1961

Geology of the Kelly Hill area, Stevens County, Washington

Wilbur David Kuenzi

The University of Montana

Let us know how access to this document benefits you.
Follow this and additional works at: https://scholarworks.umt.edu/etd

Recommended Citation
https://scholarworks.umt.edu/etd/2438

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
GEOLOGY OF THE KELLY HILL AREA,
STEVENS COUNTY, WASHINGTON

by

W. DAVID KUENZI

B.S. WASHINGTON STATE UNIVERSITY, 1959

Presented in partial fulfillment of the requirements for the degree of
Master of Science

MONTANA STATE UNIVERSITY

1961

Approved by:

[Signatures]

Chairman, Board of Examiners

Dean, Graduate School

[Date]
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>1</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>PREVIOUS WORK</td>
<td>1</td>
</tr>
<tr>
<td>PRESENT STUDY</td>
<td>3</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>4</td>
</tr>
<tr>
<td>PHYSIOGRAPHY</td>
<td>5</td>
</tr>
<tr>
<td>TECTONIC SETTING</td>
<td>6</td>
</tr>
<tr>
<td>STRATIGRAPHY</td>
<td>9</td>
</tr>
<tr>
<td>GLASGO MARBLE</td>
<td>10</td>
</tr>
<tr>
<td>KELLY HILL PHYLLITE</td>
<td>10</td>
</tr>
<tr>
<td>CHERTY QUARTZITE AND PHYLLITE</td>
<td>13</td>
</tr>
<tr>
<td>Cherty quartzite</td>
<td>14</td>
</tr>
<tr>
<td>Phyllite</td>
<td>15</td>
</tr>
<tr>
<td>Origin and environment of deposition</td>
<td>17</td>
</tr>
<tr>
<td>Age and correlation</td>
<td>20</td>
</tr>
<tr>
<td>GREENSTONE</td>
<td>22</td>
</tr>
<tr>
<td>Origin and environment of deposition</td>
<td>23</td>
</tr>
<tr>
<td>Age and correlation</td>
<td>24</td>
</tr>
<tr>
<td>CHURCHILL FORMATION</td>
<td>25</td>
</tr>
<tr>
<td>Argillite and graywacke</td>
<td>27</td>
</tr>
<tr>
<td>Significance of argillite and graywacke</td>
<td>29</td>
</tr>
<tr>
<td>Conglomerate</td>
<td>31</td>
</tr>
<tr>
<td>Significance of conglomerate</td>
<td>33</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Plate</th>
<th>1. Geologic map of Kelly Hill area</th>
<th>in pocket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate</td>
<td>2. Structure sections</td>
<td>in pocket</td>
</tr>
<tr>
<td>Plates 3-5</td>
<td>Triassic fauna from Kelly Hill area</td>
<td>106-108</td>
</tr>
<tr>
<td>Figure</td>
<td>1. Index map of Kelly Hill area</td>
<td>2</td>
</tr>
<tr>
<td>Figure</td>
<td>2. Tectonic setting during late Paleozoic time</td>
<td>7</td>
</tr>
<tr>
<td>Figure</td>
<td>3. Stratigraphic column</td>
<td>11</td>
</tr>
<tr>
<td>Figure</td>
<td>4. Outcrop of cherty quartzite</td>
<td>14</td>
</tr>
<tr>
<td>Figure</td>
<td>5. Photomicrograph of cherty quartzite</td>
<td>16</td>
</tr>
<tr>
<td>Figure</td>
<td>6. Photomicrograph of recrystallized cherty quartzite</td>
<td>16</td>
</tr>
<tr>
<td>Figure</td>
<td>7. Photomicrograph of quartzitic phyllite</td>
<td>18</td>
</tr>
<tr>
<td>Figure</td>
<td>8. Photomicrograph of quartzitic phyllite</td>
<td>18</td>
</tr>
<tr>
<td>Figure</td>
<td>9. Photomicrograph of argillite</td>
<td>30</td>
</tr>
<tr>
<td>Figure</td>
<td>10. Photomicrograph of graywacke</td>
<td>30</td>
</tr>
<tr>
<td>Figure</td>
<td>11. Photomicrograph of chert-pebble conglomerate</td>
<td>34</td>
</tr>
<tr>
<td>Figure</td>
<td>12. Outcrop of limestone-cobble conglomerate</td>
<td>34</td>
</tr>
<tr>
<td>Figure</td>
<td>13. Typical exposure of mound type limestone body</td>
<td>37</td>
</tr>
<tr>
<td>Figure</td>
<td>14. Typical exposure of thin-bedded limestone</td>
<td>37</td>
</tr>
<tr>
<td>Figure</td>
<td>15. Photomicrograph of lime mud</td>
<td>39</td>
</tr>
<tr>
<td>Figure</td>
<td>16. Photomicrograph of bioclastic carbonate sand</td>
<td>39</td>
</tr>
<tr>
<td>Figure</td>
<td>17. Photomicrograph of calcareous sandstone</td>
<td>41</td>
</tr>
<tr>
<td>Figure</td>
<td>18. Photomicrograph of diabase</td>
<td>56</td>
</tr>
<tr>
<td>Figure</td>
<td>19. Photomicrograph of andesite</td>
<td>56</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>20</td>
<td>Poles to axial planes of minor folds in the Churchill formation</td>
<td>65</td>
</tr>
<tr>
<td>21</td>
<td>Point location of fold axes in the Churchill formation</td>
<td>66</td>
</tr>
<tr>
<td>22</td>
<td>Poles to bedding in the Churchill formation</td>
<td>68</td>
</tr>
<tr>
<td>23</td>
<td>Poles to slaty parting in the Churchill formation</td>
<td>69</td>
</tr>
<tr>
<td>24</td>
<td>Photomicrograph of coquina</td>
<td>75</td>
</tr>
<tr>
<td>25</td>
<td>Correlation of Owentian faunas</td>
<td>78</td>
</tr>
<tr>
<td>26</td>
<td>Extent of Lower Triassic seas</td>
<td>80</td>
</tr>
<tr>
<td>27</td>
<td>Phylogeny of <em>Dieneroceras</em></td>
<td>90</td>
</tr>
<tr>
<td>Table 1</td>
<td>Modal analysis of intrusive rocks of acidic composition</td>
<td>49</td>
</tr>
<tr>
<td>Table 2</td>
<td>Comparison of Lower Triassic pelecypods and gastropods of Northeastern</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>Washington with those</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of other areas</td>
<td></td>
</tr>
<tr>
<td>Table 3</td>
<td>Measurements of <em>Dieneroceras cf. D. dieneri</em></td>
<td>93</td>
</tr>
<tr>
<td>Table 4</td>
<td>Comparison of <em>Dieneroceras cf. D. dieneri</em></td>
<td>94</td>
</tr>
<tr>
<td>Table 5</td>
<td>Measurements of <em>Arnautoceltites aff. A. dieneri</em></td>
<td>96</td>
</tr>
<tr>
<td>Table 6</td>
<td>Comparison of <em>Arnautoceltites aff. A. dieneri</em></td>
<td>96</td>
</tr>
<tr>
<td>Table 7</td>
<td>Measurements of <em>Owenites aff. O. koeneni</em></td>
<td>99</td>
</tr>
<tr>
<td>Table 8</td>
<td>Comparison of <em>Owenites aff. O. koeneni</em></td>
<td>99</td>
</tr>
</tbody>
</table>
GEOLOGY OF THE KELLY HILL AREA,
STEVENS COUNTY, WASHINGTON

W. David Kuenzi

ABSTRACT

The Kelly Hill area includes 23 square miles in T.37N. and T.38N., R. 37E., and lies between the Kettle and Columbia rivers north of their convergence in Stevens County, Washington.

Permian(?) and (or) Carboniferous (?) sedimentation is represented by cherty quartzite and phyllitic quartzite which probably originated as silica gel in sea water. Greenstone, slightly younger than the cherty quartzite, probably represents submarine intrusions into the consolidating silica gel.

The fusulinid Parafusulina substantiates the Permian, probably Middle Permian age for part of the Churchill formation. Ammonoids indicate that part of the formation is of Lower Triassic age. Stratigraphic and structural relationships of the Middle Permian and Lower Triassic rocks can not be definitely determined. The Lower Triassic exposures are probably within a down-dropped fault block.

Sediments of the Churchill formation accumulated in a rapidly but differentially subsiding marine basin near emergent areas periodically subjected to rapid erosion. Graywacke and conglomerate were probably deposited from turbidity currents triggered by slumping conditions on unstable slopes. The occurrence of limestone pods in texturally consistent belts suggests accumulation parallel to ancient shorelines.
Textural differences from belt to belt are interpreted as the result of fluctuations in relative sea level and corresponding differences in current intensity at any one geographic point in the depositional basin.

Small granitic bodies, possibly related to the Jurassic and Cretaceous granitic intrusions of the western Cordillera, and Tertiary (?) andesite and diabase dikes intrude the sedimentary units.

**Owenites aff. **O. koeneni, **Arnauceltites aff. **A. dieneri, and **Dieneroceras cf. **D. dieneri indicate a correlation with the lower Owenian Meekoceras fauna of the Great Basin, establish the existence of Lower Triassic rocks in the northwestern Cordillera, and indicate that the lower Owenian sea extended northward to northeastern Washington.

The upper Owenian sea believed to connect the Fort Douglas, Utah area and northeastern British Columbia may represent a northward extension of the lower Owenian seaway.
INTRODUCTION

This thesis is the result of a detailed study of the geology of the Kelly Hill area in Stevens County, Washington. Because previous geological work in this vicinity had been largely of a reconnaissance nature, it appeared desirable to study a small area in greater detail, giving equal consideration to the stratigraphy, structure, paleontology, and petrography, to better understand the geology of the area.

The Kelly Hill area forms the southern extension of the Rossland Mountains, and lies between the Kettle and Columbia rivers just north of their convergence. The area mapped includes approximately 23 square miles in T.37N. and T.38N., R.37E., Washington. Latitude 48°45' N. and Longitude 118°05' W. pass through the area.

To the west of the Kelly Hill area and paralleling the Kettle River is U.S. highway 395. Access to the area from U.S. highway 395 is via graveled roads which lead to bridges that span the Kettle River. One of these is at the southern end of the area, one at Boyds, and a third at Barstow near the northwestern corner of the area. A secondary dirt road encircles the Kelly Hill area. Numerous old logging roads, many of which are impassable, lead to various points within the area (see Figure 1).

Previous Work

Weaver (1920) mapped Stevens County on a scale of 1:125,000. This work was done in one field season and resulted in a reconnaissance map of the region. Weaver mapped the area presently under consideration as
Figure 1. Index map of the Kelly Hill area and vicinity. The area mapped is shown in red. (From U.S. Dept. of Agriculture Forest Service map of the Colville National Forest, 1953).
Carboniferous Mission argillite, which includes argillite, quartz mica schist, and limestone. Bowman (1950, Thesis, Harvard Univ.) mapped the Orient area which includes the northern one-third of the Kelly Hill area and extends northward to the 49th parallel. Daly (1912, 1915), Jones (1959), Waters and Krauskopf (1941), Dawson (1896), Pardee (1918), and Park and Cannon (1943) have published pertinent papers on the geology of northeastern Washington and southern British Columbia. Eardley (1951), McKee et al. (1959), and McLearn and Kindle (1950) are especially valuable sources on broad regional aspects of the Pacific Northwest.

PRESENT STUDY

Field work for this study was conducted during July, August, and September, 1959, and several days during July 1960. Approximately fifty days were spent in the field. Mapping was done on aerial photographs having a scale of 1:20,000. Some mapping difficulties were encountered as a result of thick glacial deposits covering the bedrock in critical areas. Representative rock samples and fossils were collected for laboratory study.

A suitable base map was not available for this area. As a substitute a planimetric map with a scale of approximately 1:17,000 was made by transferring all cultural and geologic data from the aerial photographs. This was done with a radial planimetric plotter. The section line grid was drawn by plotting section corners obtained from photographs on file in the U.S. Forest Service office at Colville, Washington.
Preparation of fossil and rock samples, petrographic study of 38 thin sections, taxonomic study and correlation of fossil assemblages, and other phases of this investigation were carried out during the summer of 1960 and the academic year of 1960-61.

ACKNOWLEDGMENTS

I am grateful to Dr. J. W. Mills of Washington State University, who suggested the problem and offered valuable suggestions during the period of field work. The comments and criticisms of Doctors R. W. Fields, R. M. Weidman, and F. S. Honkala, and Mr. R. Brodersen have aided greatly in the completion of the work.
PHYSIOGRAPHY

Kelly Hill is a deeply dissected north-south trending ridge drained on the east by the Columbia River and on the west by the Kettle River. The maximum relief in the area is 2000 feet. The water level of Franklin D. Roosevelt Lake at the southern end of the area stands at 1300 feet. The topography rises gently but irregularly northward to an elevation of 3300 feet. The elevation decreases rapidly westward and eastward to the level of the Kettle and Columbia rivers.

The entire area has been glaciated as evidenced by rounded topography, glacial erratics, and striated outcrops observed at higher elevations. Striations indicate that glacial movement was in a direction slightly west of north. The east-west valleys are filled to moderate depths by morainal deposits. River terraces such as those reported by Weaver (1920) in the valleys of the Columbia and Kettle rivers are present along the southeastern side of the Kelly Hill area.

The area has a vegetative cover of grass and coniferous trees. Commercial logging operations have reduced much of the area to second growth timber and underbrush. Only a small part of the land area at the lower elevations is under cultivation. Annual precipitation in the field area is approximately the same as that for the town of Colville, located approximately 10 miles southeast of Kelly Hill. Weaver (1920, p. 40–41) reports that the annual rainfall at Colville ranges from 16 to 20 inches. The average temperature at Colville for the coldest months is 21.9° and for the warmest month is 68.1°.
TECTONIC SETTING

The Kelly Hill area is a part of the Okanogan Highlands physiographic province of the northern Rocky Mountain system and the Columbia system of the western Cordilleran geosyncline. During Paleozoic time, the Cordilleran geosyncline is considered to have consisted of a western and an eastern trough.

Eardley (1951, p. 43) states that sediments of geosynclinal proportions were received by both troughs with heavier sedimentation probably occurring in the western trough. The main difference in sedimentation is in the character of the sediments. The western trough is characterized by graywacke; and volcanic material including tuffs, flows, and pyroclastics. This is in strong contrast to the orthoquartzites, shales, and limestones of the eastern trough (see Figure 2).

Metamorphism is a second basis of comparison between the two troughs. In contrast to the unmetamorphosed sediments of the eastern trough, the western trough is characterized by thick sequences of phyllite, slate, argillite, recrystallized chert, schist, greenstone, and metamorphosed pyroclastic material. A third characteristic of the western trough is the later intrusion of large acidic igneous bodies which lie in a belt coincident with the volcanic trough (see Figure 2).

Volcanism in the western trough was most pronounced during Permian time, and volcanic rocks of this age have been traced from California and western Nevada, through Oregon, Idaho, Washington, and British
Figure 2. Map showing distribution of the Permian volcanic western trough assemblage and the orthoquartzite eastern trough assemblage. The coincidence of the Permian volcanic trough and zone of Mesozoic intrusion is also indicated. (From Eardley 1951).
Columbia, to Alaska. The great extent of these volcanics indicate that a belt of volcanoes lay to the west (Eardley, 1951, p. 591).
STRATIGRAPHY

Rocks referable to the Precambrian and every Paleozoic, Mesozoic, and Cenozoic period except the Silurian have been reported from north­eastern Washington. The Paleozoic rocks are predominantly sedimentary in origin, although volcanic rocks are present in quantity. In con­trast, Mesozoic rocks are predominantly igneous and are referred to the Jurassic and Cretaceous. Of special note are the numerous batholithic intrusions of granite, quartz monzonite, and granodiorite. Reeside (in Waters and Krauskopf, 1941, p. 1366) suggests the presence of Triassic sediments in the region. Reeside's suggestion is based on a fauna collected near the border of the Colville Batholith. Triassic sediments are otherwise unknown except for a Lower Triassic fauna collected in the Kelly Hill area, and discussed in this report. Cenozoic deposits include both consolidated and unconsolidated sediments and intrusive and extrusive igneous rocks.

The nomenclature used for lithologic types follows that of Bowman (1950) where his units can be traced into the Kelly Hill area. Lithologic units heretofore undescribed have not been given formational names and are referred to by their lithologic types.

At the base of the section and exposed near the northeast corner of the map area is a sequence of sediments previously described and questionably referred to the Cambrian and Ordovician by Bowman (1950). Cherty quartzite, phyllite, and associated greenstone bodies crop out in the southwest corner of the area and are tentatively referred to
the Permian(?) and (or) Carboniferous(?). The structural relationship of these rocks to the older rocks mentioned above and the younger Middle Permian rocks in the area is unknown. Middle Permian sedimentary rocks compose most of the Kelly Hill area. Within this sequence the presence of Lower Triassic rocks is indicated by paleontologic evidence. The Lower Triassic rocks are believed to be in fault relationship, but the bounding faults can not be definitely determined. Mesozoic and Cenozoic rocks in the Kelly Hill area consist of intrusive rocks of acidic, intermediate, and basic composition (see Figure 3).

**GLASGO MARBLE**

The northeastern boundary of the Kelly Hill area in Sections 24 and 25, T.38N., R.37E., is marked by the contact of the Glasgo marble with the Kelly Hill phyllite. The Glasgo marble lies outside the area mapped. However, in the vicinity of the contact, the unit consists of medium gray to very light gray limestone and dolomite, interbedded with minor amounts of light gray, fine grained, platey quartzite. The thickness of the unit is approximately 2300 feet (Bowman, 1950). No fossils have been found but Bowman (1950, p. 24) tentatively places the Glasgo marble in the middle Cambrian. He indicates that it is probably equivalent to the Metaline limestone, first described by Park and Cannon (1943) from the Metaline area and also reported by Campbell (1947) in the vicinity of Northport.

**KELLY HILL PHYLLITE**

The Kelly Hill phyllite is exposed in the northeastern corner of
<table>
<thead>
<tr>
<th>Period</th>
<th>Unit</th>
<th>Thickness</th>
<th>Lithology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quaternary</td>
<td></td>
<td></td>
<td>Alluvium and glacial gravels, silts, and clay undivided</td>
</tr>
<tr>
<td>Tertiary(?)</td>
<td></td>
<td></td>
<td>Intrusives of intermediate and basic composition, commonly andesite and diabase</td>
</tr>
<tr>
<td>Jurassic(?)</td>
<td></td>
<td></td>
<td>Intrusives of acidic composition, quartz monzonite and granodiorite</td>
</tr>
<tr>
<td>Lower Triassic and Middle Permian</td>
<td>Churchill formation</td>
<td>11,000(?)</td>
<td>Argillite, graywacke, conglomerate, and limestone</td>
</tr>
<tr>
<td>Permian(?) and (or) Carboniferous(?)</td>
<td></td>
<td>2,000</td>
<td>Greenstone, metavolcanic in origin Cherty quartzite and interbedded phyllite</td>
</tr>
<tr>
<td>Ordovician(?)</td>
<td>Kelly Hill phyllite</td>
<td>8,500*</td>
<td>Phyllite, quartzitic siltstone, and limestone</td>
</tr>
<tr>
<td>Middle Cambrian(?)</td>
<td>Glasgo marble</td>
<td>2,300*</td>
<td>Limestone, dolomite, and quartzite</td>
</tr>
</tbody>
</table>

Figure 3. Columnar section for the Kelly Hill area. (Modified from Bowman 1950).

*Thicknesses are those given by Bowman.*
the area (see Plate I). The contact between the Kelly Hill phyllite and the Glasgo marble is covered by alluvium. However, structural relations between the two units indicate to Bowman (1950, p. 35) that the Kelly Hill phyllite conformably overlies the Glasgo marble.

Lithologically the Kelly Hill phyllite consists of phyllite, siltstone, and thin discontinuous beds of limestone. The phyllite is very dark gray, weathers to medium-light gray, and is very fine grained. The rock is thinly foliated, finely crinkled, and locally very contorted. The siltstone is dark gray, weathers medium gray, and is quartzitic. In some outcrops bedding is indicated by banding. The typical limestone layer is dark gray, weathers medium gray, is fine grained and platey with argillaceous partings approximately every three inches. Bowman (1950, p. 35) gives a thickness of 8,500 feet for the unit but indicates that this figure is unreliable because of the possibility of structural repetition.

No fossils were found in the Kelly Hill phyllite. Bowman (1950, p. 36), on the basis of higher grade of metamorphism and greater degree of deformation, believes the Kelly Hill phyllite is older than the Permian Churchill formation. I am in general agreement with this interpretation. On the same basis Bowman separates these units by an unconformity. It seems more logical, however, to explain the local absence of rocks of Devonian, Mississippian and Pennsylvanian age by faulting rather than by a hiatus. It must be kept in mind that rocks of Devonian age are reported by Park and Cannon (1943) from the Metaline area only 35 miles to the east, and that rocks containing Mississippian and Pennsylvanian faunas are known to the south within
50 miles of the area (Enbysk, 1956).

On the basis of stratigraphic position, Bowman (1950, p. 37) tentatively correlates the Kelly Hill phyllite with the Ordovician Ledbetter slate of the Metaline and Northport areas (Park and Cannon, 1943; and Campbell, 1947).

CHERTY QUARTZITE AND PHYLLITE

Cherty quartzite and interbedded phyllite compose one of the mappable lithologic units to which no formal name is applied. Stratigraphic position of the unit is suggested by its degree of metamorphism and correlation with units outside the Kelly Hill area. Thus, it has been placed in a correlative stratigraphic position (see Figure 3). Bowman (1950) does not report this unit from the Orient area and it is not represented in the Metaline or Northport areas.

Rocks of this unit are best exposed along the northeast-southwest trending ridge in Section 22, T.37N., R.37E. (see Figure 4). The outcrop area covers approximately three-quarters of a square mile, parts of which are overlain by glacial deposits.

The lower contact of the cherty quartzite and phyllite unit is not exposed in the Kelly Hill area and the upper contact is thought to be a fault contact; therefore, measurements are incomplete.

Marker beds are not present; thus, repetition of strata by folding or faulting is possible. If there is no repetition, and if there are no changes of dip in covered areas, the unit has a thickness of approximately 2000 feet.
Figure 4. Typical outcrop of cherty quartzite and some interbedded quartzitic phyllite. Note the banding in the upper left corner.

**Cherty quartzite**

In hand specimen fresh surfaces of cherty quartzite range from very light gray or green to medium-dark gray or green in color. The rock may weather the same color but is often coated with secondary yellowish brown limonitic or reddish hematitic stain. Individual grains cannot be resolved with a hand lens. Beds range from 1/16 inch to 2 feet in thickness and are separated by argillaceous layers. In some outcrops the rocks are massive and no bedding is apparent. In other exposures the rocks are thin-bedded and individual beds may thicken, thin, or pinch out. Consequently, beds are traceable for only short distances along strike. The rock is thoroughly fractured and breaks with a subconchoidal fracture.

In thin section the cherty quartzite consists of greater than 95
per cent quartz. The rock has a nonclastic texture with anhedral quartz grains so tightly interlocked that no intergranular pore space is visible (see Figure 5). The grain size is cryptocrystalline ranging from 0.004 mm to 0.01 mm in diameter; however, in local areas recrystallization may increase grain size to 0.40 mm in diameter. Recrystallization of the quartz grains can be observed to some degree in every thin section. Inception of recrystallization was along randomly oriented fractures. In rocks that have undergone considerable recrystallization, it is common to find large irregular patches of coarse-grained quartz grains. Within the patches the grains are largest centrally and decrease in size toward the edges (see Figures 5 and 6).

In thin section analysis sericite, chlorite, limonite, and rutile compose less than 5 per cent of the cherty quartzite. Siderite may also be present. Sericite shreds are abundant and distributed randomly throughout the rock. They have a maximum length of approximately 0.02 mm, show parallel extinction, moderate birefringence, and moderate to high relief. Chlorite occurs as small anhedral grains. Secondary limonite occurs in irregular earthy aggregates or streaks. The limonite is not completely opaque near the edges, and in reflected light is yellowish-orange. Small grains of rutile may be associated with the iron oxide. When present siderite is associated with iron oxide as a result of oxidation of the siderite. In plain light the siderite grains are colorless, but they have a distinct absorption which makes them appear shaded.

**Phyllite**

The phyllite is generally quartzitic. It is interbedded with the
Figure 5. Cherty quartzite (K-3) illustrating incipient recrystallization of quartz grains along randomly oriented fractures, and the cryptocrystalline texture of the original ground mass. Crossed nicols, x 25.

Figure 6. Cherty quartzite (K-1), largely recrystallized. Note the transition from coarse to finer grains towards the edges of the central area of recrystallization. Crossed nicols, x 25.
cherty quartzite and, although generally less abundant, it locally exceeds the volume of the cherty quartzite. Parting surfaces have a silky sheen imparted by the mica present. On a cut surface thin banding of the constituents is megascopically visible.

Thin sections K-7 and K-8 indicate that the mineralogy and texture of the rock is essentially the same as that of the cherty quartzite. In the quartzitic phyllite, however, there is a greater percentage of sericite and chlorite. The sericite and chlorite occur in irregular layers that alternate with the quartz bands (see Figure 7). These layers show aggregate extinction because of a parallelism of the grains. Minor amounts of carbonate and limonite are present as previously described for the cherty quartzite. Opaque material partially altered to leucoxene is very abundant in the micaceous zones. Along the southern margin of the area some of the quartzitic phyllite contains a fibrous mica much larger in grain size than that previously described. These rocks are megascopically contorted on a small scale and the mica layers are further crenulated (see Figure 8).

Origin and environment of deposition

Detrital quartz grains are largely derived from phaneritic crystalline source rocks, and usually do not undergo further decomposition, and as a result they are generally of sand size (Pettijohn, 1956, p. 113). Thus, size sorting results in a decrease in the clastic quartz content where sediments show a decrease in grain size. Grout (1925, p. 441) calculated the quartz content of some silt size (0.005 mm to 0.05 mm in diameter) clastic sediments to be 36.7 per cent. This figure is in close agreement with Leith and Mead who according to
Figure 7. Quartzitic phyllite (K-7) with a layer of sericite and chlorite (light), between two quartzitic layers (dark). Crossed nicols, x 75.

Figure 8. Contorted quartzitic phyllite (K-498). Note the crenulation of the mica (light). Crossed nicols, x 25.
Pettijohn (1957, p. 117) estimated the clastic quartz content of the average shale to be 32 per cent.

Although quartz in the cherty quartzite and quartzitic phyllite is comparable in grain size to the fine-grained clastic material, the quartz content, in some cases, is greater than 95 per cent. Thus, it does not seem possible that the quartz in these rocks could be of clastic origin. The nonclastic texture, cryptocrystalline and (or) microcrystalline grain size, and the percentage of quartz, indicate that these rocks are partially metamorphosed bedded cherts which probably originated by precipitation of a silica gel from sea water. The variable amount of sericite and chlorite is thought to represent the recrystallized fine detrital fraction of the original sediment.

The silica gel must have accumulated in a marine basin that was also receiving small and variable amounts of fine detrital material from source areas which were either very low or distant. The cherty quartzite probably represents deposition of the silica gel during periods when little or no clastic material was available. The phyllitic quartzite and quartzitic phyllite on the other hand record periods when greater amounts of fine clastic material were contributed to the gel. According to Pettijohn (1957, p. 422), recent deposits of nearly pure silica are restricted to "...waters too acid (too deep) for the deposition of calcareous sediment." If such conditions were necessary for accumulation of precipitated silica in past times it follows that the cherty quartzite and phyllite of the Kelly Hill area were deposited in the deeper part of the basin.
As previously mentioned (p. 6), the late Paleozoic was a time of widespread volcanism in the western Cordillera. The cherty rocks presently under consideration are associated with greenstones, here considered to be metavolcanic rocks of an intrusive nature. In areas where similar associations of chert and volcanic rocks exist, volcanism is given as the source of supply for the silica in the chert. The cherty deposits of the Kelly Hill area show no evidence of organic origin, and so it is concluded that volcanism is the logical source of supply for the high silica content of the sediments.

Age and correlation

No fossils were found in the cherty quartzite and phyllite unit; therefore, any age assignment must be drawn from stratigraphic position and lithologic correlation with rocks of known age in nearby areas. The unit is in fault contact with the Middle Permian Churchill formation, but it is slightly more metamorphosed than the Churchill formation. On the basis of this evidence I consider the cherty quartzite and phyllite unit to be older than the Churchill formation.

Waters and Krauskopf (1941, p. 1358-1366) describe phyllites, fine quartzites, and associated metavolcanics as common rock types in the Anarchist series of the Okanogan Valley. A quartzite from the Middle Anarchist series is described by Waters and Krauskopf as "...gray to black with a little graphite and muscovite and so fine grained as to resemble chert." Lithologically, then, this unit is similar to the sediments described as cherty quartzite in the Kelly Hill area. They further state that fossils found in the Anarchist series are considered
to be "...probably Carboniferous and most likely Permian."

The Cache Creek series of southeastern British Columbia is in part, cherty quartzite which resembles the cherty quartzite described here. As reported by Dawson (1896, p. 38B-39B) and by Daly (1915, p. 120-121) the lower part of the series, as exposed in the vicinity of Kamloops, contains cherty quartzites associated with volcanic tuffs, submarine flows, and fine-grained clastic rocks. In the Vernon map area approximately 50 miles to the east, Jones (1959, p. 42) describes very fine-grained quartzites which break with a subconchoidal fracture. The quartzites are associated with lavas, tuffs, and argillites, and are most common in the middle and upper portions of the series. According to Jones (1959, p. 47), approximately the upper one-third of the series is "...Permian—probably Middle Permian..." However, the age of the lower two-thirds of the series "...can only be stated as Permian or ?Carboniferous or older."

The Hozomeen series described by Daly and exposed along the 49th parallel in southern British Columbia and northern Washington consists of greenstone believed to represent basic flows, and cherty quartzite sometimes interbedded with phyllite. Daly (1912, p. 501) states that microscopically the cherty quartzite has "...the common cryptocrystalline to microcrystalline texture of chert..." Daly (1912, p. 504) correlated these rocks with the Anarchist and Cache Creek series on basis of lithology. These rocks are lithologically very similar to the rocks presently under consideration.

In conclusion, the cherty quartzite in the Kelly Hill area is considered to be older than Middle Permian and assigned a Permian(?) and (or) Carboniferous(?) age.
GREENSTONE

A number of irregular and discontinuous greenstone bodies considered to be intrusively related to the cherty quartzite-phyllite unit are exposed in the southwestern part of the Kelly Hill area (see Plate I). The two most extensive and best exposed greenstone bodies occur along the Kettle River. The southernmost body is traceable for three-quarters of a mile. Vertical exposures of 200 feet are present along the river. The greenstone bodies are homogenous and despite a careful search attitudes were not obtained. Thus, the actual thickness of the greenstone bodies is unknown.

In hand specimen the greenstone is medium-greenish gray to medium-grayish green and usually weathers a somewhat lighter tone of the same colors. Locally the exposed rock surface is coated with limonite and hematite stain. The rock has an aphanitic texture, is usually massive although locally schistose, and is cut by numerous fractures. Locally the fractures may be large. Secondary quartz veins up to a foot thick cut the greenstone for distances up to twenty feet. Pyrite and other megascopically unidentifiable metallic minerals are sparsely disseminated throughout the rock. Microscopically the mineralogy and texture of all the greenstone bodies are almost identical. In thin section K-208, relic plagioclase laths are almost entirely converted to saussurite; however, albite twinning is still preserved in a few laths. The maximum extinction angle determined was 20°. Other optical properties could not be obtained because of the intense degree of alteration, and so the composition could not be definitely determined.
The extinction angle indicates the composition is approximately albite (An\textsubscript{0}) or andesine (An\textsubscript{38}).

With the exception of the altered plagioclase laths, the rock is completely composed of secondary minerals. Abundant carbonate, chlorite, and leucoxene are associated with lesser amounts of epidote in every greenstone thin section studied. Quartz is also abundant in all thin sections except K-208 made from a sample of the greenstone exposed in the S.W. 1/4, N.E. 1/4, Section 22, T.37N., R.37E. In this greenstone quartz is absent, the carbonate content is decreased, and the fibrous amphibole uralite is present. The slight difference in mineralogy reflects the somewhat less intense degree of alteration of this rock.

**Origin and environment of deposition**

The relic igneous texture and mineralogy indicate that the greenstone bodies originated from basic volcanic rocks, either as flows or shallow intrusive equivalents. Data which indicate an intrusive origin are: 1) the very limited extent of the greenstone bodies, 2) the great irregularity of the greenstone-quartzite contact where observed, 3) the random stratigraphic distribution of the greenstone, and 4) the presence of what appears to be an 8 by 15 foot cherty quartzite xenolith surrounded by greenstone. Thus, there appears to be ample evidence that the greenstone bodies are of an intrusive igneous origin.

A careful search was made for pillow structures which would be indicative of submarine formation, but none were found. Nevertheless, it is believed that these rocks represent shallow submarine intrusive equivalents of what are considered to be submarine flows in adjacent areas, and were intruded into the cherty quartzite shortly after
consolidation of the original silica gel on the sea floor. The complete absence of greenstone bodies (except for a fault block association) in the Middle Permian Churchill formation supports the idea that these basic intrusions are older than Middle Permian. It is interesting to note that greenstone bodies are closely associated with the cherty quartzite in the adjacent areas previously discussed (p. 20). Although most of these greenstone bodies are considered to be submarine flows, in some cases they may represent intrusions.

Age and correlation

The greenstone bodies are considered to have been intruded shortly after consolidation of the cherty quartzite and prior to Middle Permian time. The cherty quartzite is considered to be Permian(?) and (or) Carboniferous(?) and thus the greenstone is also referred to this age. The greenstone is correlated by lithology and association with the greenstone occurring with the cherty quartzite in the Anarchist series of the Okanogan Valley and the Cache Creek and Hozomeen series of southern British Columbia. These units have been previously discussed (p. 20).

Greenstone exposures northeast of Kettle Falls are associated with rocks identical to those of the Churchill formation. The greenstone is considered by Mills to be probably of Permian age; however, others consider the greenstone to be Carboniferous (J. W. Mills, 1960, personal communication). Although cherty quartzite does not occur with the greenstone of the Kettle Falls area, the greenstone is megascopically very similar to the Kelly Hill greenstone, and thus may be equivalent.
In the vicinity of Hunters, approximately 40 miles to the south, greenstone occurs stratigraphically below an argillite-graywacke unit (A. Campbell, 1959, personal communication). Although fossil evidence is lacking, this argillite-graywacke unit is similar in lithologic aspect to the Churchill formation and is probably equivalent. Thus, the stratigraphic position of the greenstone suggests that it may be correlative with the Kelly Hill greenstone.

CHURCHILL FORMATION

The name Churchill formation was proposed by Bowman (1950, p. 38) to include the "dark-colored, highly endurated conglomerate, graywacke, and argillite..." exposed in the northeastern quadrant of the Marcus quadrangle in the vicinity of Churchill Lookout. He also considered the clastic sediments exposed along the north-south trending ridge between the Kettle and Columbia rivers (Kelly Hill) to be Churchill formation.

The outcrop area of the Churchill formation in the Kelly Hill area is approximately ten square miles. The Churchill formation is predominantly a thick section of argillite with numerous beds of graywacke, and local lenses of limestone and conglomerate. Exposures are best where the topography is steep, but even there individual beds can be traced for short distances only.

In parts of Sections 9, 10, 11, T.37N., R.37E., exposures of graywacke, argillite, and conglomerate have been so severely altered that they are hardly distinguishable one from the other. They are heavily brecciated, somewhat silicified, impregnated with hematite
and limonitic iron stains, altered to a lighter color, and partially recrystallized. Evidence of recrystallization is most easily observed in outcrops of original chert-pebble conglomerate which have been partially recrystallized to quartzite. Smaller areas of similarly altered rocks occur in a random pattern throughout the formation.

A possible cause for the alteration was suggested when similar effects were observed on a minor scale at the intrusive contact of a small (15 feet wide) diabase dike with argillite. An aureole of altered argillite extends for several feet from the intrusive contact. Numerous diabase dikes intrude the Churchill formation and the relationship mentioned above suggests that these areas of alteration may be associated with diabase dikes which do not reach the present surface.

The massive limestone pods in the S.W. 1/4, Section 3, T.37N., R.37E., have been in large part silicified. Nevertheless, such outcrops retain the outward appearance of limestone. Thin section K-287, made from a limestone which in hand specimen appeared to be relatively pure, is composed of approximately 35 to 45 per cent microcrystalline silica. These limestones are closely associated with intrusive rocks which may have been responsible for the silicification.

Neither the base nor the top of the Churchill formation is exposed in the Kelly Hill area. Graded bedding indicates that the top of the series is generally to the north, but in the absence of traceable marker beds the possibility of stratigraphic repetition resulting from complications is possible. Furthermore, fossil evidence indicates the presence of structure which is unmappable in the field. Therefore, any estimate of thickness may include considerable error.
In the vicinity of Churchill Lookout in the northeast corner of the Orient area, Bowman (1950, p. 47) gives a thickness of 7,400 feet for the Churchill formation. He reports a 4,000 foot thickness for the unit between the Kettle and Columbia rivers (Kelly Hill). I do not agree with Bowman's structural interpretation (p. 73) in the latter area. My interpretation indicates a maximum thickness for the Churchill formation of approximately 11,000 feet.

**Argillite and graywacke**

In the Churchill formation, argillite is generally interbedded with graywacke; however, there are local areas within the formation where argillite or graywacke occur alone.

In hand specimen the argillite is generally very dark gray to dark-olive gray and weathers medium to dark gray. Both the argillite and graywacke are often covered with a yellow and red stain, which appears to be a result of oxidation and hydration of pyrite. The argillite may be massive and irregularly fractured, or slaty, with a well developed parting which usually has a slight sheen. Bedding in the massive argillite is often difficult to recognize except where occasional beds of graywacke appear. In the slaty argillite bedding is quite evident. Alternation of silt and clay-sized sediments is often visible as bands less than 1 cm to greater than 2 cm thick.

A thin section of a typical slaty argillite (K-A48) consists of a subordinate amount of detrital quartz fragments enclosed in a matrix composed of carbonaceous and chloritic material, and minor amounts of micaceous clay and carbonate (see Figure 9). The quartz grains are angular to subangular, have low sphericity, and range in size from
0.004 mm to 0.080 mm in diameter. The average diameter is approximately 0.03 mm. Chloritic material in the rock is brown, and under crossed nicols, interference colors are generally masked. The micaceous clay occurs in small amounts within the chloritic material and is distinguishable from the latter by its higher apparent birefringence. Carbonate is represented by a few secondary anhedral grains. The rock is microscopically laminated, with abundant brownish black and black laminae of opaque organic material approximately 0.008 mm thick, separated by buff colored layers up to 0.04 mm thick. Under high magnification the laminae bend and pinch out very irregularly. Strong parallel orientation of the constituents is further indicated by the excellent aggregate extinction.

The graywacke is medium to dark gray, and often weathers reddish, thus appearing identical in gross aspect to the basic dikes in the area. Upon close inspection the graywacke can be readily distinguished by the angular quartz and rock fragments which are easily observed on the weathered surface. Bedding ranges from beds of several inches to beds several feet thick, but most commonly the beds are between 12 and 18 inches thick. Graded bedding is common in almost every bed. Cross-bedding and ripple marks were not observed in a single outcrop. Bowman (1950, p. 43) observed channel filling and cross-bedding at only two localities in the Churchill formation of the Orient area.

Bowman (1950, p. 43) reports a graywacke specimen from the Churchill formation consisting of 30% feldspar, 15% quartz, and 55% matrix material. In contrast, graywacke specimen K-G48 consists of 44% quartz, 15% feldspar, 12% rock fragments, 5% chert, 6% argillite,
1% volcanic rock, and 29% matrix material (see Figure 10). The matrix consists of chlorite, carbonate, organic material, sericite, pyrite and other metallic minerals, and silt. Pettijohn (1957, p. 305) and Williams, Turner, and Gilbert (1958, p. 298) consider all matrix minerals to be authigenic and a result of recrystallization of an original argillaceous matrix during long deep burial. Recrystallization of the matrix is indicated by reaction between the detrital grains and the matrix, which results in penetration and corrosion of the borders of the detrital material.

The quartz and feldspar grains in the Churchill formation graywacke are partially corroded, subangular to subrounded, of low to high sphericity, and range from silt size to 1.2 mm in diameter. Feldspar grains are generally heavily sericitized; however, some plagioclase grains are fresh and exhibit distinct albite twinning. The included rock fragments generally occur as splinters with a length up to three times their width. The maximum length of the fragments is 3 mm. A rough parallel orientation of the splintery grains gives a crude stratification to the graywacke.

Significance of the argillite-graywacke sequence. The presence of unstable feldspar grains indicates that an environment existed in which erosion, transportation and deposition were too rapid to allow complete chemical decomposition (Pettijohn, 1957, p. 312). This implies a nearby source of rather high relief.

The presence of rock fragments (argillite, chert, and greenstone) in the graywacke suggests nearby positive source areas. Krynine (1941, p. 1916) believes that rocks containing such fragments are characteristic
Figure 9. Argillite (K-A48) with quartz fragments enclosed in a fine matrix. Note the irregular lamination. Plain light, x 25.

Figure 10. Graywacke (K-G48) showing quartz and chert fragments in a finer matrix. Note the poor sorting and gradation in grain size. Crossed nicols, x 25.
of the medium and late depositional stages of a geosyncline, during which time moderate orogeny may cause geanticlines to be raised within the geosyncline, as well as cause uplift along the margins. Thus, previously deposited sediments which had undergone only low grade metamorphism because of shallow burial and moderate deformation would be elevated to a position of erosion and produce the rock fragments found in graywacke-type sediments.

According to Baily (1936, p. 1716), the complete absence of cross-bedding and presence of graded bedding is indicative of relatively deep-quiet water deposition below the depth of current activity. The simultaneous accumulation of argillaceous detritus and sand-sized grains in an environment of little or no bottom current activity, and thus with insufficient current for the transport of the sand-sized particles, is difficult to explain by normal sedimentary processes. It can best be explained by deposition from turbidity currents. Kuenen experimentally produced graded deposits identical in character to graywacke by suspension currents (Kuenen and Migliorini, 1950). The most probable cause of such suspension currents is considered to be "...slump down a slope on which rapid sedimentation is taking place," (Kuenen and Migliorini, 1950, p. 124). Considering the field occurrence and nature of the Churchill formation graywacke, and the experimental work of Kuenen, the graywacke is believed to represent deposition from turbidity currents caused by submarine slump.

**Conglomerate**

Conglomerate occurs as isolated, irregular, randomly distributed discontinuous lenses throughout the Churchill formation. Exposures
range from a size too small to map to masses with a maximum diameter of 2000 feet. Chert pebble conglomerate, so named because it consists largely of chert pebbles, is the most common variety and will be described first.

The chert pebble conglomerate is medium gray and usually weathers the same color; however, the rock is commonly iron stained. Well rounded grains of chert, quartz, and argillite range in size from 1 mm to 3.5 cm, and have an average size of approximately 5 mm. The rock is very tough and so firmly cemented by the matrix material that when fractured the break is across the grains. Outcrops are massive and bedding is absent.

A thin section of chert-pebble conglomerate (K-Cl) consists of 53.4% light to dark gray chert, 8.8% argillite, 10% volcanic rock, 1.8% greenstone, and 26% matrix material (see Figure 11). The pebbles are rounded and generally have a low sphericity. The matrix is composed of poorly sorted sand of graywacke-like composition and texture. It consists of abundant subangular to subrounded quartz fragments, a few feldspar grains, rock fragments predominantly of chert, chloritic material, carbonate (probably ankerite), and metallic minerals. Recrystallization of the matrix, as in the graywacke, is evidenced by interaction between matrix material and pebbles.

In Section 34, T.38N., R.37E., three small isolated outcrops of massive limestone-cobble conglomerate surrounded by argillite and graywacke are exposed. The rock consists of subangular limestone cobbles, together with very angular argillite chips and subangular chert pebbles all enclosed in a very poorly sorted matrix of sand to
clay sized material (see Figure 12). The maximum diameter of the limestone cobbles is approximately 18 cm. The majority of the argillite and chert fragments fall into the middle of the pebble size range. They are generally elongated and in outcrop the long axes are crudely aligned giving the rock a rough stratification.

**Significance of conglomerate.** The most striking character of the chert-pebble conglomerate is the coexistence of highly rounded pebbles with a very poorly sorted sandy (graywacke) matrix. The roundness of the pebbles indicates that the pebbles were well worked by wave action. This implies rough water conditions characteristic of a beach line environment of deposition. However, if deposition took place under such conditions one would not expect to find pebbles enclosed in a matrix containing clay, silt, and fine sand. Such material would have been easily winnowed out, leaving a much better sorted sediment. It might be argued that the currents were only periodically strong enough to transport the coarse material, and that they were not steady enough to winnow out the fine size fraction. If this were the case one would not expect the pebbles to be so well rounded. The above considerations indicate that the well-rounded pebbles are a product of strong wave action and that they were probably originally deposited in shallow water. It is possible that as a result of slump they were later moved in suspension currents downslope and deposited from a turbidity current in deeper water.

The chert-pebble conglomerate contains 74 per cent rock fragments, which, like the rock fragments in the graywacke, supports the concept of emergent areas within the geosyncline.
Figure 11. Chert-pebble conglomerate (K-Cl). Note the degree of roundness of the two large pebbles and the unsorted matrix in which they are enclosed. Crossed nicols, x 25.

Figure 12. Limestone-cobble conglomerate exposed in Section 34, T.38N., R.37E.
The limited number of limestone-cobble conglomerate exposures in the area is an indication that the conditions necessary for the formation of such rocks were uncommon. Two suggestions for the origin of the limestone-cobble conglomerate are considered. This rock may, as in the case of the chert pebble conglomerate, represent deposition from a turbidity current as a result of slump on a submarine slope. The limestone cobbles and argillite chips could have been derived from material deposited farther upslope at an earlier time. This detritus, when carried down slope in association with sand and silt, could have resulted in deposition of a completely unsorted mass on the sea floor. Kuenen and Migliorini (1950, p. 122) believe that when there is strong turbulence on steep slopes even large boulders can be carried in turbidity flows.

A second possibility is that these rocks represent a time of relative lowering of sea level, thus causing the accumulating sediments to be locally and temporarily subjected to strong wave and current activity. This could result in the tearing up of previously deposited, now semiconsolidated argillaceous sediments, and also the breaking off of cobble-sized chunks of limestone from nearby carbonate bodies. After only slight reworking the limestone cobbles and argillite chips could have been redeposited with the sand and silt accumulating simultaneously by normal sedimentary processes.

Of the two possibilities noted, the idea of turbidity flow appears to present the best explanation. The very poorly sorted matrix is indicative of little wave and current action, and is typical of sediments deposited from a turbidity current. If, on the other hand,
deposition of the limestone-cobble conglomerate were a result of increased wave action in response to a lowering of sea level, one would expect that current and wave action would have been strong enough to winnow out the silt and clay from the sandy matrix.

**Limestone**

Scattered outcrops of limestone occur throughout the Churchill formation; however, exposures are most abundant in the upper one-third of the section. Two distinct types of limestone occur; those which are generally massive featureless mounds, and have a reefoid aspect, and those which exhibit well developed bedding (see Figures 13 and 14).

The massive mound-forming limestone is the most common, and occurs as isolated elongated bodies completely surrounded by argillite and rarely by very fine grained graywacke. These bodies usually occur in belts and normally trend parallel to the strike of the surrounding rocks. Individual bodies in these belts range from too small to map to those with a length of approximately 1700 feet, a width of 500 feet, and observed topographic relief up to 40 feet. A complete cross section with the base exposed was not observed, and thus stratigraphic thicknesses are unknown.

Two lithologically distinct types of limestone comprise these mounds. The belt of limestone exposures extending east-west for approximately 1 1/2 miles along the southernmost edge of Sections 26 and 27, T.38N., R.37E., and several other isolated bodies throughout the formation, are composed of dark to very dark gray micro-grained limestone which weathers light to medium gray (see Plate I). Micro-bedding, visible in thin section K-69, indicates that the rocks are finely
Figure 13. Typical exposure of mound type limestone body in the S.W. 1/4, N.W. 1/4, Section 34, T.38N., R.37E.

Figure 14. Typical exposure of thin-bedded limestone in the N.W. 1/4, S.W. 1/4, T.38N., R.37E.
laminated accumulations of lime mud (see Figure 15). Visible clastic and bioclastic grains are not present.

The other massive limestone bodies, notably the belt trending north-south for one mile along the section line separating Sections 33 and 34, T.38N., R.37E., and the belt extending through the southern part of Sections 34 and 35, T.38N., R.37E., are a medium gray, bioclastic limestone (see Figure 16). These rocks are poorly sorted, and are composed of very fine to very coarse sand-sized fossil debris; very fine sand-sized quartz grains, which compose less than 10 percent of the rock; and a minor amount of carbonate rock fragments, clay, and silt. Secondary chert is also present in small amounts.

In order of decreasing abundance, the fossil material consists of crinoid, bryozoan, and fusulinid remains. Locally fusulinids may be the most abundant. The material is generally fragmental and worn as a result of transportation. Transportation is also indicated by banding of the fusulinids. The long axes of the fusulinids have a parallel orientation, which is attributed to current activity. Such occurrences are uncommon and those discovered were found in the float at the base of the outcrops. The absence of any kind of reef binding organism adds support to the idea that these rocks are current-transported accumulations of carbonate debris, and thus could not have formed as organic reefs.

Bedded limestone occurs in isolated outcrops, and like the limestone mounds, it is also most abundant in the upper part of the section. Individual lenses have a traceable lateral extent of less than 30 feet and a stratigraphic thickness not exceeding 50 feet. Where observed,
Figure 15. Lime mud (K-69). Note the micro bedding. Plain light, x 25.

Figure 16. Fine to coarse grained bioclastic limestone (K-412). Note the fragmental fossil detritus. Plain light, x 25.
the bedded limestone is underlain conformably by argillite or siltstone.

Physical characteristics of the limestone vary in different exposures. It is usually dark gray on a fresh surface and light to medium gray on a weathered surface. Grain size ranges from micro to medium grained, and bedding varies from 1/2 to 12 inches in thickness. Like the mound type limestone, the micro-grained rocks are the result of accumulations of lime mud, and the medium-grained deposits indicate accumulations of transported bioclastic carbonate sand.

A third rock type is considered here, although it is not a true limestone, but rather a calcareous sandstone. The rock is not important volumetrically but is important for its environmental significance. Two outcrops of this rock, too small to map, were observed among the limestone exposures in the S.E. 1/4, Section 34, T.38N., R. 37E. (see Plate I). The rock is very well sorted and contains extremely well rounded grains having an average size of 0.5 mm (see Figure 17). Approximately 55 to 65 per cent of the rock is composed of chert, quartz, and argillite grains in order of decreasing abundance. The chert grains are by far the most abundant. The remainder of the detrital fraction consists of carbonate rock fragments, and badly broken and worn crinoid and fusulinid (rare) material. The detrital constituents are cemented by spary calcite cement.

**Significance of the limestone.** The accumulation of limestone in a rock section characterized by terrigenous sediments indicates periods during which normal flow of terrigenous material was either completely or partially cut off from the basin of accumulation. The micro-bedded limestone indicates a very low energy environment of accumulation. This
Figure 17. Calcareous sandstone (K-433). Note the rounded chert grains (speckled dark), the large elongated carbonate rock fragment, and the carbonate detritus and cement (light). Crossed nicols, x 25.

suggests either lagoonal deposition or deposition below wave base. Deeper water offshore deposition is favored because of the absence of any terrigenous material, and the general sedimentary and tectonic framework of the region at the time.

The bioclastic limestone represents material definitely transported by currents and indicates a higher energy environment of deposition than that of the lime mud. As noted previously (p. 38), sorting is poor, probably because currents were not persistent enough to winnow out the fine material.

The calcareous sandstone referred to on page 40, with its high degree of sorting and roundness of grains, is considered to represent a beach sand. According to Folk (1959, p. 22), carbonate rock fragments imply calm water deposition of partially consolidated lime mud,
which, as a result of a sudden change, such as a relative lowering of sea level and consequent lowering of wave base, are torn up and redeposited in the new higher-energy environment. Shallow water deposition in an environment of strong, persistent currents is further indicated by the high degree of sorting in this sediment.

In summary, field evidence indicates that the micro-bedded limestone, bioclastic limestone, and the calcareous sandstone occupied approximately the same geographic location on the sea floor during their respective time of accumulation. They indicate environments of deposition characterized by differences in current intensity. These differences may be interpreted as the result of fluctuations in relative sea level. This could be brought about by differential subsidence and (or) sedimentation whereby the sea floor would be placed either above or below wave base. Either possibility would be evidence of the unstable tectonic environment prevailing in the region during Churchill time.

**Environment of deposition**

The sediments forming the Churchill formation were probably deposited in a rapidly but differentially subsiding marine basin within the western trough of the Cordilleran geosyncline. The basin was in close proximity to local positive areas of moderate to high relief, which, as indicated by the feldspar content and great thickness of sediment, were undergoing both rapid and widespread erosion. Detrital material was carried by streams to the coastal areas where it

---

1The mode of accumulation described for the terrigenous sediments was originally proposed by Migliorini for a similar series of sediments in the Apennines (Kuenen and Migliorini 1950, pp. 109-110).
was reworked and deposited. The coarser material was deposited in turbulent water relatively close to shore, and the finer fraction was carried farther offshore and subsequently settled in deeper water of reduced current activity. Locally the detrital grains were well worked and by the time of deposition were highly rounded and sorted. The sea floor possibly dropped fairly rapidly from the coastline. Under conditions of rapid sedimentation the angle of repose of the sediments on the seaward side was frequently exceeded. This probably resulted in submarine slumping and movement of previously deposited coarse material downslope. This in turn caused agitation of the finer sediment fraction originally deposited in deeper water down the slope, and resulted in high density turbidity currents. Upon reaching the bottom of the slope these currents spread over large areas, and with decrease in velocity and dilution, sedimentation in relatively deep water took place. Turbidity currents such as these probably produced the graded graywacke beds. Occasionally such suspensions involved a greater percentage of pebble-sized materials which, upon reaching the bottom of the submarine slope, were deposited immediately to form local bodies of chert-pebble conglomerate. At other times limestone cobbles were carried down-slope, tearing up and transporting along with them previously deposited clays and silts. These heterogenous masses were carried to the base of the slope where they were deposited to form the limestone-cobble conglomerate.

Keunen and Migliorini (1950, p. 95) have shown that increased density of a turbid media will reduce the mobility of the suspension. The localized deposition in the Kelly Hill area can probably be accounted
for in the same way. Where coarse material is included the mobility of the suspension will be reduced and deposition of the coarser material will take place in localized areas. Between periods of slumping normal sedimentation took place with the size of sediments accumulating dependent upon the currents available.

If normal overburden slumping is inadequate to explain the apparent turbidity current deposition it may be necessary to turn to other causes. The submarine slumping could have been initiated by earthquakes, storms, or waves. Baily (1936, p. 1717) states that submarine slumps along the margins of positive areas in ancient geosynclines could have been triged by seaquakes. He points out that present day seaquakes originate under the ocean deeps and are quite common in seismically active areas.

It appears that occasionally there was either an interruption in the rate of uplift of the source area with a subsequent reduction in the rate of erosion, or merely a failure of terrigenous sediments to reach certain portions of the basin. At such times bioclastic debris and lime mud transported from within the basin accumulated as isolated pods and less commonly as continuous layers. Although these deposits are a result of current activity, the cause of such deposition is uncertain. The isolated pods may be the result of eddy currents causing localized deposition of the carbonate detritus.

The consistent texture of the bodies within each belt suggests simultaneous accumulation under identical conditions of current activity. This implies accumulation at equal depth on the slope of the sea floor, and suggests that the belts of limestone probably accumulated parallel
to ancient shorelines. The textural difference of individual limestone belts is attributed to differential subsidence which resulted in the increase or decrease in sea depth and increase or decrease in distance from shore of any one geographic point in the basin. As a response to these variations the belts of bioclastic detritus accumulated over the same geographic location where at another time lime mud accumulated.

Age and correlation

The age of the Churchill formation exposed on Kelly Hill was previously determined by the identification of fusulinids collected from a single locality by Bowman (1950, p. 48). The fusulinids were identified by Henbest of the U.S. Geological Survey who states, (Bowman 1950, p. 48-49),

"This sample of arkosic limestone contains a number of large fusulinids. On the basis of the specimens crossed by a few polished sections of the limestone, it seems that two species of Parafusulina sp. are present. The cuniculae in these parafusulinid shells are highly developed. The presence of multiple tunnels was suggested by two specimens, but insufficient evidence was seen to justify determining the form as a species of Polydiexodina.

The age of this rock is definitely Permian and is not older than Middle Permian. Whether it is middle or upper Permian cannot be decided on the evidence at hand, but Middle Permian, roughly equivalent to the Word formation of Texas is suggested."

Fusulinids were collected from nine localities of the massive mound-type limestone. The localities all lie within a mile radius of the locality where Bowman (1950) made his collection, and all but one are located in Section 24, T.38N., R.37E. (see Plate I). The fusulinids were locally associated with bryozoa, a few poorly preserved productid brachiopods, a single spirifiroid brachiopod, and rarely
with unidentifiable pelecypod hash. Poorly preserved corals have also been found in association with the fusulinids (Bowman, 1950, p. 48). Two thin sections (K-433, K-519) containing abundant fusulinid material referrable to *Parafusulina* were examined. There are no specimens in these two slides which resembled *Polydiexodina*. These fusulinid localities together with the one reported by Bowman substantiate the Permian (probably Middle Permian) age for at least part of the Churchill formation cropping out on Kelly Hill.

Almost directly to the east of the known Permian limestone outcrops and essentially along strike, a molluscan fauna was collected from outcrops of thin-bedded, medium-gray limestone. The best collection was made from a small limestone outcrop in the N.W. 1/4, Section 2, T.37N., R.37E. The fauna is characterized by three ammonoids referrable to: *Dieneroceras* cf. *D. dieneri*, *Owenites aff. O. koeneni*, and *Arnauto-celtites aff. A. dieneri* (see Plate I). These three genera are restricted to rocks of Upper Lower Triassic (Owenitan) age.

With the exception of the thin-bedded, medium-grained limestone containing the Lower Triassic fauna, thin-bedded limestone is almost nonexistent in the Churchill formation as exposed on Kelly Hill. It should be noted that the rock sequence exposed north of Kettle Falls is identical in every respect to the Churchill formation of Kelly Hill except that thin-bedded limestone is entirely absent (J. W. Mills, 1960, personal communication). In those beds argillites containing Middle Permian brachiopods surround belts of massive limestone containing *Parafusulina*.

Pod type limestone development seems to be typical of Permian
sedimentation in the Kelly Hill area and adjacent areas, and as most of the limestone throughout the Churchill formation is of this nature, it is concluded that most of the Churchill formation of this area is also Permian. The Lower Triassic rocks have apparently been faulted into their present position; however, with the exception of the thin-bedded fossiliferous limestone, they can not be differentiated from Middle Permian rocks.

The banded slates of the Mt. Roberts formation described by Drysdale (1915, p. 193-220) from the Rossland area 25 miles to the north are considered to be Upper Carboniferous. The Cache Creek series of southern British Columbia described by Dawson (1894), Daly (1915), et al., is also late Paleozoic in age. According to Jones (1959, p. 49), the Permian and probably Middle Permian age of the upper portion of the Cache Creek seems to be fairly well established. The Anarchist series of the Okanogan Valley described by Waters and Krauskopf (1941, p. 1364) is considered to be "...probably Carboniferous and most likely Permian." Bowman (1950, p. 50) correlates the Mt. Roberts formation, the upper part of the Cache Creek series, and the Anarchist series with the Middle Permian rocks of the Churchill formation.

As previously noted the Permian part of the Churchill formation seems equivalent to the Permian rocks exposed north of Kettle Falls. The Covada group described by Pardee (1918) and well exposed on both sides of the Columbia River approximately 40 miles to the south, consists of rocks showing close lithologic similarity to the Churchill formation and may be in part equivalent. A part of the Elkhorn Ridge argillite and (or) the Clover Creek greenstone described by Gilluly
(1937) from northeastern Oregon may be equivalent to the Churchill formation. The Elkhorn ridge argillite consists of a thick sequence of argillite, tuff, and chert. According to Dunbar et al. (1960, p. 1780) Taubeneck has shown these rocks to be of Leonardian age. The Clover Creek greenstone overlies the Elkhorn Ridge argillite and consists predominantly of volcanic material with less abundant argillite, conglomerate, limestone and chert. Gilluly (1937) reports a Permian brachiopod fauna from this unit.

Correlation of the Triassic is considered in a later section.

INTRUSIVE ROCKS OF ACIDIC COMPOSITION

Fine to medium-grained rocks ranging in composition from quartz monzonite to granodiorite intrude the Churchill formation in the southern and northern parts of the Kelly Hill area (see Plate I). Evidence for the intrusive nature of the rocks is seen in: 1) discordant contacts with the surrounding rocks, 2) contact metamorphism of the Churchill formation near the contact zone, 3) decrease in grain size at the contact zone, and 4) presence of an argillite xenolith in the southeastern part of the northern intrusive.

In the southern part of the area, in the N. 1/4, Section 14, R.37E., T.37N., there are three small intrusive bodies. The largest has a maximum width of approximately 1300 feet.

The granitic body exposed in the northern-most part of the Kelly Hill area was named the Barstow granodiorite by Bowman (1950, p. 77). It extends approximately 2 1/2 miles in an east-west direction and has a north-south dimension of about one mile. The stock is bounded on the
south and north by the Churchill formation; however, most of the northern contact is with alluvium. Bowman (1950, p. 77) considers the east side of the stock to be bounded by a fault.

Outcrops of these rocks in the Kelly Hill area are generally smooth, rounded, and cut by numerous joints; however, the northern intrusive has weathered differentially. Certain parts appear fresh and stand out prominently as rounded topographic highs. In marked contrast, other areas are severely weathered and reduced to low areas by differential erosion. In the deeply eroded areas quartz is the only megascopically visible mineral remaining of the original constituents, and the rock weathers to a rusty yellow color as a result of hydration and oxidation of the iron bearing minerals.

Lithology

The rocks composing these intrusives are light gray to light green in color, equigranular, and range from fine to medium grained. The three southern intrusives are fine grained, whereas the northern intrusive is medium grained except at the contact zone. The rocks are massive and there is no visible lineation. Quartz, plagioclase, alkali feldspar, biotite, hornblende, and secondary chlorite are visible megascopically; however, they are not all visible in every hand specimen.

A brief petrographic consideration of these rocks follows. Modal analyses of four samples are given in Table I, with modal percentages based on a 500 point count. Plagioclase occurs as elongated subhedral to euhedral grains with somewhat corroded borders and moderately to heavily serizitized cores. Albite twinning is common and is often combined with Carlsbad twinning. Normal zoning, restricted to peripheral
Common accessories are apatite, zircon, and ore mineral.

** "Unidentifiable feldspar" probably represents altered plagioclase.

* Modal analysis of sample from northern intrusive by Bowman (1950)
  
  The location is unknown.

Note: The first three samples are from the northern intrusive and the last is from the westernmost of the southern intrusive bodies.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Qtz</th>
<th>Plag</th>
<th>Alkali felds</th>
<th><strong>Felds</strong></th>
<th>Bio</th>
<th>Chl</th>
<th>Hbd</th>
<th>Musc</th>
</tr>
</thead>
<tbody>
<tr>
<td>K-55</td>
<td>28</td>
<td>30</td>
<td>20</td>
<td>12</td>
<td>3</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>K-482</td>
<td>33</td>
<td>18</td>
<td>10</td>
<td>26</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>*</td>
<td>27</td>
<td>37</td>
<td>10</td>
<td>-</td>
<td>10</td>
<td>-</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>K-51</td>
<td>36</td>
<td>9.8</td>
<td>-</td>
<td>43</td>
<td>-</td>
<td>7</td>
<td>-</td>
<td>3</td>
</tr>
</tbody>
</table>

Table I. Modal analyses of intrusive rocks of acidic composition.

Margins, is evident in some grains. The composition of the plagioclase as determined by the Michel Levy Method is andesine and ranges from An$_{35}$ to An$_{41}$. Bowman (1950, p. 79) gives a composition of An$_{25-30}$ and An$_{35}$ for samples from the northern intrusive.

The alkali feldspar is slightly perthitic as evidenced by tiny blebs of exsolved material arranged in a parallel-linear pattern. The grains are usually anhedral, interstitial, and little altered. Sample K-51, from one of the southern acidic intrusives, is so severely altered that alkali feldspar could not be identified.

Quartz occurs as fresh anhedral grains which are interstitial and sometimes exhibits undulatory extinction. In sample K-51 there seems to have been a second generation of quartz. This quartz is much smaller in grain size and often occurs as inclusions in altered feldspar grains.

Biotite is present as subhedral flakes and basal plates and is characterized...
by its pleochroism (x-yellow, y-z-brown), uniaxial negative sign, and parallel extinction. Almost every biotite grain is partially converted to chlorite and ore mineral. Most ore mineral occurring in these rocks is associated with the biotite and chlorite.

Hornblende occurs only in sample K-482 taken from the southeastern part of the northern intrusive. It occurs as euhedral to subhedral grains which have moderate to strong dark green to light yellowish pleochroism, and displays distinctive amphibole cleavage. In sample K-51, muscovite appears to be a primary constituent and in some cases encircled by chlorite.

Common accessory minerals are apatite, zircon, and ore. Aggregates and individual grains of sericite, carbonate, and epidote are present in the centers of some of the severely altered plagioclase grains. The alteration of some feldspar grains is so complete that more specific identification is impossible. However, such grains probably represent altered plagioclase.

The mineralogical composition of the three samples from the stock in the northern part of the Kelly Hill area should be noted (see Table I). According to the classification of Moorhouse (1959, Table 17), the alkali feldspar content indicates that Bowman's sample and sample K-G5 are quartz monzonite and that sample K-482 is a granodiorite. However, the two quartz monzonite samples differ in that Bowman's sample contains hornblende and sample K-G5 does not. The granodiorite (sample K-482) also contains hornblende. As previously indicated, the plagioclase composition ranges from An_{25} to An_{41}.

Thus, considering the small size of the stock, there is a rather
significant mineralogical variation. Such variation possibly could be a result of assimilation or of multiple intrusion; however, sufficient data are not available to propose any interpretation. The severely altered condition of sample K-51 makes it difficult to compare with samples from the northern intrusive. However, the quartz and total feldspar content compare closely with the other samples. It is probable that the three small intrusives are comagmatic with the larger intrusive in the northern part of the Kelly Hill area, three miles to the north.

Age and relation to folding

The granitic rocks of the Kelly Hill area intrude (p. 48) the sediments of the Churchill formation. This indicates that intrusion was at least post-Middle Permian. No further determination of the time of intrusion can be made in the Kelly Hill area. However, other granitic intrusions in this region are correlated with the Upper Jurassic and Lower Cretaceous Coast Range intrusions (see Figure 2). Bowman (1950, p. 80-81) correlated the stock in the northern part of the Kelly Hill area with the Fifteen Mile granodiorite exposed four miles to the north. He suggests that the Tertiary (?) First Thought formation was deposited on the exposed and eroded surface of the Fifteen Mile granodiorite. Thus, he considers the stock in the Kelly Hill area to be upper-Mesozoic and probably Jurassic. On the basis of Bowman's evidence, all the granitic intrusions in the Kelly Hill area are probably of upper-Mesozoic age and are also referred to the Jurassic.

Bowman 1950 (p. 80-81) states that the Churchill formation was strongly folded at least once before the intrusion of the quartz
monzonite stock in the northern part of the Kelly Hill area. However, field relations are of little value in determining the relationship between folding and intrusion. Fossil evidence in the Kelly Hill area indicates that part of the Churchill formation is Lower Triassic. Although the structural and stratigraphic relationship between the Triassic and Middle Permian rocks could not be determined, the relationship between rocks of these ages in other areas does not indicate strong tectonic activity between Middle Permian and Early Triassic time. Therefore, folding of the Churchill formation was probably post-Lower Triassic. Eardley (1951, p. 13) states that strong folding preceded batholithic intrusion during Jurassic and Early Cretaceous time. Buddington (in Eardley, 1951, p. 270) in discussing the relation of the Coast Range intrusions to folding assumes that intrusion took place within the same general period as Jurassic or Cretaceous folding. The granitic intrusions of the Kelly Hill area are correlated with this period of intrusion; thus, it seems probable that folding of the Churchill formation probably preceded the granitic intrusions, and that it probably occurred during approximately the same period of time. If the above assumptions are correct, this implies a Jurassic folding of the Churchill formation.

**INTRUSIVE ROCKS OF INTERMEDIATE AND BASIC COMPOSITION**

Dikes of intermediate and basic composition, here referred to as andesite and diabase, have intruded rocks of the Churchill formation, the cherty quartzite unit, and the quartz monzonite stock in the north. The intrusive nature of the diabase and andesite masses is indicated by:
their sharp discordant nature; the inclusion of a metamorphosed lime-
stone xenolith in a diabase body; the severe alteration of the host rock
in the case of one diabase intrusion (see page 26); and the chilled con-
tacts of some andesite bodies.

Intrusions of diabase are most numerous and are sporadically but
evenly distributed throughout the Churchill formation. Individual dikes
range from those too small to map to bodies with a maximum width of
approximately 1/2 mile. Outcrops of diabase are typically low and
rounded, severely weathered, and thoroughly fractured.

Andesite dikes are abundant in the northern part of the exposed
Churchill formation. The size of the andesite bodies is variable, and
the largest has a maximum width of 1100 feet. Outcrops are generally
rounded and relatively unweathered.

Lithology

The diabase is dark gray to dark green, usually weathers red, and is
unequigranular and generally fine grained. In fresh specimens very small
laths of plagioclase enclosed in a dark groundmass are visible.

Thin section K-37 indicates that the rock has undergone considerable
alteration; nevertheless, the fine to medium grained diabasic texture is
still recognizable (see Figure 18). The subhedral to euhedral plagioclase
laths reach a maximum length of 2 mm, although most are less than 1 mm
in length. They are corroded and in some cases have been partially
altered to saussurite. The composition of the plagioclase as determined
by the Michel Levy Method is andesine (An$_{41}$).

The original pyroxene in the rock is altered so completely that
optical properties needed to make distinctions within the group cannot be obtained. The pyroxene is almost completely altered to a fibrous amphibole displaying the distinct bluish-green pleochroism typical of actinolite. Small amounts of chlorite are distinguishable by their anomalous bluish interference color. Probably the chlorite is also an alteration product of the original ferromagnesian minerals. Skeletal structures of ilmenite, some of which are altered to leucoxene, generally occur as anhedral grains enclosed in the actinolite. Quartz occurs in very small amounts as primary interstitial grains, and as resorbed grains.

The andesite is medium gray and generally fine grained. The texture is porphyritic with euhedral phenocrysts of plagioclase, chlorite (pseudomorphs after both amphibole and pyroxene), and quartz (rare) enclosed in a groundmass of felted plagioclase crystals (see Figure 19). Phenocrysts have a maximum length of 2 mm, but the average length is less than 1 mm.

The plagioclase phenocrysts are subhedral to perfect euhedral crystals exhibiting albite and Carlsbad twinning. They often display normal and reversed zoning. The composition of the plagioclase as determined by the Michel Levy Method is andesine (An_{41}). The original presence of amphibole and pyroxene phenocrysts is indicated by perfect euhedral pseudomorphs of chlorite and associated carbonate and ore mineral. A few anhedral grains of quartz with a maximum diameter of 0.4 mm also occur as phenocrysts in the rock.

The matrix consists predominantly of plagioclase microlites, with less abundant quartz, chlorite, carbonate, ore mineral, and apatite. As one would expect, the matrix plagioclase is more sodic than that in the
Figure 18. Plagioclase laths enclosing ferromagnesian alteration products in diabase (K-37). Crossed nicols, x 25.

Figure 19. Andesite (K-347) with euhedral crystals of plagioclase enclosed in a felty matrix of plagioclase microlites, and less abundant quartz, chlorite, and carbonate. Crossed nicols, x 25.
phenocrysts. The composition, when determined by the maximum extinction angle of the twinned microlites is calcic oligoclase, approximately $\text{An}_{30}$. Quartz in the matrix occurs as small anhedral grains. The minute aggregates of chlorite and carbonate suggest the original occurrence of ferromagnesian minerals in the matrix as well as in the phenocrysts. A generalized modal analysis based on 500 points consists of 44% phenocrysts and 56% matrix. The phenocrysts consist of 57% plagioclase, 38% chlorite (amphibole pseudomorphs most common), and 5% quartz.

According to Williams, Turner and Gilbert (1958, p. 93) this rock is an andesite. The absence of alkali feldspar distinguishes it from closely associated rocks. However, it must be kept in mind that these rocks are altered. Thus, any distinction that is made is of necessity open to question.

Age

Several small dikes of intermediate composition and a single basic dike were observed, which intrude the quartz monzonite stock in the north part of the Kelly Hill area. Assuming a Jurassic age for the quartz monzonite, the intrusion of the dikes is post quartz monzonite, perhaps post-Jurassic. Bowman (1950, p. 81) thinks it is probable that the dikes of intermediate composition are related to the Hodgson Creek monzonite, an intrusive body exposed on the west side of the Kettle River approximately one mile west of the stock. Furthermore, he considers the Hodgson Creek monzonite to be comagmatic with the andesite flows of the Tertiary First Thought formation. These flows are exposed approximately five miles to the north of the Kelly Hill area. This suggests that the andesite dikes are probably of Tertiary age. If such a
relationship does exist between the andesite dikes and the Hodgson Creek monzonite, it might well explain the concentration and increase in number of the andesite dikes in the northwestern part of the Kelly Hill area, particularly in the vicinity of Section 33, T.38N., R.37E. (see Plate I).

Nowhere in observed outcrop areas do the andesite and diabase dikes intersect one another, nor is there any stratigraphic evidence available concerning their respective times of intrusion. However, basic dikes in adjacent areas have been referred to the Tertiary (Drysdale, 1915; Jones, 1959; et al.). For want of more direct evidence the diabase dikes of the Kelly Hill area are also tentatively referred to this age.
STRUCTURE

The structure of northeastern Washington and adjacent areas is complex. Folds of all grades are present and range from simple open folds to closely compressed overturned and isoclinal flexures. Variation in the complexity of folding is probably an expression of multiple regional deformation. Study in the adjacent Orient area led Bowman (1950, p. 104) to conclude that five periods of folding had occurred. Folds are poorly defined and difficult to trace.

The structure is further complicated in the region by numerous faults, which are usually hidden by alluvium or vegetation. Where known, fault traces are not controlled by topography. Thus, they are generally considered to be high angle faults. Bowman (1950, p. 119) states that "...the lack of folding associated with the faults suggests that they are due to tension rather than to compression." On the basis of Bowman's observations and those made during the mapping of the Kelly Hill area, the faults in the Kelly Hill area appear to be high angle gravity faults.

Faulting, which may occur within individual stratigraphic units of the Kelly Hill area is not recognizable, as distinct horizons are absent and much of the area is covered by vegetation. Near the section line separating Sections 34 and 35, T.38N., R.37E., thin-bedded limestone containing a Lower Triassic fauna strikes into pods of massive Middle Permian limestone. The argillite and siltstone surrounding the fossiliferous rocks are identical in both cases. The Triassic rocks are thought to have been faulted into their present position; however, the absence of stratigraphic marker beds and masking of the bedrock by
alluvium and vegetation prevents determination of the position and extent of the bounding faults.

Unfortunately even the major faults in the Kelly Hill area are covered by Pleistocene and Recent unconsolidated sediments. It is however, possible to say that the youngest rocks in the Kelly Hill area involved in faulting are of Jurassic age. A more accurate estimate of the age of faulting can not be made in the Kelly Hill area. To the north, in the Orient area, Bowman (1950, p. 127) reports that the faults cut the Tertiary(?) First Thought formation. Approximately 35 miles east of the Orient area, Daly (1912, p. 344, 398) reports faulting of the Oligocene Kettle River formation and the overlying andesites. Bowman (1950, p. 127) considers it probable that the faults cutting the First Thought formation may also be post-Oligocene in age. The faults in the Kelly Hill area are probably of the same age as those cutting the Tertiary(?) First Thought formation of the Orient area. If these faults are post-Oligocene as suggested by Bowman, then faulting in the Kelly Hill area is also probably post-Oligocene.

FAULTS

A north-south trending fault of considerable displacement is present in the Kettle River valley on the west side of the Kelly Hill area. According to Bowman (1950, p. 119-121), the Kettle River fault at First Thought Mountain, approximately seven miles north of the Kelly Hill area, has a stratigraphic throw of approximately 14,000 feet. He considers the minimum displacement at Barstow, at the northwest corner of the Kelly Hill area, to be 2000-3000 feet. On the west side of the Kettle River,
opposite the southern portion of the map area, relatively high grade metamorphic rocks occur. These rocks are identical to rocks exposed to the north in the Orient area, and which Bowman (1950) has referred to the Precambrian(?) Boulder Creek formation. On the east side of the Kettle River, rocks of Permian and Permian(?) and (or) Carboniferous(?) are exposed. This indicates that relative movement on the east side of the fault has been down.

A northwest trending fault was mapped by Bowman (1950) in the valley separating the Kelly Hill phyllite on the northeast from the quartz monzonite stock and associated Churchill formation on the southwest. This fault was again noted during mapping of the Kelly Hill area. The stratigraphic position of the Kelly Hill phyllite and the Churchill formation respectively, indicate that the Kelly Hill phyllite has moved up relative to the quartz monzonite and Churchill formation.

Much of the bedrock in the southwest part of the Kelly Hill area is covered by glacial debris which causes the structure to remain ambiguous. For this reason intrusive relationships in this area must be discussed concurrently in order to clarify the structural interpretation.

The cherty quartzite and greenstone now in contact with the Churchill formation are considered to represent an upthrown fault block. The fault relationship of the cherty quartzite and Churchill formation is best indicated by the abrupt discontinuity and truncation of structure in the N.E. 1/4, Section 22, T.37N., R.38E. (see Plate I). The contact between the two units is diagonal to the strike of each unit; thus, the possibility of an unconformable relationship is eliminated (Billings, 1954, p. 252). Faulting is further indicated in the S.E. 1/4, N.E. 1/4,
Section 22, T.37N., R.37E., by a narrow 15-20 foot zone of grayish-green phyllite which appears to be altered Churchill argillite and by adjacent Churchill graywacke outcrops that are so altered in color and texture that the rock is scarcely recognizable.

Where the fault is best defined (N.E. 1/4, Section 22, T.37N., R.38E.), it is generally directed westward. In order to fault the older (p. 20) cherty quartzite block into a position adjacent to the younger Churchill formation the fault must in all practicality, but questionably, be extended westward to the Kettle River. As a result, all but one of the five greenstone masses outcrop in association with the cherty quartzite on the upthrown side of the fault block.

The greenstone masses in the N.E. 1/4, Section 22 and N.W. 1/4, Section 27, T.37N., R.37N. are closely associated with cherty quartzite and show intrusive relationships (p. 23). The two greenstone bodies exposed along the Kettle River are in direct contact with alluvium; however, the northern body in the central portion of Section 18, T.37N., R.37E., is discordant to the strike of exposures of the Churchill formation on the northwest and east sides of the body.

It is improbable that the intrusion of these rocks was post faulting, as faulting is believed to be Tertiary in age. Conversion of igneous rocks of Tertiary age to greenstone is considered highly unlikely, especially in view of the fact that the Tertiary (?) andesite and diabase intrusions throughout the area are relatively fresh. Therefore, in all probability the discordant greenstone body mentioned above was either intruded into its present position prior to faulting and after deposition of the Churchill formation, thus being intrusively related to the
Churchill formation, or it was intruded prior to Churchill time and was later faulted into its present discordant relationship with the Churchill formation (see Plate I).

As far as I am aware, the Jurassic Rossland volcanic group of the Orient area, described by Bowman (1950, p. 50-58), contains the only greenstone in adjacent areas considered to be younger than the Middle Permian Churchill formation. The Rossland group is considered to be in part intrusive, and is interbedded with argillite, graywacke, conglomerate, and a minor amount of chert. Bowman's mineralogical description indicates that the greenstone of the Rossland volcanic group is much less altered than the rocks under consideration. Thus, it seems unlikely that the greenstone of the Kelly Hill area is genetically related to that of the Rossland volcanic group.

Considering the absence in adjacent areas of comparable greenstone units younger than the Churchill formation, and the fact that the greenstone in the area is largely restricted to an intrusive association with the cherty quartzite unit, I believe the greenstone is older than the rocks of the Churchill formation and only slightly younger than the cherty quartzite. Thus, the body of greenstone in discordant relationship with the Churchill formation in Section 18, T.37N., R.37E., is interpreted as a fault block. The displacement along the two faults bounding this block must be relatively small, and must decrease rapidly towards the north. The displacement along the major east-west trending fault is unknown; however, it may be considerable.
Strikes and dips indicate that the cherty quartzite has been folded into a syncline plunging northeast. The fold is poorly defined. Only a few minor folds were observed and their attitudes are variable and of little value.

Most of the bedding in the Churchill formation is striking northeast and dipping west (see Figure 22). When Bowman (1950, p. 117-118) mapped the portion of the Churchill formation north of the southern boundary of T.38N., R.37E., and south of the quartz monzonite stock (Barstow granodiorite), he considered the structure in this area to consist of an overturned anticline on the east and a syncline to the west, both plunging northwest. The strike and dip symbols on his map generally correspond to those shown on Plate I, and as interpreted do not indicate the above structure. Bowman's interpretation was apparently based on minor folds exposed on the slopes adjacent to the Columbia River. However, I consider the minor folds in the Churchill formation to be of little value. Poles to axial planes of minor folds were plotted on the lower hemisphere of an equal area stereonet and although the number of points is very limited, the poles fall into three quadrants (see Figure 20). Furthermore, minor fold axes plotted on a stereonet fall into all four quadrants (see Figure 21). With such variability in the attitude of the minor folds they can scarcely be relied upon for structural interpretation.

I believe the strikes and dips in the area indicate a broad anticline plunging to the northwest. In the eastern part of Section 14, T.37N., R.37E., attitudes strongly indicate such a structure (see Plate I).
Figure 20. Poles to axial planes of minor folds in the Churchill formation.
Figure 21. Point location of bearing and plunge of minor fold axes in the Churchill formation.
Toward the north, the strikes and dips indicate the continuance of an anticlinal structure. However, in the northern part of the Kelly Hill area the presence of both Lower Triassic and Middle Permian rocks and the absence of marker beds makes the structural interpretation very uncertain.

SLATY PARTING

The argillites of the Churchill formation have a well developed parting which will here be termed "slaty parting." In every outcrop where slaty parting and bedding are present their attitudes coincide (see Figures 22 and 23). However, more often than not only slaty parting is visible. Attitudes of both slaty parting and bedding were recorded wherever possible, and poles were plotted on equal area stereonets. The area of point concentration on one stereonet is almost a mirror image of the other. Thus, the slaty parting found in the argillites is in all probability reflecting bedding fissility rather than secondary axial plane cleavage. If the slaty parting did represent axial plane cleavage and yet was always parallel to bedding, it would have very complex structural implications. This, however, is not considered to be the case. It probably should be noted that in contrast to the Kelly Hill area, similar rocks in the Kettle Falls area, and near Hunters, approximately 50 miles to the south, display well developed bedding and cleavage relationships.

METAMORPHISM

The major map units of the Kelly Hill area range from unmetamorphosed
Figure 22. Concentration of 170 poles to slaty parting contoured per two per cent area.
Figure 23. Concentration of 150 poles to bedding contoured per two per cent area.
rocks to those of low metamorphic grade. Bowman (1950) reports that
the rocks comprising the Glasgo marble were recrystallized during meta-
morphism and represent low grade metamorphic rocks. He further notes
that the mineral assemblage of the Kelly Hill phyllite is characteristic
of the quartz-albite-epidote-biotite subfacies of the green schist facies.²

The cherty quartzite and associated phyllitic rocks have a mineral
assemblage of quartz, sericite, and chlorite, an assemblage characteristic
of rocks subjected to temperatures and pressures within the quartz-albite-
muscovite-chlorite subfacies of the green schist facies. The mineral
assemblage of quartz, albite, chlorite, and carbonate found in the intru-
sively associated greenstone bodies is typical of basic rocks exposed to
the same conditions of metamorphism. Thus, the greenstone is also repre-
sentative of the quartz-albite-muscovite-chlorite subfacies of the green
schist facies.

As reported by Bowman (1950), the rocks of the Churchill formation
are generally not metamorphosed. However, the rocks along the northern
and southern contact of the quartz monzonite stock in the northern part
of the area have been converted to hornfels as a result of contact
metamorphism. Microscopic study of a sample (K-540) from the northeastern
contact zone in the S.E. 1/4, Section 21, T.38N., R.37E. shows that the
rock is largely recrystallized. The texture is porphyroblastic, with anhedra
grains of biotite, quartz, microperthite, plagioclase, and garnet enclosed
in a matrix of quartz, feldspar, and muscovite. The high quartz content

²All references to the green schist facies are from Fyfe, Turner,
and Verhoogen (1958, p. 222-223).
(79%) strongly suggests its sedimentary origin. The composition of the plagioclase is andesine \((An_{41})\). This is based on a maximum extinction angle of \(15^\circ\), and refractive indices which are both greater and less than quartz. The garnet is dark red in hand specimen. Sample K-457, taken near the southwestern contact, differs somewhat from Sample K-540. Garnet is absent, and the mica is segregated into bands, which give the rock a distinct foliation. Although feldspar is visible, alteration prevents further distinction.

The mineral assemblage of quartz, microperthite, muscovite, biotite, and plagioclase seen in sample K-540 is characteristic of rocks subjected to contact metamorphic conditions of the hornblende hornfels facies. The presence of a lime-bearing plagioclase distinguishes the rock from one of the lower grade albite-epidote hornfels facies, and the muscovite-biotite in the assemblage differentiates it from the higher pyroxene hornfels facies (Fyfe, Turner, and Verhoogen, 1958, p. 206). Bowman (1950) reports a mineral assemblage from the contact zone consisting of quartz, albite, sericite, and biotite, and refers the rock to the biotite chlorite subfacies of Turner (1948, p. 94). This subfacies is the same as the quartz-albite-biotite-epidote subfacies of the green schist facies and is a facies characteristic of low grade regional metamorphism. However, the mineralogy of Bowman's sample is probably a result of contact metamorphism, and, because his assemblage is also a characteristic assemblage of the albite-epidote hornfels facies of contact metamorphism, it should probably be referred to that facies.

In the vicinity of the N.W. 1/4, N.W. 1/4, Section 34, T.38N., R.37E., rocks of the Churchill formation have locally been converted to
a low metamorphic grade. A sample (K-424) from this area contains quartz, muscovite, and chlorite, which is a characteristic mineral assemblage of rocks derived from pelitic sediments and belonging to the quartz, albite, muscovite, chlorite subfacies of the green schist facies.
TRIASSIC PALEONTOLOGY

FAUNAL AND STRATIGRAPHIC

Occurrence and mode of accumulation

Lower Triassic fossils were collected from four small outcrops of thin-bedded limestone exposed in the upper part of the Churchill formation. The exposures all occur within 1/2 mile of one another in the vicinity of the W. 1/2, S.W. 1/4, Section 35, T.38N., R.37E. (see Plate I). The fossiliferous outcrops from which the specimens described in this report were collected are as follows:

Locality

K-376. N.W. 1/4, N.W. 1/4, Section 2, T.37N., R.37E.
K-445. N.E. 1/4, S.E. 1/4, Section 34, T.38N., R.37E.
K-448. N.W. 1/4, S.W. 1/4, Section 35, T.38N., R.37E.
K-518. N.W. 1/4, S.W. 1/4, Section 35, T.38N., R.37E., approximately 800 feet S.W. from locality K-448.

Two additional outcrops are indicated on Plate I as of probable Lower Triassic age on the basis of their lithology, and geographic and stratigraphic position.

Most of the specimens were collected from locality K-376. This exposure of thin-bedded limestone (similar to Figure 14) has a lateral extent of less than 50 feet and a stratigraphic thickness of approximately 30 feet. The exposure is underlain by a siltstone which grades upward into a silty, friable, medium-brown limestone. Near the middle of the stratigraphic thickness medium-brown limestone is gradually
replaced by a clean dark-gray limestone.

The contained fauna is from the upper part of the dark-gray limestone. It is entirely molluscan in nature and is represented by ammonoids, pelecypods, and gastropods. The impure limestone near the base of the exposure produces only sparse pelecypod hash. In places above the base the fossils are so abundant, that locally the limestone could be termed a coquina. One limestone sample which megascopically appears to be unfossiliferous, is in thin section (K-376) a coquina (see Figure 24). Greater than 75 per cent of the thin section is fossil material, most of which is pelecypod shells, although ammonoid and gastropod material is present in lesser amounts. The shell material is poorly sorted and ranges from 0.25 mm to 4.5 mm in diameter. The pelecypod shells are disarticulated but not broken and show no evidence of transportation. The only orientation expressed is that normally expected to occur from flat forms accumulating on the bottom of the sea. Some pelecypod shells occur concave up whereas others are concave down.

Individuals in all stages of growth are represented. Minute juvenile ammonoids, just beginning to coil, occur with adult forms up to 5 cm in diameter. Similar variations were observed for some of the more abundant pelecypods.

The unsorted and unabraded condition of the fossil materials indicates that deposition of the organic remains took place essentially in situ. The matrix consists of limestone mud which leads to a similar inference. Conditions of deposition in which material of this type might collect could be found in protected lagoonal areas or in relatively deep water. The faunal composition, with a mixture of benthonic and
pelagic forms implies a protected shallow water site of deposition where there was access to the open sea.

Figure 24. Coquina (K-376), composed predominantly of pelecypod remains and minor amounts of ammonoid and gastropod material. Plain light, x 25.

Faunal list

The fauna consists of the following forms.

Phylum Mollusca

Class Pelecypoda

- Anodontophora cf. A. breviformis
- Anodontophora? sp.
- Myalina cf. M. shamarae
- Pecten cf. P. sojalis
- Pecten sp. indet.
- Pecten sp. indet.
- Pecten sp. ?
- Pseudomonotis (Eumorphotis) cf. P. (E.) multiformis

Class Grastropoda

- Naticopsis sp. indet.
- Loxonema? sp.
- Worthenia sp. indet.

Class Cephalopoda

- Dieneroceras cf. D. dieneri
- Arnautoceltites aff. A. dieneri
- Owenites aff. O. koeneni
Correlation and age of the fauna

Owenites aff. O. koeneni, Dieneroceras cf. D. dieneri, and Arnautoceltites aff. A. dieneri, are all restricted to the Lower Triassic Meekoceras fauna which is well developed in various parts of the western United States. Smith (1932, p. 7) separates the Meekoceras zone into three subzones, which are in ascending order the Pseudosageceras multilobatum, Owenites, and Anasibirites subzones. Owenites koeneni, which is represented in the Kelly Hill fauna, is one of the characteristic species of the Owenites subzone.

Smith (1932, p. 9) reports the occurrence of Owenites koeneni, Arnautoceltites dieneri, and several species of Dieneroceras in the Owenites subzone of the Meekoceras zone in the Inyo Range of southeastern California. Smith (1932, p. 10) also reports a fauna containing Owenites cf. O. koeneni and Arnautoceltites dieneri from a 50 foot section of limestone in Elko County, northeastern Nevada. He believes the fauna represents the base of the Owenites subzone.

The Meekoceras fauna of the lower limestone unit of the Thaynes formation is very widespread in the middle Rocky Mountains, and Dieneroceras dieneri and Arnautoceltites dieneri have both been collected from this horizon in southeastern Idaho (Kummel, 1954, p. 185). In addition, Smith (1932, p. 10) reports Owenites cf. O. koeneni from a locality one mile west of Paris, also in southeastern Idaho. However, at this locality O. koeneni does not occur with either Arnautoceltites dieneri or Dieneroceras dieneri.

The most recent revision of Lower Triassic faunal chronology is by Spath (1934, p. 27), and he has divided the Early Triassic into six
faunal divisions or ages. The ages are as follows.

| Upper Eo-trias | Prohungaritan
|               | Columbitan
|               | Owenitan
| Lower Eo-trias | Flemingitan
|               | Gyronitan
|               | Otoceratan

The Meekoceras fauna, characterized by the zone of Owenites, is considered to be lower Owenitan. The ammonoids indicate that the Kelly Hill fauna is correlative with the Lower Triassic Meekoceras fauna, and thus also probably of Owenitan age (see Figure 25).

The pelecypods and gastropods associated with the Meekoceras fauna of the western states have received little attention. As a result, comparison with species of the Kelly Hill fauna is impossible. The pelecypod and gastropod species are in some instances very similar to specimens found in the upper Otoceratan Dinwoody fauna of western Wyoming and southeastern Idaho (Newell and Kummel, 1942). Specimens described by Kiparisova (1938) from the Ussuri Bay region near Vladivostok, on the sea of Japan, and those of the East Greenland fauna described by Spath (1930, 1935) also show a striking similarity to the pelecypods and gastropods of the Kelly Hill fauna (see Table 2). It is interesting and probably significant to note that Kiparisova (1938) found species of Anodontophora, Pseudomonotis (Bumophotis), Myalina, and Pecten, in the same horizon with Meekoceras.
|-------------|-------------------------|-------------------------|-----------------------------|-------------------------|------------------------|--------------------------------|----------------------------------------|

**Anasibirites fauna**  
**Wasatchites**  

**Owenitan**

<table>
<thead>
<tr>
<th>Meekoceras fauna</th>
<th>Meekoceras fauna</th>
<th>Meekoceras fauna</th>
<th>Meekoceras fauna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owenites koeneni</td>
<td>cf. O. koeneni</td>
<td>Owenites cf. O. koeneni</td>
<td>Owenites aff. O. koeneni</td>
</tr>
<tr>
<td>Arnautoceltites dieneri</td>
<td>Arnautoceltites dieneri</td>
<td>Arnautoceltites dieneri</td>
<td>Arnautoceltites aff. A. dieneri</td>
</tr>
<tr>
<td>Dieneroceras dieneri</td>
<td>Dieneroceras dieneri</td>
<td>Dieneroceras dieneri</td>
<td>Dieneroceras cf. D. dieneri</td>
</tr>
</tbody>
</table>

Figure 25. Correlation of Owenitan faunas. (modified in part from F. H. McLearn, 1945).
Table 2. Generic comparison of the Lower Triassic pelecypod and gastropod fauna of northeastern Washington with the East Greenland, Ussuri Bay (near Vladivostok), and Dinwoody (western Wyoming and southeastern Idaho) faunas.

Paleogeographic considerations

McKee et al. (1959) record known Lower Triassic rocks from southern California, Nevada, and many of the interior western states. According to Ketner (in McKee et al. 1959, p. 12), the known distribution of these rocks "...suggests a straight across southern California connecting the southern part of the Early Triassic interior seaway with the open seaway to the west" (see Figure 26). During Late Triassic time the restricted sea occupying the southern part of the west coast region during Early Triassic time is believed to have expanded through Oregon to Washington and Canada (Ketner, in McKee et al. 1959, p. 17). This concept has been supported by the supposed absence of Lower Triassic rocks in Oregon, western Idaho, Washington, and that part of British Columbia lying west of the Rocky Mountain trench.
Figure 26. Map showing the interpretation of the extent of Early Triassic seas in western America made by McKee et al. (1959). The modified shoreline as suggested by the Lower Triassic fauna of N.E. Washington is also indicated. Approximate locations of faunas used in correlation are designated.
The fauna from northeastern Washington is of particular importance as it establishes for the first time the existence of Lower Triassic rocks in the northwestern Cordillera, and indicates that Early Triassic seas were much more widespread than previously considered. The occurrence of species in northeastern Washington, which are common to the Lower Triassic faunas of southern California, northeastern Nevada, and southeastern Idaho, indicates that in all probability the Early Triassic sea of northern Nevada and southeastern Idaho extended northward to northeastern Washington (see Figures 25-26). A further paleogeographic implication is that parts of eastern Oregon and western Idaho were also covered by this seaway.

McLearn (1945, p. 4) reports a Wasatchites fauna from the Laird River area, located east of the Rocky Mountain trench in northeastern British Columbia. The fauna is correlated with the Wasatchites fauna from the Anasibirites beds in the Fort Douglas area of Utah. According to McLearn (1945, p. 4), Mathew states that the Wasatchites fauna occurs above beds containing Meekoceras and below the Columbites horizon (see Figures 25-26). Spath (1934, p. 345) indicates a geologic range for Wasatchites of upper Owenitan to Columbian. This faunal correlation indicates the probable existence of a connecting seaway. According to McLearn and Kindle (1950, p. 129), the Early Triassic Wasatchites sea may have extended south of the international boundary and at least had "...some direct communication with the Wasatchites sea of Utah."

The occurrence of a Lower Triassic fauna in the vicinity of the International boundary in northeastern Washington suggests the possible location of the Wasatchites seaway. The upper Owenitan sea connecting
the Fort Douglas, Utah area and northeastern British Columbia may simply have represented a northward extension of the seaway which had already reached northeastern Washington during lower Owenitan time.

SYSTEMATIC PALEONTOLOGY

Phylum Mollusca
Class Pelecypoda
Genus Anodontophora Cossman
Anodontophora cf. A. breviformis Spath
Pl. 5, fig. 1.

Anodontophora sp. ind. (breviform) Spath, 1930, p. 55, pl. 10, figs. 8, 9; pl. 11, figs. 3a-c; pl. 7, fig. 6.
Anodontophora breviformis Spath, 1935, p. 75, pl. 22, figs. 3, 4; pl. 23, figs. 2, 3.

The species is represented by a smooth internal mold of a left valve. The specimen is closer to Anodontophora breviformis Spath than to other species of this genus. It bears closest resemblance to the specimen figured by Spath (1935, pl. 22, fig. 4). Spath's figured specimen has a height of 20.0 mm, length of 30.0 mm, and a height to length ratio of 0.67. My specimen has a height of 15.5 mm, a length of 21.0 mm, and a height to length ratio of 0.74. In addition, the umbo of the Kelly Hill specimen is slightly more posterior and that part of the hinge line extending forward from the beak makes a smaller angle with the umbo. These differences are probably not too significant as the form of this species is quite variable (Spath 1935). More specimens are needed before the exact relationship of the species from the Kelly Hill fauna can be determined.
**Occurrence.** Locality K-448.

**Figured specimen.** M7241; Montana State University, Dept. of Geology.

**Anodontophora? sp.**

Pl. 5, fig. 3.

The species is represented by a single rather poorly preserved internal mold of a left valve. Valve nearly equilateral with slight convexity, umbo anterior, beak prosogyrous, hinge line straight. Shell height 16.0 mm, length 19.0 mm. **Anodontophora borealis** (Spath, 1935, p. 76, text fig. 5a, b) also has the umbo in an extremely forward position, but it is not to the extreme as in this specimen. In addition, **A. borealis** is more elongated in an anterior-posterior direction.

**Occurrence.** Locality K-448.

**Figured specimen.** M7242; Montana State University, Dept. of Geology.

**Genus Myalina Koninck, 1842**

**Myalina cf. M. shamarae** Bittner

Pl. 5, fig. 2.

**Myalina aff. M. shamarae** Spath, 1935, p. 70, pl. 20, figs. 2, 3, 12; pl. 21, fig. 15.

The internal mold of a left valve is the only representation of this species in the Kelly Hill fauna. Shell shape mytiliform. Terminal beak dorsally projected, posterior border of beak pocketed. Shell height 13.0 mm, length 23.0 mm.

This specimen differs from the example of **Myalina aff. M. shamarae** Bittner figured by Spath (1935, pl. 20, fig. 12), in that the valve is not only more elongated but also more convex. However, the specimen is
comparable to *M. aff. M. schamarae* figured by Spath (1935, pl. 20, figs. 2, 3), particularly in the dorsally projected beak and the slightly pocketed posterior part of the beak region. The Kelly Hill specimen differs from *M. aff. M. schamarae* (Spath, 1935, pl. 20, figs. 2, 3) in being smaller and more elongated. According to Spath (1935), these specimens are transitional from *M. aff. M. schamarae* to *M. kocki*.

**Occurrence.** Locality K-448.

**Figured Specimen.** M?243; Montana State University, Dept. of Geology.

Genus *Pecten* Osbeck, 1765

*Pecten cf. P. sojalis* Witt

*Pecten aff. P. sojalis* Kiparisova, 1938, pi. 5, figs. 14-17.

The species is abundant in the Kelly Hill fauna. Shell small, pectinoid, only slightly oblique, only moderately convex, equilateral and orbicular. Hinge line straight. Ears distinct and almost symmetrical. Ornamentation consists of fine growth lines.

The Kelly Hill specimens are similar in form and ornamentation to *Pecten aff. P. sojalis* Witt figured by Kiparisova (1938, pl. 5, figs. 14-17). A comparison of measurements\(^3\) of specimens figured by Kiparisova and the Kelly Hill specimens follows:

<table>
<thead>
<tr>
<th></th>
<th>Kiparisova, 1938</th>
<th>Kelly Hill specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M7244</td>
<td>M7245</td>
</tr>
<tr>
<td>H</td>
<td>8.5</td>
<td>11.0</td>
</tr>
<tr>
<td>L</td>
<td>9.0</td>
<td>13.0</td>
</tr>
<tr>
<td>H/L</td>
<td>0.94</td>
<td>0.85</td>
</tr>
</tbody>
</table>

\(^3\)All specimen measurements are in millimeters.
Occurrence. Locality K-376.

Figured Specimen. M7245; Montana State University, Dept. of Geology.

Pecten sp. indet.
Pl. 4, fig. 8.

This species is represented by a single left valve. Shell shape orbicular, unequilateral, and moderately convex. Hinge line straight. Ears well developed. Shell height 15.3 mm, length 14.0 mm. Ornamentation consists of concentric growth lines as described above for Pecten aff. P. sojalis Witt. However, this species is distinctly different because of its strong obliquity.

Occurrence. Locality K-347.

Figured Specimen. M7247; Montana State University, Dept. of Geology.

Pecten sp. indet.
Pl. 4, fig. 7.

This species is represented by two left valves. Valve elongated in dorsal-ventral direction. Convexity moderate. Umbonal angle small. Hinge line straight. Ears distinct, well developed and slightly assymetrical. Ornamentation consists of fine but distinct concentric growth lines.

This species differs considerably from the two species just described. It has a smaller umbonal angle and a greater ratio of height to length. Dimensions are as follows:

<table>
<thead>
<tr>
<th></th>
<th>M7248</th>
<th>M7249</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>10.0</td>
<td>9.0</td>
</tr>
<tr>
<td>L</td>
<td>6.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>
Occurrence. Locality K-376.

Figured Specimen. M7248; Montana State University, Dept. of Geology.

_Pecten s.l. sp. indet._
_Pl. 4, figs. 4, 5._

This large pectinoid species is well represented in the Kelly Hill localities. Valves subcircular excluding auricles. Left valve decidedly more convex than right valve. Hinge line straight, shorter than shell length. Anterior and posterior extension of auricles equal but of different shape. Auricular sulcus very well developed on anterior auricle of left valve. Shell slightly prosocline. Concentric ribs present. Two orders of radial ribs; coarse first order ribs separated by fine radii of the second order, up to seven second order ribs between two first order ribs. Swellings or nodes on the heavy first order ribs, possibly caused by irregular arrangement of concentric ribbing.

This is one of the most abundant species occurring with the ammonoids. Unfortunately, the Lower Triassic faunas of East Greenland and of Ussuri Bay described by Spath (1930, 1935) and Kiparisova (1938) do not contain a species comparable to the Kelly Hill specimens. A search of the literature indicates that this is probably a new species, but the specimens are too incomplete for description of a new species. Measurements are as follows:

<table>
<thead>
<tr>
<th>Left valves</th>
<th>Right valves</th>
</tr>
</thead>
<tbody>
<tr>
<td>M7250 M7252 M7253</td>
<td>M7251 M7254 M7256 M7257 M7258 M7259</td>
</tr>
<tr>
<td>H</td>
<td>46⁺</td>
</tr>
<tr>
<td>L</td>
<td>38⁺</td>
</tr>
<tr>
<td>H/L</td>
<td>1.21</td>
</tr>
</tbody>
</table>
Occurrence. Locality K-376.

Figured Specimens. M7250, M7251; Montana State University, Dept. of Geology.

Subgenus *Eumorphotis* Bittner, 1901

*Pseudomonotis (Eumorphotis)* sp. *P. (E.) multiformis* Bittner

Pl. 5, figs. 4, 5.

*Pseudomonotis (Eumorphotis) multiformis* Spath, 1935, pl. 74, pi. 22, fig. 8.

*Pseudomonotis (Eumorphotis) multiformis* Kiparisova, 1938, p. 224, pl. 2, figs. 4, 5, 8; pl. 3, fig. 4.

Valves acline, not equal; left valve with considerable convexity, right valve relatively flat. Hinge line straight. Wings weak but distinct, show the general shape of the species. Ornamentation consists of radii of varying strength grouped into sets; each set defined by two heavy radii, divided in two by a radius of somewhat lesser strength, each half divided by very fine radii which may reach five in number. Concentric growth lines with strength of finest radii.

Bittner's figures were not available; however, comparisons were made with the many figures of the species figured by Kiparisova (1938). Spath (1935) also reports the species in the East Greenland fauna. A comparison of the Kelly Hill specimens and those figured by Kiparisova follows:

<table>
<thead>
<tr>
<th></th>
<th>Kiparisova, 1938</th>
<th>Kelly Hill specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pl. 2</td>
<td>pl. 3</td>
</tr>
<tr>
<td>H</td>
<td>fig. 4</td>
<td>fig. 5</td>
</tr>
<tr>
<td>L</td>
<td>20.0</td>
<td>16.0</td>
</tr>
<tr>
<td>H/L</td>
<td>1.17</td>
<td>1.25</td>
</tr>
</tbody>
</table>

Figured Specimens. M7261, M7260; Montana State University, Dept. of Geology.

Class Gastropoda
Genus Worthenia Koninck, 1883
Worthenia sp. indet.
Pl. 5, fig. 7.

Turbinate shell with selenizones. There are five whorls present. The height of spire approximately 5.5 mm. Surface ornamentation consists of fine spiral striation.

Spath (1930) described Worthenia cf. W. humilus Boehm from the Eo-triassic fauna of East Greenland. The East Greenland species shows the spiral striation and prominent whorl edge in part characteristic of this species. The Kelly Hill specimen has the spiral striation but not the prominent edge shown on the specimen pictured by Spath (1930, pl. 10, fig. 3).

An insufficient number of specimens is available to make any specific designations.

Occurrence. Locality K-376.

Figured specimen. M7266; Montana State University, Dept. of Geology.

Genus Naticopsis McCoy, 1844
Naticopsis sp. indet.
Pl. 5, fig. 6.

The species is represented by a poorly preserved internal mold. Specimen approximately 29 mm wide and 25 mm high, 2 to 2 1/2 whorls preserved; initial whorl quite flat, second whorl broadening out rapidly, last whorl depressed. Ornamentation not preserved. Inner lip missing.
However, the naticiform shape, large final whorl, and the nearly straight but oblique outer lip are among the distinguishing characters for this genus.

The Kelly Hill specimens are not comparable to any of the species of this genus described in the pertinent literature on Lower Triassic invertebrates. Until better material is obtained no specific designation can be made.

**Occurrence.** Locality K-347.

*Figured specimen. M7267; Montana State University; Dept. of Geology.*

**Genus Loxonema** Phillips

Loxonema? sp.

Pl. 5, fig. 8.

Molds of high spired shells are tentatively referred to *Loxonema*. The rounded shape of the whorls strongly resembles those of a species pictured by Spath (1935, pl. 22, fig. 10) from the Lower Triassic beds of East Greenland. The aperture and ornamentation are not preserved on the Kelly Hill specimens; hence, identification can only be tentative.

**Occurrence.** K-347.

*Figured specimen. M7268; Montana State University, Dept. of Geology.*

**Class Cephalopoda**

**Genus Dieneroceras** Spath, 1934

Dieneroceras cf. *D. dieneri* (Hyatt and Smith)

Pl. 3, figs. 1-6.

Tables 3, 4.

*Ophiceras dieneri* Hyatt and Smith, 1905, p. 118, pl. 8, figs. 16-29.

*Dieneroceras dieneri* (Hyatt and Smith). Spath, 1934, p. 123-125, figs. 34, 35.
The genus *Dieneroceras* was established by Spath (1934) for species which Hyatt and Smith (1905) originally considered to be *Ophiceratids*. The genotype of the new genus was originally referred to *Ophiceras* by Hyatt and Smith, but because of its association and suture line Spath considers *Dieneroceras* to be a primitive Flemingitid and because of its strigation (spiral lines) places it in the family Flemingitidae. However, Spath further notes that the suture line is simpler than is characteristic of ordinary Flemingitids, and therefore considers *Dieneroceras* to be transitional to several groups.

In the recent classification of Triassic ammonoids by Kummel (1952, p. 852), *Dieneroceras* is placed in a separate family Dieneroceratidae. The families Flemingitidae and Xenoceltitidae and other groups of the superfamily Meekoceratacae are believed to represent Lower Triassic radiations from the Ophiceratidae and Dieneroceratidae (see Figure 27).

![Figure 27](image_url)

**Figure 27.** Phylogeny of *Dieneroceras* and related forms (from Kummel 1952, p. 848).

The specimens from the Kelly Hill localities exhibit the somewhat compressed evolute shell, arched venter, and simple suture with two
lateral lobes, listed by Spath (1934) as being among the diagnostic characteristics of *Dieneroceras*; however, certain Xenoceltitids display the same features. Ornamentation, which is present on only one very poorly preserved specimen, does not exhibit the spiral striation of Hyatt and Smith's type specimen of *Dieneroceras dieneri*. This could be a result of poor preservation, but in addition, the radial folds or low costa of the Kelly Hill specimen appear to be closer together and are associated with very fine slightly convex striae. The striae are absent on the type.

The septa are less complex, yet very similar in shape to those on the specimen figured by Hyatt and Smith (1905, pl. 8, fig. 18). The first and second lateral lobes are comparatively simple, i.e., just beginning to show serration. The first lateral lobe has several denticulations; however, the second lateral lobe has only a single digitation. The ventral lobe is divided by a secondary saddle which is subdivided by a tertiary lobe. The tertiary lobe is rather flat, like that of the type of the species on two of the three specimens where it is visible (see pl. 3, figs. 4, 5), but on the other Kelly Hill specimen figured (see pl. 3, fig. 3) this lobe appears deeper and more rounded. The prongs of the ventral lobe have a single denticulation comparable to that of the type specimen. Some sutures were observed which are entirely gonatitic.

Two of the Xenoceltitids, *Xenoceltites gregoryi* and *X. spitsbergensis* (Spath, 1934), known only from Spitzbergen, have simple suture patterns very similar to those of the Kelly Hill specimens. The only significant difference is that the ventral lobe is not divided as deeply and there
is no tertiary lobe. Ornamentation of these two species consists of radial costa. *X. spitsbergensis* is strongly costate on the inner whorls as well as on the outer whorls, a condition not observed on inner whorls of any of the specimens from Kelly Hill. *X. gregoryi* is less strongly costate on the outer, and smooth on the inner whorls, a condition which is similar to what ornamentation can be observed on the Kelly Hill specimens. *X. gregoryi*, however, has a narrower venter than the species under consideration. *Xenoceltites gregoryi* and *X. spitsbergensis* are believed to be of Columbian age. Furthermore, they are not known to be associated with *Arnauceltites aff. A. dieneri* and *Owenites aff. O. koeneni* of lower Owenitan age. There is a near equal possibility that the species under consideration is either a species of *Dieneroceras* or *Xenoceltites* or a transitional species (see Figure 27). However, on the basis of the faunal association with *Arnauceltites aff. A. dieneri* and *Owenites aff. O. koeneni*, and the similarity in outward form and measurement with *D. dieneri*, the specimens in the Kelly Hill collection are tentatively referred to *Dieneroceras cf. D. dieneri*.

Measurements of the Kelly Hill specimens are given in Table 3. In Table 4 the Kelly Hill specimens and specimens described and figured by Hyatt and Smith (1905) are compared. Specifications for the latter are taken directly from the illustrations.
Table 3. Measurements of *Dieneroceras cf. D. dieneri* (Hyatt and Smith).

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Diam. (D)</th>
<th>Width last whorl (W)</th>
<th>Umbil. width (Um)</th>
<th>W/D</th>
<th>Um/D</th>
<th>Ht. last whorl (Ht)</th>
<th>W/Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>M7210</td>
<td>42.8</td>
<td>9.8</td>
<td>19.1</td>
<td>0.23</td>
<td>0.45</td>
<td>12.7</td>
<td>0.77</td>
</tr>
<tr>
<td>M7211</td>
<td>41.0</td>
<td>8.3</td>
<td>16.4</td>
<td>0.20</td>
<td>0.40</td>
<td>13.5</td>
<td>0.62</td>
</tr>
<tr>
<td>M7212</td>
<td>48.6</td>
<td>10.0</td>
<td>19.5</td>
<td>0.21</td>
<td>0.40</td>
<td>17.0</td>
<td>0.59</td>
</tr>
<tr>
<td>M7213</td>
<td>37.5</td>
<td>8.5</td>
<td>13.0</td>
<td>0.23</td>
<td>0.35</td>
<td>14.0</td>
<td>0.61</td>
</tr>
<tr>
<td>M7214</td>
<td>35.6</td>
<td>8.9</td>
<td>14.0</td>
<td>0.25</td>
<td>0.39</td>
<td>13.7</td>
<td>0.65</td>
</tr>
<tr>
<td>M7215</td>
<td>30.0</td>
<td>7.6</td>
<td>12.8</td>
<td>0.25</td>
<td>0.43</td>
<td>10.5</td>
<td>0.74</td>
</tr>
<tr>
<td>M7216</td>
<td>43.0</td>
<td>9.0</td>
<td>18.5</td>
<td>0.21</td>
<td>0.41</td>
<td>14.0</td>
<td>0.64</td>
</tr>
<tr>
<td>M7217</td>
<td>24.9</td>
<td>5.3</td>
<td>9.0</td>
<td>0.21</td>
<td>0.36</td>
<td>9.0</td>
<td>0.59</td>
</tr>
<tr>
<td>M7218</td>
<td>24.0</td>
<td>6.0</td>
<td>7.0</td>
<td>0.25</td>
<td>0.29</td>
<td>11.0</td>
<td>0.55</td>
</tr>
<tr>
<td>M7219</td>
<td>17.0</td>
<td>3.75</td>
<td>5.5</td>
<td>0.20</td>
<td>0.32</td>
<td>6.5</td>
<td>0.53</td>
</tr>
</tbody>
</table>


Figured specimens. M7210, M7216, M7217, M7218; Montana State University, Dept. of Geology.

**Genus Arnautoceltites** Diener, 1916

*Arnautoceltites aff. A. dieneri* (Hyatt and Smith)

Pl. 3, figs. 16-18; pl. 4, figs. 1-3.

Tables 5, 6.

*Nannites dieneri* Hyatt and Smith, 1905, p. 79, pl. 7, figs. 5-25.


The subglobose form, constrictions, and simple septa are indicative of the genus. The specimens referred to this species comply very closely with Hyatt and Smith’s description. The suture pattern (see pl. 4,
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Diam. (D)</th>
<th>Width last wh. (W)</th>
<th>Umbil. width (Um)</th>
<th>W/D</th>
<th>Um/D</th>
<th>Ht. last whorl (Ht.)</th>
<th>W/Ht</th>
<th>Ht. last wh., impressed area to venter (Htd)</th>
<th>Htd/Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>M7215</td>
<td>32.0</td>
<td>7.5</td>
<td>14.0</td>
<td>0.23</td>
<td>0.44</td>
<td>11.0</td>
<td>0.68</td>
<td>8.0</td>
<td>0.73</td>
</tr>
<tr>
<td>*1.</td>
<td>30.0</td>
<td>7.6</td>
<td>12.8</td>
<td>0.25</td>
<td>0.42</td>
<td>10.5</td>
<td>0.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M7217</td>
<td>24.8</td>
<td>6.0</td>
<td>9.5</td>
<td>0.24</td>
<td>0.39</td>
<td>9.0</td>
<td>0.68</td>
<td>7.0</td>
<td>0.73</td>
</tr>
<tr>
<td>*2.</td>
<td>24.9</td>
<td>5.3</td>
<td>9.0</td>
<td>0.21</td>
<td>0.36</td>
<td>9.0</td>
<td>0.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M7218</td>
<td>24.0</td>
<td>6.0</td>
<td>7.0</td>
<td>0.25</td>
<td>0.29</td>
<td>11.0</td>
<td>0.55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M7216</td>
<td>43+</td>
<td>9.0</td>
<td>18.5</td>
<td>0.21</td>
<td>0.41</td>
<td>14.0</td>
<td>0.64</td>
<td>11.5</td>
<td>0.82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Width 2nd last wh. (W₂)</th>
<th>Ht. 2nd last wh. (Ht₂)</th>
<th>W₂/Ht₂</th>
<th>Ht. 2nd last wh., impressed area to venter (Htd₂)</th>
<th>Htd₂/Ht₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1.</td>
<td>4.5</td>
<td>7.0</td>
<td>0.64</td>
<td>0.86</td>
</tr>
<tr>
<td>*2.</td>
<td>3.8</td>
<td>5.5</td>
<td>0.69</td>
<td>0.73</td>
</tr>
<tr>
<td>M7216</td>
<td>7.0</td>
<td>9.0</td>
<td>0.77</td>
<td>0.78</td>
</tr>
</tbody>
</table>

*Specimens figured by Hyatt and Smith (1905, pl. 8).  
*1. Type specimen, figs. 16, 17.  
*2. Figs. 19, 20.

Table 4. Comparison of Kelly Hill specimens of Dieneroceras cf. D. dieneri to specimens figured by Hyatt and Smith (1905, pl. 8).
fig. 3) is almost identical to one of Hyatt and Smith's specimens (Hyatt and Smith, 1905, pl. 7, fig. 9). The sutures differ from Hyatt and Smith's type specimen (Hyatt and Smith, 1905, pl. 7, fig. 13) in the absence of the shallow auxiliary lobe on the umbilical slope. However, the umbilical slope is not fully visible on the Kelly Hill specimens, and the sutures extend only to the umbilical border. On one specimen a minute denticulation (see pl. 3, fig. 18) is visible in the first lateral lobe. According to Spath (1934, p. 191), this lobe is usually entire in the genus, but as evidenced by what Smith (1927, pl. 21, fig. 10) figured as the adolescent state of Amautoceltites kaffti, there may be minute toothing in the lobe.

Surface constrictions typical of the species are visible, but fine radial striae characteristic of the outer shell surface are absent. This is believed to be a result of poor preservation.

Measurements of the Kelly Hill specimens and their comparison to specimens described and figured by Hyatt and Smith (1905) are given in Tables 5 and 6 respectively.
### Table 5. Measurements of *Arnautoceltites aff. A. dieneri* (Hyatt and Smith).

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Diam. (D)</th>
<th>Width last wh. (W)</th>
<th>Umbil. width (Um)</th>
<th>W/D</th>
<th>Um/D</th>
<th>Ht. last whorl (Ht)</th>
<th>W/Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>M7234</td>
<td>16.0</td>
<td>8.5</td>
<td>3.7</td>
<td>0.53</td>
<td>0.23</td>
<td>7.5</td>
<td>1.13</td>
</tr>
<tr>
<td>M7235</td>
<td>11.9</td>
<td>8.4</td>
<td>2.7</td>
<td>0.71</td>
<td>0.23</td>
<td>7.0</td>
<td>1.20</td>
</tr>
<tr>
<td>M7236</td>
<td>12.5</td>
<td>6.9</td>
<td>3.0</td>
<td>0.55</td>
<td>0.24</td>
<td>7.0</td>
<td>0.99</td>
</tr>
<tr>
<td>M7237</td>
<td>7.8</td>
<td>6.0</td>
<td>2.5</td>
<td>0.77</td>
<td>0.32</td>
<td>---</td>
<td>----</td>
</tr>
<tr>
<td>M7238</td>
<td>12.0</td>
<td>7.0</td>
<td>2.4</td>
<td>0.58</td>
<td>0.20</td>
<td>6.8</td>
<td>1.03</td>
</tr>
<tr>
<td>M7239</td>
<td>10.5</td>
<td>6.0</td>
<td>2.2</td>
<td>0.57</td>
<td>0.21</td>
<td>5.2</td>
<td>1.15</td>
</tr>
<tr>
<td>M7240</td>
<td>8.7</td>
<td>5.0</td>
<td>---</td>
<td>0.58</td>
<td>---</td>
<td>---</td>
<td>----</td>
</tr>
</tbody>
</table>

*Specimens figured by Hyatt and Smith (1905, pl. 7).

**Table 6. Comparison of Kelly Hill specimens of *Arnautoceltites aff. A. dieneri* to specimens figured by Hyatt and Smith (1905, pl. 8).**

**Occurrence.** Locality K-376.

**Figured specimens.** M7234, M7235, M7237; Montana State University, Dept. of Geology.
The Kelly Hill specimens generally fit the description given by Hyatt and Smith (1905) in that they show the lenticular, involute, oxycone form; and ceratitic suture line with numerous lobes and saddles indicative of the genus.

Sutures are only preserved well on one adolescent specimen (M7230) with a diameter 12.7 mm (Pl. 3, fig. 13). According to Hyatt and Smith (1905), the septa do not start to become serrated until about diameter 10 mm. Therefore, as expected, the suture pattern is much simpler than that of Hyatt and Smith’s type specimen (Hyatt and Smith, 1905, pl. 10, fig. 4). The secondary ventral saddle on specimen M7230 has a sharp assymetrical tertiary lobe, and the ventral prongs are serrated. First and second lateral saddles are round and complete, and the corresponding lobes are only slightly denticulated. There are four auxiliary saddles and lobes with the fourth auxiliary lobe being on the umbilical seam. According to Spath (1934, p. 185), the auxiliary elements may vary in number.

Young specimens exhibit ornamentation in the form of constrictions and radial striae; however, the larger adult specimens are smooth.

The closely related Owenites egrediens Welter, known from Timor and also from California where it occurs with $O$. koeneni, is the only other species with which these specimens might be compared. Spath (1934,
186) believes that *O. egrediens* differs from *O. koeneni* only in proportion and simpler septa. In addition, Smith (1932, p. 101) considers the greater egression of the whorl of *O. egrediens* to be a distinguishing feature. Spath is in disagreement with this. Specimens in the Kelly Hill collection with comparable diameter to the specimen of *O. egrediens* illustrated by Smith (1932, pl. 52, fig. 6) clearly exhibit less egression of the whorl.

As previously mentioned, septa visible on the Kelly Hill specimens are on young individuals. Thus, critical comparison can not be made with the septa of *O. egrediens* figured by Smith (1932, pl. 52, fig. 6). However, the specimen illustrated by Smith has a complete ventral saddle similar to that of specimen M7224 (see pl. 3, fig. 14).

The lateral sides of the Kelly Hill specimens are not flattened as much as on the type specimen of *O. koeneni*. However, they are much closer to *O. koeneni* in this respect than to the robust shell of *O. egrediens*. Among the specimens under consideration there is considerable variability in dimensions. Spath (1934, p. 186) has also noted this variability among specimens of this species.

Measurements and comparisons are recorded in Tables 7 and 8 respectively.
<table>
<thead>
<tr>
<th>Specimen</th>
<th>Diam. (D)</th>
<th>Width last wh. (W)</th>
<th>Umbil. width (Um)</th>
<th>W/D</th>
<th>Um/D</th>
<th>Ht. last whorl (Ht)</th>
<th>W/Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>M7220</td>
<td>32.6</td>
<td>11.5</td>
<td>4.5</td>
<td>0.38</td>
<td>0.14</td>
<td>18.5</td>
<td>0.62</td>
</tr>
<tr>
<td>M7221</td>
<td>37.0</td>
<td>14.0</td>
<td>3.5</td>
<td>0.38</td>
<td>0.10</td>
<td>20.5</td>
<td>0.68</td>
</tr>
<tr>
<td>M7222</td>
<td>21.8</td>
<td>9.0</td>
<td>---</td>
<td>0.41</td>
<td>----</td>
<td>11.0</td>
<td>0.82</td>
</tr>
<tr>
<td>M7223</td>
<td>19.5</td>
<td>7.4</td>
<td>---</td>
<td>0.38</td>
<td>----</td>
<td>10.8</td>
<td>0.69</td>
</tr>
<tr>
<td>M7224</td>
<td>21.0</td>
<td>7.6</td>
<td>2.8</td>
<td>0.36</td>
<td>0.13</td>
<td>10.5</td>
<td>0.72</td>
</tr>
<tr>
<td>M7225</td>
<td>16.0</td>
<td>5.8</td>
<td>2.0</td>
<td>0.36</td>
<td>0.13</td>
<td>9.0</td>
<td>0.64</td>
</tr>
<tr>
<td>M7226</td>
<td>20.5</td>
<td>8.8</td>
<td>3.0</td>
<td>0.43</td>
<td>0.15</td>
<td>12.0</td>
<td>0.73</td>
</tr>
<tr>
<td>M7227</td>
<td>23.0</td>
<td>10.5</td>
<td>3.5</td>
<td>0.45</td>
<td>0.15</td>
<td>15.0</td>
<td>0.70</td>
</tr>
<tr>
<td>M7228</td>
<td>26.0</td>
<td>9.6</td>
<td>---</td>
<td>0.37</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>M7229</td>
<td>12.7</td>
<td>5.0</td>
<td>---</td>
<td>0.39</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>M7230</td>
<td>12.7</td>
<td>6.4</td>
<td>1.5</td>
<td>0.50</td>
<td>0.11</td>
<td>8.5</td>
<td>0.75</td>
</tr>
<tr>
<td>M7231</td>
<td>26.8</td>
<td>11.7</td>
<td>3.0</td>
<td>0.44</td>
<td>0.11</td>
<td>16.0</td>
<td>0.73</td>
</tr>
<tr>
<td>M7232</td>
<td>25.5</td>
<td>9.8</td>
<td>3.0</td>
<td>0.38</td>
<td>0.12</td>
<td>14.0</td>
<td>0.70</td>
</tr>
<tr>
<td>M7233</td>
<td>18.0</td>
<td>7.0</td>
<td>2.5</td>
<td>0.39</td>
<td>0.14</td>
<td>10.0</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 7. Measurements of *Owenites aff. O. koeneni* Hyatt and Smith.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Diam. (D)</th>
<th>Width last wh. (W)</th>
<th>Umbil. width (Um)</th>
<th>W/D</th>
<th>Um/D</th>
<th>Ht. last whorl (Ht)</th>
<th>W/Ht</th>
</tr>
</thead>
<tbody>
<tr>
<td>*1.</td>
<td>30.3</td>
<td>9.0</td>
<td>3.0</td>
<td>0.30</td>
<td>0.10</td>
<td>16.0</td>
<td>0.56</td>
</tr>
<tr>
<td>**1.</td>
<td>33.0</td>
<td>13.5</td>
<td>6.0</td>
<td>0.41</td>
<td>0.18</td>
<td>14.0</td>
<td>0.96</td>
</tr>
<tr>
<td>M7220</td>
<td>32.6</td>
<td>11.5</td>
<td>4.5</td>
<td>0.38</td>
<td>0.14</td>
<td>18.5</td>
<td>0.62</td>
</tr>
<tr>
<td>*2.</td>
<td>15.0</td>
<td>6.0</td>
<td>1.5</td>
<td>0.40</td>
<td>0.10</td>
<td>8.5</td>
<td>0.71</td>
</tr>
<tr>
<td>M7225</td>
<td>16.0</td>
<td>5.8</td>
<td>2.0</td>
<td>0.36</td>
<td>0.12</td>
<td>9.0</td>
<td>0.64</td>
</tr>
<tr>
<td>M7230</td>
<td>12.7</td>
<td>6.4</td>
<td>1.5</td>
<td>0.50</td>
<td>0.12</td>
<td>8.5</td>
<td>0.75</td>
</tr>
<tr>
<td>*3.</td>
<td>53.0</td>
<td>16.0</td>
<td>8.0</td>
<td>0.30</td>
<td>0.15</td>
<td>24.5</td>
<td>0.65</td>
</tr>
</tbody>
</table>

*Owenites koeneni* specimens figured by Hyatt and Smith (1905, pl. 10).


*2. Figs. 7-10.

**1. *Owenites egrediens* specimen figured by Smith (1932, pl. 52, figs. 6-8).

Table 8. Comparison of Kelly Hill specimens of *Owenites aff. O. koeneni* to *O. koeneni* and *O. egrediens* figured by Hyatt and Smith (1905) and Smith (1932).
Occurrence. Locality K-376.

Figured specimens. M7220, M7230, M7233, M7224, M7232; Montana State University, Dept. of Geology.
SUMMARY OF GEOLOGIC HISTORY AND CONCLUSIONS

The geologic history of northeastern Washington is in general typical of the history of the sedimentary belt within the western trough of the Cordilleran geosyncline which extends from northern California to Alaska. During most of the Paleozoic era northeastern Washington was submerged and receiving marine sediments. With the exception of the Silurian, rocks referrable to every Paleozoic period are represented somewhere in northeastern Washington. The fact that some of these periods are unrepresented in the Kelly Hill area and immediate vicinity, can probably be attributed to block faulting and erosion rather than non-deposition.

A summary of the geologic history of the Kelly Hill area follows.

1. Marine sediments were deposited during Cambrian and Ordovician time, and are believed to be represented in the Kelly Hill area by the Glasgo marble and Kelly Hill phyllite respectively.

2. Cherty quartzite and phyllitic quartzite of Permian (?) and (or) Carboniferous (?) age represent partially metamorphosed bedded cherts which probably originated by the precipitation of a silica gel from sea water. Silica gel probably accumulated in a marine basin receiving small but variable amounts of clay and silt, which allowed grading and interbedding of quartzitic and phyllitic rocks. The fine size and relative paucity of terrigenous sediments during the accumulation of the cherty quartzite indicate that terrigenous source areas were either very low or distant.

3. The greenstone associated with the cherty quartzite and
phyllitic quartzite was derived from a basic volcanic rock, and probably represents shallow submarine intrusions into the cherty quartzite shortly after the consolidation of the original silica gel on the sea floor. Thus, the greenstone is probably nearly the same age (Permian? and (or) Carboniferous?). The cherty quartzite and associated greenstone may or may not be conformable with the Middle Permian part of the Churchill formation, but they are considered to be older because of their higher degree of metamorphism. Mineral assemblages of the cherty quartzite and greenstone indicate that both have been subjected to the metamorphic conditions characteristic of the quartz-albite-muscovite-chlorite sub-facies of the green schist facies.

4. Sediments of the Middle Permian part of the Churchill formation accumulated in a rapidly but differentially subsiding marine basin in close proximity to local positive areas, which were periodically subjected to rapid erosion with the subsequent production of course terrigenous materials. Graywacke and conglomerate of the Churchill formation were probably deposited from turbidity currents, possibly as a result of submarine slump on slopes receiving a heavy supply of sediment. Isolated limestone pods are considered to be concentrations of carbonate material transported by currents from other areas within the basin of accumulation. The arrangement of the mounds in texturally consistent belts suggests that the limestone accumulated parallel to ancient shorelines.

5. Collection of fusulinids referrable to Parafusulina from nine Churchill formation limestone localities in the Kelly Hill area substantiates a Permian, probably Middle Permian age for at least a part
of the formation. Ammonoids referrable to Owenites aff. O. koeneni, Arnautoceltites aff. A. dieneri, and Dieneroceras cf. D. dieneri were collected from the Churchill formation and indicate that at least part of the Churchill formation is of Lower Triassic age; however, most of the formation here exposed is considered to be Middle Permian. The extent of the Lower Triassic rocks cannot be determined, but they probably are in a down-dropped fault block. The stratigraphic relationship between the Middle Permian and Lower Triassic rocks of the area is unknown.

6. Sedimentary rocks younger than those of Lower Triassic age do not occur in the Kelly Hill area. The Rossland volcanic group exposed several miles to the north of Kelly Hill has been referred to the Lower and Middle Jurassic. It is probable that during Late Triassic and Early and Middle Jurassic time the Kelly Hill area remained covered by marine waters.

7. Late Jurassic and Early Cretaceous folding and uplift of the western Cordillera were accompanied by the intrusion of large granitic bodies. The bodies occur in a belt coincident with the late-Paleozoic and early-Mesozoic Cordilleran geosynclinal trough that extended from California to Alaska. This period of intrusion is probably represented in the Kelly Hill area by the quartz monzonite stock and other smaller granitic bodies.

8. Cretaceous strata are unknown from the region. It is probable that the Kelly Hill area was undergoing erosion during Cretaceous time.

9. Diabase and andesite dikes intrude the upper Mesozoic granitic bodies and older rocks of the Kelly Hill area. In all probability these dikes are of Tertiary age.
10. Tertiary(?) faulting caused the large block of Churchill formation to be down-dropped with respect to the Kelly Hill phyllite, the cherty quartzite and greenstone, and the Precambrian(?) rocks on the west side of the Kettle River. The Lower Triassic rocks probably represent a fault block down-dropped with respect to the Middle Permian rocks.

11. Analysis of slaty parting indicates that it is always parallel to bedding, and therefore in all probability represents bedding fissility rather than a secondary cleavage.

The significance of the Lower Triassic fauna in relation to the age relationships and paleogeography of the Kelly Hill area is as follows.

1. Ammonoids indicate that this fauna should be correlated with the Lower Triassic *Meekoceras* fauna of southeastern California, northeastern Nevada, and southeastern Idaho, and thus lower Owenitan in age.

2. The pelecypods and gastropods of this fauna are in some cases similar to Lower Triassic species of East Greenland, the Ussuri Bay region near Vladivostok, and the Dinwoody fauna of western Wyoming and southeastern Idaho.

3. This fauna establishes for the first time the existence of Lower Triassic rocks in the northwestern Cordillera, and indicates that the sea known to have existed in northern Nevada and southeastern Idaho during Early Triassic time was more extensive than previously considered and extended northward to northeastern Washington.

4. The existence of this lower Owenitan (Upper Early Triassic) sea in northeastern Washington may give support to the contention of McLearn and Kindle (1950) that an upper Owenitan sea connected the Fort Douglas
area of Utah and northeastern British Columbia. Simply, the upper Owenian sea may represent a northward extension of the seaway that had already reached northeastern Washington by early Owenian time.
Plate 3


1-3. Side and front views and septum of specimen M7210; diameter 42.8 mm; septum drawn at whorl height of 9.5 mm, x 3.

4. Septum of specimen M7218, x 3; diameter 24.0 mm; drawn at whorl height of 6.0 mm.

5. Septum of specimen M7217, x 3; diameter 24.9 mm; drawn at whorl height of 3.0 mm.

6. Cross section showing whorls, x 1 1/2, M7216.


7, 8. Side and front views of specimen M7220; diameter 32.6 mm.

9, 10. Side and front views of specimen M7233; diameter 18.0 mm.

11-13. Side and front views x 1 1/2, and septum x 3 of an adolescent specimen (M7230); diameter 12.7 mm; septum drawn at whorl height of 7.5 mm.

14. Ventral saddle of specimen M7224, x 3; diameter 21.0 mm; drawn at whorl height of 8.5 mm.

15. Cross section showing whorls, x 1 1/2, M7232.


16, 17. Side and front views of specimen M7234, x 1 1/2; diameter 16.0 mm.

18. Septum of specimen M7237, x 3; diameter 7.8 mm; drawn at whorl height of 3.5 mm.

All specimens figured are from locality K-376.
Plate 4

Figures 1-3. *Arnautoceltites aff. A. dieneri* (Hyatt and Smith) (p. 93). Side and front views x 2, and septum x 3 of specimen M7235; diameter 11.9 mm, septum drawn at whorl height 4.5 mm.

Figures 4, 5. *Pecten sp. indet.* (p. 86).
4. Right valve, specimen M7251.
5. Left valve, specimen M7250.

Figure 6. *Pecten cf. P. sojalis* Witt, x 1 1/2 (p. 84).

Figure 7. *Pecten sp. indet.*, x 1 1/2 (p. 85).

Figure 8. *Pecten sp. indet.* (p. 85).

All specimens figured are from locality K-376.
Figure 1. Anodontophora cf. A. breviformis Spath, specimen M7241 (p. 82).

Figure 2. Myalina cf. M. shamarae Bittner, x 1 1/2, specimen M7243 (p. 83).

Figure 3. Anodontophora? sp., specimen M7242 (p. 83).

Figures 4, 5. Pseudomonotis (Eumorphotis) cf. P. (E.) multiformis Bittner (p. 87). Fig. 5 x 2, specimens M7260, M7261 respectively.

Figure 6. Naticopsis sp. indet. (p. 88).

Figure 7. Worthenia sp. indet., x 2 (p. 88).

Figure 8. Loxonema? sp., x 1 1/2 (p. 89).

Figures 1-3, specimens from locality K-448; figures 3-8, specimens from locality K-376.
REFERENCES CITED


