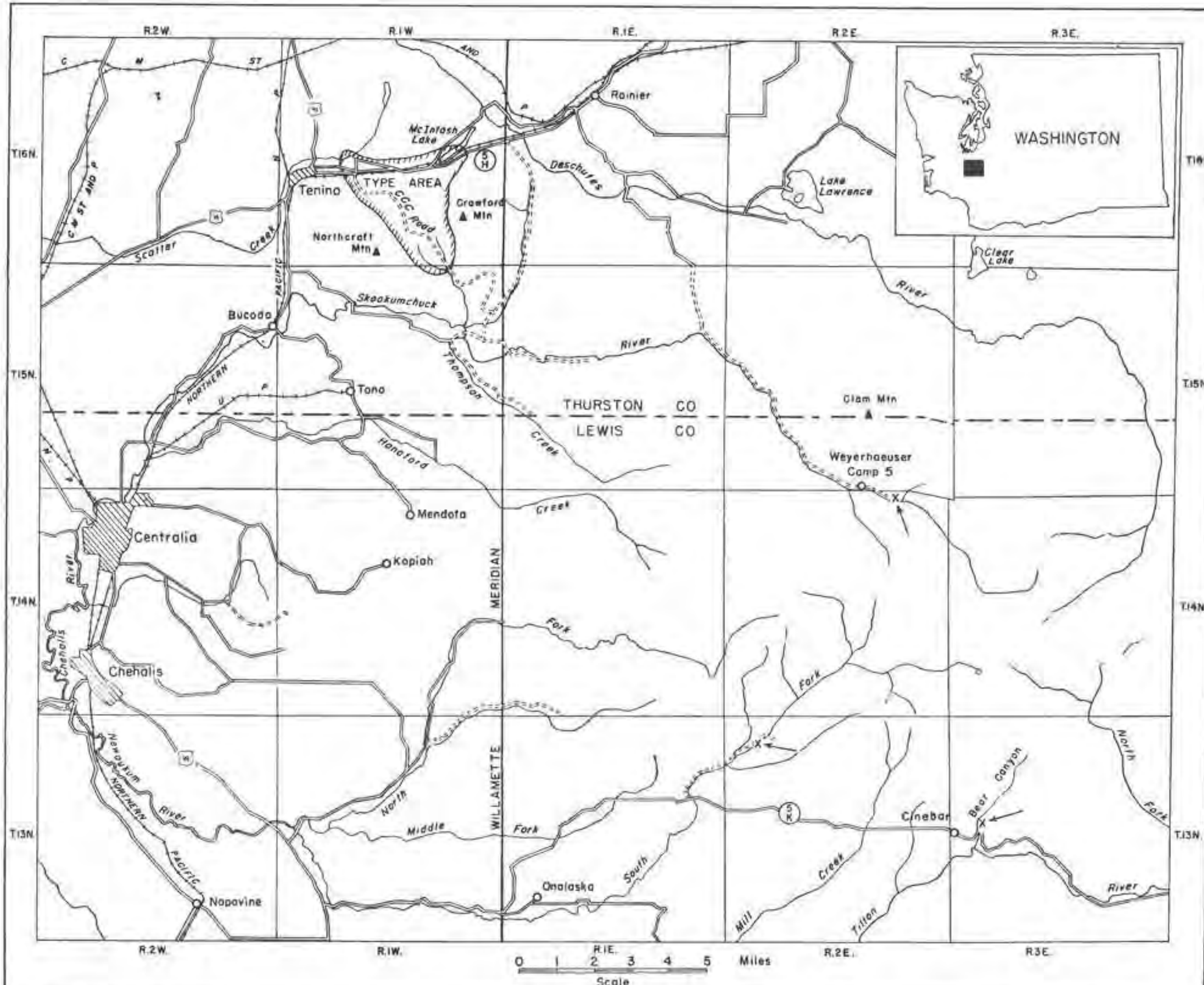


FIG. 1.—Map of part of southwest Washington showing location of type area and known areas of outcrop of McIntosh formation.

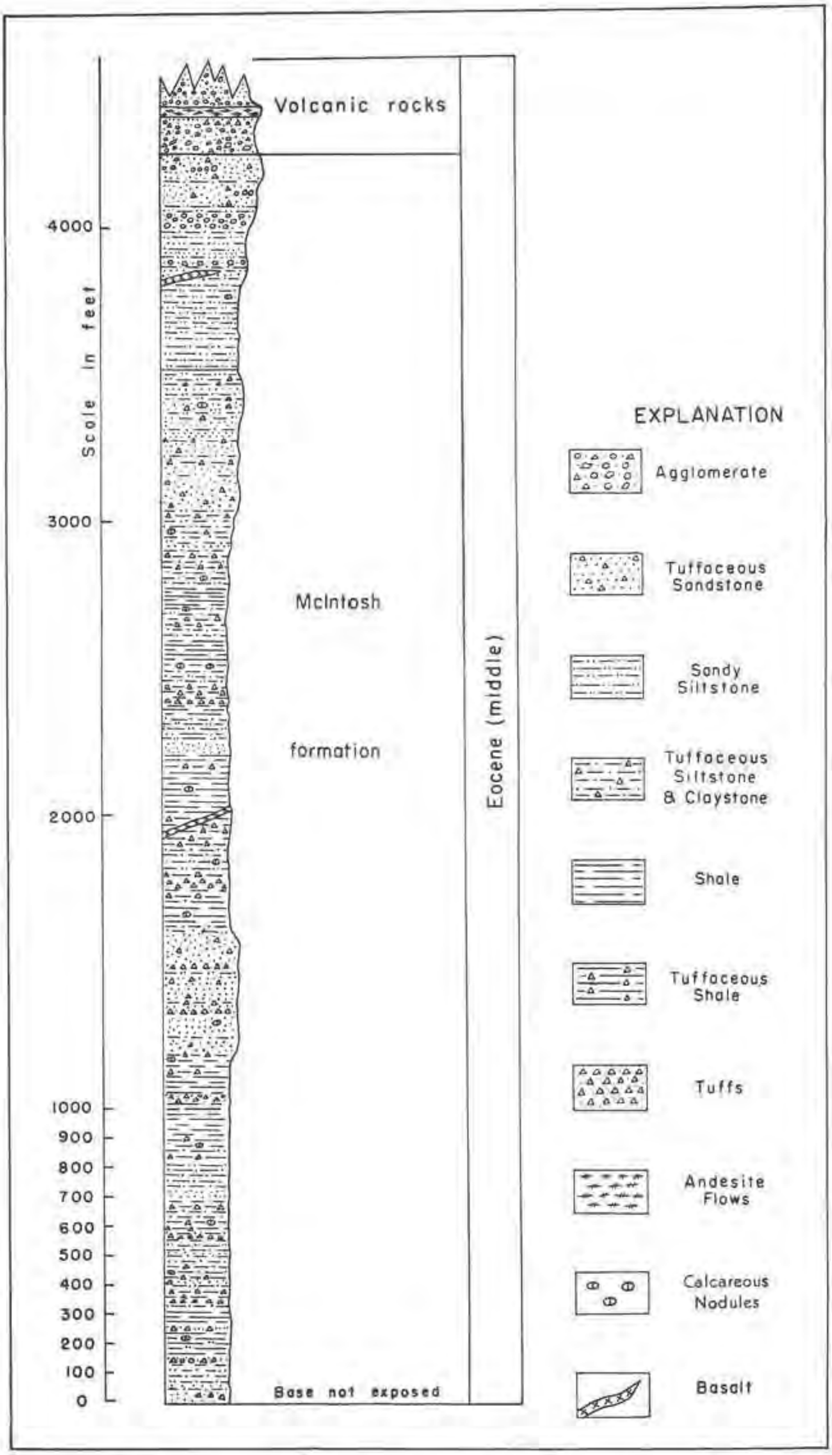


FIG. 2.—Composite stratigraphic section of McIntosh formation in vicinity of Tenino, Washington.


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FIG. 3.—McIntosh formation along State Highway 5H, $3\frac{1}{2}$ miles east of Tenino, Washington. Stratification is apparent by light gray tuff beds.

FIG. 4.—Massive arkosic sandstone in upper part of McIntosh formation, Western Quarry, Tenino, Washington.

FIG. 5.—Tuffaceous basaltic sandstone along State Highway 5H, $2\frac{1}{2}$ miles east of Tenino, Washington.

age of 40–50 per cent of the rock, and plagioclase (andesine) grains constitute 20–30 per cent. Magnetite is present in amounts up to 10 per cent; augite and quartz grains average less than 5 per cent of the rock. Shards of glass compose 10–30 per cent of the thin sections of rock studied. Secondary minerals recognized are chalcedony, calcite, zeolite, chlorite, and limonite, which make up 15–30 per cent of the rock.

The arkosic sandstone of the McIntosh formation is massive to cross-bedded, micaceous, and tuffaceous. Most of the mineral grains common to this sandstone appear to be derived from metamorphic and igneous rocks and pyroclastic material. Locally, the sandstone is conglomeratic and contains a few megafossils. Good exposures of this arkosic sandstone may be seen in three quarries adjacent to the town of Tenino.

Microscopic examination reveals that the arkosic sandstone is composed of 75–90 per cent clastic grains and 10–25 per cent calcite, clay minerals, chlorite, and glass, which form the matrix. Plagioclase (andesine) makes up 25–40 per cent of the rock and occasionally is in euhedral form with pronounced zoning. Subrounded grains of quartz, commonly strained, make up 15–30 per cent of the rock; they contain inclusions of biotite or muscovite. In all of the sections studied, biotite and muscovite made up 10–25 per cent of the rock. Grains composed of basalt commonly are present, but they average less than 10 per cent of the sandstone. Glass, which commonly is altered to chalcedony, is present in some of the rocks. Other minerals identified are magnetite, augite, zircon, apatite, and hornblende.

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

## AGE RELATIONSHIP

The poorly preserved megafossils collected throughout the McIntosh formation are not indicative of age. However, microfossils, which can be collected from most fresh outcrops, indicate middle Eocene age for these beds.

The following species were identified from material collected from the exposures of the formation south of Lake McIntosh.

*Ammodiscus* cf. *A. incertus* (d'Orbigny)
*Haplophragmoides?* sp.
*Cyclammina* cf. *C. simiensis* Cushman and McMasters
*Textularia* sp.
*Gaudryina* sp.
*Quinqueloculina* sp.
*Sigmoilina* cf. *S. tenuis* (Czizek)
*Robulus inornatus* (d'Orbigny)
*Dentalina jacksonensis* (Cushman and Applin)
*Dentalina* cf. *D. consobrina* d'Orbigny

*Dentalina colei* Cushman and Dusenbury
*Nodosaria latejugata* Gümbel
*Pseudoglandulina turbinata* Detling
*Pseudoglandulina* sp.
*Amphimorphina californica* Cushman and McMasters
*Bulimina* cf. *B. guayabalensis* Cole
*Bulimina jacksonensis* Cushman
*Eponides* cf. *E. guayabalensis* Cole
*Eponides minimus* Cushman
*Eponides* sp.
*Baggina* cf. *B. washingtonensis* Rau
*Cibicides* cf. *C. pseudowuellerstorfi* Cole
*Cibicides* sp.

A few of the forms have not been identified with certainty, and some will undoubtedly be proved to be new species. Essentially all of those forms identified as described species are known in middle and upper Eocene beds.

Many of the foraminiferal species of the McIntosh formation are identical with, and many others are similar to, those illustrated and discussed by Cushman and McMasters (1936) from McMasters' Llajas formation of California. Laiming (1940) has designated the Llajas fauna of Cushman and McMasters as typical of the B-1A foraminiferal zone of upper Domengine age. The B-1A zone is characterized principally by the occurrence of *Amphimorphina californica*, which also occurs in the McIntosh formation at the type locality. The foraminiferal evidence strongly suggests that the type McIntosh is equivalent, at least in part, to the B-1A foraminiferal zone of California and therefore is probably late middle Eocene in age.

Foraminiferal samples collected near the top of the McIntosh formation were studied by H. Billman of the Union Oil Company of California who concluded:

The microfossils from this part of the McIntosh formation are a recognizable assemblage and represent a somewhat younger age than the material along the south side of McIntosh Lake. The upper part of the formation, however, is probably not younger than Laiming's B-1A zone.

The Tyee formation of Oregon (Diller, 1898) is most frequently considered to be equivalent in age to a part of the middle Domengine of California. Several slides of Foraminifera from the type locality of the Tyee formation at Basket Point, Oregon, were loaned for study by R. E. Stewart, of the Oregon Department of Geology and Mineral Industries. The microfauna contained in these slides yielded no *Amphimorphina californica*, and several prominent elements in the assemblages of the Tyee are not known from the McIntosh formation. Examinations of the microfaunas from the type Tyee and McIntosh formations suggest that these two assemblages are quite different and that the type specimens of the Tyee are older, possibly Laiming's B-1 zone. However, Foraminifera from the lower part of the McIntosh, stratigraphically below the rocks exposed in the type area, may indicate an age older than B-1A.

Slides containing the foraminiferal assemblages of the McIntosh were sent to R. E. Stewart for comparison with the microfauna assemblages of Oregon material. Stewart offered the following opinion.

. . . The McIntosh foraminiferal assemblages are remarkably similar to assemblages of Oregon material in our collection from Mill Creek near the northern boundary of the Dallas quadrangle and from Sacchi Beach south of Five Mile Creek near the southern boundary of the Empire quadrangle. Although I believe that we should proceed with caution in applying standard California control to details of foraminiferal correlation in Oregon and Washington, it would seem that your additional field evidence justifies correlating the type McIntosh and, therefore, the beds of Mill Creek and Sacchi Beach localities with Laiming's upper Domengine zone B-1A. This strongly implies that our Mill Creek and Sacchi Beach assemblages are from beds which, with the underlying Tyee formation, constitute the Oregon stratigraphic equivalent of the Domengine stage of California.

East of the Centralia-Chehalis district, 2 miles southeast of Clam Mountain, the McIntosh formation crops out along the Skookumchuck River about a mile east of Camp 5 of the Weyerhaeuser Timber Company. The strata in this area are in part of shallow-water origin and contain coarser-grained clastic deposits with thin coal beds and well preserved leaf imprints.

Roland Brown identified the following species from a collection made in the NW. ¼ of Sec. 2, T. 14 N., R. 2 E.

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

Brown made the following comment on this flora.

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

The evidence thus far available suggests therefore that the McIntosh formation is late middle Eocene in age, and is at least in part equivalent in age to the upper Domengine B-1A zone of California.

## CORRELATION

Outcrops of the McIntosh formation or of equivalent rocks are probably widely distributed in southwestern Washington. In the northwestern part of T. 10 N., R. 3 W., Cowlitz County, outcrops of dark gray siltstone and arkosic sandstone in the stream bed of Stillwater Creek, ¾–1 mile west of Ryderwood, contain a microfauna correlative with that of the McIntosh formation. Dark gray siltstone exposed in road cuts near the Bear Canyon, Sec. 18, T. 13 N., R. 3 E., also contains a typical foraminiferal assemblage of the McIntosh.

In the Morton coal field in eastern Lewis County, the exposed rocks include dark gray siltstone and shale interbedded with massive arkosic sandstone and coal beds. Although microfossils have not been found in these shales, floras similar to those found in the McIntosh formation are present. The writers suggest that the coal beds in the vicinity of Morton are in a near-shore facies of the McIntosh formation. The massive arkosic sandstone beds associated with the shale

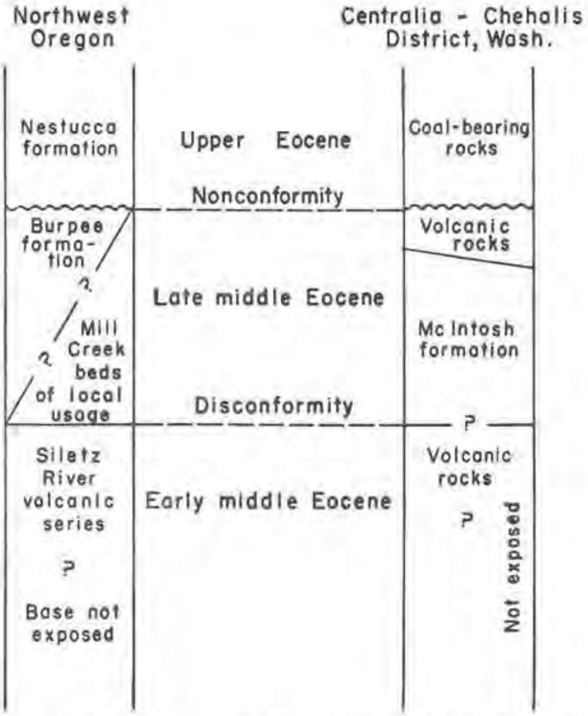


FIG. 6.—Chart showing correlation of Eocene formations of northwestern Oregon and Centralia-Chehalis coal district, Washington.

and coal beds in this area are remarkably similar to the sandstone in the middle Eocene Burpee formation of Oregon (Schenck, 1927).

The McIntosh formation is older than the Nestucca (Snavely and Vokes, 1949) and Coaledo (Diller, 1899) formations of Oregon and the Cowlitz formation of Washington (Weaver, 1912), but it is younger than the Siletz River volcanic series (Snavely and Baldwin, 1948) and Tyee formation of Oregon (Diller, 1898) and the Crescent formation of Washington (Arnold, 1906). The McIntosh formation (Fig. 6) is thus to be correlated with the Mill Creek and Sacchi Beach beds of local usage and perhaps with the Burpee formation of western Oregon.

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## EDITOR'S NOTE

Since the writing of this report, geologic mapping and stratigraphic and foraminiferal studies have extended both the aerial distribution and stratigraphic range of the McIntosh formation. West of the Centralia-Chehalis coal district, the formation has been mapped by Pease and Hoover (1957) throughout the eastern and southern parts of the Doty-Minot Peak area. Unpublished mapping by H. D. Gower (personal communication) has extended the McIntosh formation along the southwestern margin of the Grays Harbor basin, more than 50 miles southwest of the type area.

In the Centralia-Chehalis coal district four foraminiferal zones have been recognized in the McIntosh formation (Snavely and others, 1958, p. 17-21). The lower two zones are considered equivalent to Laiming's B-1 and B-1A zones of the Eocene of California and the upper two equivalent to his A-2 zone of the Eocene. As the result of lateral facies changes, the McIntosh transgresses time and becomes younger toward the west, for in the Doty-Minot Peak area the formation is entirely of late Eocene age, whereas it ranges in age from middle to late Eocene in the Centralia-Chehalis area (Pease and Hoover, 1957, and Rau, 1958).

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# LYRE FORMATION (REDEFINITION), NORTHERN OLYMPIC PENINSULA, WASHINGTON

BY

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Reprinted for private circulation from
THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Vol. 40, No. 1, January, 1956

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 40, NO. 1 (JANUARY, 1956), PP. 94-107, 7 FIGS.

# LYRE FORMATION (REDEFINITION), NORTHERN OLYMPIC PENINSULA, WASHINGTON[1]

ROBERT D. BROWN, JR., PARKE D. SNAVELY, JR., AND HOWARD D. GOWER[2]

## ABSTRACT

Detailed geologic mapping in the northern Olympic Peninsula, Washington, has shown that conglomerate, sandstone, and siltstone strata, previously referred to the Lyre formation, are divisible into two mappable units. The Lyre formation, therefore, is redefined to include only a sequence of sandstone and conglomerate that comprised the lower part of the formation as previously described. These strata average about 1,300 feet in thickness but locally they may be as thick as 3,300 feet. Heretofore these rocks were thought to be Oligocene in age; however, recent field work indicates that they are early late Eocene in age and are overlain with erosional unconformity by strata containing Foraminifera of late Eocene age.

## INTRODUCTION

Recent geologic investigations undertaken by the United States Geological Survey to appraise the oil and gas possibilities of the north coastal area of the Olympic Peninsula, Washington, have been concerned with a sequence of marine sedimentary rocks that totals more than 11,000 feet in thickness and ranges in age from middle Eocene to Miocene. These strata are best exposed on the south limb of a broad west-trending syncline that probably extends from Puget Sound to the Pacific Ocean and roughly parallels the Strait of Juan de Fuca. The rocks in the central and western parts of this syncline have been mapped and described by C. E. Weaver (1937) and the lithologic units recognized by him are shown in a composite section (Fig. 2). The sequence of sandstone, conglomerate, and siltstone in the lower part of the composite section and named the Lyre formation by Weaver is the subject of this report.

The field mapping on which this report is based was done on aerial photographs and was subsequently compiled at a scale of 1:48,000 on Corps of Engineers 15-minute topographic maps of the Lake Crescent, Port Crescent, and Port Angeles quadrangles. The area mapped comprises more than 300 square miles (Fig. 1) and extends from 123° 15′ to 124° 00′ and from the Strait of Juan de Fuca southward to the north boundary of Olympic National Park. Field work was done during the summer months of 1953 and 1954.

Detailed stratigraphic studies of the Lyre formation have indicated the need for a revision of Weaver's definition of this formation, because the Lyre formation, as originally defined, consists of two distinctive and mappable lithologic units. The lower unit is composed of resistant, well cemented sandstone and conglomerate; the upper unit, of thinly bedded sandstone and siltstone with a few channels of granule sandstone and pebble conglomerate. Weaver (1937, p. 121) recognized that the Lyre formation consists of two units, but he apparently did

[1] Manuscript received, July 11, 1955. Publication authorized by the director of the United States Geological Survey.

[2] Geologists, United States Geological Survey.

not consider the contact between the units to have time or tectonic significance, because he suggests that the lower conglomeratic facies of the Lyre formation is a basal conglomerate marking the beginning of a period of deposition during Oligocene time (Weaver, 1937, p. 123). Field investigations by the writers, however, have shown that sandstone and conglomerate beds of the lower unit are interbedded with, and in some areas grade laterally into, siltstone strata that

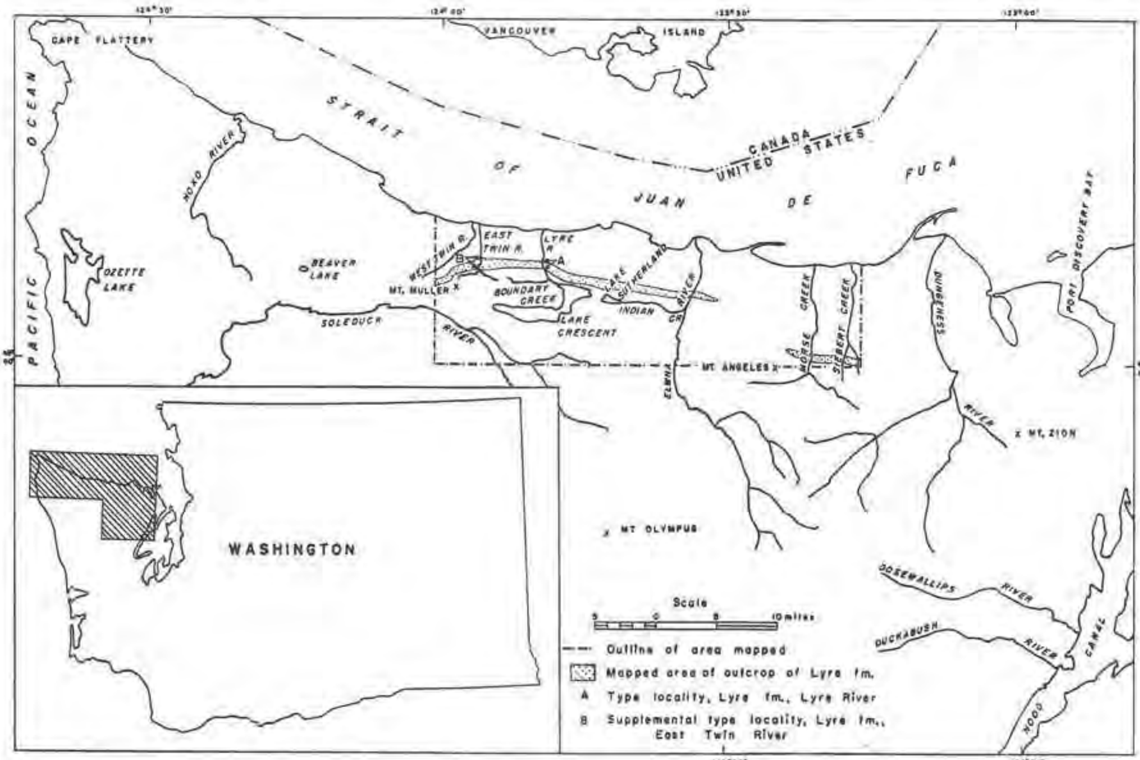


FIG. 1.—Index map of northern Olympic Peninsula, Washington, showing location of type localities and mapped area of outcrop of Lyre formation (redefined).

contain fossil assemblages of middle and early late Eocene age. These sandstone and conglomerate beds are overlain along a well defined erosional contact by beds assigned by Weaver to the upper part of the Lyre formation. Thus it seems probable that the lower and more conglomeratic part of Weaver's Lyre formation represents the closing phase of a depositional sequence of Eocene age rather than the beginning of Oligocene deposition. In this report the writers propose that the term Lyre formation be restricted to only the sequence of sandstone and conglomerate beds that comprises the lower part of the Lyre formation as originally defined.

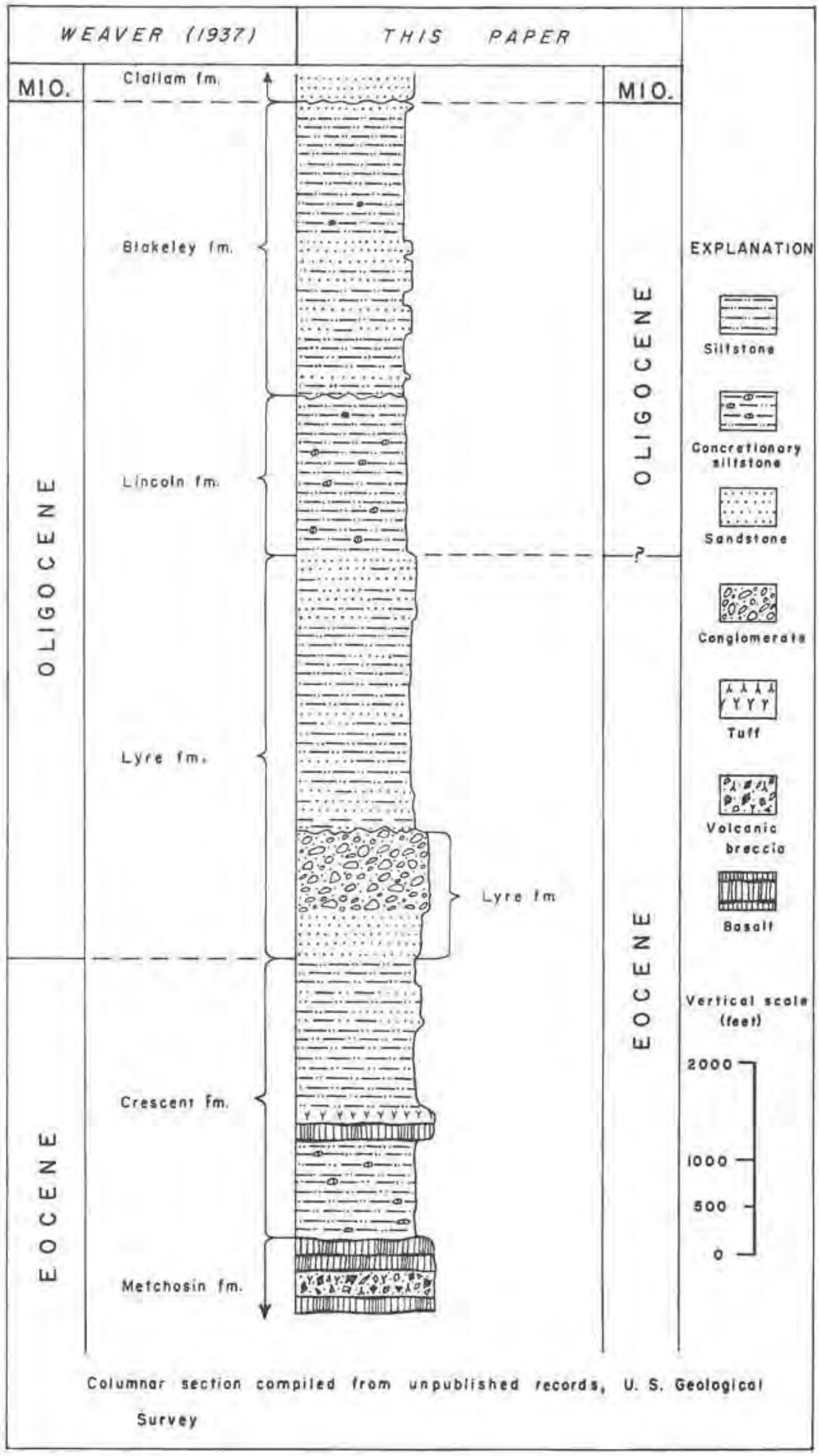


FIG. 2.—Composite columnar section of rocks of Eocene and Oligocene age, north-central Olympic Peninsula, Washington, showing proposed revision of Lyre formation.

### DEFINITION

The following quotation (Weaver, 1937, p. 121) defines the Lyre formation in its original sense.

> . . . Above these [sandy clay shale beds] rest unconformably more than 500 feet of firmly cemented massive medium- to coarse-grained conglomerate, which in the southern limb of the Clallam syncline are sufficiently resistant to erosion to allow a range of moderately high hills to exist parallel to and immediately north of the high basaltic ridge. These conglomerates are persistent along the northern border of the Olympic Peninsula for a distance of more than 100 miles, but decrease in thickness in the direction of Cape Flattery.
>
> There occur above these conglomerates approximately 4,120 feet of interbedded stratified hard gray to grayish brown coarse-grained massive sandstone, with pebbly and conglomeratic layers, together with subordinate amounts of brownish-gray thinly bedded sandy shale. These sandstones and shales, together with the thick lower conglomeratic member, appear to constitute a lithologic unit, and for purposes of reference will be referred to as the Lyre formation.

In the same report (p. 123) Weaver designates the canyon of the Lyre River as the type section of the Lyre formation.

> . . . The lower 1,450 feet of the more firmly cemented gray sandstones and sandy shale, together with the basal 750 feet of conglomerate and massive sandstone are designated as the Lyre formation and possess a total thickness of 2,200 feet as (sic) the type section in the Lyre River Canyon.

The sequence of beds referred to by Weaver as the basal 750 feet of conglomerate and massive sandstone is a distinctive and mappable lithologic unit. The name Lyre formation is here restricted to this unit and the type locality is redefined as extending along the Lyre River from a point 2,850 feet south, 3,600 feet west, of the NE. corner of Sec. 10, T. 30 N., R. 9 W., to a point 950 feet south, 3,690 feet west, of the NE. corner of Sec. 10, T. 30 N., R. 9 W.

### DISTRIBUTION

The Lyre formation has been mapped only in the north-central part of the Olympic Peninsula where it has been recognized by the writers in two general areas. In the western part of the area mapped, the formation may be traced from a point about a mile east of the Elwha River to the headwaters of the West Twin River, a distance of about 22 miles. Strata which comprise the Lyre formation in this outcrop belt have a regional strike of N. 80° W. and, because of their resistance to erosion, form a series of hills and hogback ridges which also trend N. 80° W. The topographic expression of these conglomerate and sandstone beds is marked by the ridge which lies north of the defile occupied by Boundary Creek, Lake Sutherland, and Indian Creek.

The Lyre formation also crops out near the head of Siebert Creek and at a few localities between Siebert Creek and a point about 2 miles west of Morse Creek. East of Siebert Creek a thick mantle of glacial outwash and till prevents detailed mapping of the Lyre formation. However, in the area between Siebert Creek and the Dungeness River a few exposures of sandstone and conglomerate occur along the projected strike of the formation; therefore, the Lyre formation may extend eastward for several miles beyond the mapped area.

Conglomerate and sandstone strata similar in general appearance to the Lyre formation crop out at many localities in the northern part of the Olympic

Peninsula. Exposures of these conglomeratic rocks have been noted at Cape Flattery (Weaver, 1937, p. 138), near Beaver Lake (Weaver, 1937, p. 132), and in the area south and southwest of Port Discovery Bay (Weaver, 1937, pp. 140–41). An exposure of conglomerate at Woodman's Wharf on Port Discovery Bay has been described by Durham (1944, pp. 105–06), and the writers have studied similar conglomerate strata on the east slope of Mount Zion, in the area southwest of Port Discovery Bay, and at several localities along the Strait of Juan de Fuca. The rocks exposed at many of these localities are lithologically similar to typical strata of the Lyre formation and in the past were often referred to that formation. Unquestionably, some of them should still be so assigned, as in some of the areas here listed the conglomerate and sandstone beds occupy a stratigraphic position similar to that of the type section of the Lyre formation. In a few areas, however, conglomeratic strata previously referred to this formation occur at a much higher stratigraphic position than do the rocks at the type locality; these appear to have been derived from the older conglomerate and are therefore a part of a younger depositional sequence.

The areal distribution of the Lyre formation in the northern part of the Olympic Peninsula is unquestionably much greater than shown in Figure 1. However, difficult facies problems must be solved and detailed mapping is required to differentiate the conglomerate and sandstone strata of the Lyre formation from similar appearing but younger rock sequences.

### TYPE SECTION

At the type locality the Lyre formation, as defined in this report, has a measurable thickness of 1,270 feet and may be divided into two parts: an upper conglomerate unit 890 feet thick and a lower sandstone unit of which 380 feet are exposed. These strata are exposed in the stream bed of the Lyre River and in cuts along the abandoned Port Angeles and Western Railroad which parallels the Lyre River. A generalized stratigraphic section of the Lyre formation was compiled from a plane-table traverse of exposures at the type locality.

| *Lithologic Description* | *Thickness (Feet)* |
|---|---|
| Top of Section | |
| Conglomerate, pebble, massive, poorly sorted; pebbles subrounded to subangular and average ¼ inch in diameter; contains a few lenses of granule sandstone; well cemented granule sand matrix | 380 |
| Sandstone, granule; contains abundant rock fragments | 1 |
| Conglomerate, pebble-cobble, massive, moderately well sorted; contains a few cobbles of green argillite, tuff, and basalt in lower part; grades locally into pebbly granule sandstone; well cemented granule sand matrix | 569 |
| Siltstone, medium dark gray, and fault gouge | 12 |
| Sandstone, very fine-grained, flaggy to massive; contains a few laminae of siltstone | 308 |
| Base of section not exposed | |
| Total thickness | 1,270 |

The contact between the conglomerate unit and overlying siltstone strata is well exposed in the canyon of the Lyre River about 50 feet downstream from a 20-foot waterfall. This contact is generally parallel with bedding in both the Lyre formation and the overlying siltstone and, although reworked pebbles from the Lyre formation occur in a few scour and fill channels at the base of the siltstone, the contact is obviously erosional rather than transitional. The poor induration of the younger siltstone as contrasted to siltstone in the Lyre formation suggests an unconformity is present between the conglomerate and the overlying siltstone unit. Additional evidence for this discontinuity is the abundance of locally derived subangular basalt fragments in pebble conglomerate beds in the basal part of the siltstone. Basaltic débris of any type is uncommon in the Lyre formation, which is composed chiefly of rock types derived from a metamorphic terrane. However, the sequence of bedded sandstone and siltstone that immediately overlies the conglomerate facies of the Lyre formation is commonly rich in chloritized(?) basaltic débris. This basaltic material apparently was derived from middle Eocene volcanic rocks which constitute the Crescent formation of Arnold (1906, pp. 460–61) or the Metchosin formation of Weaver (1937, pp. 26–29). The rapid influx of basaltic material and the coincidental disappearance (excluding channels of reworked material) of metamorphic rock types suggest that a significant period of time intervened between the deposition of the Lyre formation and deposition of the overlying strata.

The lower contact of the Lyre formation is concealed at the type locality; however, the lowest exposures of sandstone contain numerous intercalated beds of olive-gray siltstone similar to the underlying siltstone of middle and early late Eocene age. As this sequence of interbedded siltstone and sandstone commonly occurs near the base of the formation in other areas, the type section is probably very nearly complete.

### EAST TWIN RIVER SECTION

A well exposed section of the Lyre formation occurs in cuts along a logging road which roughly parallels the East Twin River, 5½ miles west of the type section of the formation along the Lyre River. The East Twin River section, considered as a supplemental type section, extends from a point 3.2 miles south of the Washington State Highway 9A bridge across the East Twin River to a point 3.85 miles south of that bridge. The following section was compiled from a Brunton compass and tape traverse of these exposures.

| *Lithologic Description* | *Thickness (Feet)* |
|---|---|
| Top of Section | |
| Top not exposed | |
| Conglomerate, cobble, massive, poorly sorted; contains a few boulders and pebbles of green argillite, graywacke, and volcanic rocks | 51 |
| Sandstone, granule, pebbly and conglomeratic; bedding thick and lenticular; contains a few pebble-cobble conglomerate beds up to 18 inches thick and a few boulders of green argillite | 169 |
| Conglomerate, pebble, very sandy, massive; grades into pebbly granule sandstone; contains | |

| *Lithologic Description* | *Thickness (Feet)* |
|---|---|
| Top of Section | |
| a few 2-foot beds of cobble conglomerate and a few 3-foot beds of flaggy coarse-grained granule sandstone | 139 |
| Conglomerate, pebble-cobble; becomes finer toward base | 25 |
| Sandstone, granule, pebbly; massive, poorly sorted; contains beds of pebble conglomerate | 87 |
| Sandstone, granule, pebbly, slabby to blocky | 20 |
| Sandstone, coarse-grained to granule; massive to blocky; contains thin pebbly sandstone beds less than 6 inches thick and lenses of pebble conglomerate up to 2 feet thick; bedding obscure | 50 |
| Conglomerate, pebble, massive | 8 |
| Sandstone, coarse-grained to granule; massive to blocky; contains thin pebbly sandstone beds and lenses of pebble conglomerate; bedding obscure | 115 |
| Conglomerate, pebble, poorly sorted; pebbles subangular; coarse-grained sand matrix, contains a few cobbles | 8 |
| Sandstone, granule, pebbly, slabby, bedding lenticular | 2 |
| Conglomerate, pebble, cobble, and boulder, massive, poorly sorted; pebbles subangular; coarse-grained sand matrix | 41 |
| Sandstone, coarse-grained to granule, pebbly in upper part, massive to thick-bedded; contains intraformational breccia fragments in lower part | 60 |
| Sandstone, fine- to medium-grained, irregular and lenticular bedded, platy; deformed plasticly near lower contact with coarse-grained sandstone; contains very thin beds and laminae of siltstone | 40 |
| Sandstone, coarse-grained to granule, locally pebbly with a few lenses of siltstone, massive to thick-bedded, slabby to blocky | 37 |
| Sandstone, fine- to medium-grained; thin-bedded to very thin-bedded, bedding irregular with lenses and channels; deformed plasticly near lower contact with massive medium-grained sandstone; contains less than 20 per cent siltstone in thin beds | 62 |
| Sandstone, medium-grained with thin beds of granule sandstone and a few thin beds of siltstone, thick-bedded, slabby to blocky; penecontemporaneous deformation and erosion features show in some siltstone beds; plant material locally concentrated along bedding planes | 15 |
| Sandstone, fine- to medium-grained with thin beds of siltstone, thin-bedded to very thin-bedded, generally flaggy but massive in upper 5 feet where siltstone is dominant | 30 |
| Sandstone, fine- to very fine-grained; laminated, graded bedding; with 30 per cent siltstone laminae | 133 |
| Sandstone, fine- to very fine-grained, very thin-bedded to laminated, graded bedding, flaggy, with laminae of siltstone | 189 |
| Concealed; sandstone float, fine- to very fine-grained | 78 |
| Sandstone, fine- to very fine-grained very thin-bedded, graded bedding; with 40 per cent siltstone occurring as very thin beds; groups of graded siltstone beds contain *Terrebellina*(?) tests aligned along bedding planes | 109 |
| Concealed; platy sandstone float, fine-grained | 19 |
| Sandstone, fine- to medium-grained, and siltstone; thin-bedded to very thin-bedded, graded bedding, platy to flaggy; scóur channels and crossbedding occur infrequently | 390 |
| Sandstone, fine-grained, thin-bedded to very thin-bedded, flaggy to platy, graded bedding | 175 |
| Unit of intense plastic deformation in very fine-grained thin-bedded sandstone; rock is closely folded with local healed fractures; bedding plane fault at contact with overlying unit | 189 |
| Concealed | 70 |
| Sandstone, fine-grained, very thin-bedded, flaggy to platy; some granule sandstone with sedimentary and volcanic fragments; contains siltstone laminae | 235 |
| Sandstone, fine-grained, thick-bedded, massive to blocky; contains a few siltstone beds up to 6 inches thick | 230 |
| Sandstone, pebbly, massive to blocky; contains fragments of volcanic and sedimentary rock | 11 |
| Sandstone, fine-grained, thick-bedded; massive to blocky; contains a few siltstone beds up to 6 inches thick | 140 |
| Concealed, platy sandstone float, fine-grained | 48 |
| Sandstone, fine-grained, thin-bedded; rhythmic groups of graded siltstone beds ½ inch thick occur through 25 feet of section 118 feet above base, contains *Terrebellina*(?) tests along bedding planes | 178 |

| Lithologic Description | Thickness (Feet) |
|---|---|
| Top of Section | |
| Sandstone, fine-grained, thin-bedded to laminated; slabby to flaggy; contains a few thin siltstone beds; locally sheared | 17 |
| Sandstone, fine-grained, massive | 18 |
| Sandstone, very fine-grained, silty, thin-bedded to massive in upper part, flaggy to platy; contains a few boulders of volcanic rock | 27 |
| Siltstone, sandy, conglomeratic; contains thin beds of sandstone near base, and rounded cobbles of sedimentary and volcanic rock | 19 |
| Sandstone, very fine-grained, silty, slabby; contains thin to very thin beds of siltstone | 49 |
| Base of Section | |
| Total thickness | 3,283 |

Contact relations of the Lyre formation in the East Twin River area are generally similar to those observed near the type locality on the Lyre River; however, the contact between the Lyre formation and underlying strata of middle and early late Eocene age is better shown in the East Twin River area. This contact is transitional and is marked by a zone of alternating beds of siltstone and fine-grained sandstone. The frequency of occurrence of sandstone beds decreases toward the base of the sequence and the lower contact has been placed by the writers at the point where siltstone becomes predominant over sandstone. The transitional nature of the lower contact of the Lyre formation is apparent throughout most of the area mapped for this report and is especially well shown in south-flowing tributaries to the East Twin River and Boundary Creek, and in exposures along logging roads on the ridge north of Indian Creek.

The upper contact of the Lyre formation is not exposed in the East Twin River section but it may be located within a distance of about 50 feet. Here, as at the Lyre River locality, the overlying strata consist of thinly bedded fine-grained sandstone and siltstone characterized by an abundance of basaltic débris.

### FACIES RELATIONS

Throughout most of its mapped outcrop area the Lyre formation is divisible into an upper conglomerate facies and a lower sandstone facies. The contact between the two facies is gradational and is generally marked by a zone in which the two rock types are intercalated. In some areas the conglomerate facies is composed chiefly of pebbly coarse-grained or granule sandstone, but it may still be distinguished from the finer-grained and more thinly bedded strata which underlie it.

The conglomerate facies of the Lyre formation is more widespread than the sandstone facies and maintains a more nearly constant thickness. In the western part of the mapped area conglomerate strata generally range from 700 to 900 feet in thickness. Farther east, along the ridge north of Indian Creek, this facies attains a maximum estimated thickness of 800 feet, but it is often thinner and in some areas it is absent. The thinning of the conglomerate facies may be a result, in part, of interfingering with sandstone; however, most of the evidence available to the writers indicates that variations in the thickness of the conglomerate result from erosion of the upper part of the Lyre formation.

The sandstone facies thickens and thins rather abruptly; thickness variations are especially notable in the western part of the mapped area. The sandstone facies is less than 400 feet thick at the type locality on the Lyre River, but $5\frac{1}{2}$ miles west, on the East Twin River, it attains a known maximum thickness of 2,570 feet. Studies of the area between the Lyre River and the East Twin River have shown that the westward thickening of the sandstone is a result of a facies change from siltstone to fine-grained sandstone near the lower contact of the Lyre formation. The nature of this change is manifest in the increasing number

FIG. 3.—Conglomerate facies of Lyre formation, East Twin River area, Washington.

and thickness of sandstone beds intercalated with siltstone strata west of the Lyre River. Thickening of the sandstone facies is accompanied by a decrease in the thickness of the underlying siltstone sequence.

An unusually abrupt change in the sandstone-conglomerate ratio occurs in the area north and northwest of Mount Muller. In this area, both facies of the Lyre formation are well exposed in the ridge north of the west fork of the East Twin River, and stratigraphic relations are generally similar to those at the supplemental type locality. An east-trending fault cuts these strata about 1.3 miles northwest of Mount Muller and the Lyre formation is again exposed in the southern downthrown block, along the north slope of the ridge which extends westward from Mount Muller. Conglomerate strata in the downthrown block rest directly upon volcanic rocks of middle Eocene age and, although the contact is apparently depositional and conformable, neither the sandstone facies of the

Lyre formation nor the underlying siltstone unit of middle and early late Eocene age is exposed. The absence of these two units at the surface is apparently due to onlap of the conglomerate facies of the Lyre formation against a local abnormally thick sequence of the volcanic rocks. The abrupt change in the sandstone-conglomerate ratio therefore is only apparent rather than real as the onlapped sandstone and siltstone strata presumably are present at depth.

### LITHOLOGIC CHARACTER

Conglomerate constitutes 20–80 per cent of the Lyre formation, and in most parts of the area studied it is the dominant rock type. Pebbles and cobbles are lithologically varied, but fragments of chert, quartzite, and black argillite or phyllite are by far the most common. A pebble count of a sample taken near the top of the conglomerate facies on the East Twin River yielded the following percentage distribution.

| | *Percentage* |
|---|---|
| Argillite (or phyllite), black or dark gray | 19 |
| Quartzite | 19 |
| Chert | 18 |
| Meta-volcanic rocks (undifferentiated) | 14 |
| Meta-arkose | 9 |
| Diorite(?) gneiss | 6 |
| Quartz | 4 |
| Quartz-mica schist | 4 |
| Basalt | 4 |
| Others | 3 |
| | 100 |

FIG. 4.—Platy sandstone of Lyre formation, East Twin River area, Washington.

FIG. 5.—Photomicrograph of sandstone of Lyre formation, Morse Creek, Washington: q—quartzite, f—feldspar, l—unstable lithic fragments, c—chert, ch—chlorite, r—recrystallized quartz. Plain light, ×27.8.

The pebbles and cobbles are poorly sorted and are subangular or subrounded; they occur in a matrix of medium- to coarse-grained sand with small amounts of silt and clay. The matrix is nearly everywhere well cemented, probably by secondary growth of quartz and quartzite grains; however, individual pebbles usually break cleanly from the matrix.

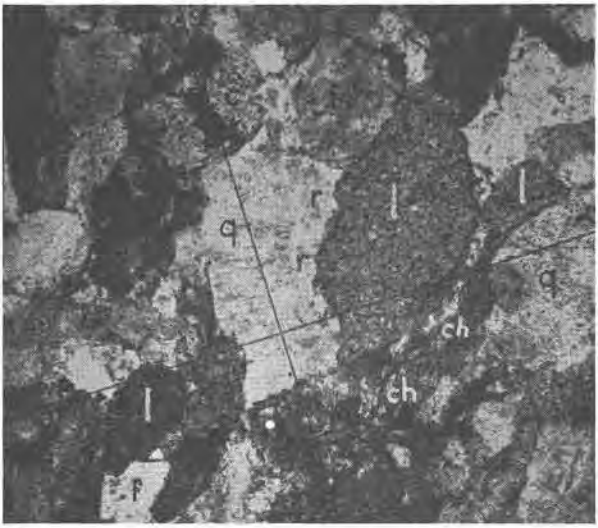

FIG. 6.—Photomicrograph of sandstone of Lyre formation, ridge north of Lake Sutherland, Washington. Plain light, ×109.

Angular to subangular cobbles and boulders of basalt and siliceous green argillite occur in places in the conglomerate. Their shape, lithologic composition, and large size imply a source area nearby, and one which was probably distinct from the terrane which supplied the metamorphic and coarse-grained igneous rocks.

Sandstone, which commonly occurs in the lower part of the Lyre formation, is olive-gray or medium dark gray and is composed chiefly of rock fragments, quartz, and feldspar, all of which are well cemented and enclosed in a silty matrix. Sand particles are subangular to subrounded and are usually fine-grained. Under most systems of field classification these poorly sorted dark-colored rocks may be considered subgraywackes and their kinship with rocks of the graywacke group is further supported by textural and mineralogical features observed microscopically.

Thin sections of sandstone of the Lyre formation show an average composition of: unstable lithic fragments, as defined by Williams, Turner, and Gilbert (1954, pp. 290–91), 30 per cent; matrix, 20 per cent; quartz, 19 per cent; quartzite, 9 per cent; plagioclase feldspar, 6 per cent; orthoclase feldspar, 4 per cent: quartz (recrystallized, occurring as cement), 5 per cent; chlorite, 4 per cent; and biotite, 1 per cent; also noted in minor amounts were symplectic feldspar, apatite, clinozoisite, epidote, augite, and ortho-pyroxene. The most common unstable lithic fragments are schist, graywacke, argillite, phyllite, meta-arkose, epidosite, and a variety of fine-grained volcanic rocks ranging from rhyolite to basalt. Most of the quartz grains are unstrained and contain numerous minute inclusions which are often in parallel lines. Some of the feldspar grains are clear and unaltered with twinning and cleavage distinctly visible, but many are altered to sericite or saussurite. Detrital biotite has been greatly deformed by pressure and in thin section appears as dark sinuous shreds which conform to the shape of adjacent grains. Most of the chlorite and some of the biotite are of authigenic origin. The cementing agent, quartz, occurs interstitially in random optic orientation and also as outward growths in optical continuity with detrital quartz. The matrix consists of clay and silt which are unidentifiable by ordinary microscopic methods. In the thin sections studied pore space amounted to only a small fraction of the rock. This low porosity is confirmed by laboratory determinations of porosity and permeability in four samples of sandstone from the Lyre formation.

| *Sample* | *Effective Porosity (Percentage)* | *Permeability-Air (Millidarcys)* |
|---|---|---|
| A | 8.5 | 1.1 |
| B | 9.4 | 0.7 |
| C | 7.4 | 0.3 |
| D | 9.7 | 1.4 |
| Average (4 samples) | 8.7 | 0.9 |

Bedding in the sandstone facies of the Lyre formation is made apparent by flaggy to slabby splitting properties and by a few beds of olive-gray siltstone ½–1 inch thick. Some sandstone beds show normal graded bedding but lithologic changes are marked more commonly by sharp but irregular bedding surfaces. Discontinuous pebble lenses and isolated pebbles occur sporadically in the sandstone and become more common in the upper part of the formation.

The induration and coarse-grained nature of the Lyre formation combine to produce an extremely resistant unit which, in the area mapped, forms ridges rising 1,500 feet above the adjacent valleys. Weathering along the steep slopes and cliffs of these ridges produces talus composed of tabular angular fragments of sandstone and rectangular blocks of conglomerate. Mass wasting of conglomerate is controlled by a poorly developed joint system as well as by bedding, and talus blocks of conglomerate are commonly 10 feet on a side. Transported conglomerate blocks of even larger size are present in the canyon of the Lyre River a mile downstream from the nearest outcrop of the Lyre formation.

### AGE AND CORRELATION

Organic material is uncommon in the Lyre formation and fossils are known to occur in it at only a few localities. A few small incomplete marine bivalves have been collected from the sandstone facies of the formation but these are not well enough preserved to permit identification. An unidentified organism similar to those called *Terrebellina* in the Yakutat formation of Alaska (Ulrich, 1904, pp. 132–33) occurs at several localities in the sandstone facies but is not considered diagnostic of age. These fossils, together with a few shell fragments in the conglomerate facies, comprise the known fossil content of the Lyre formation.

Although no diagnostic fossils have been collected from the Lyre formation several good microfossil assemblages have been collected from strata which underlie or overlie it, and its age may therefore be stated within rather close limits. The siltstone strata that underlie and are interbedded with the Lyre formation have been considered to be of middle Eocene age by most workers (Weaver, 1937, p. 42; Durham, 1942, p. 85); however, collections of Foraminifera from the uppermost part of this siltstone sequence indicate an early late Eocene age according to W. W. Rau (personal communication). Additional age data are afforded by microfossils collected from the sequence of thinly bedded sandstone and siltstone which unconformably overlies the Lyre formation. Foraminiferal faunas from these beds are late Eocene or early Oligocene in age and, according to Rau, correlate with faunas assigned to the A-1 and A-2 foraminiferal zones of the California Eocene (Laiming, 1940).

Age data obtained from Foraminifera and the stratigraphic position of the Lyre formation indicate that it is early late Eocene in age rather than Oligocene as previously supposed. The Lyre formation is therefore correlated in age with other formations of early late Eocene age in Oregon and Washington (Fig. 7).

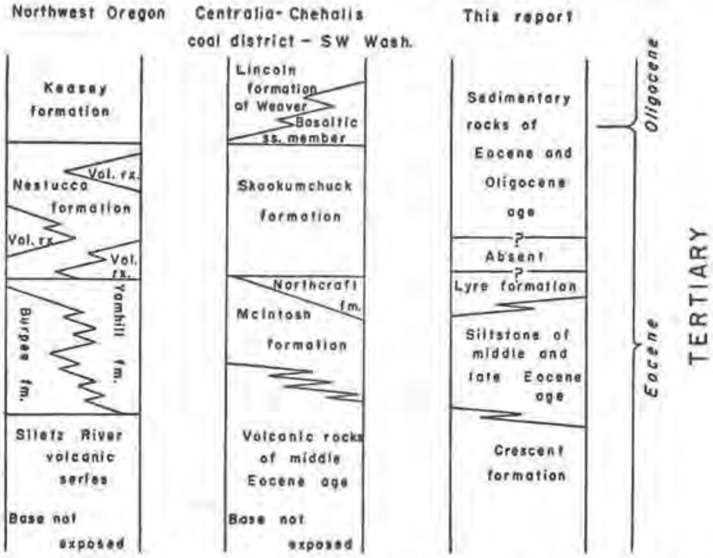


FIG. 7.—Chart showing correlation of Eocene formations of northwestern Oregon; Centralia-Chehalis coal district, Washington; and north-central Olympic Peninsula, Washington.

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# TWIN RIVER FORMATION (REDEFINITION), NORTHERN OLYMPIC PENINSULA, WASHINGTON

BY

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Reprinted for private circulation from
THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Vol. 42, No. 10, October, 1958

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 42, NO. 10 (OCTOBER, 1958), PP. 2492-2512, 9 FIGS.

# TWIN RIVER FORMATION (REDEFINITION), NORTHERN OLYMPIC PENINSULA, WASHINGTON[1]

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## ABSTRACT

The Twin River formation of Arnold and Hannibal is redefined to include a mappable sequence of predominantly argillaceous, sedimentary rocks that are exposed in the northern Olympic Peninsula, Washington. These rocks are typically exposed on Deep Creek, but well exposed sections of the formation are also present on the Lyre River and along the Strait of Juan de Fuca between the mouth of the East Twin River and the mouth of Murdock Creek. The Twin River formation overlies the Lyre formation and is overlain conformably by the Clallam formation as used by Weaver. In the south limb of the Clallam syncline, where it is best exposed, the Twin River formation has maximum thickness of 17,500 feet.

Three mappable units are recognized in the formation: a lower member consisting of thin-bedded sandstone and siltstone; a middle member of massive siltstone that grades westward into bedded siltstone and sandstone; and an upper member that is composed chiefly of massive mudstone. Lenses of conglomerate occur in places in the formation but only one conglomerate lentil in the middle member is thick enough to be mapped at a scale of 1:48,000. The Twin River formation contains marine mollusks and Foraminifera that indicate an age range of late Eocene to early Miocene.

## INTRODUCTION

A sequence of marine sedimentary rocks, ranging in age from middle Eocene to Miocene, crops out in the northern part of the Olympic Peninsula, Washington (Fig. 1). Although previous workers have described the general relations of this sequence of rocks, recent investigations by the U. S. Geological Survey have contributed new data regarding the stratigraphy and age of some of the lithologic units. A part of these data has necessitated revision or redefinition of the stratigraphic nomenclature, and it is the purpose of this paper to present data which support the revision of a previously named lithologic unit: the Twin River formation of Arnold and Hannibal (1913, pp. 584–85). The Twin River formation, as here defined, overlies the Lyre formation (Brown, Snavely, and Gower, 1956) and older rocks, and is overlain by massive sandstone and conglomerate beds of Miocene age that comprise the Clallam formation as used by Weaver (1937, p. 173).

The field work on which this report is based was undertaken by the U. S. Geological Survey as an investigation of the geology and oil and gas possibilities of the northern Olympic Peninsula. Field work was done during the summer months from 1952 to 1956 and consisted of areal geologic mapping, stratigraphic studies, and related paleontologic research. Geologic data obtained in the field were plotted on aerial photographs and were later compiled at a scale of 1:50,000 on 15-minute topographic maps of the Port Angeles, Port Crescent, and Lake

[1] Manuscript received, March 10, 1958. Publication authorized by the director of the United States Geological Survey.

[2] United States Geological Survey. The writers gratefully acknowledge the assistance of Parke D. Snavely, Jr., who has contributed to this paper both through field work and discussions of the problem. They are also indebted to J. Wyatt Durham for constructive criticism of parts of the manuscript.

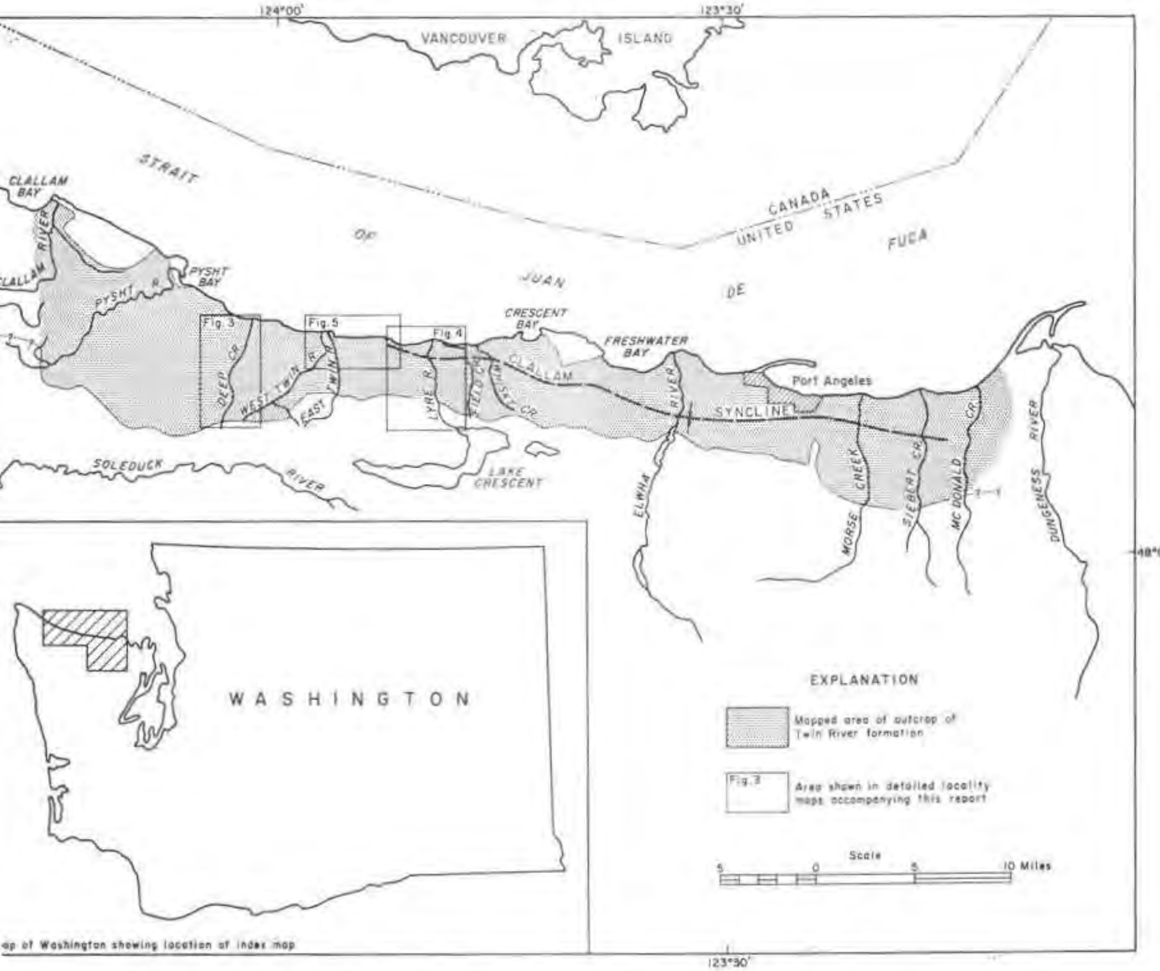


FIG. 1.—Index map of northern Olympic Peninsula, showing mapped area of outcrop of Twin River formation and location of detailed locality maps.

Crescent quadrangles of the U. S. Corps of Engineers and on the Pysht 15-minute Quadrangle of the U. S. Geological Survey. In a few areas of complex structure, or where stratigraphic relations are unusually well exposed, detailed traverses were made by plane table and telescopic alidade.

### PREVIOUS NOMENCLATURE

The name Twin River formation was introduced by Arnold and Hannibal (1913, pp. 584–85) for a sequence of "... soft clay shales and intercalated beds of sandstone ..." of late Oligocene and Miocene age, which they described as extending along the north coast of the Olympic Peninsula from a point about 3 miles east of Twin Rivers (Fig. 5) nearly to Pysht Bay (Fig. 1). These rocks were said to rest conformably on the Seattle formation of Arnold and Hannibal (equivalent to the Blakeley formation of Weaver, 1912) and, toward the west near Pysht Bay, to be in fault contact with the Monterey formation of Arnold and Hannibal. This definition of the Twin River formation in terms of underlying and overlying units is equivocal, for neither the Seattle formation nor the Monterey formation of Arnold and Hannibal was clearly defined in the paper in which they were introduced, and both names subsequently were abandoned by other workers in the Pacific Northwest. However, at least the lower part of the

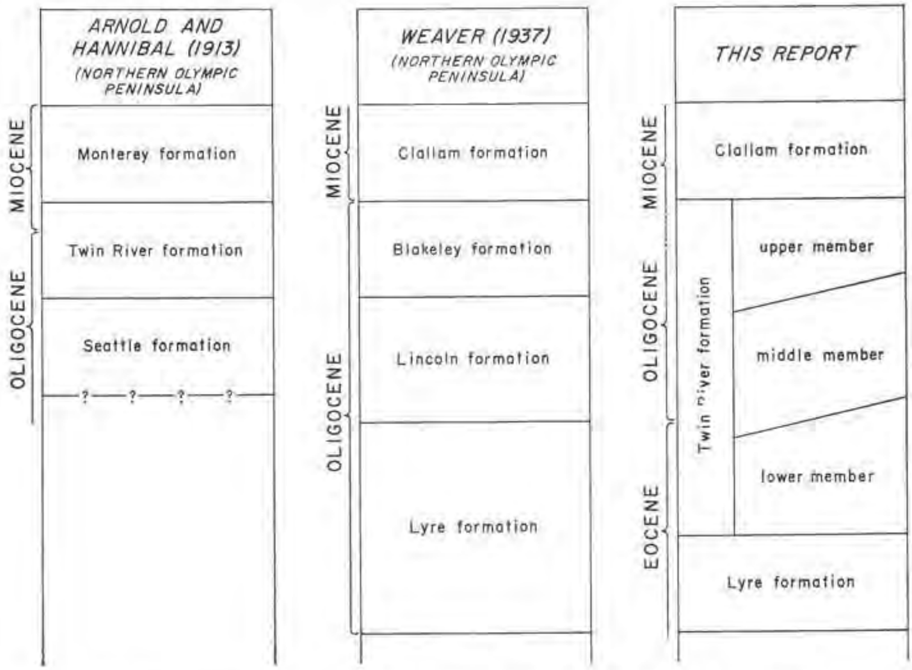


FIG. 2.—Summary of stratigraphic nomenclature, northern Olympic Peninsula.

Monterey formation of Arnold and Hannibal appears to be approximately equivalent in age and lithology to the basal part of the Clallam formation (Fig. 2). The upper contact of the argillaceous rocks that Arnold and Hannibal called Twin River formation can therefore be recognized in the field, for the overlying Clallam formation is predominantly sandstone and, in many places, has at its base lenses of conglomerate and granule sandstone that are easily distinguished from the siltstone and mudstone of the Twin River formation.

The lower contact of the Twin River formation of Arnold and Hannibal is difficult to determine, for there is some ambiguity in their definition of the unit. They describe the Twin River formation as being exposed west of a point about 3 miles east of Twin Rivers on the south shore of the Strait of Juan de Fuca; as no significant lithologic change occurs in the area, it is difficult to determine what constitutes the base of their Twin River formation. The conformable relationship described by Arnold and Hannibal for the contact between the Twin River and Seattle formations apparently does not refer to a lithologic relationship actually observed in the field, for a later paper (Clark and Arnold, 1918, p. 304, footnote 6) states that the name Seattle formation was used by Arnold and Hannibal " . . . in a faunal rather than a stratigraphic or lithologic sense. . . . " From this statement, and from their usage of the term Seattle formation in the 1913 paper, it seems likely that Arnold and Hannibal were using the Seattle formation in the same sense that stratigraphers currently apply to the term "zone" (Ashley *et al.*, 1933, p. 429).

C. E. Weaver (1916, pp. 26–27) noted that faunas collected from the type localities of the Twin River and Seattle formations of Arnold and Hannibal did not indicate sufficient grounds for separating the two units and apparently Weaver also considered at least the Seattle formation to be a faunal rather than a lithologic unit. In the same paper, Weaver (p. 27) describes the area on the south shore of the Strait of Juan de Fuca, east of Twin Rivers, where, according to him,

> . . . the strata occurring there are involved in the east and west limbs of a syncline, and stratigraphical measurements prove the strata in question on each limb of the syncline to be identical. . . .

This statement by Weaver, when read in context, may be interpreted as meaning that the Seattle formation and the Twin River formation of Arnold and Hannibal are a single formation that is exposed in opposite limbs of a syncline, and it was so interpreted by Clark and Arnold (1918, p. 304, footnote 6). The writers of the present paper have made a plane-table traverse along the coastline east from the mouth of the East Twin River for a distance of about 9 miles. Although bedrock exposures along the coast are almost continous, the syncline described by Weaver was not found. The dip of the strata is generally low and is toward the northwest, west, or southwest. Some repetition of beds occurs due to faulting or to comparatively minor drag folds, but nowhere in the exposures along the coast are reverse (eastward) dips persistent enough to cause repetition of more than a few hundred feet of strata. Therefore, the statement by Clark and Arnold (1918, p. 304, footnote 6) that,

> . . . C. E. Weaver has apparently shown that the beds forming the Twin River formation are a part of their [Arnold's and Hannibal's] Seattle formation, which has been repeated by folding. . . .

is apparently a correct interpretation of Weaver's description, but this interpretation is not supported by field evidence.

Weaver's comments regarding the faunal similarity of the Seattle formation and the Twin River formation of Arnold and Hannibal are correct, and Tegland (1933, pp. 90–93) and Durham (1944, p. 113) also have shown that the fauna of the Seattle formation at its type locality on Bainbridge Island,[3] 58 miles

[3] The term Seattle formation is used here only for clarity. The Bainbridge Island section, which apparently was intended as the type locality for the Seattle formation, had been described and named the Blakeley formation by C. E. Weaver in 1912 (pp. 17–18) and in nearly all subsequent reports the name Blakeley formation, which has priority, has been used. The Seattle formation of Arnold and Hannibal has been abandoned by recent workers.

southeast of Port Angeles, is in part identical with the fauna of the Twin River formation of Arnold and Hannibal. Thus, the Seattle (Blakeley) formation at Bainbridge Island is equivalent in age to much of the Twin River formation of Arnold and Hannibal, but in the northern coastal area of the Olympic Peninsula the Twin River formation of Arnold and Hannibal overlies the unit they referred to as the Seattle formation. The apparently conflicting evidence can be resolved if it is recognized that Arnold and Hannibal included rocks of widely differing age and lithology in their Seattle formation, and that the Seattle formation of the Twin Rivers area is considerably older than the Seattle formation of the Bainbridge Island locality.

Weaver (1937, p. 117) proposed that the Twin River formation of Arnold and Hannibal be abandoned in favor of the term Blakeley formation (Fig. 2). The reason given by Weaver for the proposed abandonment was that both the Twin River formation of Arnold and Hannibal and the Blakeley formation contained nearly identical faunal assemblages and, because of prior usage, Blakeley was a preferred term. Very little published work on the geology of the northern Olympic Peninsula has appeared since Weaver's 1937 paper, but Durham (1944, p. 113) showed that the upper part of the Twin River formation of Arnold and Hannibal is younger and contains a faunal assemblage that differs from that in the fossiliferous part of the type section of the Blakeley formation. Durham in this paper recognized both the Twin River formation of Arnold and Hannibal in the northern Olympic Peninsula and the Blakeley formation in the Puget Sound area to the southeast. In spite of the faunal differences described by Durham, Weaver's proposed extension of the Blakeley formation into the northern Olympic Peninsula would be useful, for the middle part of the Blakeley formation is lithologically very similar to the Twin River formation of Arnold and Hannibal. Moreover, the upper 2,500 feet of the Blakeley formation is not fossiliferous, but it may be equivalent in age to the fossiliferous upper part of the Twin River formation of Arnold and Hannibal, which Durham described as being younger than the fossiliferous type Blakeley. A unit approximately equivalent in age and lithology to the Blakeley formation was mapped by the writers in the eastern part of the area studied, but when mapping was extended west of the Lyre River, a lithologic distinction between these rocks and underlying strata could not be made. Such a distinction was, in fact, difficult to make in most places in the area studied. Although a fauna characteristic of the Blakeley formation and of the Twin River formation of Arnold and Hannibal is present west of the Lyre River in a thick sequence of siltstone and sandstone, fossils occur only in the upper part of this sequence. Within these rocks no widespread lithoogic unit of formation rank is apparent and the strata range in age from late Eocene to early Miocene. Because there is no lithologic basis by which the Blakeley formation can be recognized throughout the northern Olympic Peninsula, in the sense that it was proposed by Weaver and is now used by most current workers, the writers propose that the name Twin River formation be redefined to include the thick sequence of beds that overlies the Lyre formation of Brown, Snavely, and Gower (1956) and older rocks and underlies the Clallam formation (Fig. 2). Redefinition of the Twin River formation, rather than the Blakeley formation, is preferred because Blakeley has been used throughout the Pacific Northwest as a lithologic term as well as a faunal stage (Weaver, 1944, chart), and has become so well entrenched in the literature that any change in its stratigraphic and biostratigraphic connotation seems inadvisable. Moreover, the Twin River formation of Arnold and Hannibal has been referred to in relatively few publications, has not been extended beyond the northern Olympic Peninsula, and can be redefined without creating a serious conflict with previous literature. Perhaps an even better solution to the problem of nomenclature would have been the selection of an entirely new name but the area mapped is generally sparsely settled and only the more prominent geographic features have been named; those features that are named are generally unfavorably located with respect to the Twin River formation or bear names that have been pre-empted for stratigraphic purposes.

Some of the rocks here included in the Twin River formation have previously been described by C. E. Weaver (1937, pp. 121–39) as the Lyre formation and the Lincoln formation (Fig. 2). The Lyre formation has recently been redefined (Brown, Snavely, and Gower, 1956) to include only rocks which underlie the Twin River formation of this report. The Lincoln formation is a lithologic unit named by Weaver (1912, pp. 15–16) for exposures along Lincoln Creek and the Chehalis River near the town of Galvin in southwestern Washington. Strata equivalent in age to the Lincoln formation of southwestern Washington are present in the northern Olympic Peninsula, but no lithologic unit corresponding with the Lincoln formation of the type area has been mapped. Moreover, the Lincoln formation of southwestern Washington, a predominantly tuffaceous unit, is separated from correlative non-tuffaceous rocks on the northern Olympic Peninsula by structural highs of older rocks and by complexly folded and faulted rocks of unknown age south of the mapped area in the central part of the Olympic Mountains. Therefore, the extension of the name Lincoln formation into the northern Olympic Peninsula would not follow recognized rules of stratigraphic nomenclature.

### TYPE LOCALITY AND REFERENCE SECTIONS

*Type locality—Deep Creek.*—The type locality of the Twin River formation, as it is redefined here, is along Deep Creek, a north-flowing stream which enters the Strait of Juan de Fuca at a point about 3.4 miles west of the mouth of the West Twin River. The type section in Deep Creek is exposed from a point 3,600 feet S. 41° W. from the U. S. Forest Service road bridge across Deep Creek, northward to a point on the axis of a local east-trending syncline, 700 feet east, 4,350 feet north of the SW. corner of Sec. 20, T. 31 N., R. 10 W. (Fig. 3). This locality was selected as the type locality because it exhibits the thickest and most completely exposed section of the Twin River formation in the area mapped. Nevertheless, it is only a partial section, for the upper contact is not exposed. The sec-

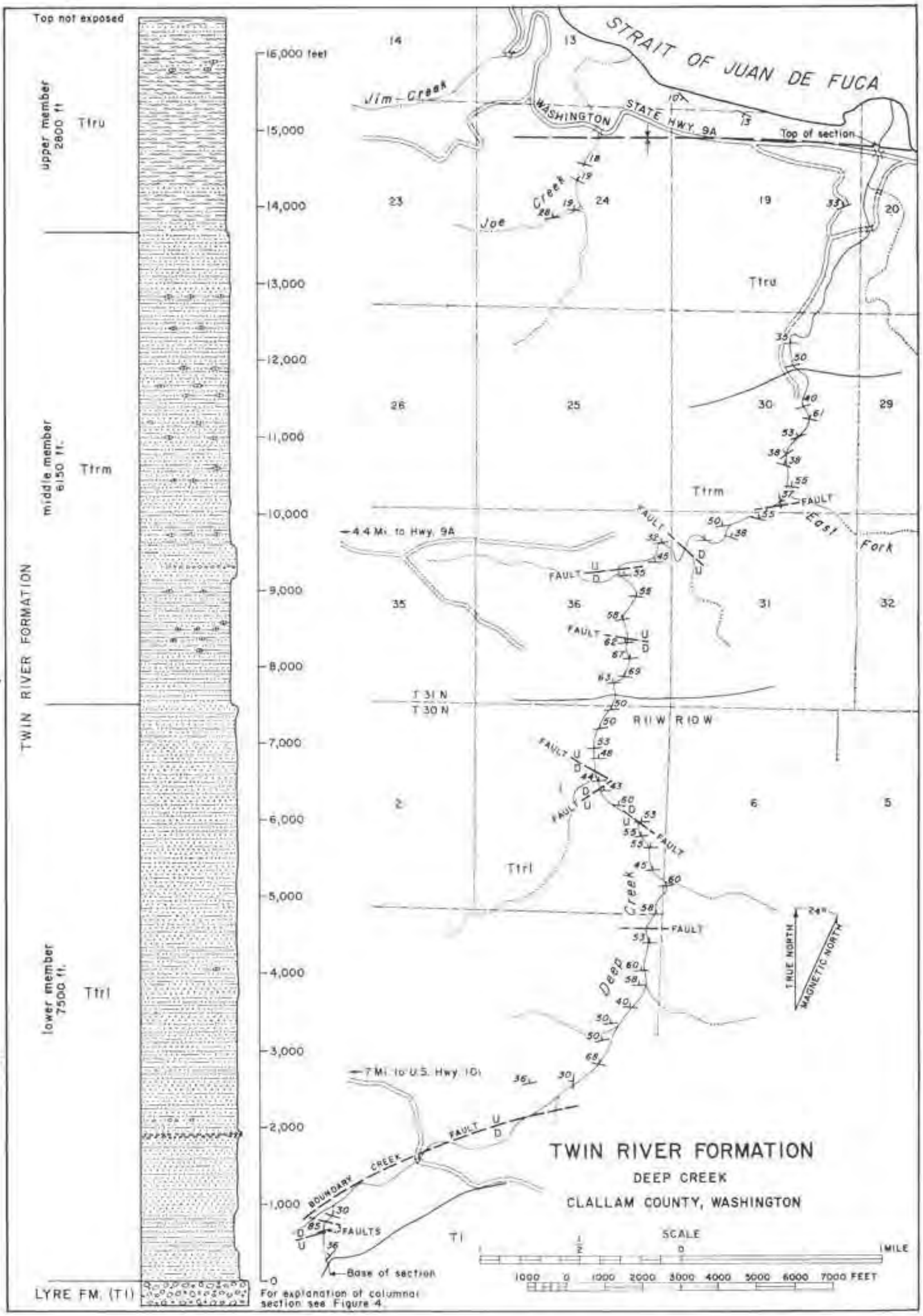


FIG. 3.—Geologic sketch map and section of type locality of Twin River formation, Deep Creek, Clallam County, Washington.

tion is cut by a number of east-trending faults. Where the relative direction of movement can be determined, about half the faults repeated the section and the other half reduced the section. Most of the faults appear to have small displacements and probably do not materially affect the stratigraphic measurements; however, the Boundary Creek fault, near the head of Deep Creek, has an estimated throw of 500 feet with relative movement down toward the south.

The thickness of rock units listed in the generalized section which follows was compiled partly from structural data obtained from plane-table traverses and partly from data plotted on aerial photographs.

| *Lithologic Description* | *Thickness (Feet)* |
|---|---|
| Top of section | |
| Upper member, top not exposed | |
| Mudstone and siltstone, medium gray, poorly indurated, massive; contains a few beds ¼–18 inches thick of light gray, subfeldspathic sandstone and some small (1–4 inches) spherical calcareous concretions | 2,850 |
| Middle member | |
| Siltstone, medium gray, indurated, very thin-bedded, with about 15 per cent very fine- to fine-grained sandstone in laminae and very thin beds; locally contains elliptical or irregularly shaped calcareous concretions | 4,100 |
| Sandstone, light gray, well cemented, fine- to medium-grained, subfeldspathic, thin- to thick-bedded, with laminae and thin beds of medium gray, well indurated siltstone; contains a cobble conglomerate bed 4 feet thick 140 feet above base | 400 |
| Siltstone, medium-gray, indurated, very thin-bedded, with about 15 per cent very fine- to fine-grained sandstone in laminae and very thin beds; locally contains elliptical or irregularly shaped, calcareous concretions | 1,650 |
| Lower member | |
| Sandstone, olive-gray, fine-grained, and medium gray to light olive-gray, well indurated siltstone in nearly equal proportions, thin-bedded | 5,550 |
| Conglomerate, pebble and cobble, massive, well cemented; clasts predominantly of metamorphic and igneous origin, contains reworked calcareous concretions in upper part of unit | 60 |
| Sandstone, olive-gray, very fine- to fine-grained, and medium gray to olive-gray, well indurated siltstone, thin-bedded | 980 |
| Siltstone, sandy, medium gray to olive-gray, thin-bedded to massive | 510 |
| Sandstone, medium gray, fine- to medium-grained, with medium gray, well indurated siltstone, thin-bedded | 400 |
| Base of section (Lyre formation) | |
| Total thickness | 16,500 |

The contact of the Twin River formation with the underlying Lyre formation is exposed in Deep Creek at a point 7,200 feet east, 2,300 feet north of the SE. corner, Sec. 16, T. 30 N., R. 11 W. At this locality thin- to thick-bedded medium gray fine-grained sandstone with laminae and thin beds of medium gray well indurated siltstone conformably overlie pebble and cobble conglomerate of the Lyre formation. The transition from conglomerate to sandstone is gradational and there is no apparent hiatus between the two units in this part of the mapped area.

The upper contact of the Twin River formation with the overlying Clallam formation, which is composed chiefly of massive sandstone, is not exposed in Deep Creek; however, this contact is exposed at several localities west of the mouth of Deep Creek. The contact can best be seen in the wave-cut bench along the Strait of Juan de Fuca about 2 miles northwest of the mouth of the Pysht

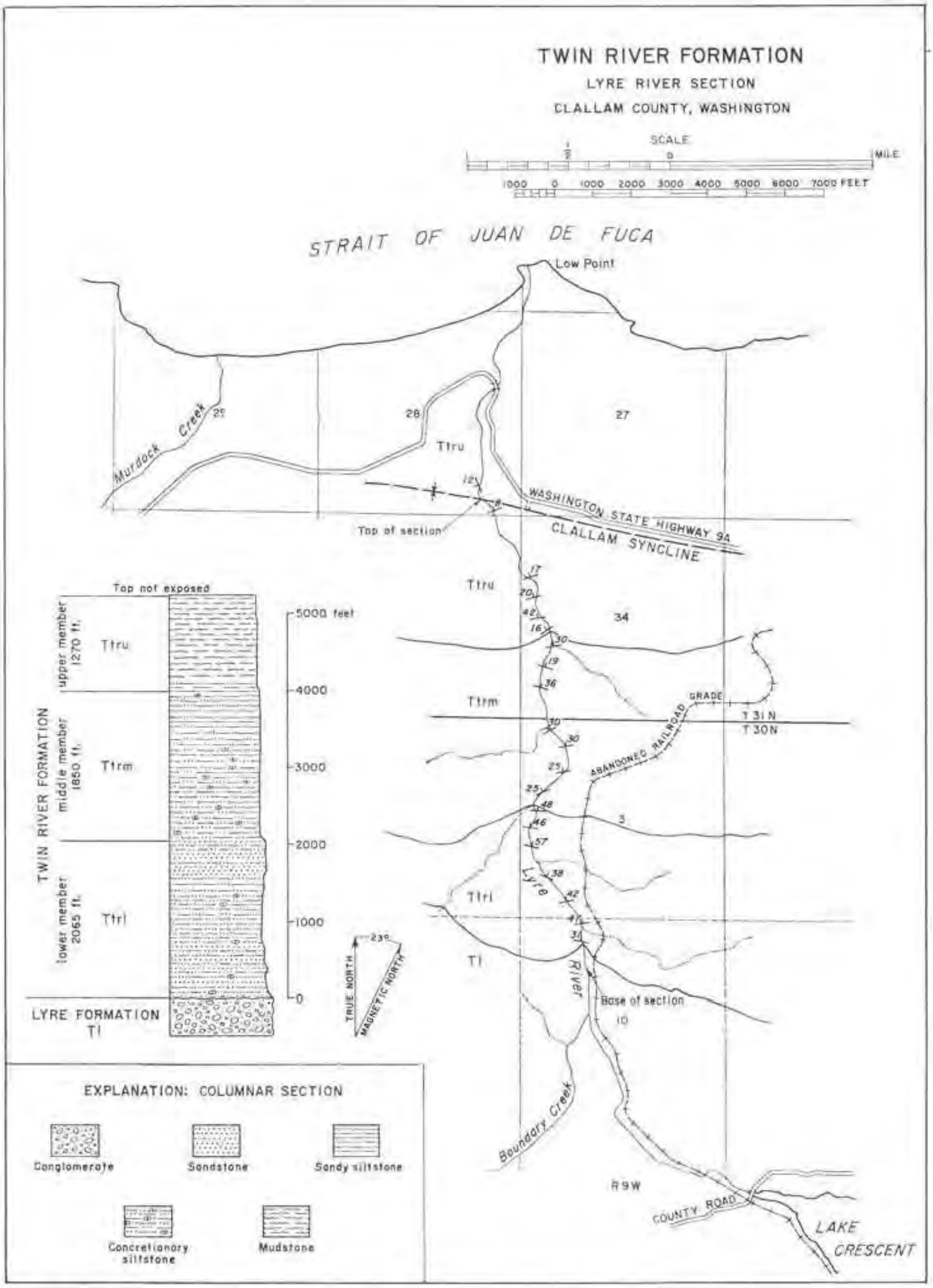


FIG. 4.—Geologic sketch map and section of reference section of Twin River formation, Lyre River, Clallam County, Washington.

River. At that locality mudstone and sandy siltstone of the Twin River formation contain numerous beds of thin-bedded to massive sandstone, which become more abundant near the top of the formation, and the contact between the Twin River and Clallam formations is drawn at the point where massive sandstone becomes the dominant lithologic characteristic.

*Reference section—Lyre River.*—A well exposed section of the Twin River formation crops out in the stream bed and canyon of the Lyre River, about 10 miles east of the type locality on Deep Creek. In the Lyre River, the Twin River formation is exposed from a point 950 feet south, 3,690 feet west of the NE. corner of Sec. 10, T. 30 N., R. 9 W., to a point 400 feet north, 1,050 feet west of the SE. corner of Sec. 28, T. 31 N., R. 9 W. (Fig. 4), and these exposures constitute a supplemental type locality or reference section of the formation. The Lyre River reference section is exposed in the south limb of the Clallam syncline and the strata are therefore inclined toward the north. The dip of the strata is low at the north end of the reference section near the synclinal axis but steepens to about 50° at the south end of the section. The following generalized section has been compiled from a plane-table traverse of these exposures.

| *Lithologic Description* | *Thickness (Feet)* |
|---|---|
| Top of section | |
| Upper member, top not exposed | |
| Mudstone and siltstone, medium gray to light olive-gray, poorly indurated, massive, micaceous, slightly carbonaceous; contains small (1-6 inches) spherical calcareous concretions and a few lenticular calcareous zones | 1,270 |
| Middle member | |
| Siltstone, medium gray, semi-indurated, massive to faintly bedded; contains nodular and spherical concretions; rock in lower half of unit gives off strong petroleum odor when freshly broken | 1,950 |
| Lower member | |
| Sandstone, medium greenish gray, indurated, fine- to medium-grained, thin-bedded, and siltstone, medium dark gray, sandy | 415 |
| Siltstone, medium gray, indurated, generally laminated or platy but massive in places; contains laminae or very thin beds of very fine-grained sandstone and calcareous concretionary lenses as much as 10 inches thick | 1,610 |
| Sandstone, medium greenish gray, indurated, granule to fine-grained, pebbly near base and conglomeratic siltstone | 40 |
| Base of section (Lyre formation) | |
| Total thickness | 5,285 |

The lowermost beds of the Twin River formation in the canyon of the Lyre River rest on pebble conglomerate of the Lyre formation. The beds above and below the contact between the two formations are parallel but are separated by a surface of erosion along which occur channels of reworked pebbles from the Lyre formation. The lower 40 feet of beds in the Twin River formation here constitute a coarse-grained basal unit which is characterized by pebbles and cobbles of basaltic rocks together with reworked pebbles, chiefly of metamorphic rock, from the Lyre formation (Brown, Snavely, and Gower, 1956).

The upper part of the Twin River formation has been removed by erosion in the Lyre River area. The youngest strata exposed there crop out in the axis of the Clallam syncline at the north end of the reference section and consist chiefly of massive olive-gray concretionary mudstone with streaks and lenses of darker gray carbonaceous material. This lithologic character occurs throughout the upper member of the Twin River formation and therefore the relative stratigraphic position of the youngest Twin River strata in the Lyre River section can not be determined from lithologic features alone. However, geologic mapping in the area west of the reference section has shown that at least 3,000 feet of strata has been eroded from the upper part of the Twin River formation in the Lyre River area.

*Reference section—East Twin River to Murdock Creek.*—A sequence of massive concretionary mudstone and siltstone, together with thin-bedded fine-grained sandstone, crops out along the Strait of Juan de Fuca from the mouth of the East Twin River to a point about 0.5 mile northwest of the mouth of Murdock Creek (Fig. 5) and constitutes a reference section for the upper member of the Twin River formation. These rocks are exposed in sea cliffs and wave-cut platforms for a distance of 3.5 miles along the coast. The strata exposed in this section are inclined toward the northwest at angles of 5°–25°, although steeper dips occur in a few places near minor faults or along drag folds. Steeply dipping normal strike faults cut the section but most of these have only a few feet of displacement. A northwest-trending normal fault near the center of the reference section has a throw of about 200 feet, with relative movement down toward the east. The following generalized section was compiled from a plane-table traverse of the area between the mouth of the East Twin River and the mouth of Murdock Creek; the section has been corrected to eliminate repetition of strata caused by faulting and folding.

| *Lithologic Description* | *Thickness (Feet)* |
|---|---|
| Top of section | |
| Upper member, top not exposed (faulted) | |
| Siltstone, sandy, medium gray to medium olive-gray, poorly indurated, massive, with a few beds of silty calcareous, fine-grained sandstone, concretionary in part | 200 |
| Mudstone, medium dark gray, massive, contains thin beds of silty claystone and in places is predominantly medium gray silty claystone, concretionary in places, fossiliferous | 1,280 |
| Siltstone and sandstone, medium gray, semi-indurated, thin-bedded, with a few beds of mudstone and claystone; lower part of unit is predominantly sandstone, medium gray to light greenish gray, calcareous, thin-bedded, fine- to very fine-grained | 900 |
| Mudstone, medium gray, poorly indurated, massive, with a few thin beds of fine-grained, calcareous sandstone | 700 |
| Base of section (faulted) | |
| Total thickness | 3,080 |

The lowest strata exposed in the reference section here defined crop out at a point about 0.5 mile northwest of the mouth of Murdock Creek along the north side of an east-trending fault. Stratigraphic displacement across the fault is about 500 feet with the south block dropped;[4] therefore, some of the rocks between the

[4] The throw of this fault can not be determined from exposures along the coast, although the fault zone is visible at low tide. The displacement given has been calculated from data obtained by geologic mapping south of the reference section.

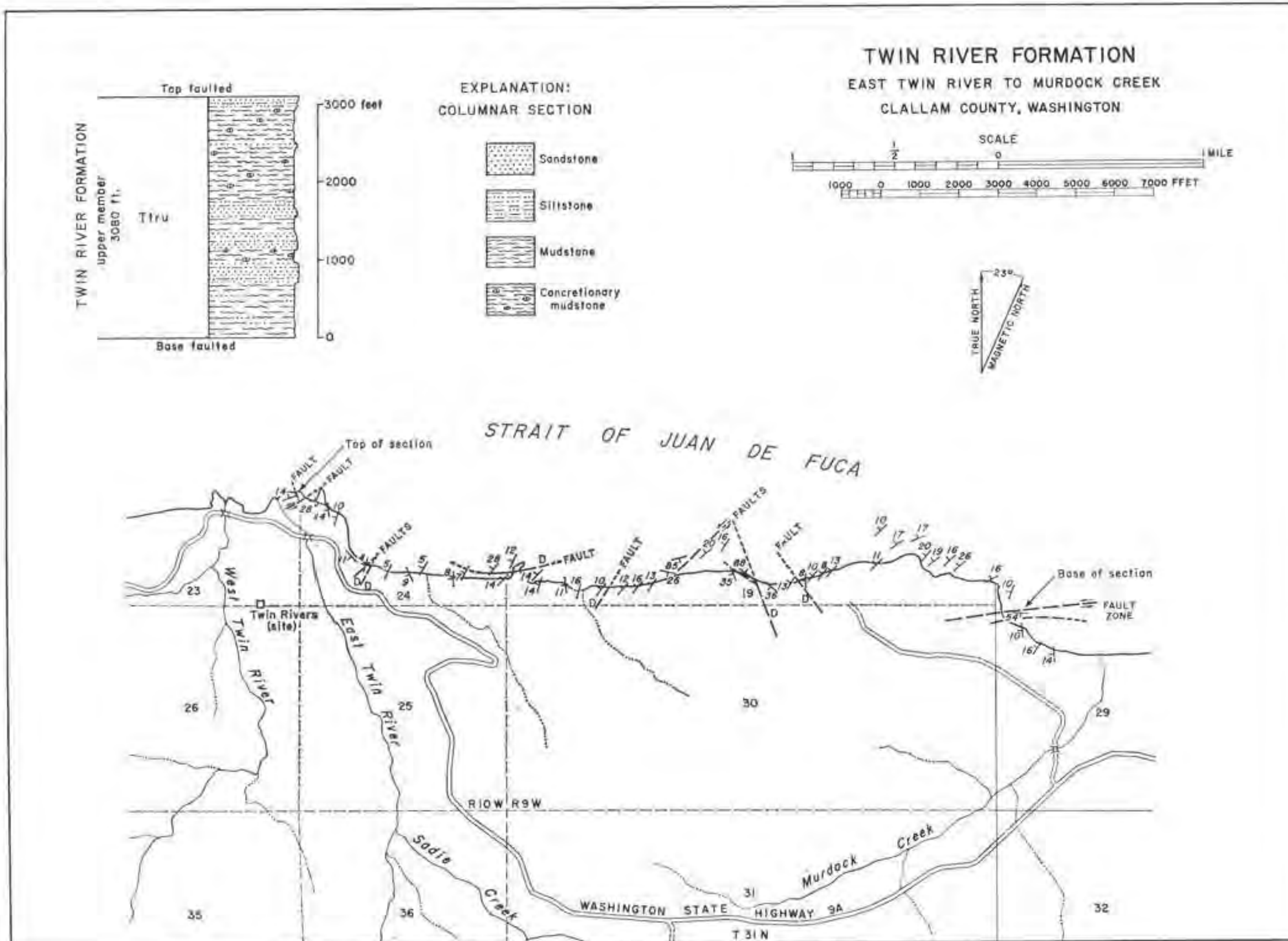


FIG. 5.—Geologic sketch map and section of reference section of Twin River formation, East Twin River to Murdock Creek, Clallam County, Washington.

fault and Murdock Creek are a repeated sequence of the lower part of the reference section. Neither the strata in the lower part of the reference section nor those south of the fault can be mapped into or correlated with any part of the Lyre River section, and areal geologic mapping between the Lyre River and Murdock Creek indicates that the oldest beds exposed in the coastal section are separated from the youngest beds that crop out at the north end of the Lyre River section by a stratigraphic interval of about 500 feet.

The strata that crop out immediately east of the mouth of the East Twin River, and which constitute the uppermost part of the reference section between the East Twin River and Murdock Creek, are in fault contact with younger strata of the upper member of the Twin River formation. The thickness of Twin River that overlies the beds at the top of the reference section can not be accurately determined because of complex structural relations and because the bedrock between the East Twin River and the base of the Clallam formation is poorly exposed.

### DISTRIBUTION AND THICKNESS

The Twin River formation has been mapped in detail in the north-central part of the Olympic Peninsula from McDonald Creek westward to the Clallam River (Fig. 1), and reconnaissance studies have shown that it may be recognized as far west as the west coast of the Olympic Peninsula and is fairly well exposed along the Hoko and Sekiu rivers. The formation forms an outcrop belt bordering the southern shore of the Strait of Juan de Fuca and in most places extends inland from the Strait for a distance of 5–8 miles. Some exposures of the Twin River formation occur in streams which cut through the glacial deposits along the coastal plain; however, exposures are more abundant in the low hills which separate the coastal plain from the high ridges that form the foothills of the Olympic Mountains. The formation is also well exposed at places in sea cliffs and wave-cut benches along the Strait of Juan de Fuca.

East of the Lyre River the Twin River formation is exposed in the limbs and axis of the Clallam syncline, a major structural feature that, in the area mapped, trends about N. 70° W. and extends from a point about 2.5 miles south of the mouth of Siebert Creek to a point about 1 mile south of the mouth of the Lyre River, a distance of 28 miles. In the south limb of this syncline the Twin River formation rests on the Lyre formation and older rocks, and is overlain by glacial till and outwash of Pleistocene age. Outcrops of the Twin River formation occur chiefly in stream valleys, and well exposed sections of the formation occur only in Morse Creek and Siebert Creek in the eastern part of the area mapped and in Field Creek and Whisky Creek near the Lyre River. A partial section of the Twin River formation is also present in McDonald Creek, in the extreme eastern part of the area studied. The areas between these streams are largely covered with glacial drift but in the south limb of the Clallam syncline scattered exposures of the Twin River formation occur in road cuts, hill slopes, and small ravines, and the contacts of lithologic units of member rank can be approximately located. Delineation of the Twin River formation and its component members is more difficult in the north limb of the Clallam syncline and along its axis where thick deposits of glacial drift conceal the bedrock; however, the formation is well exposed along the coast between Crescent Bay and the mouth of the Lyre River and also in places at Freshwater Bay.

The thickness of the Twin River formation in the south limb of the Clallam syncline, east of the Lyre River, can not be determined with certainty because the top of the formation has been removed by erosion, and even a partial thickness can be only approximate because of poor exposures and structural complexities. However, a section on the Lyre River has been measured and is approximately 5,300 feet thick. In the eastern part of the area, on Siebert Creek and Morse Creek, the exposed part of the formation is estimated to be about 9,500 feet thick. On the north limb of the Clallam syncline, at Freshwater Bay, the Twin River formation onlaps a structural high of volcanic rocks of the Crescent formation of middle Eocene age and, in some places, its total original thickness may have been less than 1,000 feet.

From the Lyre River west to the Pysht River, northward-dipping beds of the Twin River formation form an outcrop band that ranges from 3 to 7 miles wide. Glacial cover in this area is thinner and less extensive than in the area east of the Lyre River, and the lower part of the Twin River formation is well exposed in several north-flowing streams, particularly along the East and West Twin Rivers, Deep Creek, and the Pysht River. Other exposures of the formation are present on logging roads and the upper part of the formation is discontinuously exposed along the shore of the Strait of Juan de Fuca. The formation is thicker to the west of the Lyre River than to the east and at the type locality on Deep Creek it is more than 16,500 feet thick. The total thickness of the Twin River formation in the western part of the mapped area, from the top of the Lyre formation to the base of the Clallam formation, is estimated at 17,500 feet.

### LITHOLOGIC CHARACTER

The strata that comprise the Twin River formation are divisible into a lower member consisting chiefly of bedded or platy siltstone and sandstone, a middle member in which massive or thinly bedded siltstone is dominant, and an upper member characterized by massive mudstone. Recognition of these members is based on such lithologic characteristics as grain size, nature of bedding, and to less extent degree of induration; however, the distinctive features of each member can seldom be positively recognized in an isolated outcrop, for similar lithology is found in all three members. The distinction made here between members is based on stratigraphic relations observed in the four 15-minute quadrangles studied by the writers. In some parts of the area studied the members are easily distinguished and the contacts between them can be accurately placed, but in most places lithologic changes are gradational and contacts only approximate.

*Lower member*.—The lower member of the Twin River formation is composed chiefly of thin-bedded siltstone and sandstone with a few beds of conglomerate or pebbly sandstone occurring locally at or near the base. Strata assigned to this member have maximum thickness of about 7,500 feet on Deep Creek and in the area west of Deep Creek, but the average thickness of the member is about 2,000 feet in other parts of the area studied.

Siltstone is the most common rock type in the member but laminae and thin beds of sandstone are interbedded with the siltstone in most places. In the western part of the area mapped, beds of sandstone or interbedded sandstone and siltstone as much as 500 feet thick occur at the top of the member and where possible the upper contact of the member has been placed at the top of these arenaceous strata. As many of the sandstone units at the top of the lower member are lenticular or grade along the strike into siltstone, they are not all at exactly the same stratigraphic position. Thus, the upper contact of the member has lithologic significance only, and in different parts of the mapped area rocks of the same age may be placed either above or below the member boundary. In the eastern part of the area mapped, and in a few localities west of the Lyre River, no sandstone unit is present at the upper contact of the lower member and the contact has been placed at the point where thin-bedded sandstone and siltstone are overlain by the more massive and more argillaceous rocks that are characteristic of the middle member.

FIG. 6.—Thin-bedded sandstone near top of lower member of Twin River formation, Field Creek road, Clallam County, Washington.

Sandstone of the lower member of the Twin River formation is fine- to medium-grained, contains silt and clay as a matrix, and is cemented by quartz or calcite. Most exposures of sandstone are well bedded (Fig. 6) and contain alternating layers 1–12 inches thick of sandstone and siltstone. Where sandstone represents more than 50 per cent of the rock, bedding planes are sharply defined and the sand and silt layers are discrete; however, where sand and silt are present in nearly equal amounts, or where silt is the dominant grain size, the beds are graded in many places and are laminated or very thin-bedded.

Clastic grains in the sandstone are of varied origin and include some fragments of metamorphic, siliceous, or intermediate igneous rocks similar to fragments found in the Lyre formation; however, most exposures of sandstone contain significant amounts of basalt or altered basaltic debris. The basaltic material in most places is altered to chlorite and tends to give the rock an olive-gray to dark greenish gray color. Where the sandstone contains large amounts of non-clastic material (chiefly calcium carbonate) it frequently exhibits a faint pinkish or purplish color, which may be due to colloidal or precipitated manganese minerals derived from manganese and iron-bearing sedimentary rocks of the Crescent formation.

Thin sections of sandstone from the lower member of the Twin River formation yielded the following average composition: quartz, 22 per cent; unstable lithic fragments (as defined by Williams, Turner, and Gilbert, 1954, pp. 290–91), 17 per cent; chlorite, 10 per cent; feldspar (chiefly plagioclase), 11 per cent; biotite, 3 per cent; quartzite, 2 per cent; matrix (silt and clay), 19 per cent; cement[5] (quartz or calcite), 14 per cent; and epidote, clinozoisite, magnetite, and garnet (grossularite?), 3 per cent. Argillite, phyllite, fine-grained basalt, basaltic volcanic glass, and schist constitute most of the unstable lithic fragments. Biotite and muscovite, or sericite, occur as authigenic minerals and some chlorite that is present in the matrix may also be authigenic.

Siltstone in the lower member of the Twin River formation ranges in color from medium gray to dark greenish gray and in many places is sandy or contains thin laminae of silty fine-grained sandstone. The siltstone is well bedded and platy in fresh exposures but bedding is obscured in some weathered outcrops. Concretions, calcareous concretionary lenses, and sandstone beds cemented by calcium carbonate occur sporadically in the siltstone. Most of the concretions are spheroidal or ellipsoidal and range in diameter from 2 to 12 inches; the calcareous lenses are much larger, in places attaining a length of 50 feet and a thickness of as much as 10 feet.

*Middle member.*—The middle member of the Twin River formation is a sequence of massive to thin-bedded siltstone that in most places contains abundant concretions and calcareous lenses (Fig. 7). This member has an average thickness of about 2,000 feet in the central part of the area mapped, but in the extreme eastern part of the area, on Morse Creek and Siebert Creek, it is about 5,000 feet thick; it is also about 5,000 feet thick in the area west of Deep Creek.

[5] The relatively high percentage of cement shown by these thin sections is probably a result of sampling only the more firmly cemented sandstone beds.

East of the West Twin River the middle member is massive and consists almost entirely of concretionary medium gray to medium olive-gray clayey siltstone. A few thin beds of silty, fine-grained sandstone occur in places in the member but these are not common and most exposures are massive or show faint laminae of light greenish gray claystone in the siltstone. Much of the siltstone is concretionary, and calcareous concretions range in shape and size from spherical or ellipsoidal bodies about 3 inches in diameter to lenticular masses as much as 20 feet long and several feet thick.

West of the West Twin River the middle member of the Twin River formation

FIG. 7.—Massive concretionary siltstone in middle member of Twin River formation about 1½ miles east of mouth of Lyre River, Clallam County, Washington. Boulders in foreground are concretions left as lag boulders by wave action.

is thin-bedded and contains 10–20 per cent sandstone. Lenses of subfeldspathic sandstone, as much as 800 feet thick, are present in the lower part of the member and some of these are thick and extensive enough to be mapped at a scale of 1:48,000. Although the middle member is more sandy and better stratified toward the west, it is a mappable lithologic unit there as well as in the eastern part of the area. The distinction between the middle and lower members is preserved because each becomes more sandy in the western part of the area and, where the sand content of the middle member increases to about 20 per cent, the percentage of sandstone in the upper part of the lower member is nearly 50 per cent. Moreover, the sandstone in the lower member of the Twin River formation is, in most places, dark-colored, as a result of contained rock fragments and chlorite, but the subfeldspathic sandstone of the middle member is light or medium gray.

A lentil of pebble and cobble conglomerate crops out at the base of the middle member, about 2 miles west of the Elwha River. The conglomerate lentil plunges west in the axis of the Clallam syncline and is exposed in a crescent outcrop band, which is open toward the west. This lentil has maximum thickness of about 1,100 feet, but it is local in extent and has not been recognized in other parts of the mapped area. It is composed of pebble and cobble conglomerate and granule sandstone, which are similar in composition to rocks found in the Lyre formation. A conglomerate composed almost entirely of blocks and boulders of subangular

FIG. 8.—Mudstone with thin beds of claystone and sandstone overlying massive mudstone, upper member of Twin River formation, 1½ miles west of mouth of Murdock Creek, Clallam County, Washington. Notebook case is 6 inches by 9 inches.

volcanic debris is exposed in many places at the base of the lentil and apparently represents material eroded from the Crescent formation.

*Upper member.*—The upper member of the Twin River formation (Fig. 8) is composed predominantly of massive semi-indurated mudstone and sandy siltstone, which contain beds of very fine-grained calcareous sandstone. This member has a thickness of about 3,500 feet in the vicinity of the Pysht River where its upper contact with the Clallam formation is exposed, but farther east strata assigned to the member have a total thickness of more than 4,300 feet.

The upper member consists of medium gray to light olive-gray mudstone that is massive, relatively poorly indurated, and in some places concretionary. Where bedding is present in the mudstone it is poorly defined, and in some parts of the member mudstone sections as much as 100 feet thick show no stratification other than aligned concretions or laminae of clayey siltstone. However, in the western part of the area, units of thin-bedded siltstone and very fine-grained sandstone occur in the lower part of the member; some of these are as much as 300 feet thick. In other parts of the area the upper member contains a few beds 2–20 feet thick of fine- to medium-grained, calcareous sandstone. Most exposures of mudstone contain calcareous concretions that are spheroidal, ellipsoidal, or cylindrical and range from 1 inch to 1 foot in diameter.

### AGE AND CORRELATION

The Twin River formation is predominantly a marine unit and contains both mollusks and Foraminifera. Fossil leaves have been found in the formation at a few localities and, in other places, brachiopods, algae, and fish remains are present. The age of the formation, late Eocene to early Miocene, is based chiefly on identifications of molluscan fossils and Foraminifera, but where identifiable fossil leaves are found they support age determinations based on the marine fauna.

Molluscan fossils are found in a few places in the lower and middle members of the Twin River formation but those from the lower member are too few and too poorly preserved to be indicative of age. Several fossil assemblages from the middle member were identified as Oligocene in age by Ellen J. Trumbull (written communication). Mollusks are relatively abundant in the upper member of the Twin River formation and those that occur in outcrops along the Strait of Juan de Fuca have been described in detail most recently by J. Wyatt Durham (1944). Most of the fossils described by Durham from strata that are here included in the upper member of the Twin River formation were assigned by him to his *Echinophoria rex* and *Echinophoria apta* zones of late Oligocene age; however, at two of his localities, A-3692 and A-3693, Durham (1944, p. 110) reports the presence of " . . . a fauna of Miocene age, approximately corresponding to the 'Barker's Ranch' Temblor of California. . . . " The strata in which the fossils of Miocene age occur are in the uppermost part of the upper member of the Twin River formation as it is defined in this report. Additional collections of invertebrate fossils were obtained by the writers, both from resampling at some of Durham's localities and from several new localities in the upper member of the Twin River formation. These fossils, chiefly pelecypods and gastropods, were identified by Ellen J. Trumbull, who considered them to be late Oligocene or early Miocene in age.

Foraminifera are found in all three members of the Twin River formation but they are most abundant in the upper member. The Foraminifera from the Twin River formation range in age from late Eocene to late Oligocene or early Miocene, as determined by Weldon W. Rau. Foraminifera assemblage zones can be recognized within the formation, but the faunal and lithologic boundaries are

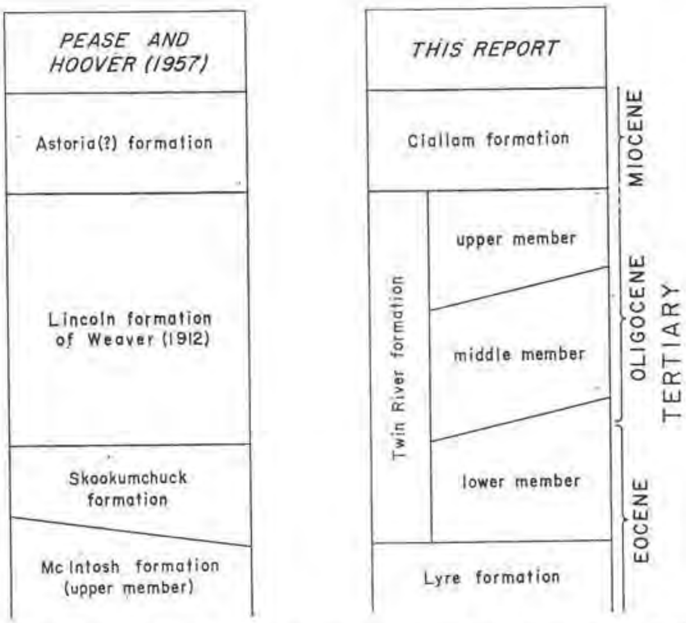


FIG. 9.—Chart showing correlation of Twin River formation with lithologic units in southwestern Washington.

not everywhere coexistent or even parallel, and it is therefore difficult to make a concise statement regarding the age of each member. However, according to Rau (personal communication), the lower member is late Eocene in age and contains foraminiferal assemblages comparable with those occurring in both the lower and upper parts of Laiming's (1940) A-2 zone of California; the middle member ranges in age from late Eocene to late Oligocene and contains a faunal assemblage comparable with those found in Schenck and Kleinpell's (1936) Refugian stage and in the lower part of Kleinpell's (1938) Zemorrian stage of California; and the upper member is late Oligocene or early Miocene in age and contains Foraminifera typical of Kleinpell's Zemorrian stage of California.

Stratigraphic units correlative in age to parts of the Twin River formation occur throughout western Oregon and western Washington, but firm correlations between these units and the Twin River formation are difficult to establish because of the scarcity of fossils in the lower two members of the Twin River. A correlation can be made, however, between the Twin River formation and marine sedimentary rocks in the drainage basin of the Chehalis River, about 75 miles south of the north coastal part of the Olympic Peninsula. This correlation, based on similar assemblages of Foraminifera, is shown in Figure 9.

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