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# THE ROCKS OF BULSON CREEK: EOCENE-OLIGOCENE SEDIMENTATION AND TECTONICS IN THE LAKE McMURRAY AREA, WASHINGTON

A Thesis

Presented to

The Faculty of

Western Washington University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science

by

Kim L. Marcus

June, 1981

3640 61

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Kim Marcus
February 16, 2018

THE ROCKS OF BULSON CREEK:

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Accepted in Partial Completion

of the Requirements for the Degree

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Dean of Graduate School

ADVISORY COMMITTEE

Chairperson

ABSTRACT

Upper Eocene to lower Oligocene sedimentary rocks in the Lake McMurray area of Skagit County, Washington, consist of approximately 1500 m of conglomerate, sandstone, shale, and siltstone which were deposited in fluvial and marine environments along the continental margin. These rocks are known as the rocks of Bulson Creek.

Two main lithofacies can be recognized within the sequence: the lowest is nonmarine and consists of poorly sorted, thick, and structureless conglomerate with interbedded sandstone, siltstone, shale, and minor coal lenses; the upper lithofacies grades from a transitional nonmarine facies to a shallow water marine facies that consists of well sorted, fossiliferous pebbly sandstone, sandstone, and siltstone. The lower lithofacies rocks lie unconformably on paleosols developed on pre-Tertiary rocks. The upper lithofacies rocks lie unconformably over the lower lithofacies rocks.

At least three periods of tectonism and two periods of deposition are recognized. The Devils Mountain fault is a major east-west trending structural feature along which there has been a long and complex history of motion. The deformation of the rocks in the Lake McMurray area can be attributed to movement along this fault, which forms the northern border along which the Bulson Creek rocks crop out. Deposition of the lower lithofacies rocks followed compressional folding associated with normal faulting. These rocks were folded prior to the deposition of the upper lithofacies, as is evident by the angular unconformity between the two units. Normal faulting along the Devils Mountain fault tilted these units to the south.

ACKNOWLEDGEMENTS

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Nothing would have come of this research without the aid of many friends, both two- and three-legged, who helped in numerous ways. Special thanks to Patty Combs for typing the manuscript and, in the final heat, to Billy Ketcham.

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TABLE OF CONTENTS

Page

LIST OF PLATES

LIST OF FIGURES

LIST OF TABLES

# INTRODUCTION

Approximately 1500 m of upper Eocene to lower Oligocene sedimentary rocks are exposed west of the crest of the Cascade Mountains, in the foothills to the south and southeast of Mt. Vernon, Washington (Fig. 1). These rocks, which consist of conglomerate, sandstone, siltstone, shale, and coalified wood, were deposited in fluvial and marine environments along the continental margin.

The rocks rest unconformably on Paleozoic and Mesozoic sedimentary rocks of the Trafton sequence (Danner, 1956, 1966, 1977; Marcus, 1980a), the rocks of Frailey Mountain (Lovseth, 1975; Dethier and others, 1980; Dethier and Whetten, 1980; Marcus, 1980a), and the rocks of Table Mountain (Danner, 1966; Lovseth, 1975), all of which are strongly deformed and moderately metamorphosed (Table 1). The upper Eocene-lower Oligocene sedimentary rocks are structurally juxtaposed against, and may possibly depositionally overlie, lower Tertiary sedimentary rocks of the Chuckanut Formation. The Chuckanut Formation here has been moderately deformed and slightly metamorphosed; locally, along faults and in the hinges or folds, higher grade metamorphism is evident by the epidote and chlorite that has formed on the rims of framework grains.

The upper Eocene to lower Oligocene sedimentary rocks are structurally juxtaposed with older rock units along the major east-west trending Devils Mountain fault. There is evidence for several different styles of motion along the fault (Lovseth, 1975; Gower, 1978; Whetten, 1978; Miller, 1979; Marcus, 1980b). Quaternary glacial and interglacial deposits are present in much of the study area.

The purpose of this investigation is to describe the late Eocene-early Oligocene rocks, which were called "the rocks of Bulson Creek" by

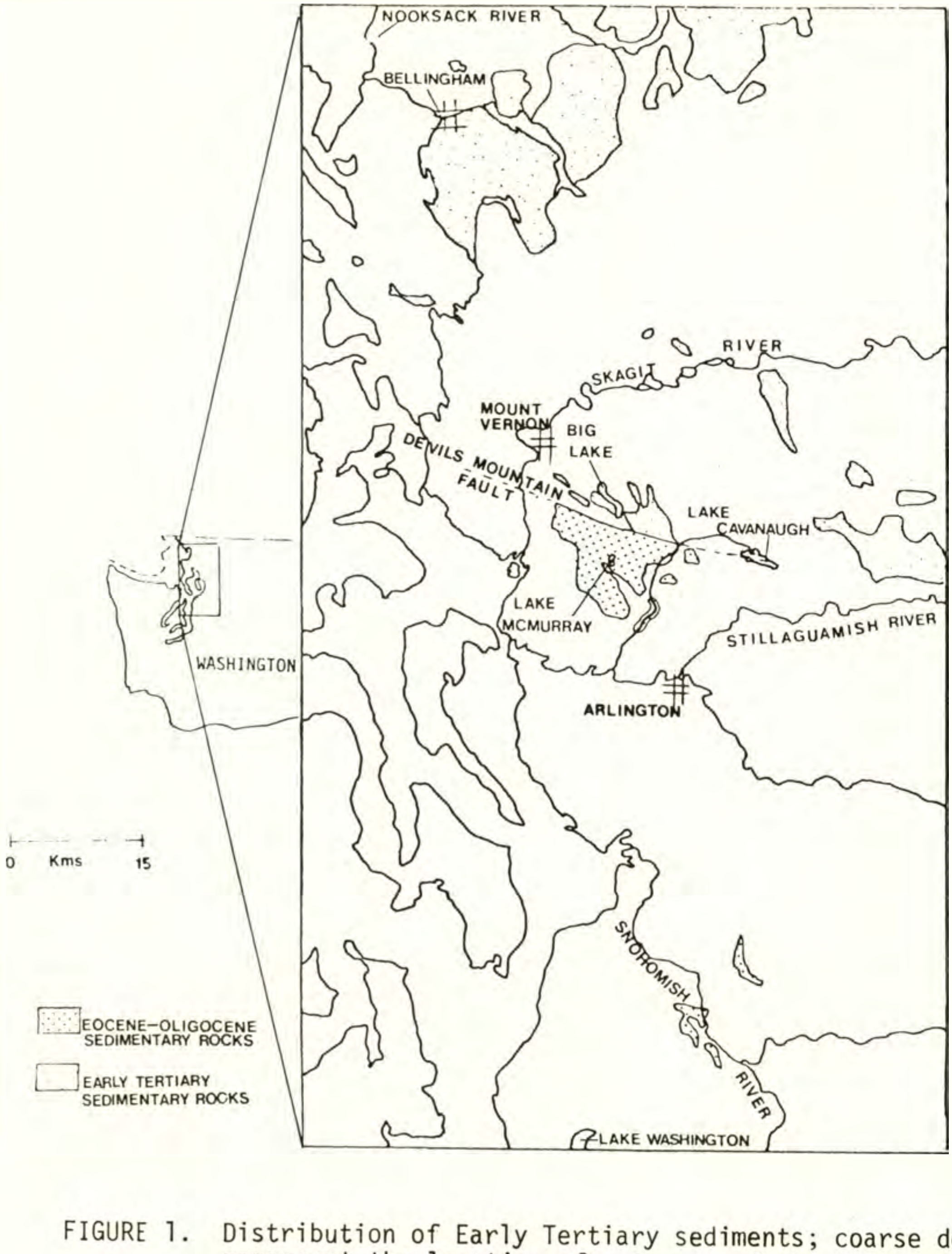



FIGURE 1. Distribution of Early Tertiary sediments; coarse dots represent the location of outcrops of the rocks of Bulson Creek; fine dots represent the outcrops of the Chuckanut and Huntingdon Formations.

TABLE 1. Description and stratigraphic sequence of the rocks of the Clear Lake area of Washington.

| UNIT | AGE | LITHOLOGY & BRIEF DISCUSSION OF FIELD RELATIONS WITH OTHER ROCK TYPES |
|---|---|---|
| Surficial Deposits | Pleistocene | Lacustrine deposits including sand, silt, and clay with minor amounts of organic debris; glacial and fluvial deposits including outwash sand and gravel, till, with kame terraces; landslide deposits containing phyllite, greenstone, chert, and sandstone debris; alluvial deposits including sand, silt, and pebbles. |
| Bulson Cr. Upper Lithofacies | Late Eocene to Early Oligocene | Shallow-water marine tuffaceous sandstone and siltstone, interbedded with fossiliferous horizons that contain minor amounts of organic material and then conglomeratic beds that contain pebbles of chert, greenstone, phyllite, and rhyolite. The sandstone shows graded bedding, scour and fill marks, and channel fill features. Sedimentary structures evident in the siltstone include crossbedding; current ripple marks; simply, wavy, and bifurcated flaser bedding; horizontal laminations. |
| Lower Lithofacies | Late Eocene to Early Oligocene | Alluvial pebbly conglomerates intercalated with sandstone and siltstone beds. The conglomerates contain clasts of phyllite, chert, vein quartz, greenstone, volcanics, gneiss, and granite with minor amounts of coalified wood. The thick to massively bedded conglomerates are well cemented with beds up to 50 m thick. The base of this lithofacies rests on a red paleosol developed in the Trafton Formation along Pilchuck Creek, and in the rocks of Frailey Mountain south of Lake Cavanaugh. |
| Volcanic Rocks | Eocene-Oligocene $43.5 \pm 3.4$ m.y. $52.7 \pm 2.5$ m.y. | Ashflow tuff, welded tuff, pyroclastic breccia containing andesitic, dacitic, and rhyolitic clasts along with autobrecciated flow banded rock intrude the Chuckanut Formation and appear to intrude along fault zones. One flow dated by fission track analysis of a zircon at $41.5 \pm 3.4$ m.y. by Lovseth (1975), recalculated by J. Vance (personal communication, 1980) at $43.5 \pm 3.4$ m.y., and another flow dated by Naeser (personal communication, 1980) at $52.7 \pm 2.5$ m.y. by the same method. |

TABLE 1. Continued

| UNIT | AGE | LITHOLOGY & BRIEF DISCUSSION OF FIELD RELATIONS |
|---|---|---|
| Chuckanut Formation | Cretaceous-Eocene | Medium- to coarse-grained feldspathic sandstone and siltstone with minor lenses of coal, pebbly conglomerate, and silty clay. The sandstone and siltstone are structureless to finely laminated and crossbedded. The Chuckanut is faulted against pre-Tertiary serpentines (Hobbs and Pecora, 1941), undifferentiated rocks of the Haystack unit (Dethier and Whetten, 1980), and the Bulson Creek rocks (Marcus, 1980a, b). |
| Rocks of Frailey Mtn. (Danner, 1957; Lovseth, 1975; part of Haystack unit of Dethier and Whetten, 1980) | Mesozoic | Well-stratified graywacke; siltstone, volcanic rock, ribbon chert, and minor limestong. The siltstone appears to be micrograywacke containing the same clasts as the graywacke (Miller, 1979). |
| Rocks of Table Mtn. (Danner, 1957; Lovseth, 1975; Miller, 1979; Haystack unit of Dethier and Whetten, 1980; Vance and others, 1980) | Jurassic | Greenstone, serpentinite, graywacke, pillow basalt, argillite, meta-plutonic rock and ultramafic rock make up this structurally broken and stratigraphically chaotic unit. Bulson Creek conglomerates rest unconformably on a paleosol developed in the "rocks of Table Mountain". Less than half a kilometer to the east, the Table Mountain rocks are in fault contact with these rocks (Plate 16). |
| Trafton Sequence (Danner, 1957, 1966) | Mid-Paleozoic to Jurassic Permian(?) | Chert, argillite, greenstone, and minor lenses of limestone occur in the Trafton sequence. The cherts are rhythmically bedded, light bluish-gray (Plate 1), and contain mid-Paleozoic to Jurassic radiolaria. Dethier and Whetten (1980) report that Permian Tethyan fusulinids have been identified in limestone pods. A thick paleosol separates fresh cherts of the Trafton sequence from the unconformably overlying sediments of the Bulson Creek unit (Plates 3 and 4). |

TABLE 1. Continued

| UNIT | AGE | LITHOLOGY & BRIEF DISCUSSION OF FIELD RELATIONS |
|---|---|---|
| Darrington Phyllite (Armstrong, 1980) | Jurassic | Chiefly consists of phyllite with abundant, interbedded quartz as veins or pods. Well developed schistosity evident in this dark gray to black rock. Quartz is usually milky white and massive (Misch, 1952; Miller and Misch, 1963; Misch, 1977). |
| Quartz Diorite to Diorite | Paleozoic | Metagranitic rocks that are medium to coarse grained. A similar quartz diorite, associated with the Trafton sequence, was dated as mid-Paleozoic (Dethier and Whetten, 1980). These rocks crop out in the southern portion of the map area. |

Lovseth (1975), and to identify the age and structural relationship of these rocks to the adjacent units.

## Location

The rocks of Bulson Creek crop out over a 400 $km^2$ area from Lake Cavanaugh on the east to Devils Mountain to the west (Fig. 1). They have not been identified north of the Devils Mountain fault but are found as far south as Arlington, Washington. Rocks similar in age and appearance have been identified in the Snohomish area by McKnight (1925) and Newcomb (1952) and on southern Vancouver Island by Sutherland-Brown (1966). Correlation of the rocks in the Snohomish area, called the Snohomish Formation (McKnight, 1925; V. Mallory, personal communication), and the Sooke Formation on Vancouver Island with the rocks of Bulson Creek has not been established.

## Methods

Mapping for this project was done on 1:62,500 scale topographic maps, 1:24,000 scale orthophoto maps, and on 1:24,000 scale enlargements of the 1:62,500 scale topographic maps. The exposures are mainly in roadcuts, stream channels, along cliffs, and in excavations for housing developments. Approximately 15 km of pace and compass traverses led to the development of the detailed stratigraphic columns. (See the explanation of Figures 5 and 7 for the location of the sections.)

Paleocurrent measurements were recorded from crossbedding in sandstone and siltstone beds as well as from the imbrication of clasts in the conglomerates (Figs. 2a and 6). Reconstruction to the normal, of folded beds, was done using a stereographic projection of the beds.

FIGURE 2A. Sample localities and paleocurrent directions are plotted. Sample sites include CS-10 to CS-12, LBC-1 to LBC-4; and UBC-5 to UBC-17.

FIGURE 2B. Locality map for Frizzell's (1979) samples that are included in this report.

a. Chuckanut sandstone samples labelled Ch-2, 3, 6, 9, 10, and Huntington sandstone samples labelled H-1 and H-2.

b. Eocene sandstone samples labelled CS-2, 3, 5, 6, and 7, and rocks of Bulson Creek labelled BC-1, 2, and 3.

c. Blakeley Formation samples labelled BF-1, 6, and 7.

FIGURE 2C. Location map for Frizzell's sample areas; Figures 2Ba, b, and c.

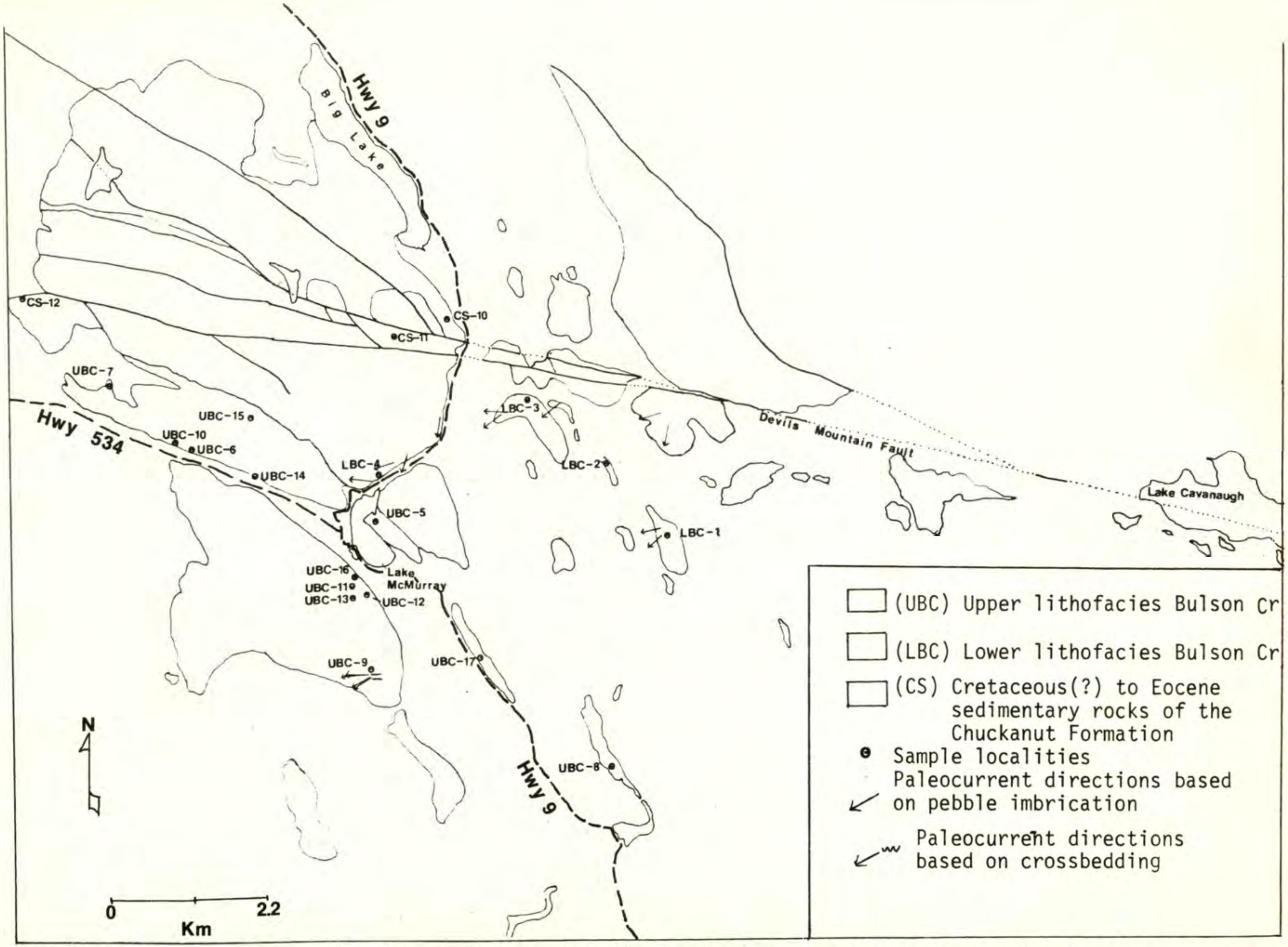



FIGURE 2A. Location map of point counted sample sites and paleocurrent directions. Sample numbers correspond to the number listed in the right hand column of Figures 5 and 7.


FIGURE 2Ba.

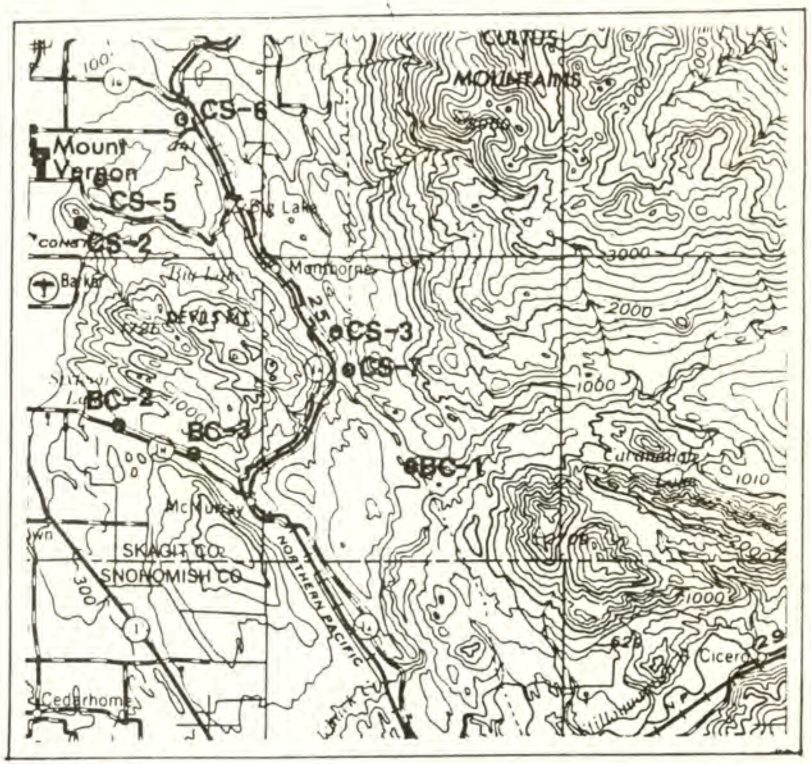



FIGURE 2Bb.

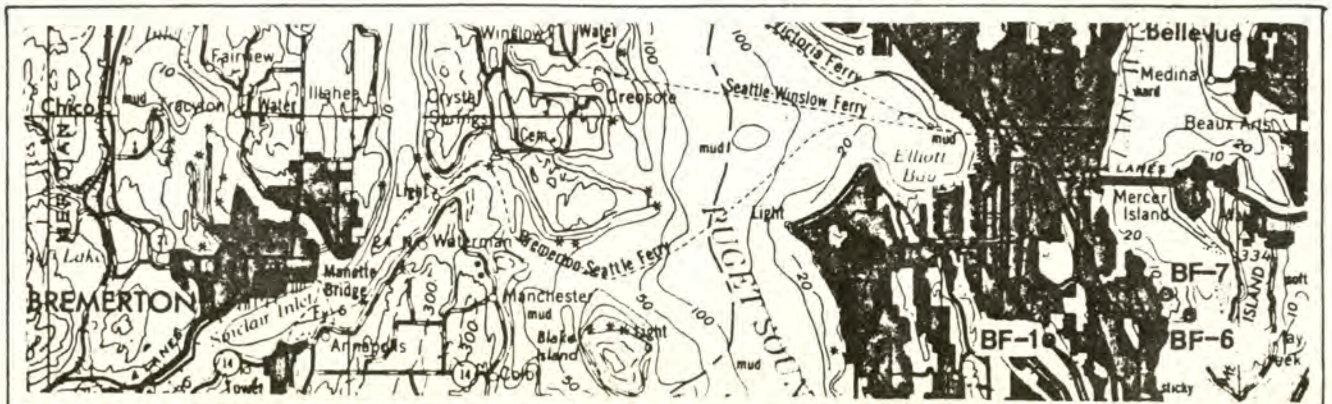



FIGURE 2Bc.

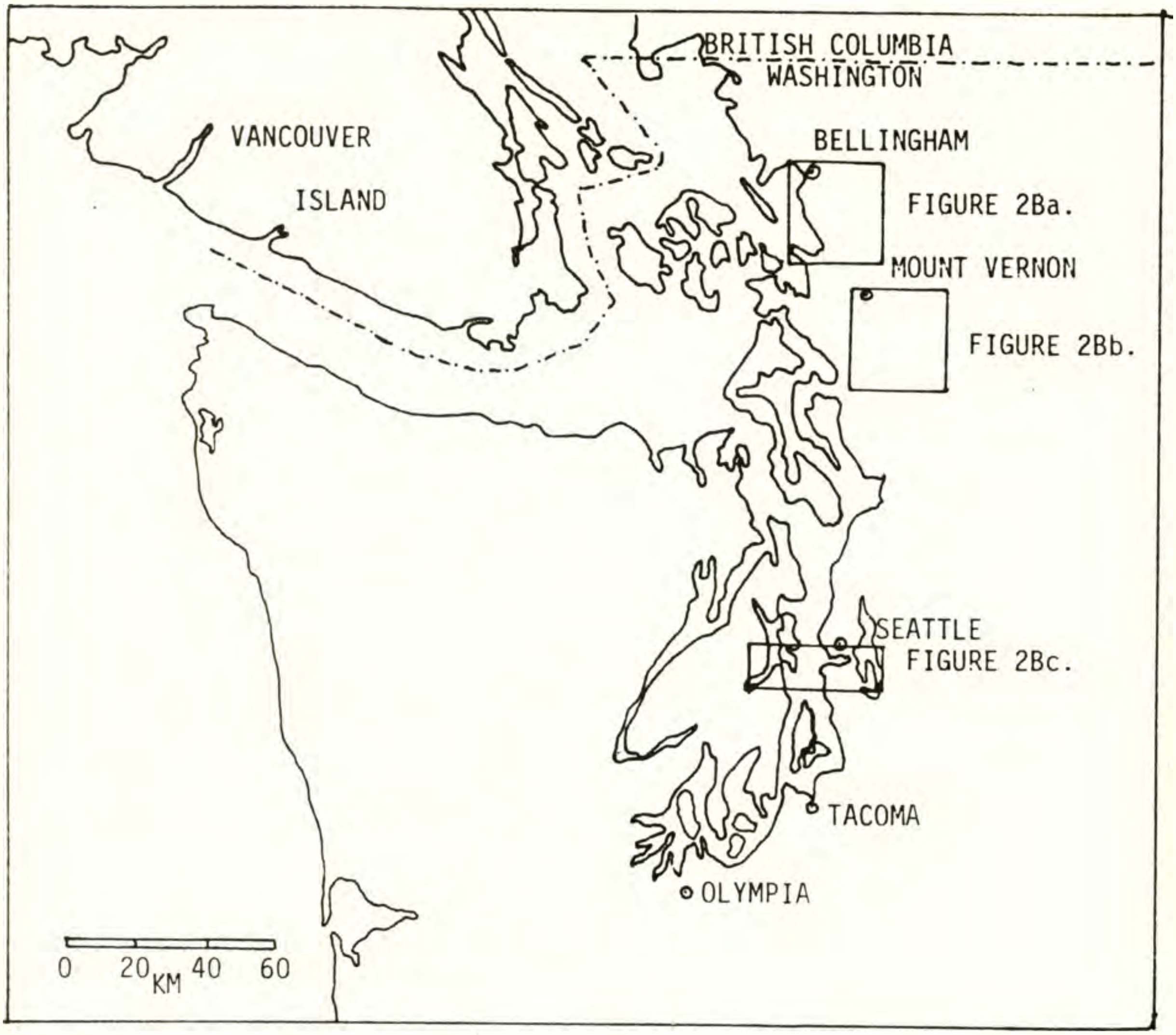

BRITISH COLUMBIA
WASHINGTON
VANCOUVER
ISLAND
BELLINGHAM
FIGURE 2Ba.
MOUNT VERNON
FIGURE 2Bb.
SEATTLE
FIGURE 2Bc.
TACOMA
OLYMPIA
0 20 40 60
KM

Figure 2C.

Samples of sandstone and siltstone were collected from both the lower and upper lithofacies of the Bulson Creek rocks and from the Chuckanut Formation arkosic sandstone that crops out north of the Devils Mountain fault (Fig. 2a). Twenty samples were point counted to determine the detrital modes (Table 2).

Point count data from Frizzell (1979) are also included (see Table 5, p. 61). He sampled Bulson Creek rocks, the Chuckanut Formation arkosic rocks north of the Devils Mountain fault, and the Huntingdon and the Blakely Formations, all of which are related in age, lithology, and/or depositional environment. His data were recalculated, as the emphasis of his work was on the determination of tectonic provenance as a function of the detrital modes. For comparative purposes some of his categories were recombined.

Grain size analyses of some of the less consolidated beds are shown in Table 3. Large samples (up to 30 kg) were collected and sieved on a rotap. The percentage of each sieve size is shown in Table 3.

Pebble counts in the pebbly sandstone and conglomerates proved helpful in determining the provenance of the clasts (i.e., were the clasts locally derived or did them come from a distance?) (Table 4). Bias in the pebble counts was minimized by drawing a square $\frac{2}{3}$m by $\frac{2}{3}$m on an outcrop and then counting all clasts greater than 2 cm within that square.

## Previous Work

Early research in northwestern Washington was aimed at identification of rock and mineral resources. Russell (1900) wrote a preliminary report on the geology of the Cascade Mountains in northern Washington. Willis (1886) described sedimentary rocks of Whatcom and Skagit Counties.

Lower Lithofacies of the Bulson Creek rocks

| | | | | | |
|---|---|---|---|---|---|
| | Map Number | BC4 | LBC 5 | LBC 6 | LBC 7 |
| | Field Sample Number | M79-10 | M75-9 | M76-7A | M76-7B |
| 1. | (Total Points Counted) | (200) | (300) | (300) | (300) |
| 2. | Quartz (sum of 3 & 4 below) | ( 29) | ( 31) | ( 21) | ( 40) |
| 3. | Monocrystalline quartz | 8 | 13 | 5 | 8 |
| 4. | Polycrystalline quartz aggretate | 33 | 18 | 12 | 22 |
| 5. | Lithic volcanic fragment | 8 | 15 | 6 | 1 |
| 6. | Lithic sedimentary fragment | 42 | 20 | 31 | 27 |
| 7. | Plagioclase | 4 | 9 | 14 | 12 |
| 8. | Potassium feldspar | 1 | 15 | 6 | 2 |
| 9. | Mica (biotite and muscovite) | | | 10 | 12 |
| 10. | Pyroxene and amphibole | | 2 | 2 | 2 |
| 11. | Garnet and rutile | | 1 | 7 | 4 |
| 12. | Miscellaneous | 2 | 4 | 5 | 6 |
| 13. | Unknown | 2 | 2 | 1 | 3 |
| 14. | Matrix | ___ | ___ | ___ | ___ |
| | TOTAL PERCENT | 100 | 99 | 99 | 98 |

TABLE 2. Point count data from the Bulson Creek rocks (for locations, see Figure 2a).

Upper Lithofacies of the Bulson Creek rocks

| | Map No. | UBC 8 M79-11 | UBC 9 M76-31 | UBC10 M79-31 | UBC11 M77-47 | UBC12 M78-5 | UBC13 M76-38 | UBC14 M79-6 | UBC15 M79-7 | UBC16 M79-8 | UBC17 M76-71 | UBC18 M79-29 | UBC19 M79-69A | UBC20 M79-69B |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. | Tot | (300) | (300) | (200) | (300) | (300) | (300) | (300) | (300) | (300) | (300) | (300) | (300) | (300) |
| 2. | Q | ( 17) | ( 26) | ( 29) | ( 7) | ( 16) | ( 35) | ( 31) | ( 30) | ( 26) | ( 21) | ( 10) | ( 24) | ( 18) |
| 3. | Qm | 4 | 18 | 9 | 10 | 9 | 28 | 19 | 17 | 19 | 12 | 7 | 20 | 13 |
| 4. | Qp | 13 | 8 | 20 | 4 | 6 | 7 | 12 | 13 | 7 | 9 | 3 | 4 | 5 |
| 5. | Lv | 39 | 23 | 35 | 45 | 50 | 20 | 31 | 39 | 38 | 47 | 66 | 41 | 40 |
| 6. | Ls | 16 | 26 | 10 | 5 | 6 | 24 | 6 | 12 | 3 | 5 | | 3 | 1 |
| 7. | P | 14 | 6 | 10 | 8 | 17 | 11 | 9 | 13 | 16 | 13 | 15 | 3 | 13 |
| 8. | K | 4 | 10 | 10 | 5 | 2 | | | 3 | 8 | 4 | 2 | 9 | 5 |
| 9. | m | 2 | 2 | 1 | 5 | 3 | 2 | 4 | 3 | 3 | | 1 | 5 | 6 |
| 10. | p & a | 2 | 1 | | 4 | 2 | 3 | 2 | | 2 | | 1 | 2 | 2 |
| 11. | g & r | >1 | 1 | 2 | 1 | | | 1 | | | 1 | 1 | 3 | 2 |
| 12. | Misc | 4 | 4 | 1 | 1 | 4 | 2 | 16 | 2 | 2 | | 1 | 4 | 10 |
| 13. | Unknown | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 1 | 1 | 6 | 2 | 5 | 2 |
| 14. | Matrix | | | | | | | | | | 3 | | | |
| | TOTAL PERCENT | 100 | 100 | 100 | 100 | 101 | 99 | 101 | 103 | 99 | | 99 | 99 | 99 |

TABLE 2. Point count data from the Bulson Creek rocks (continued).

| Lithofacies | Clast Size mm | Clast Size Ø | Pebb. Conglomerate Lower Lithofacies | Sandstone Interbed Lower Lithofacies | Pebb. Conglomerate Lower Lithofacies | Pebb. Conglomerate Upper Lithofacies | Siltstone Member Upper Lithofacies |
|---|---|---|---|---|---|---|---|
| Map Number | | | PC 11 | PC 12 | PC 13 | PC 14 | PC 15 |
| Fld. Sam. # | | | M79-12 | M79-30 | M80-3 | M80-5 | M78-24 |
| CLAY | <.0039 | <8 | | 4 | 1 | <2 | <25 |
| SILT fine | .0039 | 8 | | (5 | (1 | (1 | (29+ |
| SILT med. | .031 | 6 | 3 | 14 (7 | 9 (7 | 8 (2 | >75 (35 |
| SILT cse. | .0530 | 4 | | (2 | (1 | (5 | (11 |
| SAND fine | .0625 | 4 | | (7 | (4 | (8 | |
| SAND med. | .25 | 4 | 21 | 63 (12 | 42 (13 | 65 (47 | |
| SAND cse. | 1.50 | -1 | | (44 | (25 | (10 | |
| pebble | 2 | -1 to -6 | 62 | 19 | 29 | 21 | |
| >pebble | 64 | >-6 | 15 | | 19 | 4 | |
| TOTAL IN % | | | 101 | 100 | 100 | 99+ | 100 |

TABLE 3. Grain-size analyses of various units of the Bulson Creek rocks. Numbers in half brackets refer to the subdivisions under the sand and silt sizes.

TABLE 4. Pebble Count Data (in percentages)

| | Map Number | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 | PC7 | PC8 |
|---|---|---|---|---|---|---|---|---|---|
| | Field Sample Number | M80-101 | M80-102 | M80-103 | M80-104 | M80-105 | M80-106 | M80-107 | M80-108 |
| 1. | Phyllite | 25 | | 40 | 42 | 49 | 44 | 32 | 20 |
| 2. | Chert (red) | 4 | | 2 | 1 | | | | 2 |
| 3. | Chert (gray) | 34 | 74 | 10 | 26 | 17 | 20 | 15 | 19 |
| 4. | Vein quartz | 5 | 26 | 4 | 5 | 4 | 9 | 8 | 9 |
| 5. | Greenstone | 22 | | 31 | 12 | 10 | 13 | 32 | 26 |
| 6. | Volcanic (rhyo-dacite) | 12 | | 7 | 3 | 18 | 8 | | 1 |
| 7. | Volcanic (andesite) | | | | 2 | | 2 | 2 | 1 |
| 8. | Gneiss | 1 | | | | | 1 | | |
| 9. | Granite | | | 1 | 1 | | 1 | | |
| 10. | Sedimentary | 2 | | 6 | 5 | 1 | 2 | 5 | 19 |
| 11. | Miscellaneous | | | | | | | 3 | 3 |
| 12. | Unknown | — | — | — | 2 | — | — | 3 | — |
| | TOTAL | 100 | 100 | 101 | 101 | 99 | 100 | 100 | 100 |

Note: A two-thirds of a meter square was drawn on the outcrop. All clasts exposed between 2 cm and 25 cm (inclusive of those half-way within the square) were counted. Clasts of this size were examined because it was difficult to ascertain in hand sample what the clasts were if they were any smaller, and clasts larger than 25 cm were very few and usually not representative of most of the outcrop. Large clasts tend to be composed of rhyolite (Plate 7).

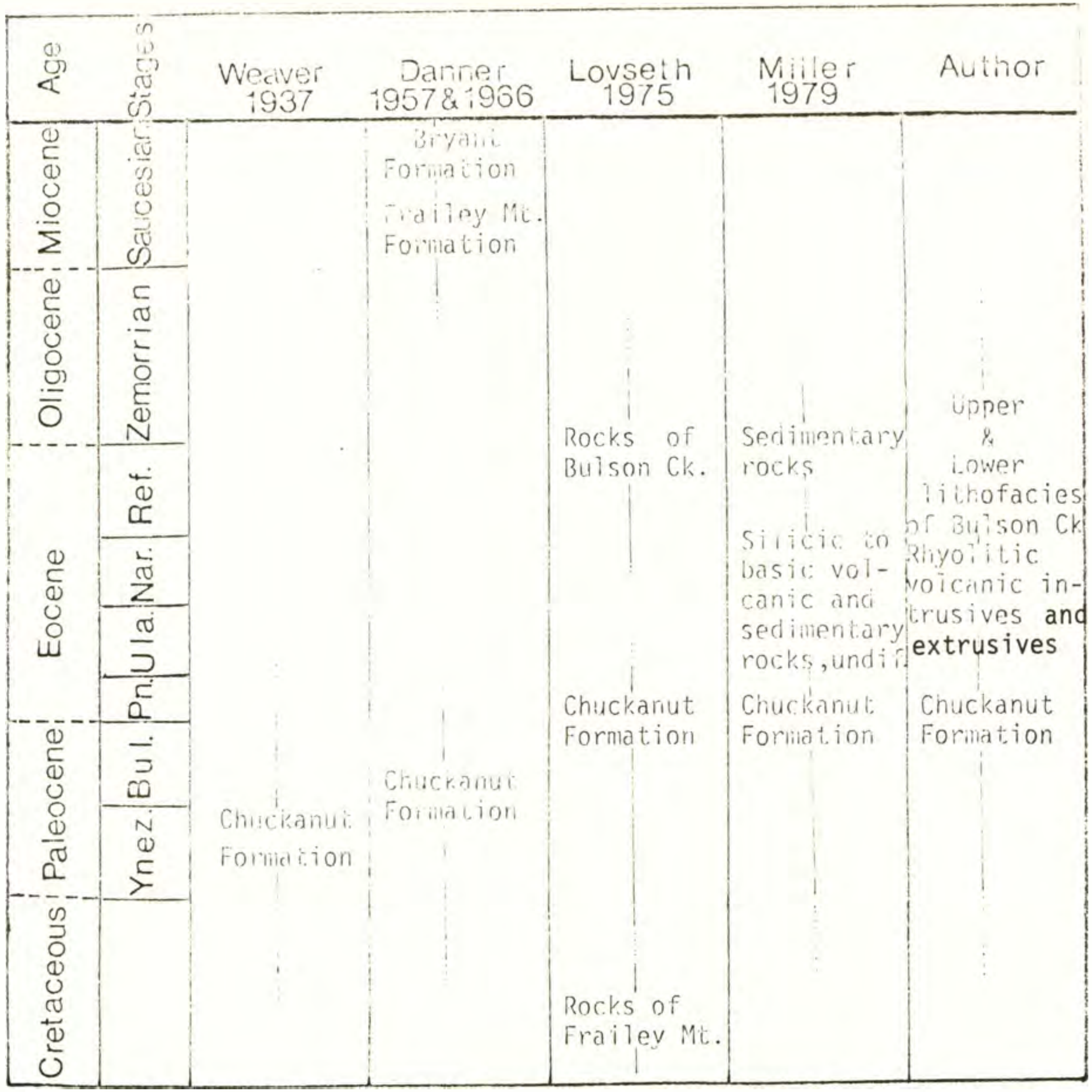



FIGURE 3. Development of stratigraphic nomenclature in the Lake McMurray area. Foraminiferal stages: Ynez.=Ynezian; Bul.=Bulitian; Pn.=Penutian; Ula.=Ulatisian; Nar.=Narizian; Ref.=Refugian.

Lesquereux (1859), Newberry (1863), and White (1889) described the faunal assemblages of rocks in Whatcom and Skagit Counties. Landes (1902) and Landes and Ruddy (1903) reported on the coal deposits of Washington, and each report discusses some geologic work in Skagit and Whatcom Counties.

Jenkins (1923, 1924) compiled the first stratigraphic column of the upper Mesozoic-lower Cenozoic rocks; however, the emphasis of his work was less to make stratigraphic correlations than to define the coal-bearing zones in northwestern Washington.

Sedimentary rocks in Whatcom and northern Skagit Counties were first called the Chuckanut Formation by McClellan (1927) for a thick sequence of these rocks that crops out along Chuckanut Drive. Glover (1935) measured two sections of the Chuckanut, as did Weaver (1937) (Fig. 3). The Chuckanut Formation consists of conglomerate, arkosic sandstone, siltstone, shale, and coal beds.

Roth (1926), Norbisrath (1939), Newcomb (1952), and Danner (1957, 1966) all mapped in the Mount Vernon area. Norbisrath investigated the grain size parameters of the Chuckanut sandstone, whereas Newcomb was interested in the porosity and water content of the Chuckanut sandstone. Danner was concerned with the Paleozoic section and described the Chuckanut only in its relationship to the older rocks.

Hobbs and Pecora (1941) investigated mineralization along the Devils Mountain fault. They attempted to ascertain the direction of motion along the fault and the history and extent of mineralization. Included in their study is a description of Mesozoic and Cenozoic rocks along the fault zone. They made no distinction between the sedimentary rocks north and south of the fault.

Lovseth (1975) was the first to recognize that the sedimentary rocks 10 km south of Mt. Vernon are of a different age and affinity than other sedimentary rocks that had been assigned to the Chuckanut Formation. He states that "over 500 m of Late Narizian or possibly early Refugian rocks (upper Eocene and lower Oligocene?) are present in the Bulson Creek-Lake McMurray area" (p. 10). He informally refers to these as "the rocks of Bulson Creek". Work by the author indicates that the rocks of Bulson Creek consist of approximately 2000 m of conglomerate, sandstone, siltstone, and shale that can be divided into two main units based on lithology and an unconformity.

The lower of the two lithofacies consists of conglomerate and pebbly sandstone with minor amounts of sandstone, siltstone, shale, and coal (Fig. 4). The conglomerate is thick, structureless, and gradational into pebbly sandstone. The contact with finer grained rocks is sharp. The color ranges from greenish-gray to yellowish-brown.

The upper lithofacies consists of pebbly sandstone, coarse- to medium-grained sandstone, fine-grained sandstone, and siltstone. Clay lenses and rare leaf fossils can be found in the sand and silt beds. The color of these rocks ranges from yellowish-brown to reddish-brown. Marine fossils found in many horizons of the finer grained beds have proven useful as indicators of paleoenvironment and in the determination of the age of the rocks.

The Bulson Creek rocks differ from other Tertiary sedimentary rocks in that the Bulson Creek rocks contain a large percentage of lithic clasts, including volcanic fragments; they were deposited in nonmarine and shallow water marine environments, and in no other sedimentary rock units are the conglomerates so thick and massive.

## Lower Lithofacies

### Conglomerate

Most of the 1200 m-thick lower lithofacies is conglomerate. The clasts in the conglomerate are subangular to subrounded, moderately spherical to elongate, and consist, in order of decreasing abundance, of phyllite, chert, vein quartz, greenstone, volcanics, gneiss, and granite, and range in size up to .4 m in diameter (Table 3 and 4, Figs. 5 and 6). The volcanic clasts are of particular importance in that they may prove helpful in determining the maximum age of the Bulson Creek

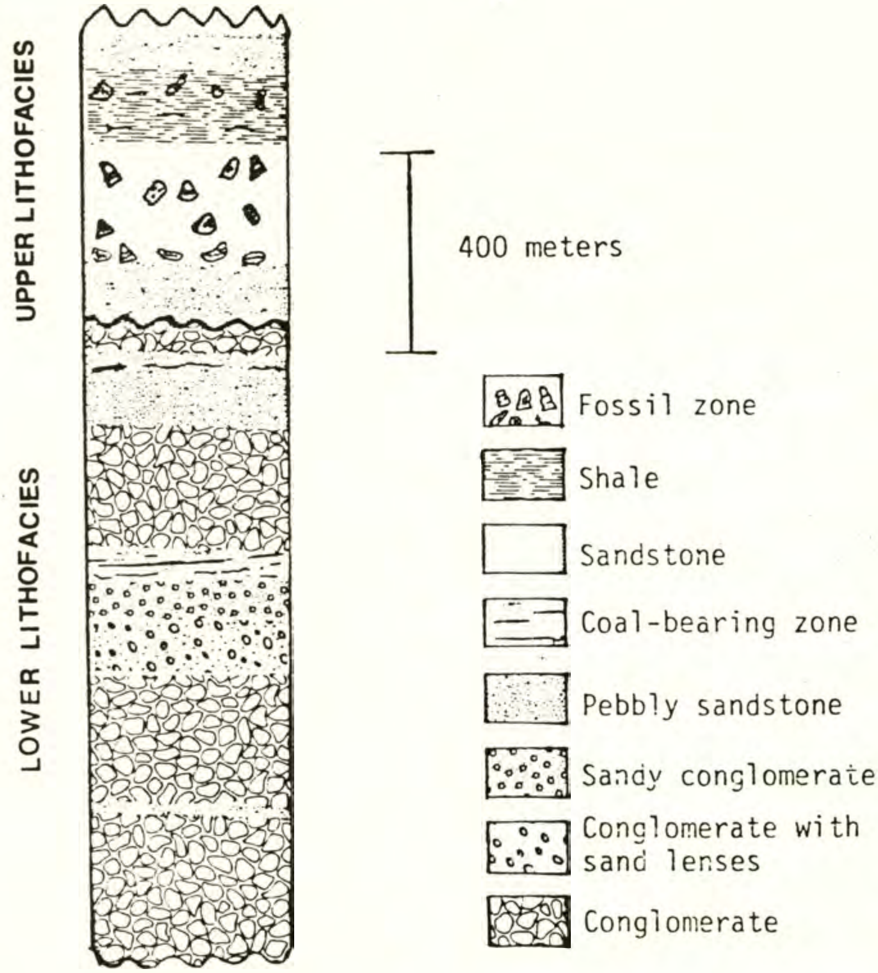



FIGURE 4. Generalized stratigraphic column of the Eocene-Oligocene rocks of Bulson Creek.

LEGEND TO FIGURES 5 AND 7.

FIGURE 5. Section A (as labelled to the right of the column) was measured from T33N, R5E, Sec. 18, SW¼NE¼, southwest to T33N, R4E, Sec. 24, SW¼SE¼. Section B was measured from T32N, R5E, Sec. 27, center, northward to T32N, R5E, Sec. 22, north-center.

FIGURE 7. Section A (as labelled to the right of the column) was measured from T33N, R4E, Sec. 36, NW¼NW¼, southwest to T33N, R4W, Sec. 36, south-center. Section B was measured from T33N, R4E, Sec. 18, SW¼NE¼, southwest to T33N, R3E, Sec. 23, SE¼SE¼.

ABBREVIATIONS USED IN BOTH FIGURES:

| | |
|---|---|
| cong. = conglomerate | cob. = cobble |
| ss = sandstone | peb. = pebble |
| sis = siltstone | cg = coarse grained |
| sh = shale | mg = medium grained |
| grad. change = gradational change | fg = fine grained |

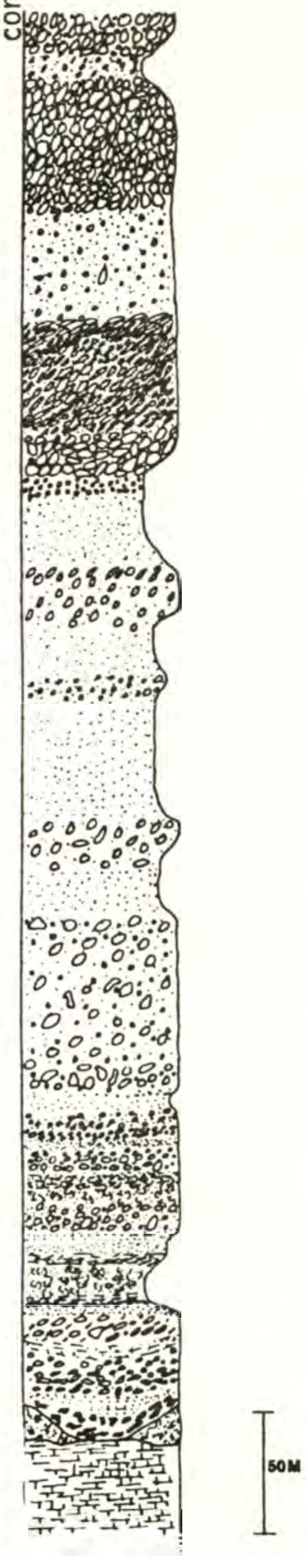
(5 YR 3/4) color term from the GSA Rock Color Chart.

SAMPLE NUMBERS

Far right-hand column Figures 5 and 7.

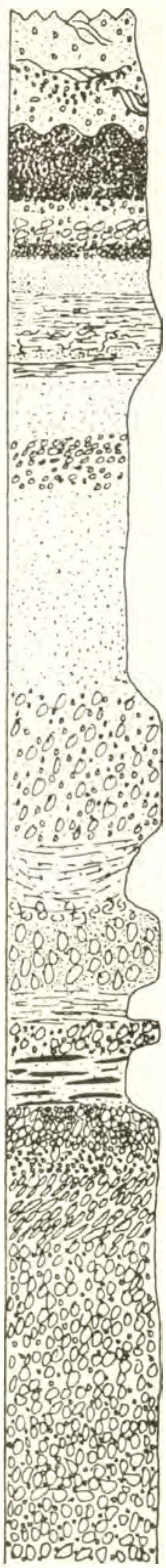
| Prefix | Data Type | Figure (location) | Table (data) |
|---|---|---|---|
| LBC | Point Count | Figure 2A | Table 2 |
| UBC | Point Count | Figure 2A | Table 2 |
| PC 1-10 | Pebble count | Figure 6 | Table 4 |
| PC 11-15 | Grain size analysis | Figure 6 | Table 3 |
| Paleo 1-11 | Paleocurrent direction | Figure 6 | Insert, Figure 6 |

Second column from the right, Figure 7, contains numbers that correspond to the numbers following the fossil names in Figure 8.



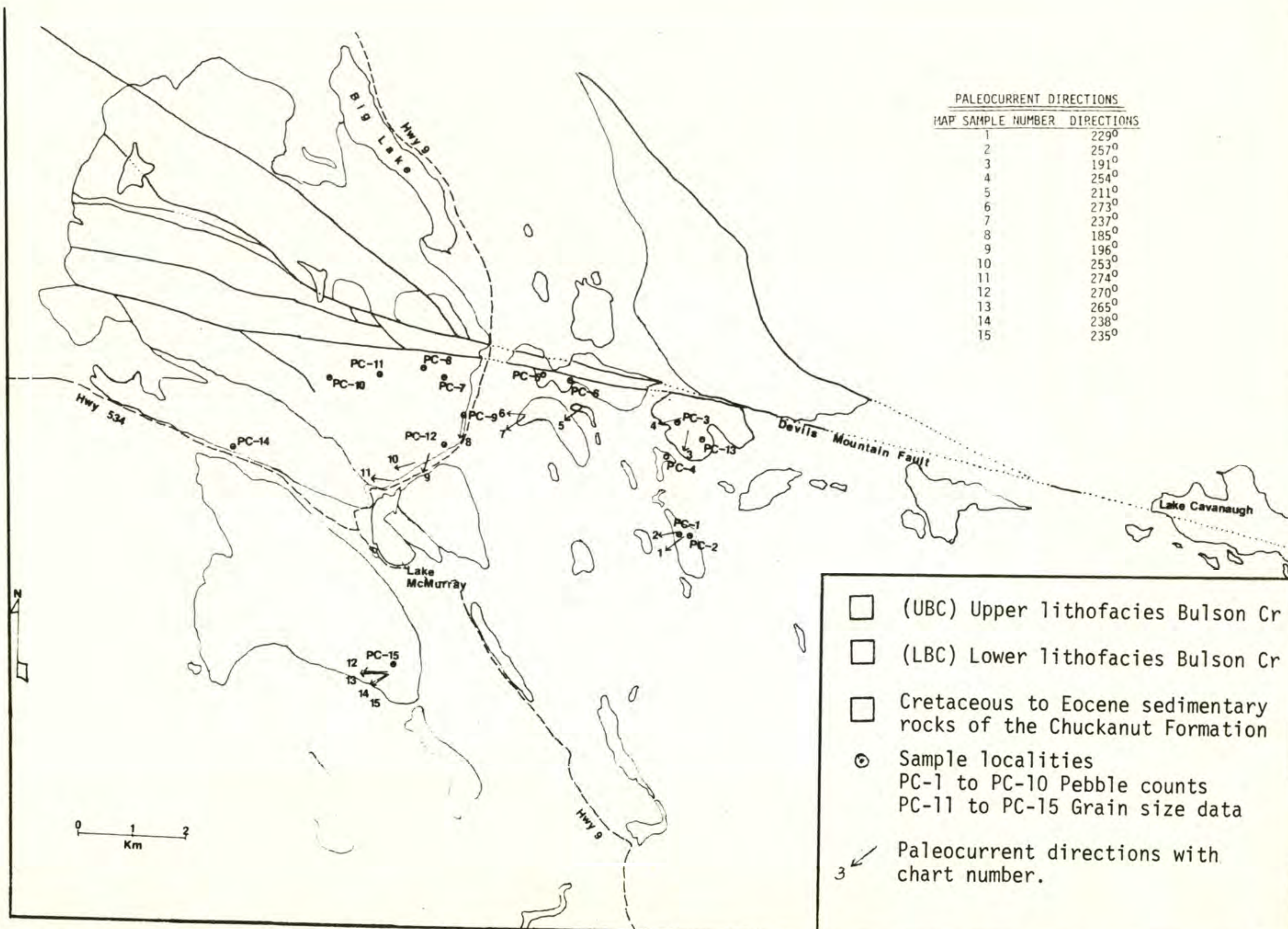

| LITHOLOGY | COLOR | STRUCTURES | SAMPLE # |
|---|---|---|---|
| peb. & cob. cong. w/ss. | | | |
| peb. ss. | | | |
| | | | PC3 |
| cob. cong. | | | |
| | | | PC4 |
| peb. ss. | | | PC13 |
| | | imbricated | Paleo 3 & 4 |
| peb. cong. w/sand | | | |
| | | poorly developed beds evident | |
| cob. cong. | | | |
| ss. m.g. | (5 GY 4/1) | structureless, thick<br>grad. change | LBC2 |
| ss. w/cob. | | | |
| | | grad. change | |
| ss. m.g. to c.g. | (5 YR 4/1) | structureless, thick | |
| peb. ss. | | grad. change | |
| | (10 YR 6/6 & 5 YR 3/2) | | |
| ss. m.g. | (5 GY 3/2) | | |
| | | structureless, thick | |
| ss. w/cob. | | grad. change | |
| | | structurless | |
| ss. m.g. | (5 YR 3/2) | grad. change | |
| | | structureless, thick | |
| peb. and cob.-bearing ss. c.g. | | | |
| | | graded beds | |
| ss. m.g. | (5 YR 4/1) | | |
| peb. cong. w/sand | | | Paleo 2 |
| ss. | (5 YR 4/1) | speroidal & hackly weathering | |
| peb. cong. | (5 GY 4/1) | | PC1 |
| peb. cong. w/s | | graded beds | LBC1 |
| ss. c.g. | | | |
| sl. | (10 GY 3/2) | hackly | |
| ss. f.g. | | | |
| | | thin beds | Paleo 1 |
| | | channelling<br>ripplemarks(?) | |
| chert & vein quartz angular clasts | | chaotic | PC2 |
| paleosol | (10 R 4/6) | brecciated | |
| clast of chert surrounded by clay | | | |
| chert | (5 B 7/1) | wavy bedding & blocky bedding | |

FIGURE 5. Detailed stratigraphic column of the lower lithofacies.




| LITHOLOGY | COLOR | STRUCTURES | SAMPLE # |
|---|---|---|---|
| peb. cong. | | thick structureless | |
| ss w/peb. | | graded bedding & imbricated clasts | Paleo 11 |
| cob. cong. w/peb. and sand | | | |
| peb. cong. | | | LBC 4 |
| ss | | thin laminae | |
| ss and sh. with wood fragments | | thin well defined beds | |
| ss f.g. to m.g. | (10 YR 4/2) | thick moderately well defined beds | |
| ss and sh. | ( 5 YR 2/2) | thin well defined beds | |
| ss m.g. to c.g. | | | |
| peb. cong. | | imbricated | Paleo 10<br>PC 10 |
| | | structureless | |
| ss m.g. | ( 5 GY 3/2) | | |
| | | | PC 11 |
| peb. and cob. cong. w/ m.g. to c.g. sand matrix | | structureless | PC 8<br>PC 7 |
| ss f.g. w/ss lenses | ( 5 YR 3/4) | channel-scour and fill ripple marks festoon crossbeds | |
| ss w/cob. | | imbricated (weak) | Paleo 8 & 9<br>PC 12<br>PC 9 |
| ss w/some f.g. ss | (10 YR 4/2) | thin horizontal lamination | |
| peb. and cob. cong. | | | |
| ss f.g. and ss w/coal seams or lenses | | coal-bearing lenticular sis. | |
| peb. and cob. cong. | | graded beds | |
| | | | Paleo 6 & 7 |
| cob. cong. w/ss | | imbricated | PC 5 |
| | | | LBC 3 |
| | | | PC 6 |
| | | | Paleo 5 |
| peb. and cob. cong. w/ss | | structureless | |

FIGURE 5. Detailed stratigraphic column of lower lithofacies (cont.)




PALEOCURRENT DIRECTIONS

| MAP SAMPLE NUMBER | DIRECTIONS |
|---|---|
| 1 | $229^0$ |
| 2 | $257^0$ |
| 3 | $191^0$ |
| 4 | $254^0$ |
| 5 | $211^0$ |
| 6 | $273^0$ |
| 7 | $237^0$ |
| 8 | $185^0$ |
| 9 | $196^0$ |
| 10 | $253^0$ |
| 11 | $274^0$ |
| 12 | $270^0$ |
| 13 | $265^0$ |
| 14 | $238^0$ |
| 15 | $235^0$ |

FIGURE 6. Location map of pebble count and grain size sample sites. Included is a table with paleocurrent measurements. The number in the table refers to the unlettered numbers on the map. Paleocurrent directions, pebble count, and grain size sample numbers are also shown in Figures 5 and 7.

rocks. These clasts appear to be petrographically similar to rhyolitic ash flows and domes that give 43.5 m.y. old fission track dates (Lovseth, 1975; J. Vance, personal communication, 1979) and intrude or overlie the early Tertiary Chuckanut Formation but do not intrude or overlie the rocks of Bulson Creek.

The various clast lithologies are present throughout the lower lithofacies except at the base where only chert (76%) and vein quartz (24%) are present (Table 2). The basal section is exposed in Pilchuck Creek and on the north flank of Frailey Mountain, south of the west end of Lake Cavanaugh (T33N, R5E, Sec. 27, NE¼SW¼; T33N, R6E, Sec. 28, NE¼SW¼, respectively) where it overlies the rocks of the Trafton Formation.

In Pilchuck Creek, just below the base of the Bulson Creek beds, a paleosol is developed on the Trafton Formation. The Trafton here is composed of bedded chert (Plate 1). At the top of the section in Pilchuck Creek, the chert is deeply weathered and broken up, forming a paleosol (Plate 2) and making it difficult to recognize any bedding that may have existed. Angular fragments that appear to have weathered in place are surrounded by brownish-red to reddish-brown kaolinite-rich clay. Two to four meter diameter blocks of bedded chert are surrounded by highly altered material. Alteration of the Trafton Formation increases in extent toward the unconformable contact with the Bulson Creek. The chert appears to be reworked in that the numerous angular clasts are randomly oriented and the percentage of altered material to unaltered rock increases upwards. This material may be the product of local slumping. The exposures of the contact are limited to the creek bed and sides. An angular unconformity separates the Trafton Formation rocks from the basal member of the lower lithofacies.

The basal member of the Bulson Creek unit consists of pebble and cobble conglomerates. The matrix of the conglomerate consists of reddish-

PLATE 1. The Trafton Formation consists of wavy thin-bedded gray to light brown chert with crosscutting calcite veins. This outcrop is located in Pilchuck Creek.

PLATE 2. Paleosol developed in the rocks of the Trafton Formation. Reddish-yellow and red clay surrounds angular to subrounded clasts of chert, graywacke, and argillite. Recent colluvium seen to the left of the photo, taken in Pilchuck Creek.

brown clay and fine- to medium-grained sand (Table 3). There is a change in the matrix of the conglomerate upsection from reddish-brown clay near the base to yellowish-brown clay, then fine-grained sand, and finally coarse-grained sand and small pebbles. Most of the conglomerate of the lower lithofacies contains only a coarse-grained sand as matrix.

The basal conglomerate of the Bulson Creek seems to have filled in a paleochannel developed in the deeply weathered Trafton Formation. The paleosol is seen beneath and on the south side of the channel. Some of the Bulson Creek rocks crop out topographically below the upper part of the Trafton Formation (Plate 3).

A similar depositional succession is evident on the northwest flank of Frailey Mountain where the Mesozoic rocks of Frailey Mountain are overlain by the lower lithofacies of the Bulson Creek rocks. The rocks of Frailey Mountain consist of graywacke, chert, argillite, and siltstone. The Frailey Mountain rocks at the contact are chert and graywacke; the base of the lower lithofacies rests on a deep red, kaolinite-rich paleosol 20 m thick which developed on the surface of the older rocks (Plate 4).

There is evidence suggesting that faulting has disturbed the basal contact in both Pilchuck Creek and along the northwest flank of Frailey Mountain. On the flank of Frailey Mountain, material resembling fault gouge, clay-rich and gray to grayish-brown in color, cuts across the bedding of both the older and younger rock units (T33N, R6E, Sec. 28, NW, SE). Sandstone beds of the lower lithofacies dip $80^{o}$-$85^{o}$ to the north at the fault, and 40 to 50 m north of the contact dips decrease to $30^{o}$-$35^{o}$ to the north. The increase of the dips towards the fault is due to drag along the fault.

PLATE 3. Bulson Creek rocks overlie Trafton Formation cherts in Pilchuck Creek, with Bulson Creek rocks filling a channel cut into the older rocks. Trace of the channel is shown trending along tick marks from center left side of the photo to the lower right corner.

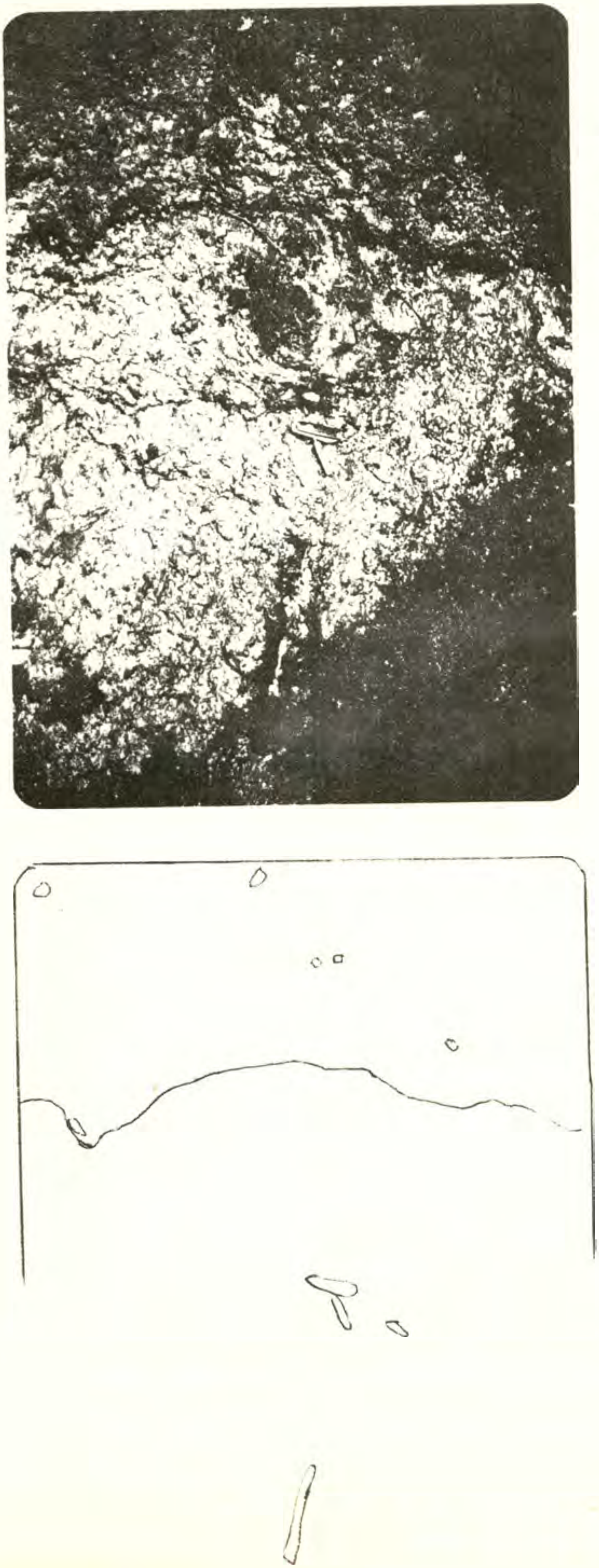


PLATE 4. Paleosol developed in the rocks of Frailey Mountain. Drawing shows inbedded Bulson Creek rocks unconformably overlying the paleosol, north of Frailey Mountain, south of Lake Cavanaugh.

In many outcrops near the base of the Bulson Creek unit and near faults, extensive post-depositional weathering of the conglomerates is evident by the deep weathering rinds on the clasts. Weathering rinds are often over 3/4 of the overall diameter of the clasts. Many of the clasts are iron stained. Clasts of volcanics and granitics can be cut in half with a knife. In most clasts the internal structure of the clasts, such as bedding or flow banding, is preserved. Cores of the larger and more resistant clasts, such as phyllite and chert remain unaltered (Plate 5). The conglomerate in the lower part of this lithofacies is well indurated whereas that higher in this lithofacies tends to be less well indurated.

Coalified wood fragments up to 1 m in length and .5 to 10 cm in diameter are found in the conglomerate; the wood is generally oriented parallel or subparallel to bedding. Fresh fragments of coal have a glassy luster, are brittle and highly fractured, and lack obvious macroscopic textures. The material resembles vitrinite, which is derived from woody plant material (Stach and others, 1975).

Bedding in the conglomerate varies from structureless to imbricated and graded (Plates 6 and 7). Outcrops are laterally discontinuous, so it is difficult to determine horizontal and vertical relationships for some of the small scale features. Imbricate pebbles indicate a paleocurrent direction of transport to the southwest and west ($230^{\circ}$-$270^{\circ}$) (see Fig. 6, p. 22).

Sandstone

Pebbly sandstone and fine- to medium-grained sandstone are interbedded with the conglomerate throughout the lower lithofacies (Fig. 5,

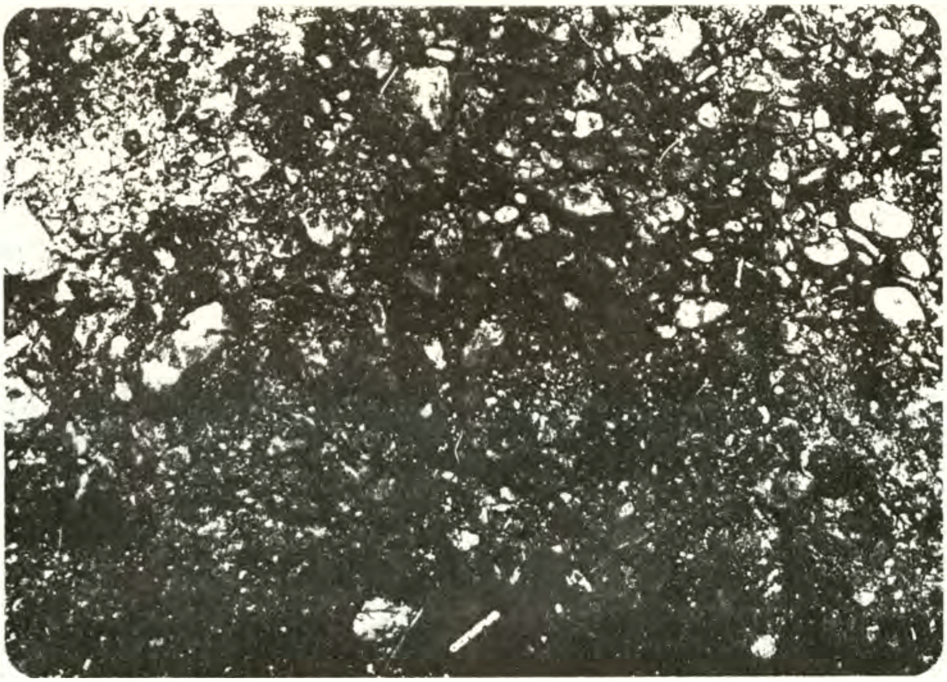


PLATE 5. Limonite stained conglomerate in the lower lithofacies near Lake Cavanaugh Road and intersection with Highway 9.

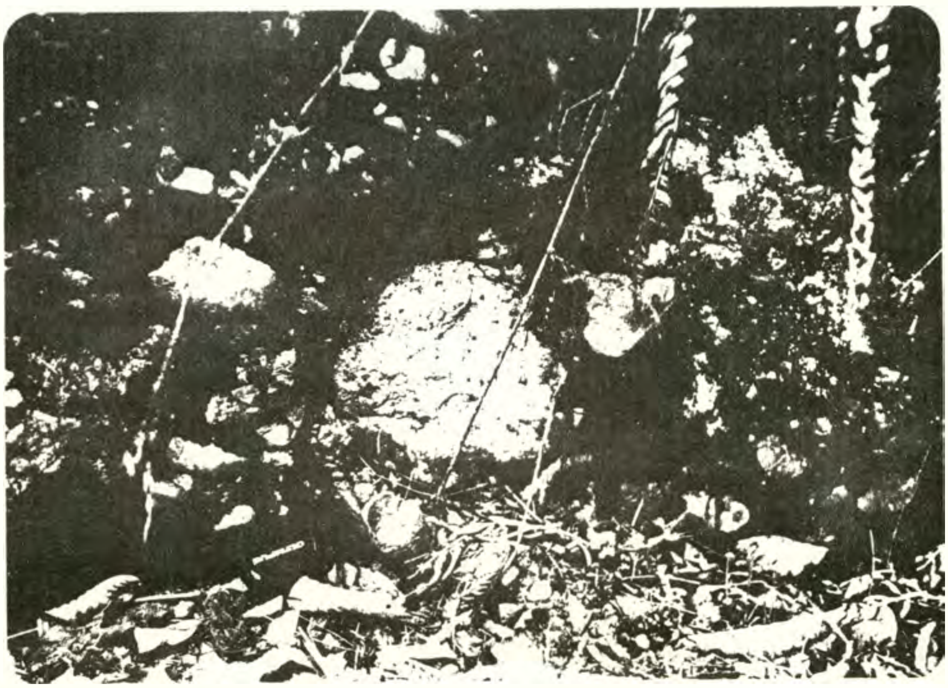


PLATE 6. Clasts in the lower lithofacies of the Bulson Creek rocks. Clasts consist of rhyolite (center), chert, quartzite, and phyllite, and greenstone. Photo taken west of Highway 9, 5 km south of Big Lake.

PLATE 7. Imbricated conglomerate of the lower lithofacies of the Bulson Creek rocks. White clasts are rhyolite, gray are phyllite and greenstone, black are argillite. Photographed in Pilchuck Creek near Pilchuck Falls.

Plate 8). The lowest of the many pebbly sandstones occurs just a few meters stratigraphically above the basal conglomerate. Sandstone appears to form approximately 20% of the section. The sandstone beds are brownish-gray to greenish-brown in color except at the top of some of the beds where there is a reddish-brown oxidized layer (5 m thick). Oxidized layers on the sandstone occur more frequently high in the lower lithofacies than at the bottom, suggesting a longer period between depositional events or an accelerated weathering rate higher in the section.

Point count data indicate that the sands consist of 42% sedimentary rock fragments other than chert, 19% chert, 14% polycrystalline quartz which includes aggregates of quartz grains, 8% monocrystalline quartz, 3% volcanic rock fragments, and 4% plagioclase (Table 4, p. 14 ). The grains are angular to subrounded. The matrix material consists of aphanitic mineral and lithic grains of chert, phyllite, and/or argillite.

Graded bedding, channelling, and festoon crossbedding are evident, although most of the sandstone and pebbly sandstone is structureless and thick-bedded (2-5 m). Pebbles contained in the pebbly sandstone average 2 cm and range up to 7 cm in diameter. The pebbles are composed of chert, phyllite, vein quartz, and argillite(?) (Fig. 6, Table 4). The best exposure of these rocks is in Pilchuck Creek where 40 m of section are exposed (T33N, R5E, Sec. 27, NE¼NE¼).

The sands contain carbonized fragments of leaves and branches. The leaves are of a broad leaf deciduous type commonly found in temperate climates (Wolfe, 1978). Organic material tends to be most abundant at the tops of beds.

PLATE 8. Pebbly sandstone, sandstone, siltstone, and silty shales occur as minor constituents of the lower lithofacies of the Bulson Creek rocks. Conglomerate occurs below (just off the lower left corner of photo) and above these beds (upper right corner). Same location as Plate 7.

## Siltstone and Shale

The siltstone and shale beds are dark gray to brownish-gray, .5 to 1 m thick, and commonly laminated (Plate 9). The siltstone and shale contain a higher percentage (10%) of phyllite and mica than do the coarser grained beds (Table 2). The lowest of the fine-grained beds occurs immediately above the basal conglomerates of the lower lithofacies. The fine-grained rocks commonly occur in a repetitive sequence in association with dark greenish-gray carbonaceous zones. generally 5 to 10 cm thick, and light gray underclay 1 to 3 cm thick (Fig. 5). The leaves in the carbonaceous zones are of a broad leaf variety, are similar to those found in the sandstone, and are indicative of temperate climates (Wolfe, 1978). There are small fragments of coal and shale mixed in with the underclays, which are generally developed on the tops of silty sandstone layers.

Spheroidal weathering is common in the siltstone and shale, overprinting the lamination that was developed during deposition. Graded bedding and some vague ripple-like structures are present.

## Age Relations

The lower lithofacies clearly overlies pre-Tertiary rock; whether it overlies the early Tertiary Chuckanut Formation is not apparent, as this relationship is not exposed. If silicic volcanic clasts found in the lower lithofacies are correlative with silicic volcanics that intrude or overlie the Chuckanut, then it is evident that the rocks of Bulson Creek are younger.

PLATE 9. Siltstone and shale interbedded with pebbly conglomerate in the upper beds of the lower lithofacies. Photograph taken near Highway 9, southeast of Devils Lake.

## Upper Lithofacies

In the field, the upper lithofacies is characterized by the absence of conglomerates and the presence of marine fossils and sedimentary structures characteristic of intertidal or near-shore deposits. Thick sections of sandstone and siltstone are unique to the upper lithofacies.

The upper lithofacies of the Bulson Creek rocks is over 550 m thick (Figs. 4 and 7). It consists (in stratigraphic order from oldest to youngest) of pebbly sandstone, coarse to medium grained sandstone, siltstone, and fine to coarse grained sandstone. Numerous fossiliferous horizons occur above the basal pebbly sandstone. Fossils include marine molluscs and terrestrial plant fragments (Fig. 8).

The rocks at the base of this lithofacies consist of dark grayish-brown to greenish-brown, moderately consolidates, pebbly sandstone that is in excess of 100 m thick (Fig. 7). The pebbles are well rounded and moderately spherical. Clasts range up to 3 cm in diameter and consist of chert, phyllite, and argillite (see pebble counts, Table 4). Pebble-sized clasts account for approximately 20%, by weight, of this pebbly sandstone (Table 3); the remaining material is medium- to coarse-grained sand. The percentage of clasts to sand varies from 12 to 57%, averaging 22%. The clast percentage is higher, averaging 43%, at the base of the channels, in lag deposits, and in the base of thick and massive beds (Plate 10).

Sand-sized material in the pebbly sandstone generally consists of volcanic rock fragments (50%), plagioclase (15%), monocrystalline quartz (10%), polycrystalline quartz (5%), and potassium feldspar (5%) (Table 2). The subangular to rounded framework grains are supported in a matrix of fine sand and silt that comprises about 5% of the rock. The pebbles of

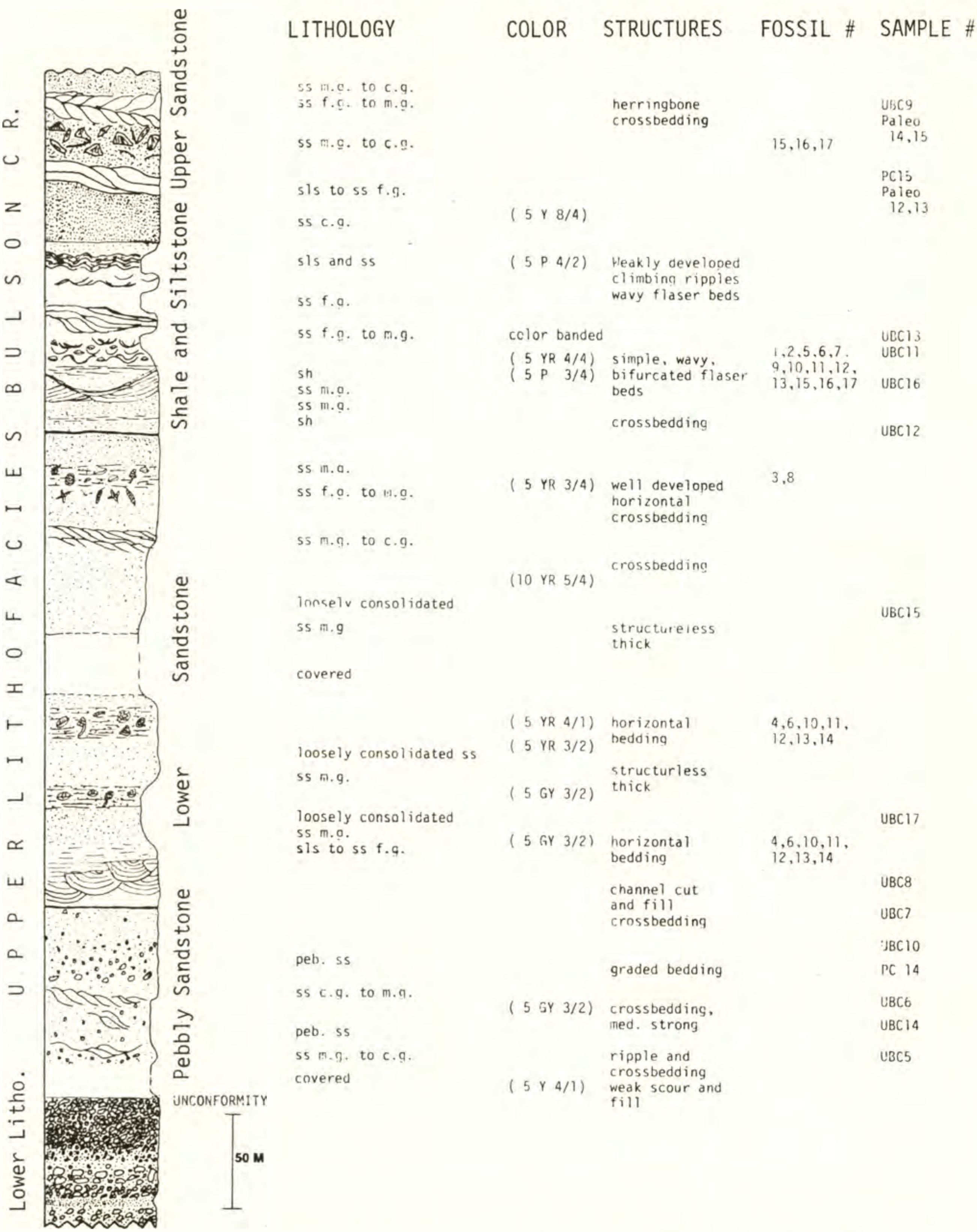



FIGURE 7. Detailed stratigraphic column of the upper lithofacies. Explanation of the abbreviations precedes Figure 5.

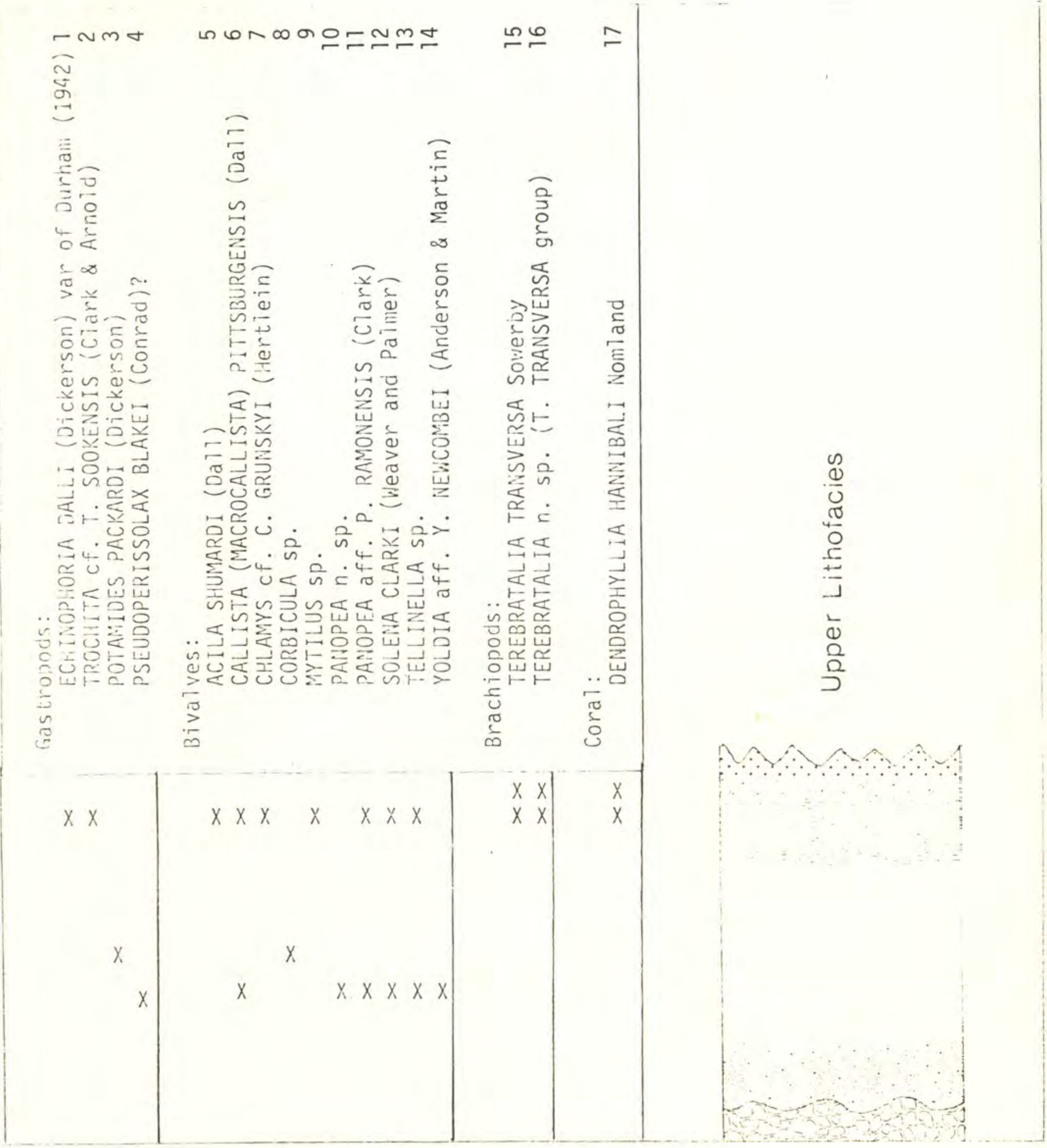
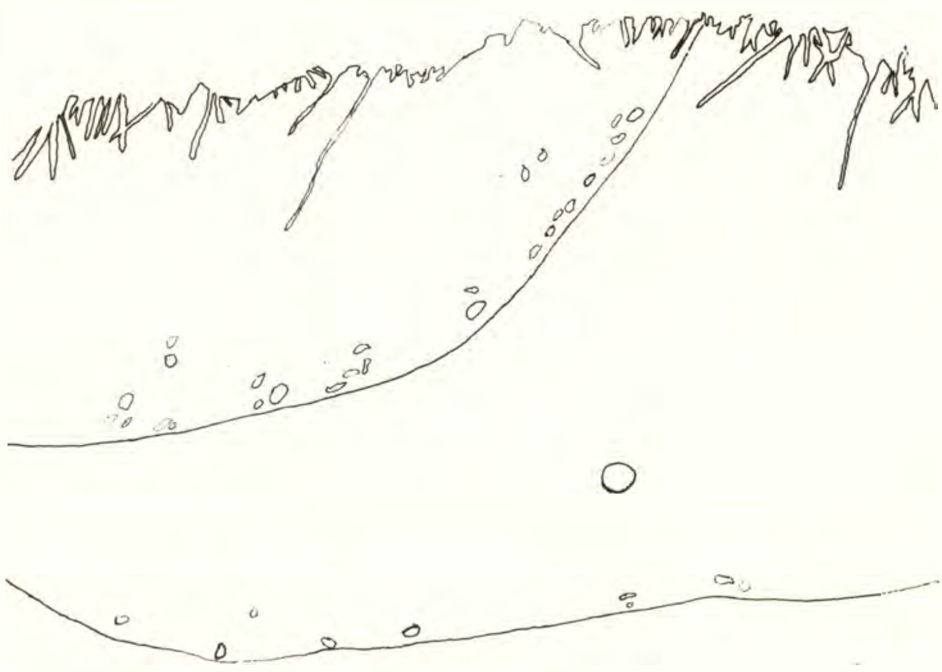



Figure 8. Distribution of fossils in the upper lithofacies of the rocks of Bulson Creek. For symbol legend, see Figure 2. Numbers at the top of the figure correspond with fossil sample site numbers listed in FIGURE 7.

PLATE 10. Pebbly sandstone in the lower beds of the upper lithofacies denote channel lag deposits and channel fills. Photograph taken along the north side of Highway 534, southeast of Lake 16.



the sandstone weather less rapidly than does the finer-grained sediment, leaving the pebbles protruding from the surface of the outcrops. The resistance of the pebbles is probably due to their composition. The resistant pebbles are composed of vein quartz which is believed to be derived from phyllite cut by numerous stringers of quartz. The vein quartz commonly contains fragments of phyllite or argillite. Weathering of the outcrop is generally deep. Iron staining is pervasive, leaving the rocks with a black coating. Pebbles have a thin oxidized rim and are relatively unaltered.

Sedimentary structures present include channel fills, weakly developed graded bedding, and scour and fill marks. The channels are generally about 3 to 5 m across (but can be up to 20 m) and 2-3 m deep (Plate 10). Massive lag deposits in the bottom of the channels consist of rounded to subrounded pebbles and a few cobbles. These coarser-grained sediments grade upward into finer-grained material. The walls of the channels are fairly steep. Scour and fill features are shallower and broader than channels. They are about 6 to 8 m wide and only a few tens of centimeters deep. Weakly developed crossbedding is evident in the scour and fill deposits. Due to the lack of continuous exposure, none of the features could be traced any distance. Sandstones are the most prominent rock type in two stratigraphic horizons in the upper lithofacies (Figs. 4 and 7).

The lower, 250 m thick, sandstone consists of greenish-brown to grayish-brown, loosely to moderately consolidated sandstone and overlies the pebbly sandstone. Calcite-cemented beds, about 1 m thick, are associated with fossiliferous sandy horizons. These calcite-bearing beds are well indurated and relatively unweathered. The sandstones of this unit are lithologically similar to those of the pebbly sandstone unit, except there are fewer lithic fragments (Table 4). The sand grains are subangular to subrounded, moderately spherical, and are more closely packed than any of the previously described units. Petrographic examination reveals that many of the lithic fragments (volcanics, granitics, and phyllite) have been altered and that many of the mafic volcanic grains are pitted and mottled. The surfaces of many of these grains are marred by concavities. The edges of the concavities have been weathered smooth creating an irregular hummocky surface. Pitting and mottling may be due to reaction with pore fluids after deposition (Pettijohn and others, 1973) or to abrasion during transport.

Where beds are cemented by calcite, weathered or oxidized zones penetrate 8-12 cm into the joint-bounded blocks of sandstone; the unweathered portions of the blocks tend to be brittle. There is an abundance of shell material preserved in the unaltered portion of the sandstone. The shells are pelecepods (1 to 2.5 cm long), many of which are fragmented, but some of which remain articulated. A typical sequence of beds contains cross-bedded sand that grades upward into fossiliferous bioturbated sand with thin wavy flaser beds separating the next sequence. The shells have been preserved through both peramineralization and replacement of the calcic shell with silt and fine sand. It appears that as the test was dissolved silt and fine sand filled the void leaving well defined shell-like casts, many of which occur in this horizon. Silt casts of gastropods (6 to 8 cm long as measured along the coiling axis) and pelecepods (2 to 4 cm along the length of the shell) can also be found in both weathered and unweathered portions of the sandstone. Shells are oriented so that the disarticulated valves are parallel to bedding. Worm boring and tree branch casts are also evident.

Crossbedding, foreset crossbeds, and horizontal beds are evident in this unit although they are poorly developed or poorly preserved. Generally the outcrops are thick and massive; only where calcite cement has made the rocks resistant to weathering are sedimentary structures preserved. Rock that contains little cement erodes easily and does not crop out well.

The middle portion of the upper lithofacies, between the two sandstone units, consists of approximately 100 m of fossiliferous siltstone and shale (Fig. 7). These sediments consist of yellowish-brown to reddish-brown, angular to subrounded silt and fine sand. There is a bimodal sorting distribution, as indicated by sieve analysis, with most of the sediment (>75%) in the silt to fine sand size range (.015-.2 mm) and the rest in the clay to silt range (<.015 mm) (Table 3). The shale is finely laminated (.1 to 1 cm thick) and is usually color banded (Plate 11). Flaser beds occur thoughout the section but most commonly in the fossiliferous zones. The clay beds are grayish-brown, wavy, and .5 to 1.5 cm thick and 25 to 40 cm long (Plate 12).

The siltstone and shale beds are generally loosely consolidated, highly oxidized, and deeply weathered. Sedimentary structures are nevertheless preserved. These include crossbedding; current ripple marks; simple, wavy, and bifurcated flaser bedding; horizontal laminations; and poorly preserved climbing current ripples (Plate 12).

The fossils in this unit have been identified as <u>Potamides packardi</u>, <u>Corbicula</u> sp., and <u>Turritella</u> cf. <u>uvasana</u> (Lovseth, 1975; W. Addicottt

PLATE 11. Color banded fine-grained fossiliferous sandstone and siltstone members of the lower part of the upper lithofacies, in a roadcut southwest of Lake McMurray.

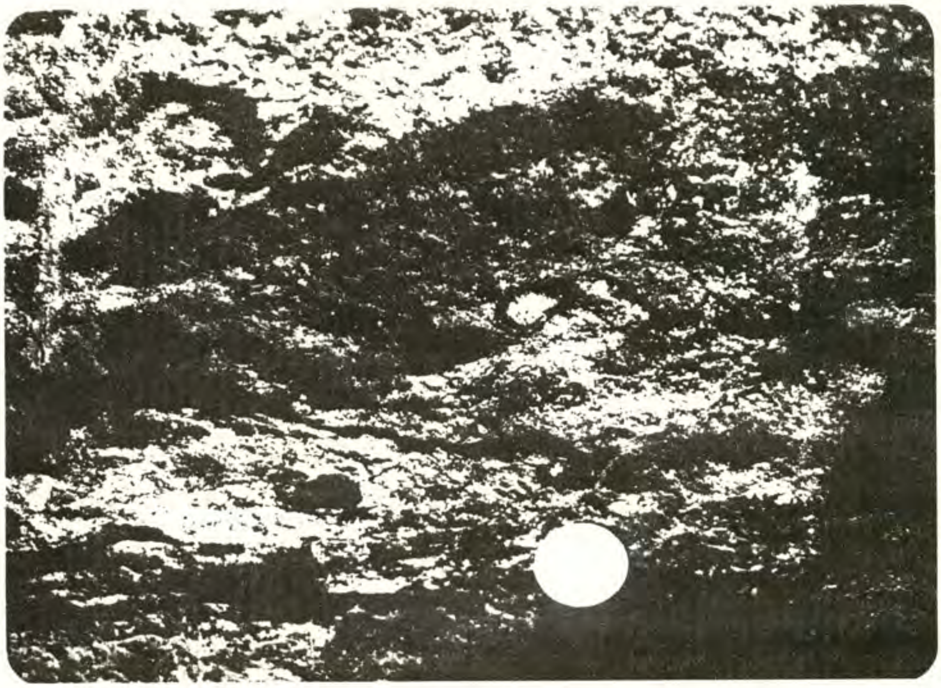
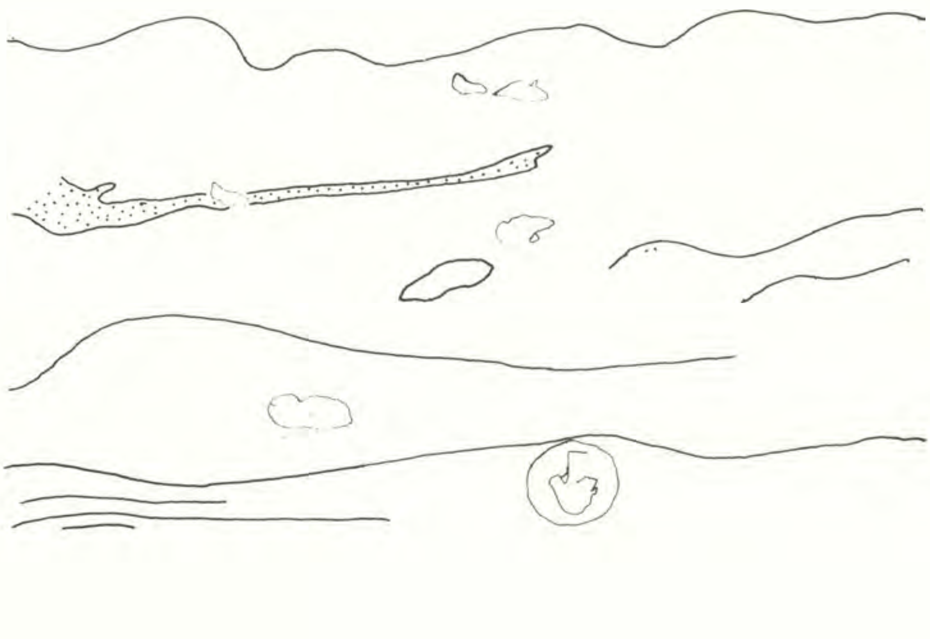


PLATE 12. Detail of Plate 11, showing fossil-bearing horizons and flaser bedding in the lower siltstone member of the upper lithofacies.



and V. Mallory, personal communication, 1977 and 1980, respectively) (Figs. 7 and 8). Many of the fossil bivalves are articulated and in growth position. A variety of sizes of one species (Potamides packardi) is evident, suggesting that both juvenile and adult members are present. All of the remains are preserved as casts. The fossils have been assigned to the upper Eocene and lower Oligocene by Addicott and Mallory (personal communication, 1980).

The >90 m thick sandstone (upper sandstone on Fig. 7) that occurs stratigraphically above the siltstone and shale consists of light yellowish-brown and greenish-brown, crossbedded, fossiliferous, medium- to coarse-grained sandstone. The sand grains are moderately sorted, moderately spherical, and consist of monocrystalline quartz (about 20%), polycrystalline quartz (5%), plagioclase (15%), volcanic lithic fragments (45%), potassium feldspar (5%), and granitic fragments (5%) (Table 2). The percentage of lithic fragments decreases as the granitic fraction and feldspar increase from the bottom to the top of the upper lithofacies (Table 2, Fig. 7). The upper lithofacies is fairly well preserved as it is moderately well consolidated. The best exposure is in a roadcut at the north end of Kahn-Hansen Road (T32N, R5E, Sec. 6, NW, SW, NW; shown as fossil locality #4 on Fig. 2, Plate 13). Well-developed crossbedding is evident, and paleocurrent indicators suggest an overall southwesterly direction of transport (Plate 14).

Macrocallista and Giant Mytilus (Lovseth, 1975; Addicott, personal communication; Marcus, 1980b), as well as fragments of coalified wood, occur in this unit (Fig. 8, Plate 15). Shells of the Giant Mytilus remain articulated, are well preserved, and are up to 15 cm in length; the valves are oriented parallel to bedding. In living specimens the

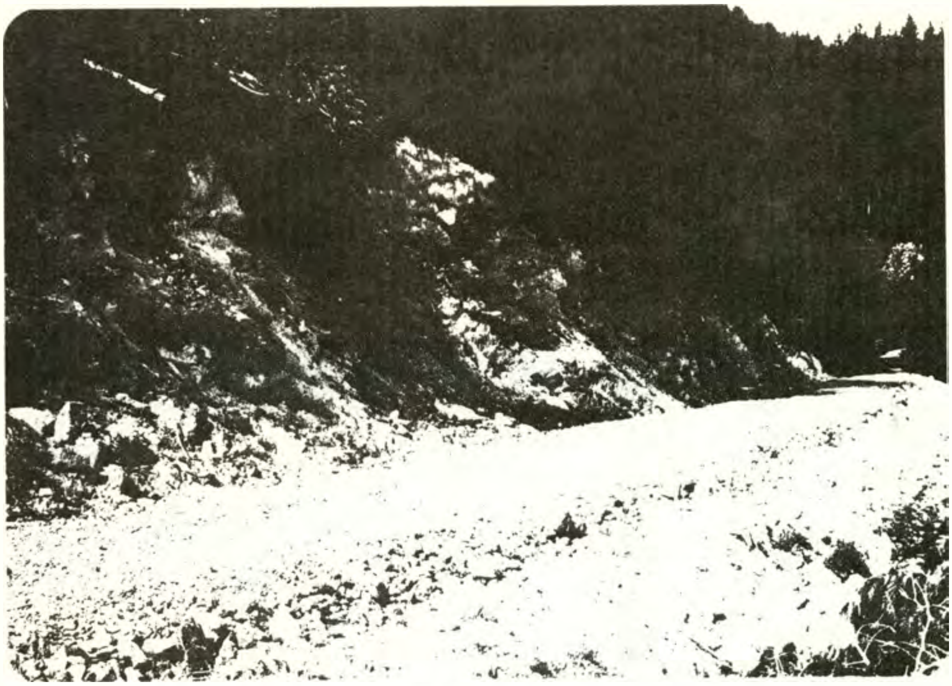


PLATE 13. Sandstone of the upper part of the upper lithofacies, one-half kilometer north of Kahn-Hanson Road.

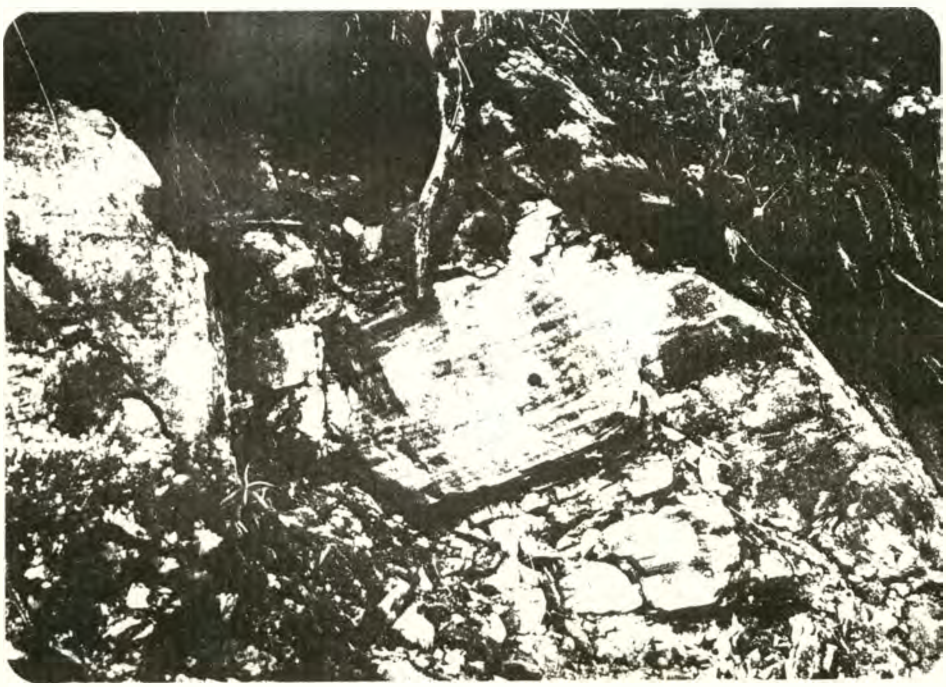


PLATE 14. Crossbedded, moderately sorted, well imbricated, color banded sandstone of the upper lithofacies. Same location as Plate 13.

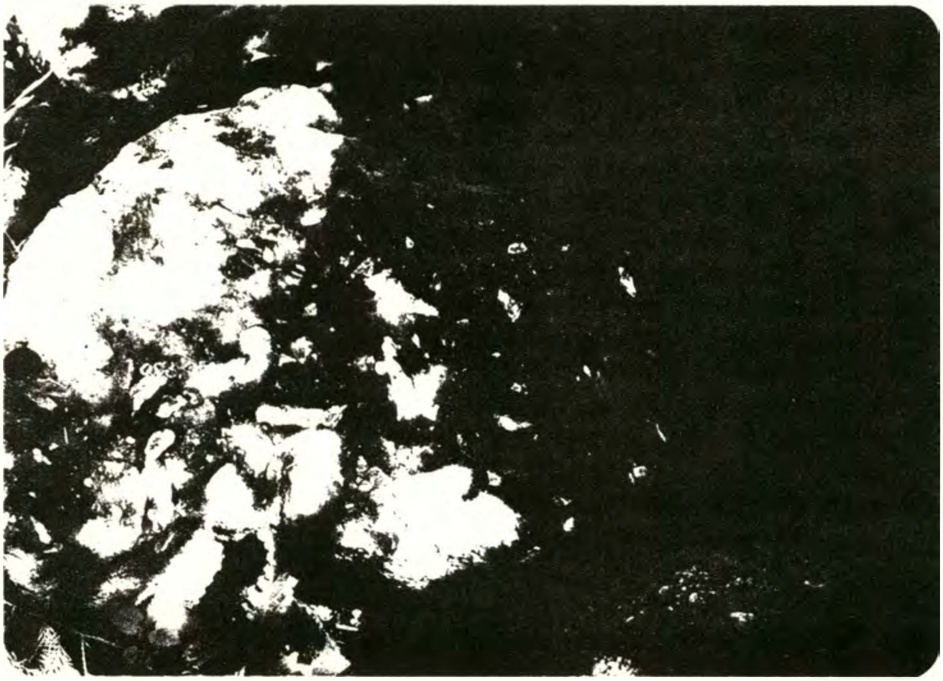


PLATE 15. Giant *Mytilus* and *Macrocallista* in the sandstone of the upper lithofacies. This sandstone also contains some fragments of wood. Same location as Plate 13.

articulated valves are oriented perpendicular to the surface to which they are attached (Moore and others, 1952). These shells must have fallen over after death but remained articulated. This suggests that they have not been transported over a great distance.

# STRUCTURAL RELATIONS

## Relationship Between Bulson Creek Lithofacies

The lower lithofacies rocks were folded along an east-west axis prior to the deposition of the upper lithofacies. The interpretation of the structural relationship between the two lithofacies is based upon detailed mapping and a knowledge of the way geomorphic features develop in the study area. Streams and sag ponds occupy all fault traces (Plate 16). In the area where the two lithofacies are 20 m apart, but where the contact is not exposed, a ridge runs parallel to the strike of both units; the absence of valleys or sag ponds suggests the absence of faults. Furthermore, in the area near the contact between the two lithofacies, the conglomerate and interbedded sands dip moderately steeply to the north, striking east-west while the sediments of the upper lithofacies dip to the south and strike east-west.

## Relation of the Bulson Creek Rocks to Pre-Tertiary Rocks

Pre-Tertiary rocks are either unconformably overlain by or are in fault contact with the Bulson Creek rocks. The best exposures of contact relationships are in Pilchuck Creek (A, T33N, R5E, Sec. 34, SE½NW¼; B, T33N, R5E, Sec. 27, Ncenter SW¼; and C, T33N, R5E, Sec. 27, NE¼SW¼) and on the north flank of Frailey Mountain (D, T33N, R6E, Sec. 28, Scenter NE¼; and E, T33N, R6E, Sec. 28, NW¼SE¼) (see map pocket). The contact where exposed in areas A and D is a fault and in exposures B, C, and E is a depositional contact with the Bulson Creek lying on a paleosol directly on older rocks.

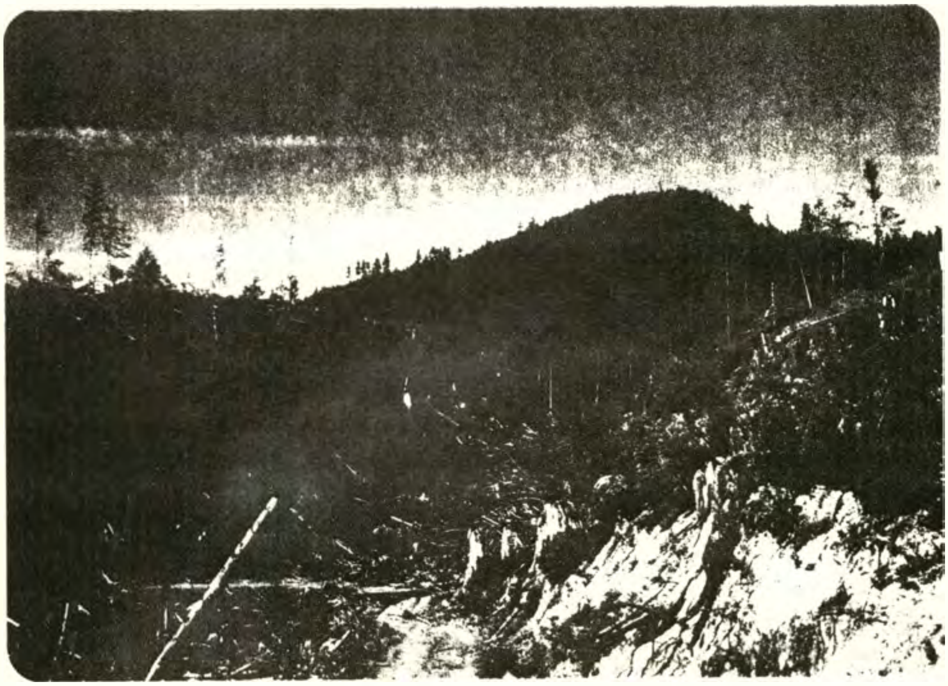


PLATE 16. Weakness in the rocks caused by faults control the location of stream, sag ponds, and the asymmetrical shape of the valleys. The up-thrown side is steeper than the down-thrown side in this photo, taken looking northwest at Devils Mountain.

On the northwest flank of Frailey Mountain (D) the lower lithofacies rocks are in fault contact with the rocks of Frailey Mountain (Plate 17). Bulson Creek rocks dip 85$^{o}$ to the north-northwest at the contact. Clay between beds in this steeply dipping section is derived from the shearing along bedding planes. This clay is absent from between the same beds 30 to 40 meters from the fault. Slickensides are evident in the fault zone and the underlying chert of the rocks of Frailey Mountain is brecciated in a zone of approximately 4 m thick.

A fault relationship between the Trafton Formation and the Bulson Creek rocks is evident in Pilchuck Creek (Plate 18, locality A). Numerous depressions contain fault gouge clay, slickensides, and bright reddish oxidation. The depressions are usually very narrow, up to 1 m wide and perhaps 10 m long.

The few other exposures (B, C, E) of the contact between older rocks and Bulson Creek rocks have been discussed in the section describing the conglomerate of the lower lithofacies Bulson Creek rocks. The basal section of the lower lithofacies unconformably overlies a paleosol in Pilchuck Creek (B) and a paleosol on Frailey Mountain (E). At locality D in Pilchuck Creek the Bulson Creek unit unconformably overlies the Trafton sequence. This outcrop is very small, less than 10 m in diameter; it appears to be in place as the dips of both units are similar to those measured in nearby outcrops.

## Relation of the Bulson Creek Rocks Tertiary Rocks

The Chuckanut Formation is an early Tertiary unit that crops out north of the Devils Mountain fault. In the type area, in exposures

PLATE 17. Gouge zone in a fault between the rocks of Frailey Mountain on the left and Bulson Creek rocks on the right. Photo taken south of Lake Cavanaugh.

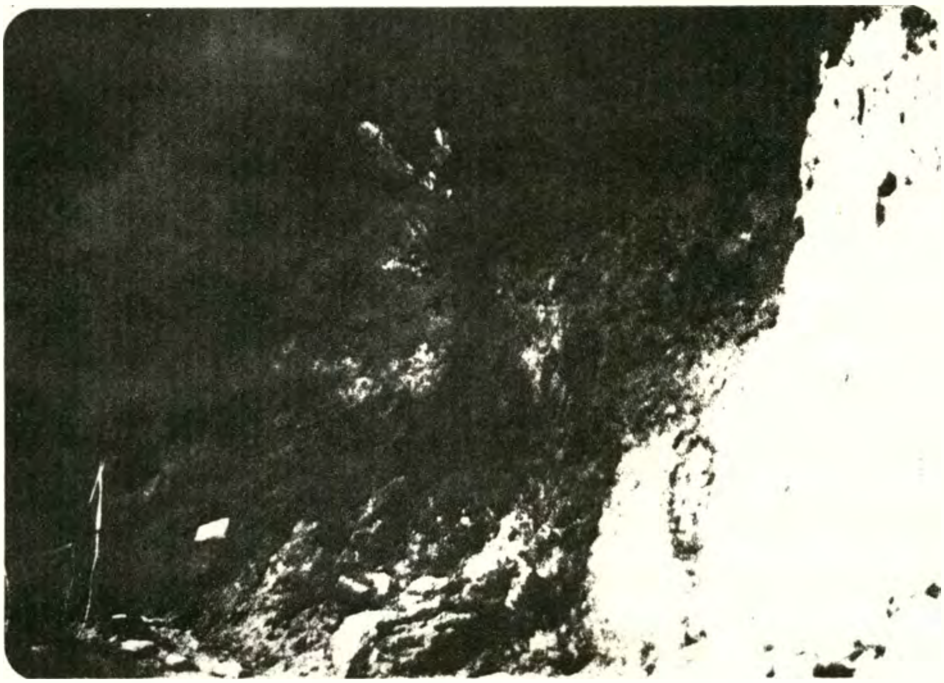


PLATE 18. Fault zone between the rocks of Bulson Creek to left and the Trafton Formation on the right, in Pilchuck Creek.

along Chuckanut Drive in Whatcom County,

> "The Chuckanut formation is composed for the most part of massive crossbedded to stratified medium- to coarse-grained grayish-brown to brownish-gray sandstone and subordinate amounts of sandy shales, varying in color from gray to light- and dark-brown depending to some extent upon the amount and dink of weathering to which they have been subjected. Certain strata assume a green to bluish tint. Intercalated within the sandstone, and, at many localities at the base of the formation, occur thick lenses of conglomerate which is usually hard and firmly cemented and varies from a few inches to over 100 feet in thickness. The well-rounded pebbles entering into the formation are composed of white quartz and various types of metamorphic and igneous rock which vary greatly in proportion in different lenses as well as in the size of the pebbles, the amount of rounding and the character of the matrix which cements them. Many of the very thick bands of conglomerate contain lenses of coarse, gritty- to pebbly-sandstone which often exhibit marked crossbedding. These sandstones either grade gradually into the more pebbly portions of the conglomerate or terminate abruptly by sharply defined contact lines. The fresh unweathered material varies from a dark brownish- to bluish-gray but upon alteration becomes stained to a yellowish- or reddish-brown." (Weaver, 1937, p. 77)

Sandstones in the type area contain quartz, feldspar (plagioclase, orthoclase, and minor amounts of microcline), sedimentary rock fragments, mica, chlorite, and smectite (Frizzell, 1979; Kelly, 1970; D. Pevear, personal communication, 1980).

The rocks immediately north of the Devils Mountain fault have been called Chuckanut Formation by Jenkins (1924), Norbisrath (1937), Weaver (1937), Hobbs and Pecora (1941), and Lovseth (1975). They contain coal and interbeds of siltstone, shale, and conglomerate. However, the mineralogy of these rocks is different than the Chuckanut Formation in the type area. These rocks contain more mono- and polycrystalline quartz, plagioclase, potassium feldspar, kaolinite, and minor amounts of sedimentary, volcanic, and granitic rock fragments (Table 2). The difference in the detrital modes may signify that either these rocks are different in age and origin or that the source was somewhat different. These rocks are 45 to 50 km south of the type area.

Petrographic examination of samples from the fault-bounded arkosic sandstone body that is south of the main splay of the Devils Mountain fault indicates that a low grade hydrothermal event has altered the rock as suggested by the presence of alteration rims of epidote around the plagioclase grains. This block otherwise appears petrographically and physically similar to the arkosic sandstone that crops out of the main fault.

## Relation of the Bulson Creek Rocks to Tertiary Intrusives and Extrusives

Numerout Tertiary subareal silicic ash flows, domes, and dikes crop out in Walker Valley and on Devils Mountain. The ash flows and domes have been chemically analyzed and can be classified as rhyolites (Lovseth, 1975; Videgar, 1978). The dike rocks are compositionally both dacites and andesites (Lovseth, 1975). Lovseth states that these igneous rocks "are spatially associated with faults and commonly have a circular outcrop pattern". A zircon separate from one ash flow yielded a fission track date of 41.5 ± 3.4 m.y. (Lovseth, 1975). This date has been recalculated by J. Vance (personal communication, 1979) using a new decay constant as 43.5 ± 3.4 m.y. Other ash flows and flow-banded and auto brecciated dome-like rocks have been dated by Bechtel, Inc., as being concordant with the 43.5 m.y. date of Lovseth (Bechtel geologist, personal communication, 1980).

Clasts of the silicic volcanics (up to .4 m in diameter) are common in the lower lithofacies Bulson Creek rocks (Plate 5). The formerly glassy clasts are partially or totally altered to soft smectitic clay.

Quartz, sanidine, and plagioclase phenocrysts remain with only a slight alteration around the rims of most crystals. Volcanic clasts from the Bulson Creek conglomerate contain grains of quartz and feldspar that show resorption. Therefore the clasts in the Bulson Creek rocks appear to be similar to the ash flow deposits north of the fault. Nowhere south of Devils Mountain fault or its splays do these silicic volcanic rocks crop out.

Volcanic clasts in the Chuckanut Formation in northern Skagit County do not show this type of resorption. No volcanic clasts have been reported in the sandstone units immediately north of the fault; either that unit predates this style of volcanism or the streams that contributed the sediments did not flow through volcanic terrane.

# DISCUSSION

## Depositional History and Paleoenvironmental Interpretation of the Bulson Creek Rocks

### Before Deposition of the Lower Lithofacies

A paleosol of Eocene or pre-Eocene age is found, in places, at the unconformity above which late Eocene-early Oligocene rocks were deposited (Figs. 4, 5). A paleosol represents in-place weathering of a rock that is above sea level. There is little to no transportation of the weathered material. Paleosols formed in warm, wet, temperate climates contain abundant kaolinite (Thompson and others, 1978), as do the paleosols in this area (D. Pevear, personal communication, 1980). Another kaolinite paleosol has been described by Horton (1978) underlying the mid-Eocene conglomerate and sandstone of the Huntingdon Formation which is exposed in northern Whatcom County and across the border in Canada.

The presence of a paleosol indicates a long period of weathering in conjunction with little active transport of the weathered material. Thompson (1978) has suggested that the presence of kaolinite as the predominant clay is an indication of a temperate climate and little active transport. Abbott and others (1976) and Peterson and Abbott (1973) have described similar paleosols developed in other areas of the west coast of North America during Eocene time. The causes of renewed transportation of sediments are either a change in climate or tectonic uplift. A change in climate is difficult to determine but it appears that although worldwide climate changed during the Eocene (as the dramatic changes in sea level or the $0^{18}$ data indicate), there was no significant change in the amount of rainfall (Wolfe, 1978). Therefore, the deposition of an extensive and thick section of conglomerate, such as those of the lower lithofacies, could only be associated with tectonic deformation.

Lower Lithofacies

The presence of cut-and-fill channel features and deposits, point bar sequences, and the presence of overbank deposits suggest that parts of the lower lithofacies consist of aluvial fan channel and point bar deposits. Heward (1978) has described two environments where thick, massive beds of conglomerate could form and suggests two possible modes of deposition: either in the channel of a river or as the produce of debris flows. The presence of sand beds that contain coal and lack of angular clasts supports the former as the best model for the B.C. conglomerates. Festoon crossbeds, foreset beds, and pebbly sandstone are commonly associated with point bar sequences as described by Allen (1965), McEwen (1969), Visher (1972), and Heward (1978). The interbedding of the conglomerate with sandstone reflects lateral motion of the stream channel. The siltstones may represent overbank deposits associated with flooding over channel levees in back swamp or flood plain environments. Underclays could develop beneath peat bogs or in swamps. Repetitive layers of siltstone, shale, and organic-rich swamp deposits represent a cyclic depositional pattern of overbank deposition.

The angular breccias found in the basal section in Pilchuck Creek could be explained as slump or soil creep deposits that post-date the development of the paleosol. The initial downcutting into the paleosol may have coincided with uplift of the area.

Upper Lithofacies

Channel and scour-fill features and graded pebbly sandstones such as those at the base of the upper lithofacies are characteristic of a fluvial environment of deposition that is normally associated with sedimentation in meandering rivers (Allen, 1965; Visher, 1972; Reineck and Singh, 1975, Vos, 1977; and BeMont, 1978). Point bar sequences generally contain four distinguishing features, two of which can be identified in the pebbly sandstone of the upper lithofacies (Reineck and Singh, 1975) (Fig. 7). These include scour pool deposits and lower point bar deposits. The latter are poorly graded or stratified deposits that can contain foreset crossbeds and small trough-fill crossbeds (Reineck and Singh, 1975). The other two features are either absent or not well developed. These include large-scale foreset cross-bedding and trough-fill crossbedding. Channels of the dimensions found in the field are normally only associated with meandering rivers and not with braided rivers (Reineck and Singh, 1975; Voss, 1977). This basal section of point bar deposits is a transition sequence. The presence of shallow water marine fossils and terrestrial plant fossils in the upper portions of the upper lithofacies require a transition from the fluvial to a estuarine or nearshore marine depositional environment (Marcus, 1980a, 1980b).

The lower sandstone member grades upward into rocks that contain flaser beds, crossbeds, current ripple marks, and the fossils Potamides p. and Corbicula that suggest an intertidal or nearshore (swash zone) environment of deposition (Allen, 1965, 1970; Pettijohn and others, 1973; Vos, 1977; W. Addicott and S. Mallory, personal communication, 1976 and 1980, respectively). The intertidal deposits grade upward into the upper sandstone member that contains crossbedded medium- to coarse-grain sandstone and Macrocallista, Giant Mytilus, and fragments of coalified wood. These features suggest a marine environment of deposition in the middle to sublittoral zone (Clifton and others, 1971; Reineck and Singh, 1975; W. Addicott, personal communication, 1977). The entire upper lithofacies is indicative of a marine transgressive sequence.

A worldwide late Eocene-Oligocene transgression has been reported by Vail (1977), Vail and others (1977), and Vail and Henderson (written communication, 1978) (Fig. 9, p. 60). This transgression may have coincided with tectonic subsidence of the basin in which the Bulson Creek rocks were deposited. The evidence for tectonic activity in northwest Washington during the early Tertiary is abundant. The Chuckanut Formation formed in a rapidly subsiding basin the the Paleocene to middle Eocene (Griggs, 1966; Schmidt, 1972; Hartwell, 1979), silicic volcanic rocks erupted in the area southeast of Mt. Vernon (43 m.y.a.), and the Bulson Creek rocks were folded and subsequently faulted beginning in the late Eocene or early Oligocene.

## Possible Correlative Units

Sedimentary rocks in the Puget Sound area that may be equivalent either lithologically or chronologically to the Bulson Creek rocks include the Paleocene to middle Eocene Chuckanut Formation, the early to middle Eocene Puget Group, the middle to later Eocene Huntingdon Formation, the early to middle Oligocene Blakely Formation, and the middle to upper Oligocene Sooke Formation (Table 5). A brief discussion of these units follows a discussion of Puget Lowland sedimentation.

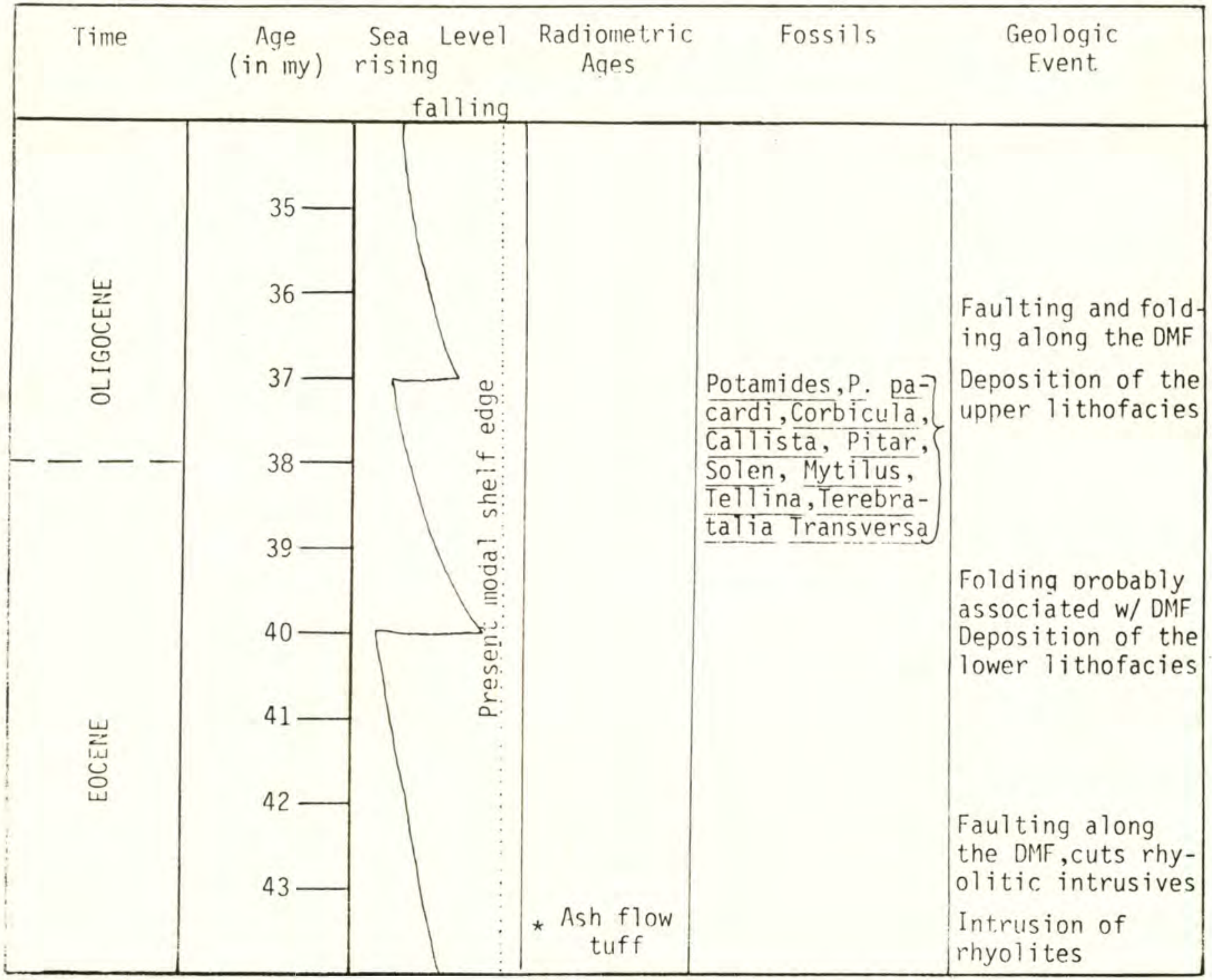



FIGURE 9. Correlation chart relating global sea level curves, radiometric data, and fossil ranges, with geologic events. Sea level data from Vail (1977) and Vail and Mitchum. DMF = Devils Mountain fault .

| | Rocks N. of DMF (Chuckanut Fm) | | | Bulson Creek | | | South of Sedro Woolley | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Map | CS-10 | CS-11 | CS-12 | BC1 | BC2 | BC3 | CS2 | CS3 | CS5 | CS6 | CS7 |
| No. | M78-C10 | M76-C24 | | JY77-8 | VF78-165 | VF78-166 | VF78-142 | JY76-38 | JY76-58 | JY77-35 | JY77-37 |
| 1. Tot | (300) | (300) | (300) | (519) | (545) | (480) | (603) | (577) | (528) | (541) | (597) |
| 2. Q | ( 36) | ( 40) | ( 41) | ( 36) | ( 15) | ( 6) | ( 43) | ( 32) | ( 39) | ( 57) | ( 45) |
| 3. Qm | 18 | 27 | 25 | 6 | 11 | 5 | 32 | 18 | 34 | 44 | 19 |
| 4. Qp | 18 | 13 | 16 | 30 | 4 | 1 | 11 | 14 | 5 | 13 | 26 |
| 5. Lv | 6 | 5 | 4 | 7 | 55 | 56 | 3 | 7 | 1 | 5 | 5 |
| 6. Ls | 3 | 2 | 19 | 32 | | | | 3 | 2 | 1 | 5 |
| 7. P | 27 | 24 | 16 | 2 | 9 | 16 | 23 | 28 | 22 | 17 | 30 |
| 8. K | 13 | 10 | 2 | 1 | 2 | 2 | 12 | 8 | 13 | 13 | 6 |
| 9. m | 6 | 2 | 5 | | | | 4 | 3 | 13 | 1 | 4 |
| 10. p & a | | | 1 | | 1 | 1 | | | | | |
| 11. g & r | 7 | 13 | >1 | 3 | 1 | | 7 | 17 | 6 | 5 | 1 |
| 12. Misc | 2 | 2 | 1 | 19 | 18 | 18 | 8 | 1 | 2 | 1 | |
| 13. Unknown | | 1 | 1 | 1 | 1 | 1 | | 2 | 2 | 1 | 3 |
| 14. Matrix | | | 8 | | | | | | | | |
| TOTAL PERCENT | 100 | 99 | 99 | 101 | 102 | | 100 | 101 | 100 | 101 | 99 |

TABLE 5. Point count data from Frizzell (1979) rocks. For sample locations, see Figures 2b and 2c.

| | Map No. | CH2 VF78144 | CH3 VF78145 | CH6 VF78149 | CH7 VF78150 | CH9 VF78152 | CH10 VF78153 | H1 VF78154 | H2 VF78156 | BF1 VF78101 | BF6 VF78132 | BF7 VF78134 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Chuckanut Formation | | | | | | Huntingdon | | Blakeley Formation | | |
| 1. | Tot | (553) | (460) | (443) | (501) | (625) | (653) | (584) | (655) | (601) | (606) | (383) |
| 2. | Q | ( 30) | ( 37) | ( 34) | ( 45) | ( 32) | ( 33) | ( 25) | ( 39) | ( 1) | ( 12) | ( 5) |
| 3. | Qm | 21 | 24 | 22 | 15 | 15 | 23 | 17 | 14 | 1 | 8 | 4 |
| 4. | Qp | 9 | 13 | 12 | 30 | 17 | 10 | 8 | 25 | | 4 | 1 |
| 5. | Lv | 5 | 4 | 1 | 13 | 13 | 5 | 5 | 8 | 34 | 23 | 50 |
| 6. | Ls | 2 | 3 | 2 | 6 | 5 | 2 | 5 | 12 | | 1 | 1 |
| 7. | P | 32 | 34 | 35 | 20 | 23 | 17 | 20 | 16 | 12 | 34 | 31 |
| 8. | K | 3 | 10 | 12 | 3 | 1 | 6 | 5 | 5 | | 2 | 1 |
| 9. | m | 3 | 10 | 12 | 3 | 3 | 16 | 35 | 8 | 5 | | |
| 10. | p & a | | | | | | | | | 1 | 1 | 3 |
| 11. | g & r | 6 | | 1 | 2 | 2 | 11 | 2 | 12 | 41 | 19 | |
| 12. | Misc | 15 | 2 | 4 | 3 | 17 | 9 | 2 | 1 | 1 | 5 | 6 |
| 13. | Unknown | 3 | 1 | 1 | 5 | 4 | 2 | 1 | 2 | 4 | 4 | 3 |
| 14. | Matrix | | | | | | | | | | | |
| TOTAL PERCENT | | 99 | 101 | 102 | 100 | 100 | 101 | 100 | 103 | 99 | 101 | 100 |

TABLE 5. Point count data from Frizzell (1979) rocks (continued).

Snavely and Wagner (1963) have shown that late Eocene arkosic sediments were deposited along a narrow band north of the present day northern shore of the Olympic Mountains and south of the San Juan Islands. The band swings south and parallels the west side of the Cascade Range. Snavely and Wagner (1963) state that nonmarine arkosic sand was deposited in coastal swamps that were northeast of the deposition of marine arkosic sand and silt. Drummond (1979), Nilsen and McKee (1979), and Cameron (1979) describe late Eocene to early or middle Oligocene sediments deposited chiefly at bathyal depths along the southern shore of Vancouver Island in the Tofino Basin (Fig. 10). No shallow water marine or terrestrial late Eocene to early Miocene sediments in the area immediately north of the Leech River-Devils Mountain fault have been described in the literature. The Paleocene to middle Eocene Chuckanut Formation crops out in its type area 50 km north of the Lake McMurray area. Although there are conglomerates containing rare silicic volcanic clasts in the Chuckanut Formation, the conglomerates are not as massive, do not contain clasts that are as angular, and do not contain as much volcanic or phyllitic material as do the Bulson Creek rocks (Griggs, 1966; Kelly, 1970; Frizzell, 1979). No marine fossils have been identified in the Chuckanut, but pollen in the Chuckanut suggests that at least part of the Chuckanut may be Paleocene while other parts are as young as middle Eocene (Griggs, 1966; K. Reiswig, personal communication, 1980).

The early to late Eocene Puget Group consists principally of nonmarine (deltaic) deposits with subordinate interbeds of shallow and deep water marine deposits that intertongue with terrestrial volcanics

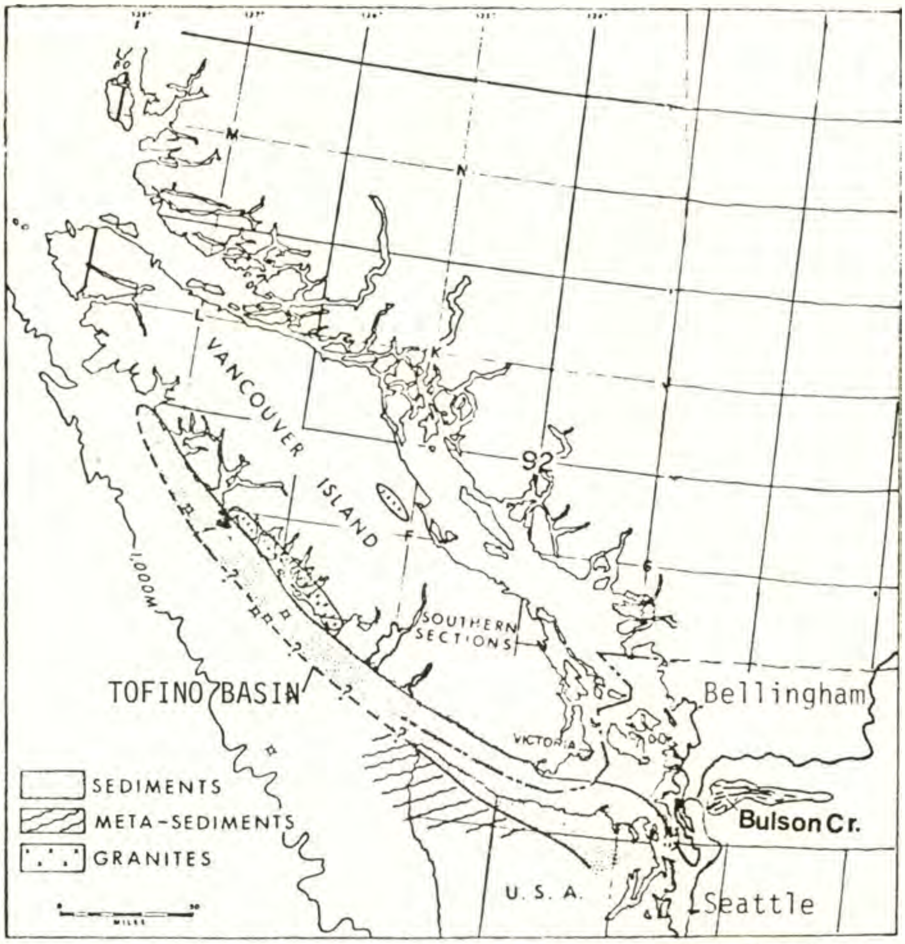



Figure 10. The Tofino depositional basin as defined by Drummond (1979).

(Vine, 1969; Buckovic, 1979). The Puget Group is a similar age to the Bulson Creek rocks. Buckovic (1979) states that the Puget Group is restricted to the area roughly between Centralia and Issaquah, Washington, by topographic highs created by volcanic deposits.

Another formation of similar age is the middle to late Eocene Huntingdon Formation, which consists of thick, massive beds of conglomerate interbedded with sandstone and shale (Miller and Misch, 1963; Hopkins, 1966). The Huntingdon was deposited unconformably on a paleosol developed on pre-Tertiary rocks (Horton, 1978; D. Pevear, personal communication, 1980). The southernmost exposures of this unit are 70 km north of Lake McMurray in Whatcom County. Due to the great distance between outcrops of the Huntingdon Formation and Bulson Creek rocks it is unlikely that these units were layed down in the same depositional basin. The Bulson Creek rocks were not transported a great distance from their source area, as is evident by the angularity of the clasts and the presence of silicic volcanics that appear similar to the local volcanics. I suggest that similar conditions of paleosol development on pre-Tertiary rocks followed by Eocene-Oligocene uplift, erosion, and deposition prevailed in the two areas to produce rocks that are environmentally and chronologically similar.

The lower to middle Oligocene Blakely Formation consists of deep water marine turbidite sequences. It is exposed in the Seattle-Bremerton area, 80 km to the south of Lake McMurray (McLean, 1977; Buckovic, 1979). The Blakely contains thick sequences of conglomerates that were deposited in underwater channels and covered over by finer-grained turbidites. This type of sequence may represent a deep-water version of the depositional stages of the Bulson Creek rocks, although it may be too young to be correlated with the Bulson Creek rocks.

The middle to upper Oligocene Sooke Formation crops out on the southern end of Vancouver Island, British Columbia, Canada. It is located on the south side of the Leech River faults and, as has been suggested by W. R. Danner (personal communication), has been deposited under similar environmental conditions to the Bulson Creek rocks. The Sooke Formation contains thick and massive beds of conglomerate, interbedded with sandstone, siltstone, and shale (Sutherland-Brown, 1966). The Sooke Formation appears to be younger than the Bulson Creek rocks (Weaver, 1937; Sutherland-Brown, 1966) and contains abundant basaltic clasts that are not evident in the Bulson Creek unit; it is therefore probably not correlative with the Bulson Creek rocks. It may, however, have been deposited as a result of the same processes of basin formation and very rapid deposition.

It is suggested that the Bulson Creek rocks were deposited in an isolated basin of limited extent. There were similar basins throughout the Puget Lowland, as evident from the previously described units. Many of these deposits were localized by the structural or topographic basin into which they were deposited and/or by the meandering rivers that emptied into the Puget Lowland on the continental margin. H. Gower (personal communication, 1975) suggested this hypothesis some years ago, referring mainly to the Puget Group and the Chuckanut Formation, but I think this hypothesis will be found to apply to more units as more detailed studies of each are conducted.

## The Devils Mountain Fault

The Devils Mountain fault is a fault zone which contains three main splays and numerous shorter faults (Fig. 1 and see map pocket). The main faults join together in Walker Valley (northern Lake McMurray area), continuing eastward as one main fault.

The structural complexities of the Lake McMurray area were first recognized by Jenkins (1924). He believed that these rocks are the limbs of an anticline with an east-west trending fold axis. Roth (1926) hypothesized that tectonism had complicated the depositional and structural history of the area. Norbisrath (1939) mapped a fault in the Devils Mountain area along which he recognized two periods of motion, evident by brecciation and mineralization during the first period and a repositioning of the early Tertiary sedimentary rocks during the second period.

Hobbs and Pecora (1941) mapped and named the main splay of the Devils Mountain fault and state that there were three major periods of faulting. The first period of deformation (normal faulting) coincided with the folding of the Eocene Chuckanut sandstone and the formation of silica-carbonate rock along the fault zone; the second period of deformation (also normal faulting) caused brecciation of the silica-carbonate rock; the last period of faulting produced gouged, grooved, and slickensided surfaces and localized cross-facturing in the Mesozoic deposits as well as in the adjacent Eocene sandstone. They were able to determine on the basis of observation in outcrops, mining tunnels, and drill cores, that the attitude of the fault plane ranges from vertical to a dip of sixty degrees to the south. Hobbs and Pecora (1941) state the Eocene sandstone exposures north and south of the fault are limbs of an east-west trending anticline.

Lovseth (1975) believed that the motion along the fault was strike-slip. He concludes that the Bulson Creek rocks were transported to their present position from the west along the Devils Mountain fault.

Whetten (1978) refers to the Devils Mountain fault as a major east-west trending left-lateral fault that links San Juan Island thrust terrane with Cascade range thrust terrane. Whetten believes that displacement along the fault began in mid-Cretaceous time and may have coincided with motion along Mesozoic thrusts (Shuksan, Church Mountain, and Haystack thrust plates).

Miller (1979) presents a complicated set of possibilities with regard to the motion along the fault. He states that early movement along the fault may have been vertical with the north side down-dropped. This style of motion would agree with Hobbs and Pecora's (1941) early deformation. Normal faulting during late Eocene time, down-dropping the south side of the fault, could explain the relationship of the Bulson Creek rocks with the arkosic Chuckanut Formation.

Sutherland-Brown (1966), Lovseth (1975), MacLeod and others (1977), Gower (1978), and Fairchild (1979) suggest that the Devils Mountain fault is related to the Leech River fault of southern Vancouver Island, Canada (Fig. 11). The Leech River fault is of late Eocene-early Oligocene age (Sutherland-Brown, 1966; Fairchild, 1979). The unmetamorphosed Sooke gabbro, sedimentary rocks of the Sooke Formation and the volcanic rocks or the Metchosin Formation on the south side are faulted against strongly metamorphosed pelitic rocks, sandstone, and volcanics of the Leech River

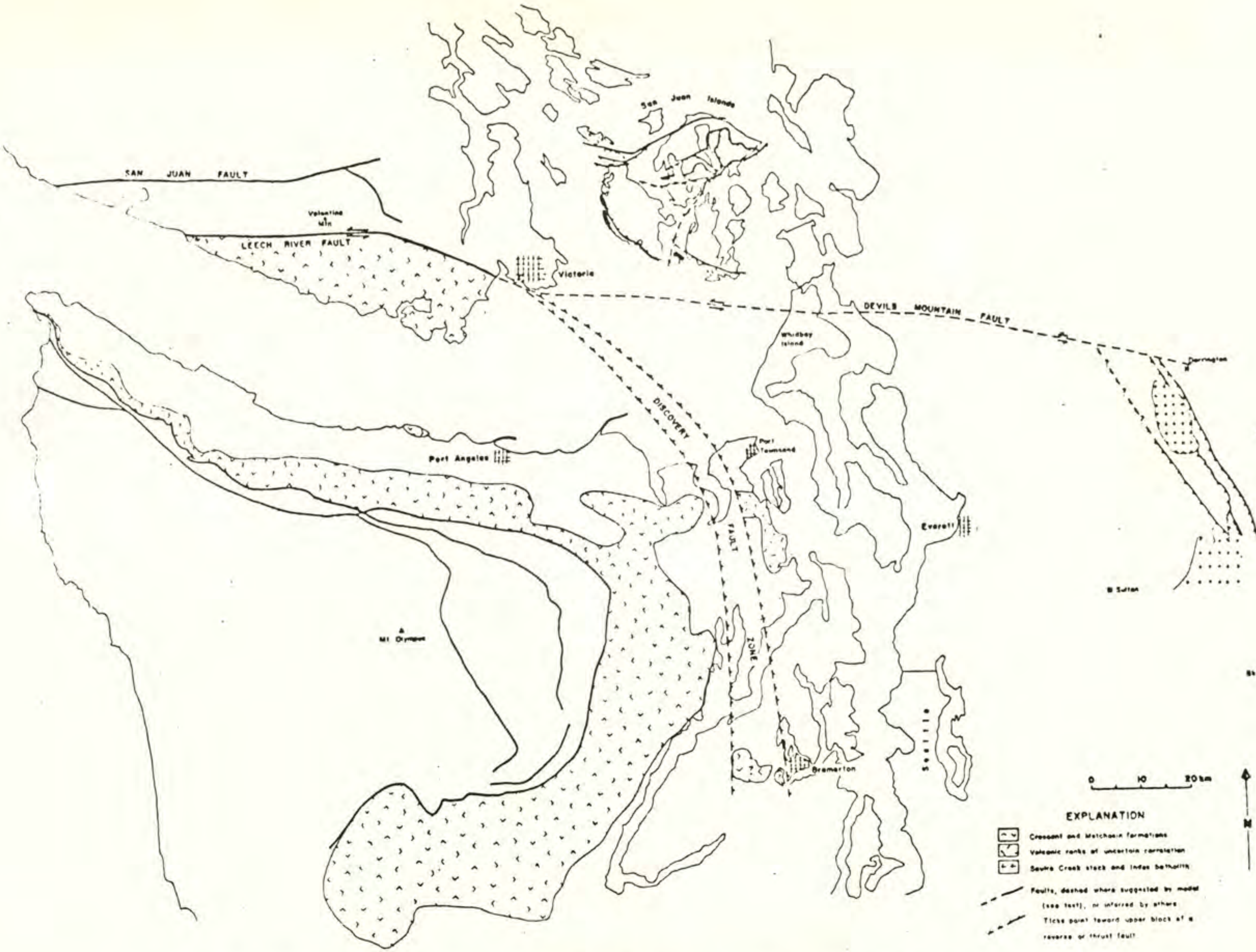



FIGURE 11. Map showing the relationship between the major faults in the northern Puget Sound of Washington.(Fairchild , 1979)

unit on the north side (Fig. 11) (Fairchild, 1979). The Leech River unit is interpreted by Fairchild (1979) to be allochthonous, emplaced after 40 m.y. ago along the strike-slip faults that have 60 to 70 km of left-lateral displacement. Seismic reflection profiles taken directly offshore of the trace of the Leech River and Devils Mountain faults substantiate on-shore mapping (Snavely and others, 1974; Tiffin and others, 1975; MacLeod and others, 1977). Also the axes of gravity and magnetic anomalies trend parallel to the supposed trace of the faults (Snavely and others, 1974).

Geologic mapping and geophysical surveys also suggest the presence of an east-dipping fault along the east side of the Olympic Peninsula (Fig. 11) (Fairchild, 1979; P. Snavely, personal communication, 1976). The fault has been called the Discovery fault by Fairchild (1979). He proposes that the arcuate pattern of rocks of the Olympic Peninsula suggests eastward structural arching resulting in eastward shortening. This shortening was absorbed or transmitted principally in the form of underthrusting along the Discovery fault system. Fairchild (1979) states that the deformation caused by arching of the Olympics was confined on the north by the Leech River-Devils Mountain fault. The amount of shortening diminished eastward the Leech River-Devils Mountain fault to a point where faulting ended and no shortening occurred. The furthest eastward expressions of the compressional forces are evident as reverse faults in the western Cascade Range (Fairchild, 1979) (Fig. 11). These faults dip westward approximately $70^{0}$ and strike north-south (Misch, 1966; Vance and Dungan, 1977; Fairchild, 1979). These reverse faults are intruded by the 34 m.y. old epizonal granodioritic Squire Creek pluton and the 32 m.y. old Index pluton (Vance and Dungan, 1977). Therefore, faulting in this area must have begun and terminated prior to 34 m.y. ago. Localized arching in the Olympic Peninsula must have continued into the Miocene, because Miocene rocks of the Clallam Formation were deformed (Fairchild, 1979).

As previously demonstrated, the Bulson Creek rocks were deposited in both non-marine and shallow water marine (inner neritic to tidal) environments. Many of the shells are articulated and in growth position. The sediments were not transported far from the source area (Roth, 1926; Norbisrath, 1939; Marcus, 1980a, 1980b). There is an abundance of silicic volcanic clasts in the Bulson Creek rocks that are very similar petrographically to the ash flows found north of the fault. Phenocrysts of quartz and potassium feldspar from the ash flows and the silicic volcanic clasts both show resorption characteristics that have not been identified with any other volcanics of the area (Roth, 1926).

Within the Devils Mountain area the Tertiary sedimentary rocks on both sides of the fault are deformed. From half a kilometer to several kilometers north of the fault the Chukcanut Formation is gently folded with fold limbs dipping $20^o$-$30^o$ away from the east-west axis of folding. Within half a kilometer of the fault the beds are overturned $80^9$-$85^o$ to the south with a strike that is parallel to the fault (N80W). Deformation in the lower lithofacies of the Bulson Creek rocks is also evident. Dips are steep ($75^o$-$85^o$) at and near the fault, but shallow toward the south. Two kilometers south of the fault these rocks dip only $25^o$-$30^o$ north, creating an asymmetrical syncline (map in pocket). The upper lithofacies rocks dip to the south $35^o$-$45^o$ at the nearest outcrops to the fault, but dip only $5^o$-$15^o$ to the south at Highway 534.

The Bulson Creek rocks lend credence to Fairchild's (1979) hypothesis in several ways. First, compression called crustal buckling which created a basin into which these sediments were rapidly deposited. Crustal buckling was due to up-arching of the Olympic Peninsula causing shortening to the north and east. Second, continued deformation, originating to the west, is apparent because the Bulson Creek rocks were deformed prior to deposition of the lower and upper lithofacies. Third, the rocks adjacent to the Devils Mountain fault underwent several periods of deformation along both vertical and strike-slip faults (Roth, 1926; Norbisrath, 1939; Hobbs and Pecora, 1941; Snavely and Wagner, 1963; Whetten, 1978; Miller, 1979; Marcus, 1980b). These periods of deformation occurred simultaneously with periods of deformation noted on southern Vancouver Island and the Olympic Peninsula (Snavely and Wagner, 1963; Miller and Misch, 1963; Sutherland-Brown, 1966, and Fairchild, 1979).

Finally, field mapping and interpretation of the rocks on both sides of the fault indicate that the Bulson Creek rocks probably were displaced along a left lateral strike-slip fault but that the distance of displacement was not great, as most of the displacement along the Devils Mountain fault took place prior to deposition of the Bulson Creek rocks. The Shuksan and Church Mountain faults were offset 20 to 30 km by the Devils Mountain fault prior to the deposition of the Bulson Creek rocks (Miller, 1979). The volcanic clasts in the Bulson Creek rocks seem to be associated with the intermediate stages of faulting, which was normal in motion, as there are no similar volcanic clasts in the Chuckanut sandstone to the north of the fault. The fault zone and the Chuckanut north of it are intruded by rhyolite domes. The absence of intrusives south of the fault may be the result of strike-slip displacement of the Chuckanut Formation sandstones and their possible intrusives from this area.

Angularity of the clasts and grains, the thickness of the conglomerates, the probable local source of the volcanic clasts, the deltaic and nearshore sedimentological structures, and the presence of terrestrial plant fragments preclude the deposition of the Bulson Creek units very far to the west where Nilsen and McKee (1979), Snavely and Wagner (1963), and Drummond (1979) have determined that the water depth was deep (bathyal).

This evidence supports Fairchild's (1979) arguments that there was compression of deposits now in the Puget Lowland during the late Eocene. Compression may have caused the uplift or basin subsidence that preceded deposition of the Bulson Creek rocks as well as the unconformity between the two lithofacies. The depth of the water to the west and the necessity to have a local source area for the sediments supports Fairchild's (1979) contention that the 60-70 km of left-lateral strike-slip displacement that he has inferred along the Leech River fault has been dissipated to only a few tens of kilometers in the Devils Mountain area by compression of Puget Lowland sediments and the absorption of some of the crustal shortening to the west by the Discovery fault system.

# CONCLUSION

In conclusion, the rocks of Bulson Creek consist of two mapable late Eocene to early Oligocene lithofacies in the Lake McMurray area of Washington. The lower unit, which consists of conglomerate, pebbly sandstone, sandstone, and siltstone, was deposited in a fluvial environment and rests unconformably on paleosols developed on pre-Tertiary rocks.

The upper lithofacies, which consists of pebbly sandstone, sandstone, siltstone, and shale, was deposited in a fluvial to near-shore environment. An angular unconformity exists between the lower and upper lithofacies. Sediment of these two lithofacies was at least partially locally derived.

Uplift of the Olympic Mountains to the west caused compressional folding and faulting along the continental margin. The Bulson Creek rocks were deposited in one of the compressional basins and were subsequently faulted by the Leech River-Devils Mountain fault system along which deformation began in pre-Tertiary time. Motion along the fault continued into the late Oligocene. The lower lithofacies rocks were folded prior to deposition of the upper lithofacies. Both units were then offset along the Devils Mountain fault to their present position.

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