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Abstract approved: Redacted for privacy
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The southern half of the upper Nehalem River basin contains the most complete section of lower to middle Tertiary marine sedimentary and volcanic rocks in northern Oregon. Determination of stratigraphic relationships of six formations, and their depositional environments and provenance is the chief objective of this paper.

More than 75 percent of the sedimentary rocks comprising the Cowlitz, Keasey, Pittsburg Bluff and Scappoose Formations is tuffaceous arkosic sandy mudstone and siltstone. Much of this has been incorrectly called "shale" in the past. Goble Volcanics, consisting of basaltic lava, breccia, dikes and irregular bodies are interbedded with and intruded into the late Eocene lowermost Cowlitz Formation, made up of immature volcanic siltstone and lithic arkose. Conglomerate is locally associated with the volcanics.

The lithologic identity between the mudstone and muddy

volcanic arenite of the uppermost 1,500 feet of the Cowlitz and the lowermost Keasey Formations as previously mapped indicates that they should both be called lower Keasey. The sandy mudstone of the Pittsburg Bluff Formation is easily distinguished from the lithic arkose with minor siltstone of the overlying Scappoose Formation. Smectitic clays present in nearly all rocks were formed diagenetically from volcanic detritus. Kaolin is restricted to the mudstone of the uppermost Cowlitz Formation. The lithologic similarity of the four sedimentary units is so pronounced that it is recommended that they be combined to form the Nehalem Group.

The Columbia River Group overlies the sedimentary rocks unconformably in the eastern part of the area. It once had wide distribution, as shown by lateritic soil, remnant patches of basalt, and feeder dikes.

The sediments accumulated in an environment which changed from shallow marine, flanking volcanic islands, in the late Eocene, to shallow shelf and delta during the Oligocene. Besides local volcanic sources of these sediments, there were volcanic sources to the east and plutonic igneous and metamorphic sources in the northern Rocky Mountains.

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by

Robert Otis Van Atta

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SEDIMENTARY PETROLOGY OF SOME TERTIARY FORMATIONS, UPPER NEHALEM RIVER BASIN, OREGON

INTRODUCTION

Eocene to Miocene argillaceous marine sediments of the Cowlitz, Keasey, Pittsburg Bluff and Scappoose Formations are exposed in stream beds and road and railroad cuts adjacent to U. S. Highway 26 (Sunset Highway) from Manning to the Washington County-Tillamook County line in northwestern Oregon. In an area of about 75 square miles it is possible to find representative outcrops of these rocks. The terrain is especially well-suited for study because excellent cross sections of all of these formations are exposed as well as basalts of the underlying Goble Volcanics and the overlying Columbia River Group. Several intrusive bodies appear to be feeders to flows which, no longer present, are represented now by ferruginous soils on upland surfaces.

Although these strata and their contained fossils have been studied and mapped previously, this report describes the only detailed work on the sedimentary petrography and petrology. The composition, texture and sedimentary structures of these rocks were studied in order to more fully interpret the sources from which the sediments came and the nature of the environments in which they were deposited. Since the gross stratigraphy has been outlined earlier by Warren and Norbisrath (1946), no attempt will be made here to re-define the formations cropping out in this area. However, some refinements are suggested and two major stratigraphic problems were discovered as a result of studies of sedimentation units and contacts. Emphasis upon detailed stratigraphic sections in this study is restricted to a sequence of relatively fresh, almost continously exposed beds of the Cowlitz and Keasey Formations found along the Nehalem River from the bridge on U. S. Highway 26 southward toward Timber (see Appendix A).

These Tertiary sediments are richly fossiliferous, with the exception of the sandstone which is considered part of the Cowlitz Formation, although megafossils are commonly represented only by molds in weathered exposures. Along fast-flowing streams and in quarries, excellently preserved mega- and microfossils can be collected.

Paleontological studies have been more intensive in this area than in any other part of northwestern Oregon, as a glance at Warren and others' work (1945) will show. Except in rare instances, all megafaunas found in these rocks are thanatocoenose and therefore of limited usefulness in interpretation of immediate environments of deposition of the sediments. Some inferences may be drawn, however, with respect to the contiguous parts of the environment from which these fossils were transported. It is probable, because of the abundance of fossils, that further detailed paleontological work in this area would be of value. The emphasis of this study, however, is upon the physical parameters of the environments as revealed by textures and structures of the sedimentation units, and upon the provenance of the sediments as revealed by their composition.

Area of Study

The area of study includes the extreme northwestern corner of Washington County, the extreme southwestern corner of Columbia County (see index map, Figure 1) and small adjacent areas in Clatsop and Tillamook counties. The villages of Buxton and Manning are located in the southeastern corner of the area and Timber, a nearly deserted logging town, in located in the southwestern corner of the area. U.S. Highway 26 traverses the area from southeast to northwest, Oregon Highway 47 (the Nehalem Highway) traverses from south to north on the eastern margin and the Glenwood-Timber-Vernonia road traverses from south to north in the western half of the area. The region is also crossed from south to north by a spur of the Spokane, Portland and Seattle Railroad (formerly the track to Vernonia was owned by the United Railways) which runs through Buxton to Vernonia. The Tillamook spur of the Southern Pacific Railroad crosses the southern margin of the area, passing through Buxton and Timber.

The eastern half of the region is drained by the West Fork of

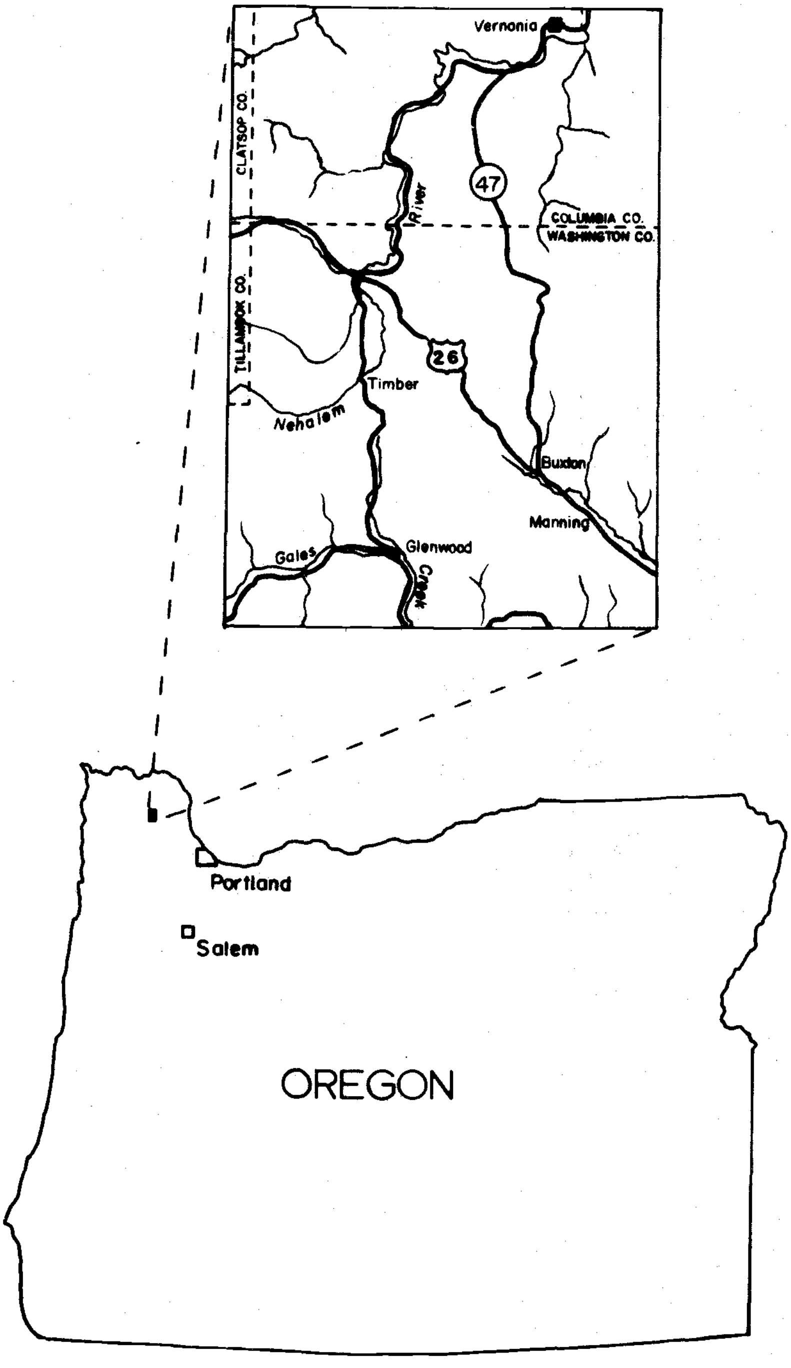


Figure 1. Index map showing location of upper Nehalem River basin.

of Dairy Creek, a tributary of the Tualatin River, while the western half is drained by the Nehalem River. Numerous small deeply incised creeks with fairly high gradients provide good exposure of rock. Intensive logging activity has made nearly every part of the area accessible by roads, many of which are all-weather roads, and has provided numerous road cuts with large exposures of these Tertiary sediments and associated volcanic rocks. Several quarries (see Plate I) furnish additional exposures and reveal some stratigraphic relationships very nicely.

Despite the exposures developed by streams and the activity of man, geologic work is difficult due to the heavy cover of vegetation resulting from the high annual rainfall (mean about 50 inches) of this region. Repeated cutting of timber has induced a dense growth of shrubs and several forest fires have resulted in a growth of bracken, berry vines, vine maple, fireweed and other luxuriant vegetation. Although many persons (Deacon, 1953, p. 4-5; Warren and Norbisrath, 1946, p. 213) speak of weathering and a deep soil profile, careful examination of the outcrops reveals that the soil is rarely more than 12 to 15 inches deep. Weathering in road cuts and stream banks, although causing rapid alteration of a few feet of rock, rarely penetrates more than 4 or 5 feet because of the very low permeability of these mudrocks. Thin sections of siltstone from the Pittsburg Bluff Formation 0.5 mile northwest of Staley's

Junction on U. S. Highway 26 (samples 1-20, Table 15, Appendix C) show 30 percent volcanic glass from rock surfaces exposed for a little more than 20 years. Point counts of thin sections from the very same rock exposed in widening of the road from two to three lanes at this point during the summer of 1965 show up to 50 percent volcanic glass. Much of this 20 percent difference can be attributed to destruction of the glass by weathering, judging from the very fresh nature of the glass shards from the newly exposed rock as compared to cloudy, altered glass in the older outcrop.

Mudrocks make up the largest volume of these Tertiary sediments. These are of nearly uniform dark gray color throughout a given formation and weather to similar shades of yellows and browns. Lack of cement and consequent poor induration make exposures, other than in stream beds, subject to continual slope wash which obscures even major structures. The pick-mattock is an essential tool if one is to see much of the rock. The incompetence of these rocks promotes much slumping and larger scale landsliding. The gross lithology of these mudrocks is remarkably similar in exposed vertical sequences of a formation, with continual repetition of mudstones, siltstones and a few pebbly sandstone beds, parts of which may be concretionary over a few tens of feet laterally. In addition to concretionary parts of some beds, discontinuous glauconitic beds and 4 to 6 inch thick layers of claystone derived from tuffaceous mudstone are found at many horizons, especially in the Pittsburg Bluff and Keasey Formations. The thickness of these units and the order of repetitive sequences found at any one outcrop generally vary so much laterally that correlation from even one roadcut to another must be uncertain. Facies changes from one size grade of muddy sediment to another are without doubt the rule so that lateral correlation of all but the thickest sections of formations is difficult. The only clear-cut differences in lithology occur with the relatively "clean" (matrix-free) sands which are considered to be in the Cowlitz Formation and in the sandstones of the Scappoose Formation. No such sandstones are found in the Pittsburg Bluff Formation of the area of the study and only one 16 foot thick bed of sandstone was observed in the lowest part of the Keasey Formation.

Attitudes of beds commonly range from 3° to 10° dips; a few dips of 15° to as much as 30° are probably related to faulting. The common occurrence of such low angle attitudes makes observation of more than a few tens of feet of stratigraphic section difficult except in the largest quarries, or in road and railroad cuts. A few of the streams (the Nehalem River, Robinson Creek, Lousignont Creek) have sufficiently high gradients and volume runoff during the spring of the year to sweep their channels clean of alluvium and to expose unweathered rock over considerable distances.

Physiography

The northwestern part of the area of study is dissected by the upper reaches of the Nehalem River, a few tributaries of which have eroded some remarkably deep and broad canyons (see Figure 2). Upland surfaces range in elevation from a maximum of 1, 860 feet on Rocky Point, a northwest-trending ridge of basalt, to a little over 1, 200 feet in ridges throughout the area south of Rocky Point. The fact that almost every ridge crest in the western half of the area stands at about 1, 200 feet suggests that the Nehalem River once had a temporary base level about 400 feet higher than the present elevation of 800 feet. Warren and Norbisrath (1946, p. 215) believe that the steep-sided deep valleys are caused by rejuvenation, a theory which is further substantiated by incision of the Nehalem and its tributaries some 8 to 10 feet into the present flood plain deposits and bedrock. Incision along antecedent meanders, controlled in many cases by the strike of concretionary beds (see Figure 3) is well developed along the Nehalem River for several miles upstream from the U. S. Highway 26 crossing and along the lower reaches of Lousignont, Robinson and Castor Creeks (see Plate II).

In general, lithologic similarity between formations and discontinuity of what few well cemented beds there are result in little topographic expression of structure or lithology. In the

Figure 2. Upper Nehalem River valley, looking southeast from Rocky Point.

Figure 3. Nehalem River, looking along the strike of a resistant calcareous pebbly sandstone bed, upper mudstone member, Cowlitz Formation.

southeastern part of the area, numerous concretionary beds in the uppermost part of the Keasey Formation form a ridge which trends northeast-southwest except in the area just south of Johnson Road where it turns to an east-west direction (see Figure 29). This ridge forms the drainage divide between the Nehalem River system on the west and the Dairy Creek-Tualatin River system on the east. On the west side of this ridge the relief is commonly 500 to 700 feet within a mile of the ridge crest; east of the ridge the surface dips gently to form a cuesta-like dip-slope. Some farming of berries, Christmas trees and hay is supported on this surface, which I shall refer to as the "Scofield Surface," after the hamlet of Scofield, located on the Southern Pacific Railroad. The land is so precipitous to the west of Scofield Surface that three tunnels were excavated to allow passage of the two railroad lines and U. S. Highway 26 (see Plate I). The tunnel on the Spokane, Portland and Seattle Railroad, just north of Tophill, has been removed and replaced by a narrow cut through the ridge. Judging from remnants of basalt flows found in cuts along the Southern Pacific Railroad on the southern part of the Scofield Surface, the presence of basalt in quarries exposing feeder dikes at Scofield and just north of Strassel, and a brick-red lateritic soil over most of the area, this gently southeast-sloping surface may have been preserved by mantling lava flows most of which have subsequently been removed.

The upland surface in the extreme eastern and southeastern parts of the area of study is underlain by basalts of the Columbia River Group, which overlie the Tertiary sediments of the region.

Previous Work

Historically the upper Nehalem River basin has been the locus of a great deal of study, especially paleontologic. The earliest work was that of Diller in 1896 (Warren and Norbisrath, 1946, p. 215) who described the sediments along Rock Creek above Vernonia and near Pittsburg, Oregon. The richly fossiliferous sandstones exposed in cliffs along the Nehalem River north of Vernonia and at Pittsburg have an excellently preserved molluscan fauna which has been described by Arnold and Hannibal (1913), Washburn (1914), Anderson (1914), Clark and Arnold (1918) and Schenck (1927, 1928).

Schenck defined the Keasey and Pittsburg Bluff Formations (1927, p. 457; 1928, p. 36). C.E. Weaver's extensive and thorough treatise on the Tertiary stratigraphy of northwestern Oregon and his monograph on the paleontology of the marine Tertiary of Oregon and Washington (1937) describe the Pittsburg Bluff and Keasey faunas and relate them to the stratigraphy of the upper Nehalem River basin.

Because of the rather distinct lithologic differences between what are now known as the Keasey Formation and the Pittsburg Bluff

Formation and because of the excellent paleontologic evidence in the Pittsburg Bluff sandstones, all the studies of these formations, until 1945, have been concentrated in the northern part of the upper Nehalem River basin.

In 1945, Warren, Norbisrath and Grivetti published their Geologic Map of Northwestern Oregon which included the area of this present study. Although the region covered by that map included seventeen 15 minute quadrangles and was done in one and one-half years (Snavely, P. D., Jr., personal communication, 1962) the mapping was of high quality. For example, the contact between the Keasey Formation and the Pittsburg Bluff Formation from Tophill southward across U. S. Highway 26 and to the Southern Pacific Railroad is accurately located and no further refinement of that work could be made in this study (see Plate II). Similar relationships seem to hold between the Scappoose and the Pittsburg Bluff Formations, although special problems exist when mapping these units in the field (see page 77).

Warren and Norbisrath elaborated more fully and in detail upon the stratigraphy of the upper Nehalem River basin in 1946, taking their most extensive paleontological collections from the area of this present work. The delineation of most contacts, particularly those of the Pittsburg Bluff-Scappoose Formations and the upper part of the Cowlitz and the lower member of the Keasey

Formations, was done on the basis of megafauna and microfauna, undoubtedly because of very strong lithologic similarities between these units.

A second study of part of the area of my work was done in 1953 by Deacon who attempted to revise the stratigraphy of the Cowlitz and Keasey Formations on the basis of lithology, redefining these sedimentary units, substituting the name "Rocky Point" for the Cowlitz Formation and introducing the name "Nehalem" for parts of the lower member of the Keasey Formation. These revisions of Warren and Norbisrath's work of 1946 have not been generally accepted. Discussion of their validity, based upon evidence gathered in this present work, is included under descriptions of the two formations in question (see pages 19 and 55).

Lastly a minor and informal reconnaissance of a few localities included in the area of this study, together with three other localities in the Vernonia area, was undertaken by Holmgren (unpublished report, 1967). In his report he accepts the stratigraphic nomenclature of Deacon, basing his conclusions on lithologic evidence. Due to limited observations, Holmgren's conclusions are subject to many serious reservations, although some of his observations, for example, the "Rocky Point-Keasey" contact in the SE 1/4, Sec. 36, T. 3 N., R. 5 W. (my locations 229 and 230, Plate I) are quite valuable.

A review of the studies cited above reveals that little work has been done on the petrology and petrography of these Tertiary sediments of the upper Nehalem River basin. Schenck in 1928 (p. 30) published some histograms of correlative Tertiary sediments from the Yaquina Bay region of Oregon and Deacon described a few modal analyses from the Cowlitz and Keasey Formations in localities included in this present study. A comparison of all field descriptions which have been made of rocks from these formations by various workers shows the tendency to regard as sandstones, rocks that are in reality siltstones and even mudstones. In addition, primary sedimentary structures are generally overlooked.

STRATIGRAPHY, GROSS LITHOLOGY AND STRUCTURE

General Discussion

The rocks of the upper Nehalem River basin can be divided into three distinct groups: a sequence of late Eocene basaltic lavas, a sequence of late Eocene to late Oligocene or earliest Miocene marine sedimentary strata and a series of mid-Miocene basaltic lava flows of the Columbia River Group. These lie on the northeast flank of the Oregon Coast Range. In the extreme western part of the upper Nehalem River basin inliers of sedimentary beds are preserved by downfaulting between uplifted and tilted blocks of the older basaltic lavas (see Warren and Norbisrath, 1946, p. 218-220).

The rocks exposed in the westernmost part of the upper Nehalem River basin are basaltic flow rocks, intrusives and breccias which were originally named the Tillamook Volcanic Series by Warren, Norbisrath and Grivetti (1945) and considered by them to be earliest late Eocene (1946, p. 221). These crop out only in the high and rugged westernmost margins of the area of this present study. Because of their limited occurrence in this area, no thorough study of these basalts was made in this present work other than to determine their relationship to associated sedimentary units and briefly to compare their lithology and age to that of other basalts.

Lying above the late Eocene basalts is a group of marine to brackish water sediments of the Cowlitz, Keasey, Pittsburg Bluff and Scappoose Formations, which include mudrocks and some arenites. Near the base of this sedimentary sequence fossiliferous conglomerates and clayey siltstones of the Cowlitz Formation are intercalated with basaltic lavas. Locally basaltic sills and dikes intrude the sediments. From the base upward these sediments change from siltstone and silty sandstones to tuffaceous siltstones, mudstones and pumiceous pebbly volcanic sandstones. Near the top of the sequence of sediments, tuffaceous mudstones and siltstones are interbedded with some arenites with local basaltic pebble to cobble conglomerates.

Overlying the marine sediments in the extreme eastern part of the area is a series of dense, black, finely porphyritic basaltic lava flows referred to as the Columbia River Group (Columbia River Basalt) by Warren and others (1945). There are also a number of basaltic dikes which clearly transect the marine sediments. In addition, on the Scofield Surface there are lateritic soils, numerous basaltic cobbles and patches of brick-bat jointed porphyritic basalt with nearly the same lithology as that of the Columbia River Group, indicating that these lavas once covered most of that region.

SERIES	FORAMINIFERAL STAGES		SOUTHWESTERN WASHINGTON [1]	WEST CENTRAL OREGON [1]	NORTHWESTERN OREGON (Warren, et al, 1945)	UPPER NEHALEM RIVER BASIN (Warren & Norbisrath, 1946)	UPPER NEHALEM RIVER BASIN (Deacon, 1953)	UPPER NEHALEM RIVER BASIN (This Report)
MIOCENE	Saucesian	upper	↑? Astoria Formation	Astoria Basalt	Columbia River Basalt	Columbia River Basalt	(Not involved in Deacon's report)	Columbia River Basalt
		lower	Blakeley (?) Formation	?	↑? Beds of Blakeley Age	↑? Scappoose Formation		NEHALEM GROUP: ↑? Scappoose Formation
? OLIGOCENE	Zemorrian	upper						
		lower				? ?		? ?
	Refugian	upper	↑? Lincoln Formation	Pittsburg Bluff Formation; Eugene Formation	Pittsburg Bluff Formation	Pittsburg Bluff Formation		Pittsburg Bluff Formation
		lower	Keasey Formation	Keasey Formation; Fisher Formation	Keasey Formation	? ? Keasey Formation	Keasey Formation; Nehalem Formation	Keasey Formation
? EOCENE	Narizian		↓? Cowlitz Formation	Cowlitz Formation ↓?	Cowlitz Formation	? ? Cowlitz Formation	? ? Rocky Point Formation	? ? Goble Volcanics; Cowlitz Formation

[1] After Kleinpell and Weaver, 1963, Fig. 5.

Figure 4. Correlation chart of Tertiary formations of northwestern Oregon and adjacent regions

Structure

Structurally the area of study is part of the eastern limb of the Oregon Coast Range anticlinorium (Warren and Norbisrath, 1946, p. 218). The dip of all these Tertiary sediments, except the sandstones and siltstones which crop out in the northwestern part of the area of this study (see Plate II), is consistently southeasterly to south southeasterly, ranging from a few degrees to nearly 20^{o}, and averaging about 10^{o}. In a few places dips up to 35^{o} are recorded but these are probably caused by faulting or landsliding. Although minor faults with a few feet of vertical separation are very common and probably are associated with larger faults, no great stratigraphic offsets are present, except some near the base of the sequence in the late Eocene basalts and the Cowlitz Formation. There are some anomalous stratigraphic conditions which could possibly be caused by major faulting but all efforts to resolve these problems on this basis were frustrated by difficulties arising from scarcity of outcrops and great lithologic similarity both in individual bed-types and in typical bed-sequences.

Structurally it would appear that the area is one of general simplicity.

Cowlitz Formation

In this area, the oldest sedimentary rocks are those which Warren and Norbisrath (1946, p. 221) assigned, on the basis of fossil evidence, to the Cowlitz Formation. These are correlative with the Cowlitz Formation in Washington, named by Weaver in 1912 (p. 62-66). Warren and Norbisrath (1946, p. 222) divided the Cowlitz Formation in the upper Nehalem River basin into four members: a basal conglomerate, a lower shale member, a sandstone member and an upper shale member. A few localities are mentioned for each of these but such localities are not intended to be formally described as type sections. No measured sections of any of the members are described.

Deacon regarded the beds which interfinger with the volcanic rocks along Rock Creek as lithologically distinct from the type Cowlitz Formation to the north in Washington. Hence, he proposed the name "Rocky Point Formation" (1954, p. 9), including in this a part of the lowermost Keasey Formation. This name has never been formally proposed. When the sandstones, siltstones and mudstones of the area west of the Nehalem River are compared with the descriptions of the Stillwater Creek and Olequah Creek Members of the Cowlitz Formation in the type localities described by Henrickson (1956, p. 39 and 50), the similarities are much more pronounced than the differences. Along the Nehalem River rocks of Cowlitz-age tend to be much muddier and of a much darker greenish gray to greenish black than the type Cowlitz, hence the understandable conclusion that they are lithologically distinct.

Siltstone Member

The basal Cowlitz is considered by Warren and Norbisrath to lie unconformably upon basaltic lavas which Warren and others (1945) called the Tillamook Volcanic Series. Conglomerate units in contact with basaltic lavas crop out west of Timber, on Lousignont Creek, and at a number of places along the Sunset Highway from the Washington County-Tillamook County line westward for several miles. Good exposures are found in a small quarry near the Nehalem River at Rocky Point, and just west of Keasey, along Rock Creek, at the site of the old railroad trestle. The character of this conglomerate varies greatly from locality to locality. West of Timber it is reported to be over 200 feet thick and composed of poorly sorted sand with basaltic pebbles, cobbles and a few basalt boulders up to 8 feet in diameter (Warren and Norbisrath, 1946, p. 222). Fossil plant remains are included. Along Lousignont Creek Road (S. 1/2, Sec. 18, T. 3 N., R. 5 W.), the conglomerate consists of a few feet of sandy pebble conglomerate which grades laterally into a greenish volcanic sandstone. It appears here that the finer sediments are interbedded with lava flows.

Along the Sunset Highway west of the Timber junction, siltstones and sandy siltstones, which classify as volcanic litharenites, crop out in road cuts and in the bed of Wolf Creek. Warren and Norbisrath (1946, p. 223) called this the lower shale member of the Cowlitz Formation but the rocks actually classify as siltstones (Figure 46). Good exposures of these rocks in newer road cuts show that in most places they are interbedded with basaltic lavas which at other places are interbedded with conglomerates. It is clear that the conglomerates grade into the siltstones and both are interbedded with the volcanics. These relationships make it unnecessary to distinguish the conglomerate and the siltstones as separate members of the Cowlitz Formation. In addition, the conglomerates or siltstones in contact with basaltic rocks are probably not at all equivalent, for some of the basaltic rocks are obviously intrusive and local, having no direct connection with the mass of volcanic rocks to the west of the area of study.

Goble Volcanics Member

Warren and others (1945) applied the name Goble Volcanics Member to a section of basic flows and pyroclastic rocks which interfinger with tuffaceous sediments of the Cowlitz north of this area.

Along the Sunset Highway, 2.2 miles west of the Washington and Tillamook County line, a pebble conglomerate rests with a very irregular and steeply inclined contact upon Eocene basalts on the south side of the highway. On the north side of the highway the contact is nowhere visible. On the north side about 12 feet of pebble conglomerate and claystone contains subangular to rounded blocks of basalt 4 to 5 feet in diameter, some of which have a faint suggestion of pillow structure and contain pyrite, zeolites and calcite on fracture surfaces and in vugs and veins (see Figures 5, 6, and 7). A few miles farther west, near Sunset Springs Wayside, basaltic flow rocks containing inclusions of siltstone and mudstone are interbedded with basaltic breccias and silicified lutaceous sediments. Road cuts near the Tillamook and Washington County line reveal subangular basalt boulders in a thin pebble conglomerate underlain by siltstone and sandstone. Warren and Norbisrath (1946, p. 222) report that the conglomerate along the Sunset Highway is richly fossiliferous. Just south of the Sunset Highway, near the Tillamook-Washington County line (center Sec. 6, T. 3 N., R. 5 W.), basaltic lava is overlain by 3 to 4 feet of pebble conglomerate and a pebbly sandstone composed largely of claystone clasts. Fossils are common and the brachiopod *Terebratalia* is especially abundant. Immediately below this point, along Wolf Creek, about 0.25 mile northwest of the previous locality a large Oregon State Highway Department quarry exposes slickensided Eocene basalt which is in

Figure 5. Pebble conglomerate, lower Cowlitz Formation with included blocks and slabs of basalt of Goble Volcanics. U.S. Highway 26; 2.2 miles west of Washington-Tillamook County line, locality 255.

Figure 6. Zeolitized basalt block in pebble conglomerate, lower Cowlitz Formation. (Same locality as Figure 5.) Rule is 6 feet.

Figure 7. Basalt in pebble conglomerate, lower Cowlitz Formation. Note irregular block of basalt. (Same locality as Figures 5, 6.)

fault contact with siltstones and mudstones.

At the small Columbia County Quarry on the Timber-Vernonia highway (locality 174) basalt is overlain by 9 feet of fossiliferous pebble to boulder conglomerate containing well-rounded basaltic boulders up to 6 feet in diameter (see Figure 8). At the contact between the basalt and the conglomerate there is a thin hydrothermally altered zone including both the top of the basalt and the base of the conglomerate. Zeolites, calcite and pyrite are abundant here. A part of the upper 6 feet of the basalt has a hydrothermally altered zone which includes pebbles of conglomerate in a discontinuous band 12 to 18 inches thick. Fracture surfaces in the upper part of the basalt are coated with minute cubic crystals of pyrite and cobbles and pebbles in the overlying conglomerate are also coated with pyrite cubes. Zeolites and calcite are very common in interstices in the conglomerate.

The basalt in the Columbia County Quarry appears to be intrusive between an underlying bentonitic, pyritic, silicified mudstone and the overlying conglomerate. In the upper 6 feet of the intrusion a thin sliver of the conglomerate has been included in the intruding basalt (see Figure 9). Deacon (1953, p. 77) interpreted the basalt as belonging to two flows. However, the presence of pyrite, zeolites and calcite in both the upper part of the basalt and in the conglomerate, the thin hydrothermally altered zone in the

Figure 8. Boulders in conglomerate overlying basaltic sill (lower right corner), related to Goble Volcanics, (Columbia County Quarry, locality 174.)

Figure 9. Conglomerate sliver included in basaltic sill. (Same locality as Figure 8.)

Figure 10. Fan jointing in basalt intrusion (Goble Volcanics) with overlying siltstone, sandstone member, Cowlitz Formation. (Clear Creek, NW 1/4, Sec. 28, T. 4N., R. 5W.)

uppermost part of the basalt and the lowermost conglomerate seem to militate against the basalt being flow rock. It is improbable that pyrite could be accounted for by diagenesis since it is present both in the basalt and the conglomerate. Furthermore, it cannot be accounted for by the action of ground water, since pyrite forms under reducing conditions.

A Cowlitz-type fauna has been collected from the Columbia County Quarry. Collections made at the previously mentioned locality (center Sec. 6, T. 3 N., R. 5 W.) show many of the same forms. The two lists given below show the forms found at the quarry by those who have studied them in detail.

Warren and Norbisrath (1946, p. 223)

Glycymeris cf. eocenica (Weaver)

Barbatia cowlitzensis (Weaver and Palmer)

Barbatia suzzaloi (Weaver and Palmer)

Ostrea cf. griesensis Effinger

Podoesmus n. sp

Mytilus n. sp A.

Mytilus n. sp. B.

Brachiodontes
~~Volsella~~ cowlitzensis (Weaver and Palmer)

Pitar cf. eocenica (Weaver and Palmer)

Acmaea n. sp A.

Acmaea n. sp. B.

Calyptraea diegoana (Conrad)

Terebratalia sp.

Deacon (1954, p. 63)

Nuculanids

Ficopsis sp.

Septifer sp.

Mytilus sp.

Acmea persona Eschscholtz

Rhynochonella washingtonia Weaver

Ostrea cf. griesensis Effinger

Hexacorals

Fish Teeth

Unidentifiable gastropod and pelecypod genera

Vertebrate, unidentifiable bone fragments

About 0.5 mile southwest of Keasey, Oregon (locality 38), at the west end of a destroyed railroad trestle, silicified greenish gray muddy volcanic sandstone and gray silicified siltstone are interbedded with two zeolitized, porphyritic basalt lava flows. The basalt is considered by Warren and Norbisrath (1946, p. 223) to be in the Tillamook Volcanic Series. The sedimentary interbeds are reddened and baked at their upper contacts with each of the overlying lava flows. Just below the site of the railroad trestle, on Rock Creek near this locality, a cobble to boulder andesite and basalt conglomerate crops out. Deacon reports (1954, p. 74) that the relationship of the conglomerate to underlying rocks is not clear. It is not certain that this conglomerate rests on volcanic rocks, as is the case at some other localities, but its proximity to the basalts of this area make this relationship probable.

At three different locations in the Clear Creek drainage area, small irregular basaltic bodies are intrusive into sandstones and siltstones. At each location the upper part of the basalt is brecciated and contains siltstone and claystone inclusions which show contorted laminations which parallel the margins of the basalt clasts, suggesting that the sediment was soft at the time it was incorporated into the basalt (see Figures 11 and 14). Some parts of the basalts are "peperitic," consisting of a fine breccia of basaltic glass and admixed clayey sediment. Superjacent sediments are highly silicified with chalcedony, calcite, zeolites and pyrite common. Warren and Norbisrath mapped one of these bodies as part of their Tillamook Volcanic Series but, unless this represents a high in the pre-Cowlitz topography the basalts must be slightly younger than the sediments. In this case they would be correlative with the Goble Volcanics, which are known to include submarine flows and breccias (Wilkinson and others, 1946, p. 5). Farther to the northwest, in Sec. 17, T. 4 N., R. 5 W., a similar large intrusive mass of basalt is exposed in a quarry (Figures 14, 15 and 16).

Figure 11. Laminated mudstone inclusion (lighter tone) in basalt. (Same location as Figure 10.)

Figure 12. Basalt pillow with palagonitic glass "rind." (Same locality as Figures 10, 11.)

Figure 13. Basalt pillows with included laminated mudstone. (Same locality as Figures 10, 11, 12.)

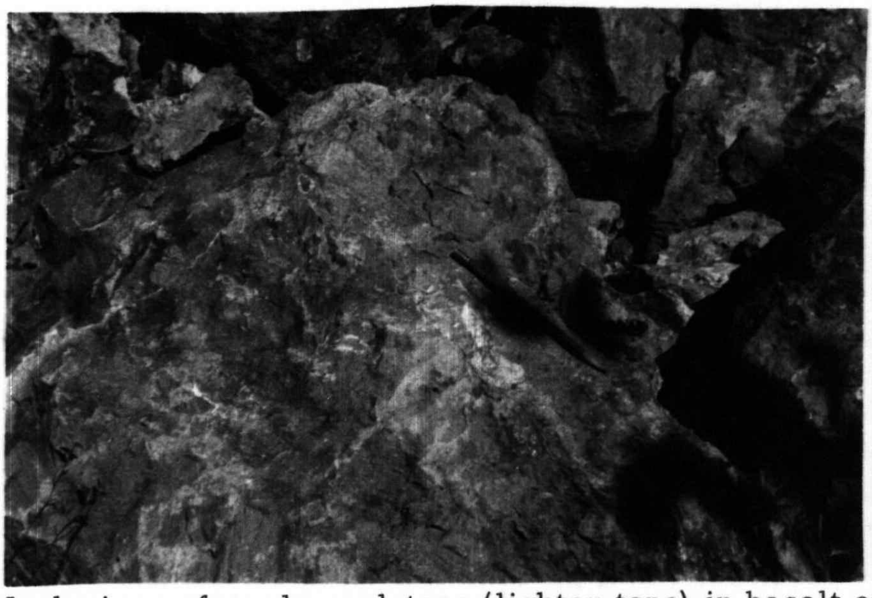


Figure 14. Inclusions of sandy mudstone (lighter tone) in basalt of Goble Volcanics in sandstone member, Cowlitz Formation. (quarry, locality 221.)

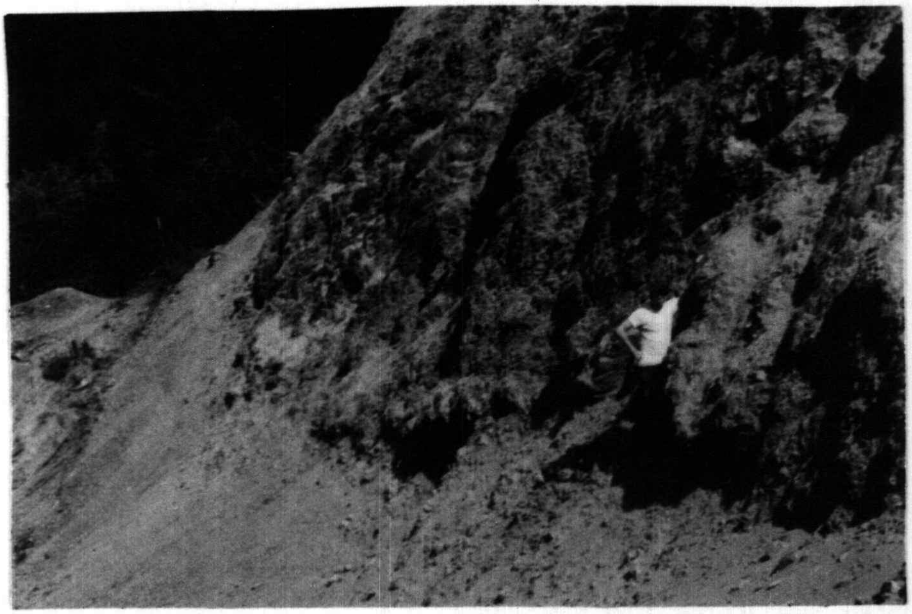


Figure 15. Sandy siltstone intruded by basalt. (Same locality as Figure 14.)

Figure 16. Photomicrograph, sandy mudstone inclusion in basaltic breccia, Goble Volcanics. (Same locality as Figures 14, 15.)

1 mm

Along the ridge crest at Rocky Point, basaltic rocks exposed in several large quarries and in road cuts appear to be dikes. At one quarry zeolites, pyrite and calcite coat fracture surfaces and hydrothermal alteration and silicification of overlying mudstone show that the basalt is intrusive. Collapsed vesicles lined with brown basaltic (palagonitic?) glass which appears as stringers up to 1 cm in length are oriented in a near vertical position and aligned vesicles appear to be steeply dipping (see Figures 17, 18 and 19). Along the highest part of the ridge trending northwesterly from Rocky Point toward Keasey there are outcrops of glassy basalt (see Figure 21), but on the flanks of the ridge, not more than 0. 1 mile from the crest, arkosic siltstones and sandstones crop out in every road cut.

In order to understand the relationships of the sediments of the Cowlitz Formation and the basalts in the Rocky Point-Clear Creek-Sunset Highway area west of the Nehalem River, it is necessary to consider similar relationships in late Eocene strata to the south and north of the upper Nehalem River basin. In the Dallas and Valsetz quadrangles Baldwin (1964) regarded the Siletz River Volcanics as party equivalent to the basaltic lavas and tuffs which were named the Tillamook Volcanic Series by Warren and others (1945). He believes (1964, p. 14 and an oral communication, 1970) that the

Figure 17. Aligned vesicles (pencil showing inclination) in basaltic intrusion of Goble Volcanics in Cowlitz Formation. (Rocky Point, locality 228.)

Figure 18. Collapsed vesicles lined with brown glass (arrow showing dark glass) in basaltic intrusion. (Same locality as Figure 17.)

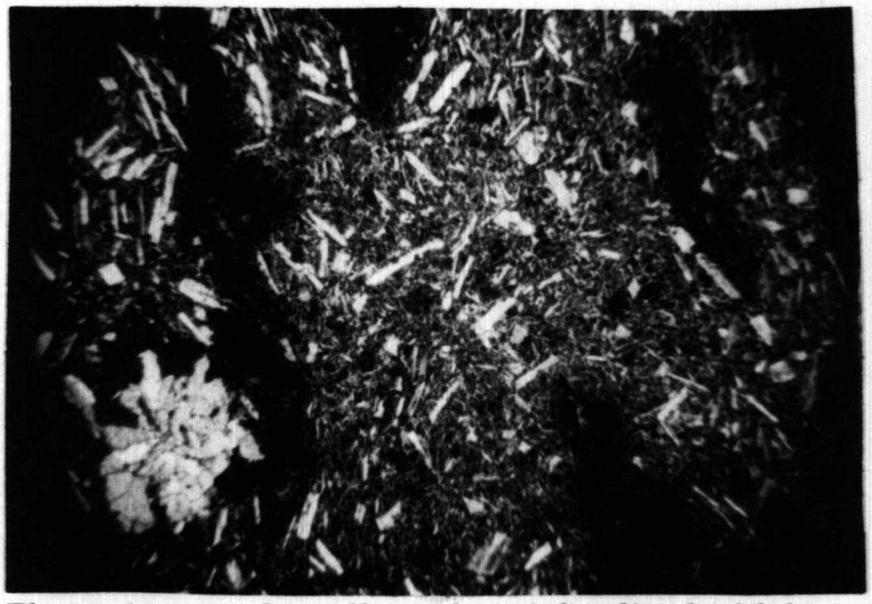


Figure 19. Photomicrograph, collapsed vesicles lined with brown glass (darker areas) in basalt porphyry with larger augite phenocryst from intrusion at Rocky Point. Crossed polars. (Same locality as Figures 17, 18.)

1 mm

Figure 20. Photomicrograph, basalt porphyry, plagioclase phenocrysts, intersertal texture, Goble Volcanics. Intrusion in Cowlitz Formation. (Columbia County Quarry, Nehalem River, locality 174.)

0.5 mm

> Tillamook Volcanics contain basalt flows equivalent to those in the Umpqua Formation to the south and another and younger series equivalent to the Goble Volcanics of Wilkinson, Lowry and Baldwin (1946) in the St. Helens area.

In the area of Baldwin's report, basaltic lava flows which he regarded as equivalent to the Goble Volcanics interfinger with the Spencer Formation, which he correlated with the Cowlitz Formation in the upper Nehalem River basin and the Nestucca Formation in the Sheridan and McMinnville area.

It is noteworthy that Baldwin and others (1955) report that the volcanic rocks which enclose tuffaceous siltstone blocks have phenocrysts which are zoned laths of andesine (An_{44}-An_{49}) and plagioclase in the ground mass which is generally labradoritic. They correlate the Nestucca Formation with the Spencer and the Cowlitz Formations and interpret the volcanics and intrusives as correlative with the Goble Volcanics.

The basalts in the western part of the upper Nehalem River basin are generally hypocrystalline, sparsely porphyritic to porphyritic or occasionally glomeroporphyritic with the An content of plagioclase phenocrysts ranging from An_{65} to An_{52} and the An content of groundmass plagioclase ranging from An_{68} to An_{42} (see Figures 19-23). A comparison of the An content of these basalts and those of the Siletz River Volcanics, the Goble Volcanics and the Columbia River Basalt is given in Figure 24. It must be noted that

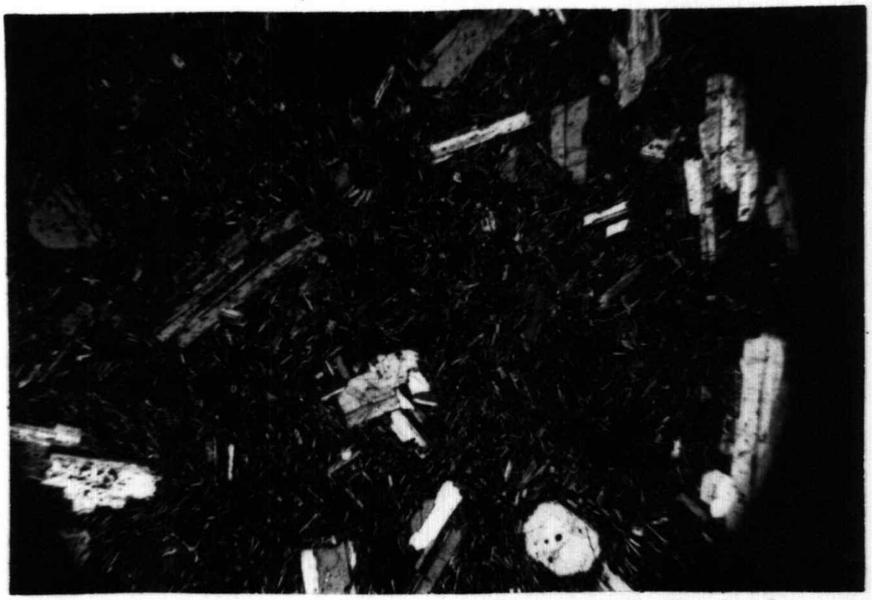


Figure 21. Photomicrograph, basalt porphyry with plagioclase and augite phenocrysts, Goble Volcanics. Note glass (circular areas, lower center and upper left, black.) Crossed polars. (Locality 277, Rocky Point.)

1 mm

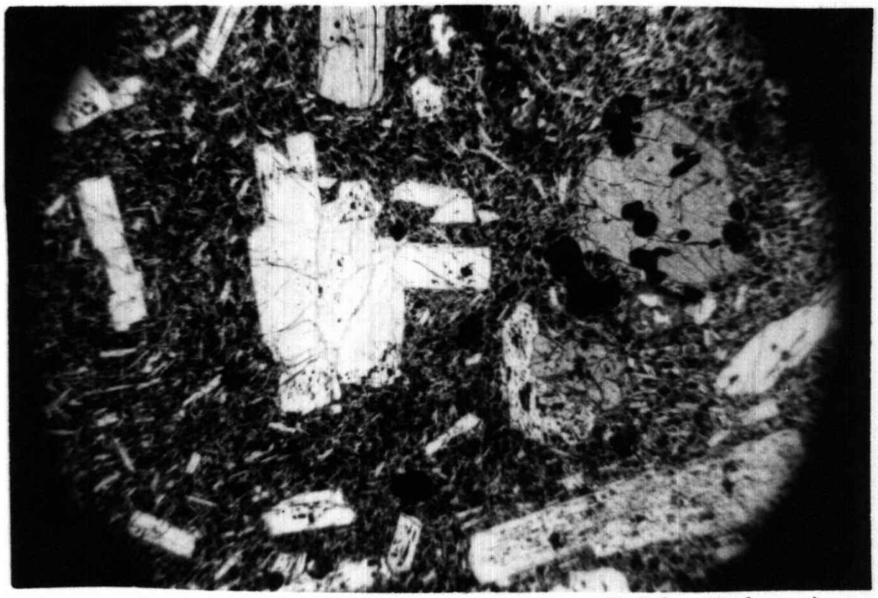


Figure 22. Photomicrograph, basalt porphyry, Goble Volcanics. Note plagioclase (white) and augite (gray) phenocrysts with magnetite (black) in ground mass with intersertal texture. (Locality 232, Rocky Point.)

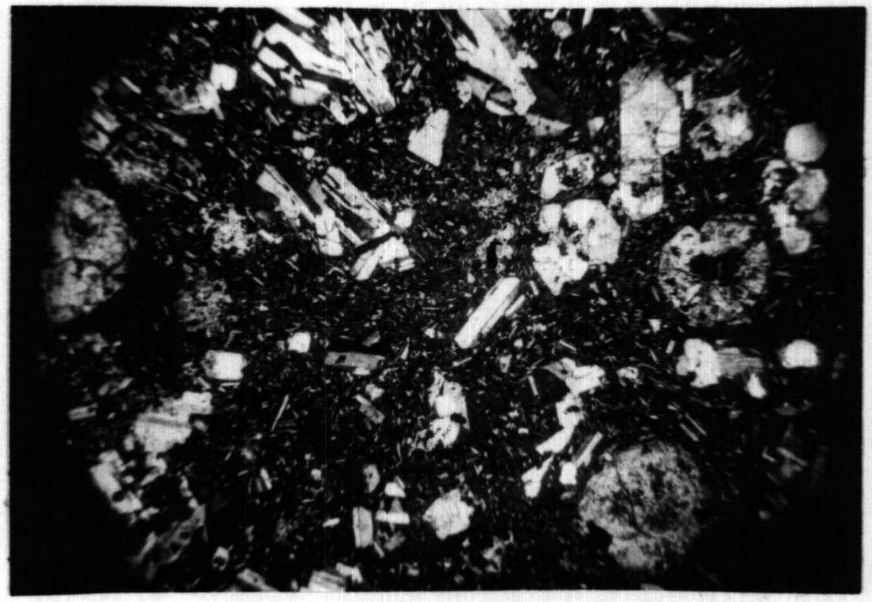


Figure 23. Photomicrograph, zeolitized amygdaloidal basalt porphyry, Goble Volcanics. Note calcite and zeolite amygdules (circular areas), glass (black), augite and plagioclase phenocrysts. Crossed polars. (Locality 172A.)

1 mm

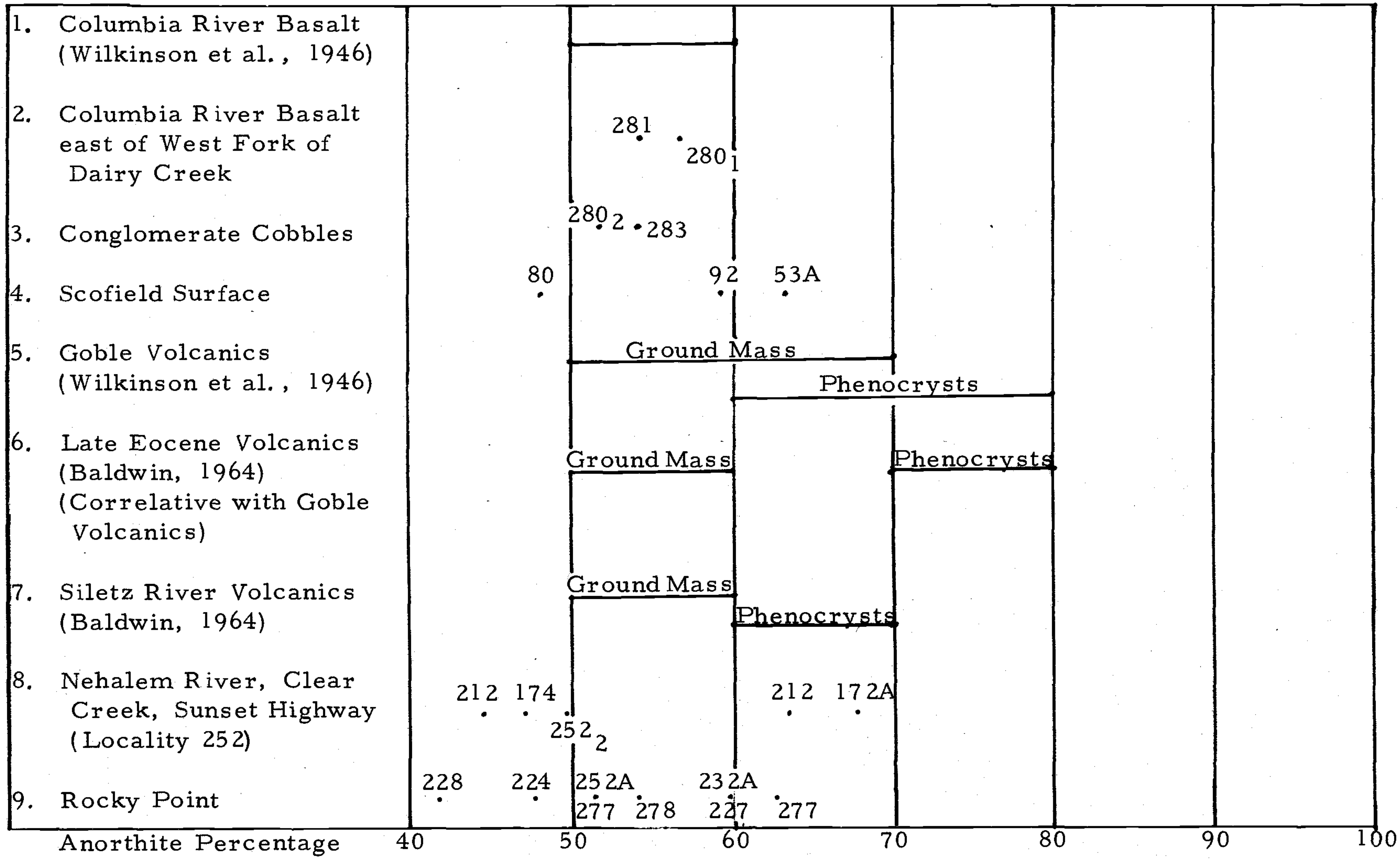


Figure 24. An content of plagioclase in basalts, upper Nehalem River basin

with respect to the An content alone, many samples classify in the range of the basalts of the Columbia River Group in adjacent areas, but textures of these basalts are not like those of the basalts of the Columbia River Group in that the latter have very small phenocrysts and much more glass (see Table 16, Appendix D). In view of these relationships it seems most probable that the isolated basalts in quarries along Clear Creek, the dikes along the Rocky Point ridge crest and southwest of Keasey (location 221) are intrusions and intercalated submarine flows of Goble Volcanics in the sandstones and siltstones of the Cowlitz Formation. The volcanics along the Sunset Highway and south of the highway which are obviously intercalated with the Cowlitz siltstones and mudstones are also Goble Volcanics. Baldwin (1964, p. 13) points out this relationship farther to the north, along the Columbia River, as do Warren and others (1945).

Newton (1969, p. 14, 17) shows in generalized geologic columns of both the Astoria basin and the Nehalem basin, interbedded Goble Volcanics in the late Eocene Cowlitz Formation. Henrickson (1946, p. 4) found the Goble Volcanics interbedded with the Cowlitz Formation in the Willapa Hills areas of southwest Washington.

There seems to be little disagreement concerning the identity of the volcanics found interbedded with the Cowlitz Formation in other areas, so it is probable that the same relationships hold in the upper Nehalem River basin.

Conglomerates associated with the volcanic rocks and with finer grained sediments are probably local and not all equivalent but represent restricted high-energy littoral or sublittoral environments present at different times during volcanism and sedimentation.

Sandstone Member

Warren and Norbisrath described a "gray, fine- to medium-grained, micaceous" sandstone which "contains much fragmentary plant material, " which they regard as overlying their lower shale member of the Cowlitz Formation. Stratification was described as fair but cross-bedding and ripple marks were said to be rarely seen (1946, p. 223). They point out that shell fragments are rare and do not mention other fossils. Typical outcrops are considered by these workers to be exposed along the Nehalem River near Rocky Point and west of Timber. They also mention a sandstone along the Nehalem River south of the bridge on the Sunset Highway. Samples taken from these localities are listed in Table 15, Appendix C. For the most part, the lithology of the samples on the east end of Rocky Point checked closely with the work of Warren and Norbisrath, except that the outcrops are very close to the contact between the Cowlitz Formation and the Keasey Formation, as shown on their map (1946, p. 219). Samples taken 0. 2 mile northeast in road cuts appear to be from the lowermost Keasey Formation. These beds (sandstones of the Cowlitz and tuffaceous pebbly sandstones and siltstones of the lower Keasey) all strike in about the same direction, N. 22–38° E. This is about 90° opposed to the contact shown on Warren and Norbisrath's map (1946, p. 219).

West of the Nehalem River from Keasey to Rocky Point, in the Clear Creek drainage area, south of the Sunset Highway and just west of the Timber-Vernonia junction, and in the Lousignont Creek drainage area, gray, micaceous, carbonaceous cross-bedded arkosic to lithic arkosic silty sandstones (Folk's classification; see page 122 this report) interbedded with gray, well-stratified sandy siltstones, claystones and a few pebbly sandstones are well-exposed in numerous cuts along logging roads. The sandstones are poorly indurated, contain no cement and only rare concretions. The siltstones are finely laminated with some disrupted laminae and much cut-and-fill structure. The arkosic sandstones of this region resemble littoral or sublittoral sands in both structure and texture (see Figures 25 and 26). They differ from the sandstones described by Warren and Norbisrath farther to the east in that they do not contain much brown plant debris, concretions are almost never seen and they are of a distinctly lighter gray color and contain less clay. A few sandstone beds contain more than 95 percent sand-sized material (see Figure 44). No fossils were observed in any of

Figure 25. Arkosic sandstone with aligned claystone clasts (darker), sandstone member, Cowlitz Formation. (Clear Creek, locality 211.)

Figure 26. Peel of arkosic sandstone, lower Cowlitz Formation, Clear Creek. (Locality 187.) Upper 14 inches cross-laminated with abundant muscovite mica flakes oriented parallel to planes of laminae, which are nearly horizontal. A large burrower hole is seen in the upper left.

The lower 20 to 21 inches is indistinctly laminated with 12 to 15 inch cross-laminae. Large flakes of muscovite (not visible in photograph) are oriented parallel to bedding planes and are inclined 30° to 40° south. Numerous clots of sand (darker) are seen in which mica is in random orientation. These are probably due to activity of burrowing organisms.

0 10 20 cm

these beds.

The most striking difference between these sandstone and siltstone beds and overlying mudstone beds considered to be of Cowlitz age is in their attitudes. Almost without exception the sandstone and siltstone beds strike northwest to west and dip southwest to south. Reversals in dip were measured just west of the Timber-Vernonia Junction, south of the Sunset Highway and between Keasey and Rocky Point. Sandstones and siltstones in the latter localities strike northwesterly and dip to the northeast. The overlying mudstones strike generally east-west and dip to the south (see Plate II). The stratigraphic position of these sandstones and siltstones is not entirely clear, but one thing is certain: their strikes are approximately 45° to 90° opposed to the strike of all other Tertiary strata exposed to the east in the area of this study. The sandstones and siltstones could possibly be in normal stratigraphic position and dip underneath the volcanics and interbedded sediments of the Sunset Highway area, but further detailed stratigraphic work is necessary before this relationship can be definitely established.

Primary Structures

Methods of Study. Where significant primary structures in sufficiently porous rock were noted or suspected, peels were made of large areas of outcrop surfaces. Bouma (1969, p. 1-83) has summarized a number of techniques for making peels, and many workers have previously described these techniques, but the two types found most effective with the mudrocks and sandstone of the upper Nehalem River basin involved the use of Glyptal 1276 (General Electric Co. product) or Elmer's Glue (a latex bonding agent) with two thicknesses of cheesecloth as a backing. An area of rock outcrop (generally about 4 or 5 square feet) was carefully smoothed. A mixture of Glyptal (one part to one part of acetone) or Elmer's Glue (two parts to one part water) was sprayed (Glyptal) or painted (Elmer's Glue) onto the rock surface. Cheesecloth was applied in overlapping strips and more Glyptal or Elmer's Glue painted on the back of the cheesecloth. The Glyptal works best for damp rock surfaces and will harden so that it can be peeled off in 4 to 6 hours. Elmer's Glue is much cheaper and satisfactory for dry rock and warm, sunny days. It will harden in 6 to 8 hours.

The peels so prepared are marked with angle of slope, compass bearing of the rock surface, and dip and strike of the beds. Peels are placed between layers of canvas or plastic for transport back to the laboratory where they can be studied under adequate illumination and magnification. Although, in many cases, no startling structural evidence was revealed which was not apparent in the field, this technique did uncover some primary structures which were not detected at the rock outcrop even after several examinations in the field (see Figures 26, 27, 31, 32). Relationships between granularity, composition, fabric and primary structures can be studied much better under laboratory conditions and the large sections of rock surface available for study through this technique greatly enhance these studies.

One other type of peel, involving a strip of cheesecloth 1 foot wide and 5 feet long, was attempted so as to gain a cross section of several beds. Although this technique showed some promise, the amount of labor and time involved in preparing such a long vertical section of rock outcrop does not seem to be worth the information gained. Making good peels depends upon the porosity and permeability of the sedimentary rock to be sampled and it was disappointing to find that many of the mudrocks and argillaceous sandstones had such low permeability that even after thorough wetting with pure acetone (solvent for Glyptal) no penetration could be effected and no peel could be obtained.

Results. Limited exposures and weathering of outcrops make detection of primary sedimentary structures in the lower siltstones of the Cowlitz Formation very difficult. Even gross stratification is almost impossible to detect. By way of contrast, much primary structure is present and readily observed in the arkosic sandstones and siltstones which locally lie above the lower siltstones. Nearly every exposure of the arkosic sandstones and siltstones show fine

(0.25 to 1.0 cm thick) laminae which are delineated by the presence of much mica and/or finely comminuted plant debris or by grading on a fine scale. Where grading is the cause, the rock has a uniform gray color and the presence of the lamination and the grading may be detected only by careful observation. A peel prepared from an arkosic sandstone in the lower Cowlitz is shown in Figure 26.

Low angle (a few degrees to 10°) cross-lamination is common, ranging from a few inches to 14 inches long. Foreset laminae are locally observed with inclinations up to 40°. Current directions range from southeast to southwest. Lack of stratigraphic correlation between outcrops makes interpretation from these data questionable. Many sets of cross-laminated beds contain larger scour channels. In one locality, 213, a laminated siltstone shows much contortion and separation of laminae which was probably due to load deformation, although it is possible that the structure was that of a turbidite.

Near locality 213 two or three bands containing angular silty claystone clasts from 0.5 to 3.0 inches in size are inter-stratified with fine- to medium-grained cross-laminated micaceous sandstone beds. These beds resemble an intraformational breccia, except that the claystone clasts are present in distinct strata rather than being scattered throughout the sandstone (see Figure 25). No other such disrupted beds were observed.

In addition to the layer properties described above, filled borer holes are common (see Figure 26). These do not greatly disrupt the bedding. They are represented by tubes which are filled with sediment containing unoriented mica flakes or very fine clayey silt.

All the primary structures seen are suggestive of a shallow neritic marine environment with moderate current action, a few bottom-dwelling organisms and moderate sediment supply. Siltstones and a few mudstones indicate facies differences both in place and time.

Mudstone Member

Along the Nehalem River, south of the Sunset Highway bridge near the Timber-Vernonia junction, an exposure of 1,115 feet of mudstone, siltstone and minor fine-grained calcareous silty sandstones, with a few calcareous pebbly sandstone beds can be traced for about a mile and one-half. Warren and Norbisrath included most of this sequence in their upper shale member of the Cowlitz Formation. In this section some of the most intensive fossil collecting in the entire area of this study was done by Warren and others, as shown on OM 42 (1945). Warren and Norbisrath (1946, p. 224) describe their upper shale member as "marine fossiliferous dark gray shale and fine-grained micaceous shaly sandstones, which contain increasing amounts of interbedded tuffaceous sandstone and water-laid tuff in the upper part." They do not specify any typical exposures nor do they give the thickness of their upper shale member. Since the predominant rock-type in the Nehalem River section is mudstone, I will refer to this as the mudstone member of the Cowlitz Formation.

The mudstone and siltstone beds of the mudstone member of the Cowlitz Formation strike generally east-west, with local variations ranging from 62° NW to 60° NE, and dip 10°-16° south. The mudstone beds in this sequence, upstream from the Sunset Highway bridge on the Nehalem River, are apparently massive and from 10 to 40 feet in thickness. Some sections of mudstones up to 88 feet in thickness were measured but these undoubtedly include several beds each of which is almost identical lithologically to the others. Exposures of these thick mudstone beds are observed in the main channel of the Nehalem River and can be sampled at almost any place during times of low water. Between thick massive mudstone beds, thin dark gray to green-gray calcareous siltstone, dark green calcareous pebbly volcanic sandstone and dark gray mudstone beds from 0.5 to 2.0 feet in thickness occur in interbedded sequences of from three to ten beds. The calcareous siltstone and sandstone beds are more resistant than the mudstone beds and control the course of the Nehalem River wherever large meanders have developed (see Plate I). Since almost continuous exposures of the mudstone member of the Cowlitz Formation and the overlying beds of the Keasey Formation can be studied along the Nehalem River upstream from the bridge on the Sunset Highway a detailed stratigraphic section was measured and sampled. The results of this study are shown in Appendix A.

Primary sedimentary structures other than graded bedding are rare in the mudstones, siltstones and pebbly sandstones of the upper part of the Cowlitz Formation exposed along the Nehalem River. By way of contrast the overlying Keasey Formation exposed in this section along the Nehalem River has well-laminated siltstone interbedded with thick massive mudstone. Calcareous pebbly volcanic sandstone interbeds are much more rare in the lower part of the Keasey Formation than in the mudstone member of the Cowlitz Formation. Only one interbedded sequence of thin pebbly volcanic sandstone, siltstone and mudstone is found in the lower Keasey Formation.

The position of the contact between the Cowlitz Formation and the Keasey Formation is in doubt. The division between the Keasey and Cowlitz Formations was made by Warren and Norbisrath (1946, p. 226) on the basis of fossil evidence. They noted that the foraminifera of the Keasey Formation have been correlated with the Bastendorff Formation and with the Gaviota Formation of California. The faunal assemblage of the Keasey Formation is considered by

Deacon (1953, p. 21) to be "diagnostic of Refugian age." In the Gaviota Formation, Kleinpell and Weaver (1963, p. 30, 34) find that the change from Narizian (late Eocene) to Refugian (latest Eocene to middle Oligocene) life occurs <u>within</u> the Gaviota Formation rather than at the contact between the Gaviota and the underlying Sacate Formation. They point out that in the West Coast Tertiary this is a common occurrence: the chronologically significant life changes "lag behind the conspicuous physical changes in the depositional record" (p. 35). If such is the case with respect to the Cowlitz and Keasey Formations, then it would be more reasonable to place all of the mudstones, siltstones and pebbly sandstones exposed along the Nehalem River within the lower member of the Keasey Formation, since the truly distinctive lithologic break occurs between these rocks and the much sandier and siltier matrix-poor beds of the Cowlitz Formation west of the Nehalem River. However, there is a slight contrast in lithology between the formations where they are exposed along the Nehalem River within the section just described. The lowermost Keasey Formation is characterized by siltier sediments and more pronounced stratification as compared to the underlying Cowlitz Formation in which massive mudstones and silstones predominate and laminated siltstones are rare. On this basis it is possible to locate the contact between the Cowlitz and Keasey Formations where Warren and Norbisrath placed it (see Plate II), but the lithologic differences in the two formations at this point are minor.

Keasey Formation

Overlying the Cowlitz Formation are dark to medium gray siltstones and massive tuffaceous gray mudstones named, the "Keasey Shale" by Schenck (1927, p. 457-458) and regarded by Weaver (1937, p. 171-172) as early Oligocene in age. The microfauna of the marine Oligocene of the west coast of North America were first described in 1928 by Cushman and Schenck from the Keasey Formation and the Bastendorff Formation near Coos Bay, Oregon. Schenck's type locality for the Keasey Formation is along Rock Creek from the hamlet of Keasey to a point about 2 miles downstream.

Warren and Norbisrath proposed division of the Keasey Formation into "a lower dark shale member (type Keasey) . . . ; a uniform middle member of massive silty tuffaceous shale with cemented beds; and an upper member of stratified tuffaceous sandy shales" (1946, p. 225). They regarded the middle member as being best exposed along the Sunset Highway east of the Nehalem River. In this latter area, the lower member was considered absent or "represented by 400 feet of glauconitic shales" (p. 226) which they had placed in the upper part of the Cowlitz Formation. The confusion with respect to these lower Keasey Formation beds is understandable when one examines the poorly exposed outcroppings along the Sunset Highway. Along the Nehalem River, south from the bridge on the Sunset Highway, the exposures of the Keasey Formation are much better.

Deacon (1953, p. 60 and 18), on the basis of what he considered a lithologically distinct series of beds between his Rocky Point Formation (Cowlitz Formation plus lowest Keasey Formation) and the Keasey Formation (as amended by him) along Rock Creek, named "a minimum of 230 feet of compact, stratified, dark gray mudstones" which had "a few thin glauconitic sandstone interbeds" the "Nehalem formation." Elsewhere (Nehalem River and Sunset Highway), these beds were described by Deacon as quite heterogeneous and exhibiting no two sections in which the details of lithology are the same. Because of the similarity of rock types in the lower part of the Keasey Formation to the rest of the Keasey Formation, there seems to be little justification for the separation of the lower part into a new rock stratigraphic unit.

In the Sunset Highway-Nehalem River area, where the Keasey Formation is most easily distinguished, the beds of the lower part are somewhat sandier than the beds of what is considered the middle and upper parts. The rocks of the Keasey Formation range from sandy mudstones and siltstones to mudstones and siltstones. Volumetrically mudstones are the most abundant, comprising at least 80 to 85 percent of all sections.

Lower Member

The lower member of the Keasey Formation appears to lie conformably upon the upper Cowlitz mudstones and siltstones. The lithology of these beds and the discontinuity which marks the probable contact of the Keasey Formation with the Cowlitz have been discussed with the stratigraphy of the mudstone member of the Cowlitz Formation (see page 52) (See also stratigraphic section, Appendix A.)

Primary Structure

Primary structures in the siltstones of the lowermost beds of the Keasey Formation exposed along the Nehalem River south of U. S. Highway 26 include cross-lamination, ripple lamination and occasional flame-structure in thin mudstone interbeds. The most distinctive differences between the siltstones of the lowermost Keasey Formation and the siltstones and mudstones of the underlying mudstone member of the Cowlitz Formation is the pronounced lamination of all the siltstones of the lower Keasey. Many of the siltstones of the lower Keasey have unusually large amounts of coarse (2-3 mm diameter) flakes of muscovite and biotite mica and carbon which define the laminae. Muscovite, biotite and carbon flakes in one series of beds form laminae up to a few tenths of a millimeter in thickness so that bedding planes are silvery with the mica. Sets of laminae often consist of highly micaceous silt alternating with dark gray mudstone. Some of the laminated beds show conspicuous disruption of stratification by burrowing organisms and burrows in finer-grained rocks are often filled with coarser sediment. Clasts of claystone are commonly dispersed throughout some beds as in an intraformational breccia. No such structures are seen in the uppermost Cowlitz Formation underlying the Keasey Formation downstream along the Nehalem River toward the bridge on the Sunset Highway.

One 16 foot thick exposure of the sandstone which is near the base of the Keasey Formation deserves special mention. Along Robinson Creek, a tributary of the Nehalem River, in Sec. 11, T. 3 N., R. 4 W., matrix-free, well-sorted, poorly indurated, cross-laminated, yellowish, arkosic silty sandstone (location 150, 152) crops out. At the base of the sandstone there is a mudstone breccia with a thin (0.5-1 inch) limonite-cemented horizon. This breccia is highly fossiliferous containing abundant mollusca, small crustacea, starfish, sharks' teeth, wood and leaves. The sandstone and the underlying fossiliferous mudstone breccia suggest a beach or very shallow neritic environment. The sandstone itself is identical with the sandstones in the Cowlitz Formation which crop out in many places west of the Nehalem River. But it is difficult to equate or even correlate this sandstone on Robinson Creek with those of the Cowlitz Formation to the west since it would lie stratigraphically above the pebbly volcanic sandstones along the lower reaches of Robinson Creek which are part of the mudstone member of the Cowlitz and because none of the sandstones west of the Nehalem River were found to be fossiliferous. It must be a local facies within the lowermost Keasey Formation. No other sandstone such as this was found in the Keasey Formation in the upper Nehalem River basin.

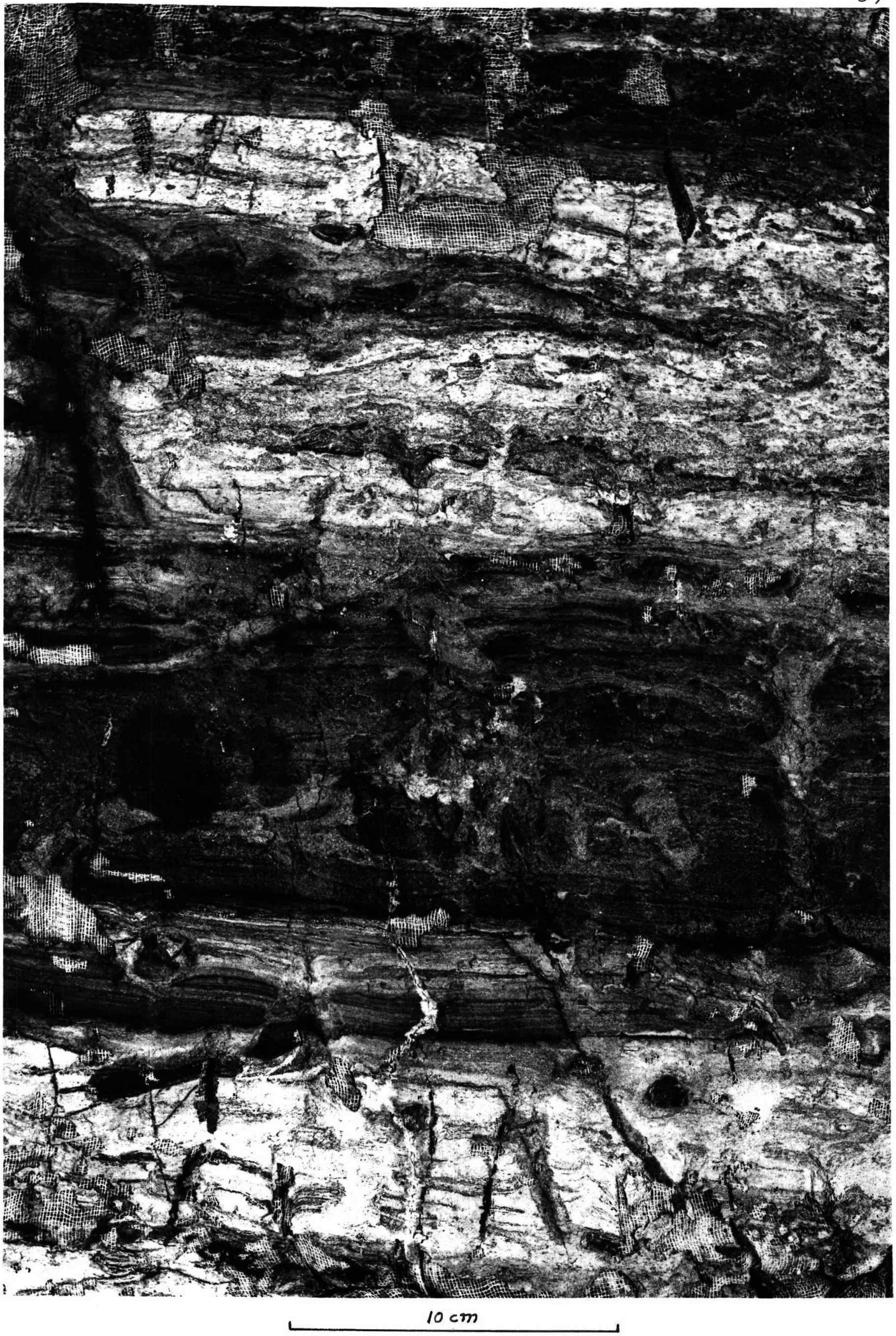
Exposures of the lower part of the Keasey Formation along the Sunset Highway, described by Warren and Norbisrath (1946, p. 225) and Deacon (1954, p. 26) are now in such an advanced state of weathering that it is difficult to make any detailed study of lithology, much less to define primary structures. A few exposures which are considered to be of the lower Keasey Formation are found along the Nehalem River north of the Sunset Highway. The lithology of these rocks is given in Table 15, Appendix C.

Between the Sunset Highway and Robinson Creek several outcrops of laminated to bedded mudstone and siltstone, some of which are glauconitic, are found (locations 154, 151). Some outcrops show contorted and disrupted laminae, due to load compaction. Burrowing organisms have disrupted or penetrated some beds (see Figure 27).

Middle Member

The most typical rocks of the middle member of the Keasey Formation are tuffaceous arkosic to lithic arkosic clayey siltstones

Figure 27. Peel of laminated to bedded mudstone and siltstone, lower member of Keasey Formation, between Sunset Highway and Robinson Creek (locality 151). Most sets of laminae are disrupted by load compaction structures and burrower holes, which are filled with mud or clots of sand. Note center and lower center. A larger burrower hole can be seen on the extreme right, just below center line of photograph.



10 cm

and mudstones, with a few thin (0.5-0.75 foot) claystone and tuffstone beds. The siltstones and mudstones are most typically exposed along the Sunset Highway, especially in the Empire Lite Rock Company Quarry at the west end of the Sunset Tunnel. Here a 200-foot section of massive gray tuffaceous mudstone beds, ranging in thickness from 8 to 12 feet interbedded with dark gray, well-indurated tuffaceous siltstone beds 0.5 to 2 feet thick, is exposed. The thinner beds are commonly graded changing from almost pure pumiceous volcanic ash at the base to tuffaceous siltstone near the top. Spherical concretions up to 8 inches in diameter are common, molluscan fossils are exceptionally well-preserved, and foraminifera are abundant. Most of the sediments are pyritiferous. Altogether at least 27 separate beds are exposed in the quarry. Active working of the quarry has changed the amount of exposure, however, and at this time probably no more than 75 to 100 feet of section is observable. Warren and Norbisrath estimated the total thickness of what they considered to be the middle member of the Keasey Formation to be 1,700 feet.

These rocks are rich in smectitic clays (see page 169, this paper) and exposed rocks crumble into chips and pea-sized detritus due to expansion and contraction by alternate wetting and drying. In older road cuts the rocks weather to an unctous brownish-yellow silty soil. Landsliding in these rocks of the Keasey Formation is common. Except for recent road cuts or quarries, exposures are difficult to find.

Upper Member

The upper 100 to 200 feet of the Keasey Formation consists of alternating gray to very dark gray tuffaceous sandy siltstone and mudstone beds from 5 feet to less than a foot in thickness, with a few beds of almost pure pumice or pumiceous volcanic ash which are water-laid. Calcareous siltstone, often concretionary, and volcanic sandstone beds stand out as resistant bands in all exposures. The coarser beds are finely laminated and exhibit poorly preserved sole markings, but orientation of these structures is never well enough defined to warrant measurement. Most of the mudstone beds have burrower holes filled with coarser pumiceous sandy silt and isolated clots of light gray silty sand.

The prevalence of well-indurated calcareous beds makes this upper part of the Keasey Formation relatively resistant to erosion. The ridge which forms the drainage divide between the West Fork of Dairy Creek on the east and the eastern tributaries of the Nehalem River on the west is held up by these resistant beds of the upper Keasey Formation. This ridge forms the highest ground in the eastern part of this area and tunnels for the railroads and the Sunset Highway have been driven through it. The contact between the Keasey

Formation and the overlying Pittsburg Bluff Formation lies slightly to the east of this ridge (see Figures 28 and 29).

Warren and Norbisrath (1946, p. 227) believed that, "the threefold lithologic division of the Keasey Formation appears to be supported by megafaunal differences." It does not seem necessary, however, to cite faunal differences when the lithologic dissimilarity of the upper and middle members is so well marked as it is in the southern part of the upper Nehalem River basin. Caution should be exercised, however, in extending these differences into adjacent regions, for it is apparent that lateral continuity is lacking in most beds throughout the upper Nehalem River basin. Within short distances facies changes occur within beds and even whole sequences may change considerably in lithology and thickness. The lithology of the upper part of the Keasey Formation in the area of this study does not agree with lithologies to the north and south. The topographic expression of the resistant beds of the upper member is not found to the north where Pebble Creek and the Nehalem River are believed to follow the contact between the Keasey Formation and the overlying Pittsburg Bluff Formation (Warren and Norbisrath, 1946, p. 219).

The micro- and megafauna of the Keasey Formation have received much study. There seems to be little question that the microfaunal assemblage is Refugian, which is considered to be late Eocene

Figure 28. Beds of concretionary siltstone with mudstone interbeds, upper member, Keasey Formation, near contact with overlying Pittsburg Bluff Formation near Tophill, S. P. and S. R. R. (Locality 114.)

Figure 29. Looking southeast from Rocky Point. Ridge (middle distance) is held up by concretionary beds of upper member, Keasey Formation. Columbia River Group basalts underlie ridge at skyline in farthest distance.

to middle Oligocene by Kleinpell and Weaver (1963, p. 1).

Pittsburg Bluff Formation

The lithologic distinctions between the Keasey Formation and the overlying Pittsburg Bluff Formation seem sufficiently pronounced in all areas so that little doubt is raised concerning the identity of these formations in the field. The problems which exist with respect to location of the contact between the two formations stem from the poor and infrequent exposures due to vegetative cover, landsliding and the low angle of dip of these beds. On the Scofield Surface, however, there are several springs which are aligned in a manner which relates them to the probable position of the contact between the Pittsburg Bluff and the underlying Keasey. The permeability of the mudstones of the Keasey is low enough that a perched water table exists along that area in the late summer when the small streams generally dry up. The springs, however, maintain a relatively constant flow at all times.

The Pittsburg Bluff Formation has been studied paleontologically quite intensively over the past 80 years. Most of this study has been in the area near the type locality at Pittsburg, Oregon.

In the type locality, near Pittsburg, Oregon, along the Nehalem River, the Pittsburg Bluff Formation consists of massive fine-grained arkosic to lithic arkosic clayey, tuffaceous concretionary

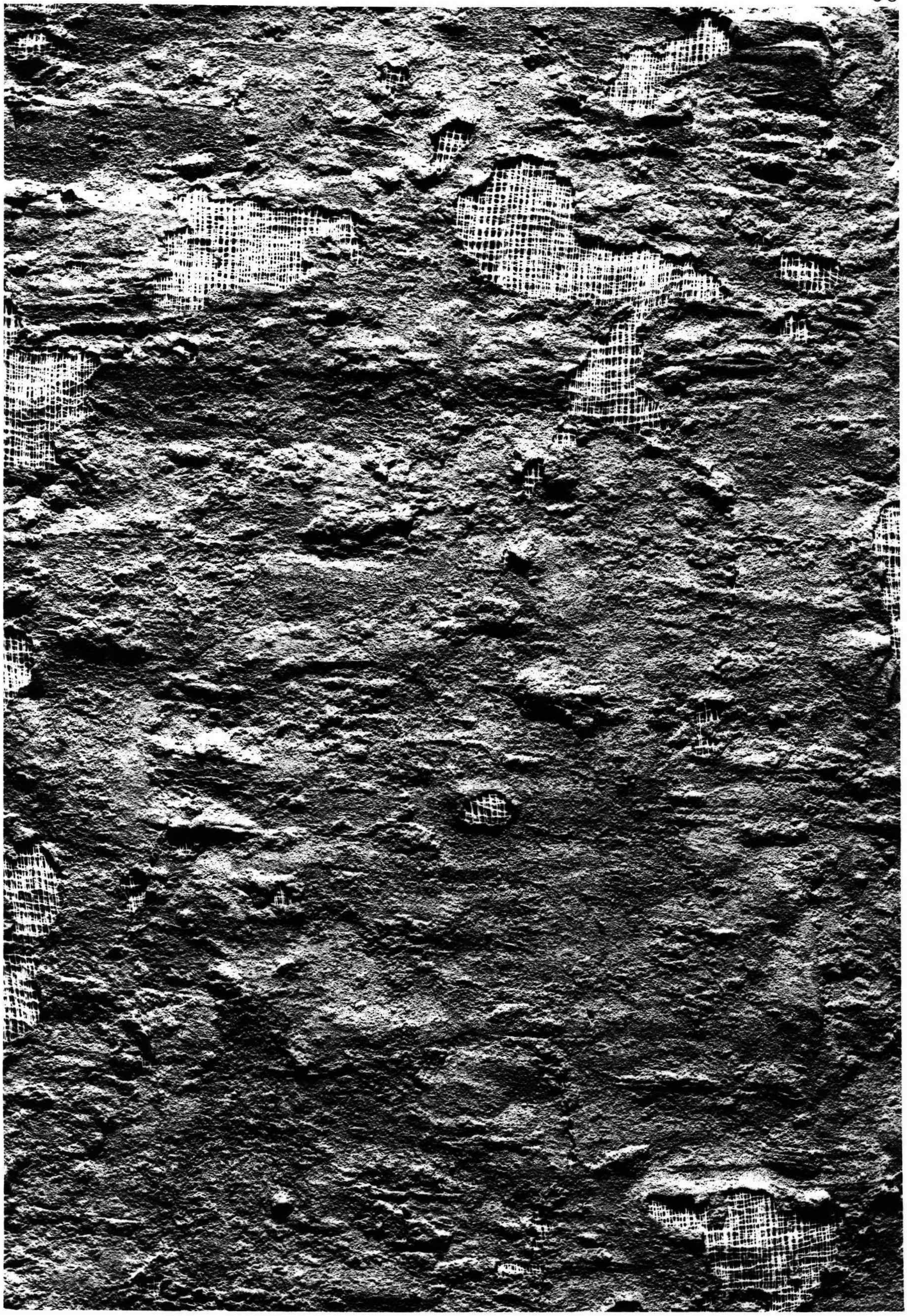
Figure 30. Sandy mudstones of the Pittsburg Bluff Formation with thin interbeds of claystone breccia. (Locality 1-20, Sunset Highway, just west of Staleys Junction.)

sandstone beds. Fossil molluscs, wood and some coaly material are common. The upper part of the formation in that area is more tuffaceous than the lower part and tends more toward a mudstone, although pebbles become more numerous and wood plant debris are locally very prominent. These upper strata are considered by Warren and Norbisrath (1946, p. 229) to have been deposited in a brackish water environment, probably deltaic. Locally, conglomerates and intraformational breccias with mudstone blocks up to 3 feet in length are found. Some of the siltier beds of the upper Pittsburg Bluff Formation near the type locality are prominently cross-laminated and, in places, according to Holmgren (1967, p. 6), are "torrentially cross-bedded with cut-and-fill structures throughout."

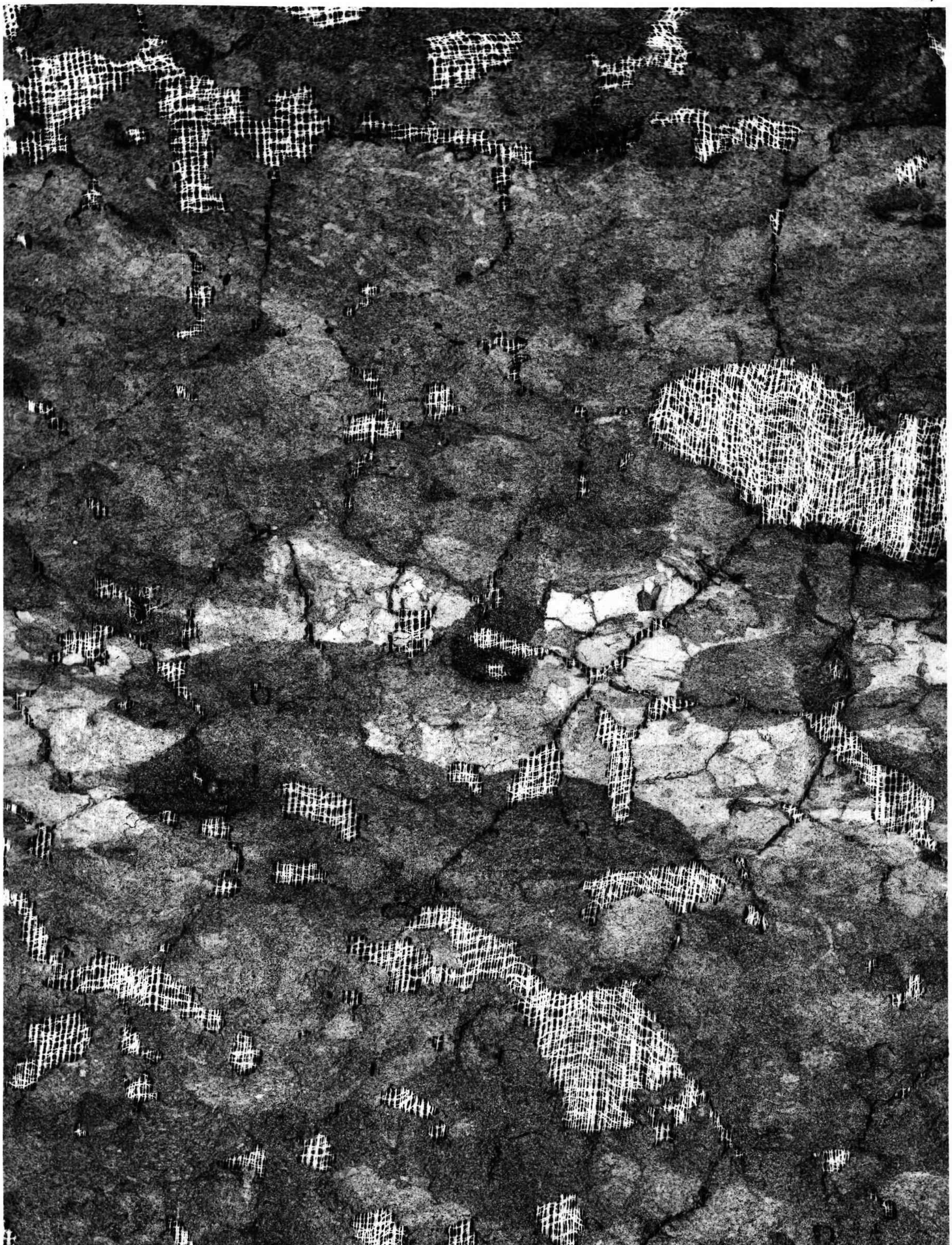
To the south of the type locality, in the area of this study, the Pittsburg Bluff Formation is finer grained, more tuffaceous and generally more massive, although primary sedimentary structure is more abundant than in the relatively structureless Keasey Formation which is underlying. The lowest 100 to 150 feet of the Pittsburg Bluff consist of finely laminated dark bluish-gray, micaceous, tuffaceous, arkosic siltstone. This crops out along the Southern Pacific Railroad, the Sunset Highway near the junction with Scofield Road and on the S. P. and S. Railroad at Tophill. The persistence of these siltstones is unique as compared with the lack of lateral continuity of most lithologic types throughout this region.

Above the siltstones the Pittsburg Bluff Formation consists of massive 8 to 12 foot thick beds of blue-gray, highly tuffaceous (up to 50 percent ash), carbonaceous sandy mudstones interbedded with 6 to 8 inch beds of very light gray to white tuffaceous claystone and claystone breccia. The mudstones almost universally weather to a very light brown color with pronounced mottled yellowish patches. The mottling is due to alteration of coarser-grained pumiceous, tuffaceous, lithic sandstone clots which are mixed throughout all these thicker beds (see Figure 31). The general appearance is that of an estuarine or bay sediment which has been stirred by the action of burrowing organisms. Burrows with coarse tuffaceous sand filling them are common (see Figure 33). This type of primary structure is unique with the mudstones of the Pittsburg Bluff Formation and not found in any other Tertiary sediments of the region. The tuffaceous claystone beds commonly consist of angular chunks of claystone, many of which have ellipsoidal load casts (?) of coarse pumiceous silt and sand impressed into them (see Figure 32). At some localities Solen (sp) were found in a nearly vertical position, which suggests that they are in living position. Concretions were not observed anywhere in the Pittsburg Bluff Formation exposures. The high ratio of matrix to framework in these muddy sediments renders them impermeable.

In the upper part of the Pittsburg Bluff Formation mudstone



5 cm



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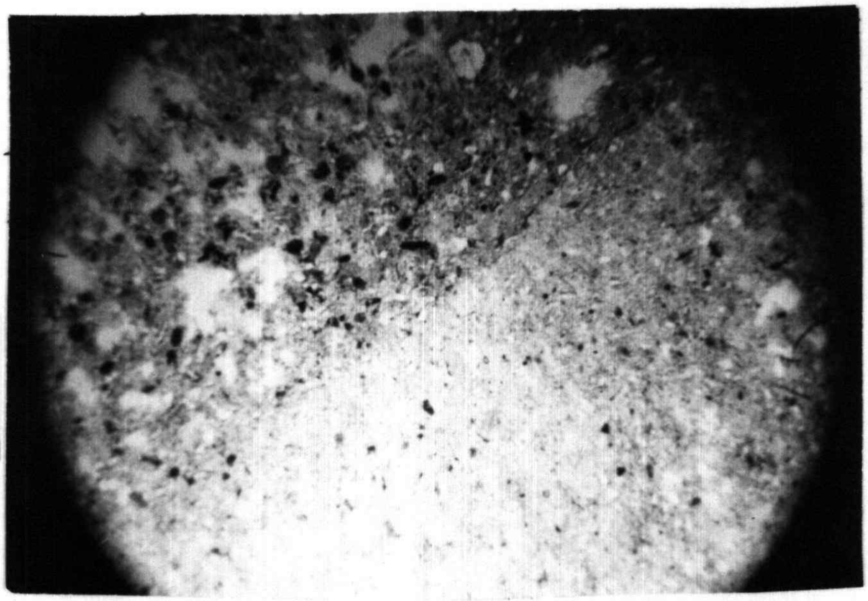


Figure 33. Photomicrograph, sand-filled burrow in sandy mudstone, Pittsburg Bluff Formation. (Locality 1-20.)

0.5 mm

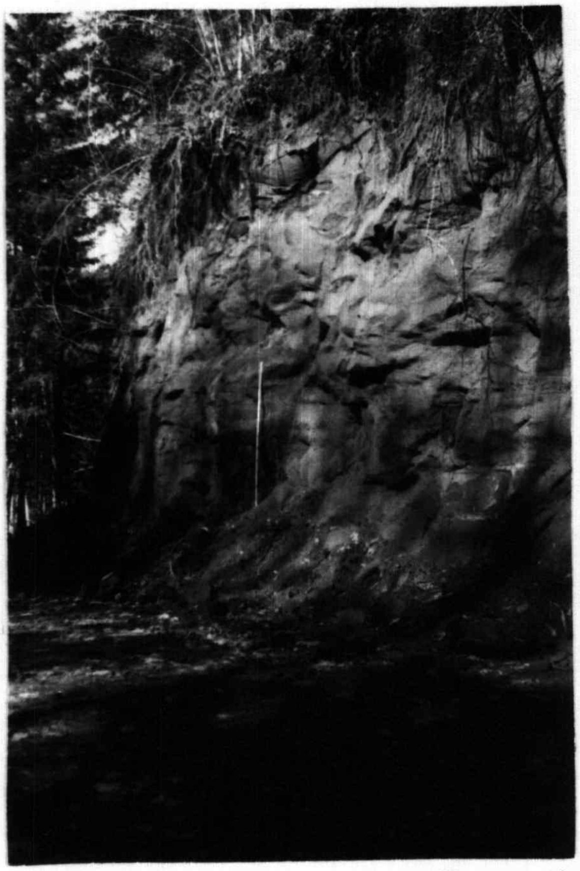


Figure 34. Arkosic sandstone beds, Scappoose Formation. Rule is 6 feet long. (Locality 202.)

beds are 2 to 3 feet thick with 2 to 6 feet thick beds of lithic arkosic carbonaceous, silty sandstone interbedded with the mudstone. In one well-exposed section on the S. P. and S. Railroad, 1.5 miles north of Buxton, the mudstone-sandstone sequence grades upward into coarse-grained pebbly sandstones, which are pumiceous and have abundant plant debris, and finally into basaltic pebble to boulder conglomerate beds. Warren and Norbisrath (1946, p. 232) consider these conglomerates to be at the base of the overlying Scappoose Formation.

About 3 miles southwest of the above-mentioned locality, just south of Staley's Junction, gray, micaceous, tuffaceous and pumiceous pebbly mudstone is found which is typical of the uppermost part of the Pittsburg Bluff Formation. Molluscan fossils, wood, leaf imprints, coal lenses and basaltic pebbles are in totally random orientation. Clots and cylindrical bodies of coarse-grained sand are common in many parts of the beds. Overlying the mudstone is a 6-8 foot graded series of siltstone beds with sole markings consisting of load casts and groove casts. Claystone interbeds show flame structures at their contacts with the siltstones. Lower in this same section an intraformational breccia crops out in which mudstone and laminated siltstone clasts from a few inches to several feet in length are enclosed in a pebbly sandy matrix. This breccia is almost identical to several found at a similar stratigraphic horizon several miles to the north, in the vicinity of Vernonia and also near Pittsburg.

The Pittsburg Bluff Formation rests with apparent conformity upon the Keasey Formation in the area of this study. The strike of beds of both formations is so similar that no real discordance is suspected. Dips range from 5° or 6° to as much as 22°. A few dips of as much as 30° were measured, but these appear to be related to faulting, since they are local and unique. The Pittsburg Bluff Formation is overlain by the Scappoose Formation with apparent conformity.

The age of the Pittsburg Bluff Formation is considered to be middle Oligocene, included in the upper part of the Refugian Stage (Kleinpell and Weaver, 1963, p. 44), correlative with the Lincoln Formation of southwestern Washington, and the Eugene Formation and the Tunnel Point Sandstone of west central Oregon.

Scappoose Formation

In the eastern part of the upper Nehalem River basin, the Pittsburg Bluff Formation is overlain by a series of tuffaceous, carbonaceous, lithic, arkosic silty sandstones and mudstones, with a few interbedded pebbly sandstones. A 6 to 8 feet thick basaltic pebble to cobble conglomerate with a highly quartzose sandy matrix appears to be the basal bed in the series where it is exposed along the S. P. and S. Railroad 1.5 miles north of Buxton. The contact between the

Pittsburg Bluff and Scappoose Formations is not exposed anywhere else in the area of this study. In the northwest corner of the NE 1/4, Sec. 33, T. 3 N., R. 4 W., this basal conglomerate is of variable thickness and interfingers with yellowish-brown non-indurated sand stringers and lenses from 2.5 to 3.0 feet thick. The conglomerate appears to pinch out to the south, suggesting that it is probably not everywhere present at the base of the Scappoose Formation.

In the canyon of Mendenhall Creek, 0.5 mile southeast of the locality described above, a non-indurated medium gray, highly carbonaceous, pumiceous, lithic, quartzose pebbly sandstone bed (sample 147, Table 15, Appendix C) crops out. Judging from the attitude of the bed here, this must also be near the base of the Scappoose Formation. Exposures farther upstream a few hundred feet reveal a gray, tuffaceous, arkosic, silty, pebbly sandstone (sample 148, Table 15, Appendix C). Such contrasting lithologies within the same stratigraphic horizon with no evidence of structural displacement must represent a change in sedimentary facies.

Above the coarser basal portion of the Scappoose Formation, yellowish-brown weathering arkosic silty sandstones crop out in a series of 4 to 8 feet thick beds aggregating at least 200 feet total thickness (Figure 34). Some of these sandstones are moderately indurated and may be calcareous or have calcareous concretions. Others are so loosely consolidated that they can be dug with a shovel.

Most of the sands are relatively free of clay matrix other than that produced by the weathering of feldspathic components. The sandstones resemble those in the Cowlitz Formation west of the Nehalem River. Interbedded with the sandstones are 2 to 3 feet thick beds of tuffaceous siltstone.

About 1.5 miles directly southeast of the above-described localities on the S. P. and S. Railroad and near Mendenhall Creek, along the ridge top and therefore stratigraphically above the beds at these former localities, a dark gray, highly tuffaceous, laminated mudstone crops out in road cuts forming sections 20 feet thick. Near the base of this unit angular fragments of claystone, carbonized wood, pumice fragments up to 1 inch in diameter, mafic volcanic rock fragments and numerous molluscan fossils all in random orientation are found in discontinuous layers. Above this lower portion of the unit, ripple- and cross-laminated siltstones a few feet thick grade upward into more or less massive tuffaceous mudstone. In other logging road cuts along the ridge separating Mendenhall Creek from Tolke Canyon pebble conglomerates, pebbly mudstones with rare 3 inch cobbles of quartzite, sandy siltstones, and claystone beds are exposed.

Since most of these outcroppings are not large and bedding is rarely seen, attitudes and correlation between outcroppings is difficult. It is probable that much of the variation in lithology observed is the result of rather rapid lateral facies changes.

From the section described above it is clear that the Scappoose Formation is a distinct rock stratigraphic unit. This sustains the conclusions of Warren and Norbisrath who differentiated the Scappoose from the Pittsburg Bluff on the basis of megafauna. They originally correlated the Scappoose Formation with the Blakely Formation of southwest Washington, calling it "Beds of Blakely Age" on their map of northwestern Oregon (1945). In their paper on the stratigraphy of the upper Nehalem River basin, they proposed the name "Scappoose Formation" (1946, p. 231). They stated here that lithologic similarity between the Pittsburg Bluff and Scappoose Formations made it "difficult to differentiate these units without the use of fossils." Careful field work reveals, however, that the Scappoose Formation is quite easily recognizable. Although there are some well-indurated fine-grained sandstone beds very similar to those of the Pittsburg Bluff Formation, most of the sandstones of the Scappoose Formation:

1) have less matrix
2) are more quartzose
3) have much less volcanic ash
4) are generally poorly indurated and often friable
5) form a prominent part of the Scappoose Formation wherever it is exposed, whereas in the Pittsburg Bluff Formation in

the area of this study, almost no sandstone units are found. The reader should refer to Appendices B and C for data which confirm these conclusions.

The mudstone units of the Scappoose Formation are more easily confused with those of the Pittsburg Bluff Formation. However, the Scappoose mudstones lack the characteristic yellow mottling which is almost universal in the more tuffaceous Pittsburg Bluff Formation of this region. It must be admitted that differentiation between individual units within these two formations is difficult, even after considerable acquaintance with the rocks in the field but given a section with several units, the separate formations may be readily recognized.

The total thickness of the Scappoose Formation in the area of this study could not be measured, due to discontinuous outcrops and frequent facies changes. Warren and Norbisrath estimated a thickness of 1, 500 feet, based upon outcrop width (1946, p. 232). They acknowledge, however, that this thickness is subject to doubt because of "the horizontal distance involved, long concealed intervals and possible faulting."

The age of the Scappoose Formation was considered by Warren and Norbisrath (1946, p. 220) to be late Oligocene or early Miocene. A study of microfauna, which must be present in the mudstone units, would probably settle the age question. Part of the Scappoose

Formation may be correlative with or equivalent to the Astoria Formation farther west. In an Oregon State Highway Department quarry on the east fork of Dairy Creek (NE 1/4 of NW 1/4, Sec. 33, T.3N., R.3W.), a sandstone lens which appears to be of the Scappoose Formation is intercalated between basaltic lavas of the Columbia River Group. Similar relationships of Miocene basaltic volcanics and sediments of the Astoria Formation are common along the Columbia River in Washington (Weaver, 1937, p. 171).

Because of the narrow range of variation in rock types, the preponderance of mudrocks in all these formations and the overall general structural concordance of these strata it would seem proper to regard the Cowlitz, Keasey, Pittsburg Bluff and Scappoose Formations as a group. The name "Nehalem Group" might be suitable since in other regions of northwestern Oregon these formations are very difficult to differentiate in the field (Warren and others, 1945). A further reason for regarding these formations as a group stems from the general similarity of conditions of deposition.

Columbia River Group

Basalts of the Columbia River Group are found capping the highlands to the east of the upper Nehalem River basin. These flows rest upon a topography carved in the underlying Scappoose Formation with local basaltic boulder to cobble conglomerate marking the contact in places (see Figure 35). In the area of the Scofield Surface several bodies of dense, glassy, fine-grained porphyritic basalt, which are dikes cutting through the underlying Tertiary sediments, are exposed in quarries (see Figure 37). On the Scofield Surface a brick-red lateritic soil occurs. The underlying Pittsburg Bluff Formation is thoroughly stained with hydrated iron oxides, imparting a brick-red color to the sediments exposed in road cuts along the Sunset Highway. Decomposed, brickbat-jointed basalt and relatively fresh, dense, fine-grained porphyritic basalt are found in separate patches, which are remnants of flows. Strewn over most of the Scofield Surface are numerous cobbles and boulders of the same basalt.

In cuts along the Southern Pacific Railroad the patches of basalt rest in low spots on an ancient topography carved into the Pittsburg Bluff Formation (see Figure 39). Farther to the west, near the Nehalem River, cobbles of dense black basalt are found along tributary canyons entering the Nehalem River from the east. In every case, these dikes, remnants of basalt flows, and the cobbles are nearly identical in texture and composition and appear to be equivalent lithologically to the Columbia River Group which crops out to the east of the upper Nehalem River basin.

For textural comparisons to basalts of the Columbia River Group see Figures 36, 38 and 40 and Table 16, Appendix D.

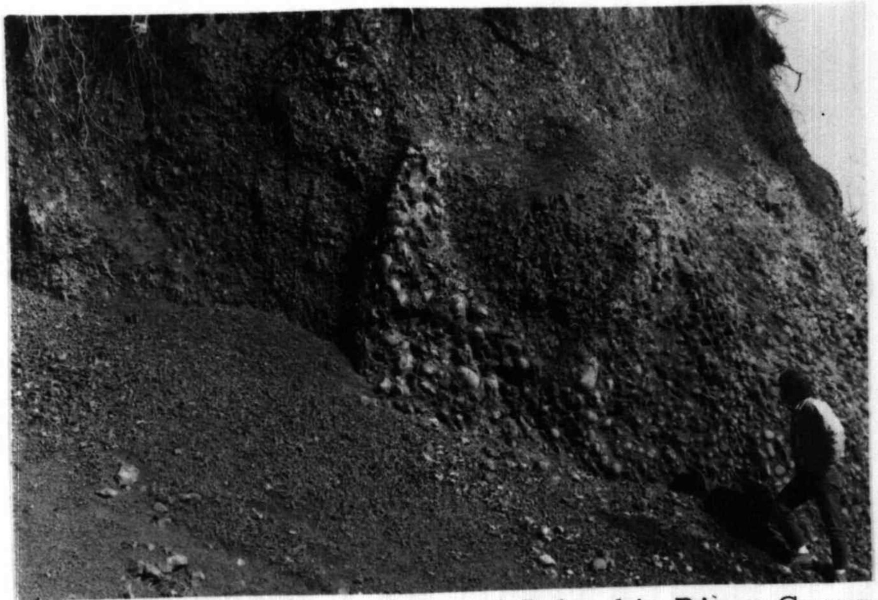


Figure 35. Cobble conglomerate, base of Columbia River Group, Bacona Road. (Locality 280.)

Figure 36. Photomicrograph, hypocrystalline basalt, Columbia River Group. (Locality 280, Bacona Road.)

1mm

Figure 37. Quarry in brickbat jointed basaltic dike of Columbia River Group, Scofield Surface near Strassel. (Locality 80.)

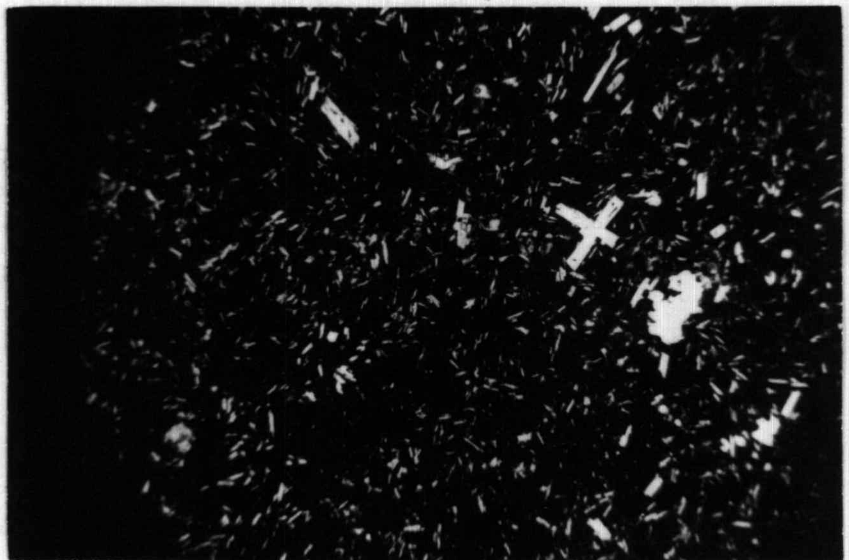


Figure 38. Photomicrograph, hypohyaline basalt (59 percent black glass), Columbia River Group. (Same locality as Figure 39.)

1 mm

Figure 39. Brickbat jointed basalt of Columbia River Group in cut on S. P. R. R., Scofield Surface. Rule is 6 feet long. (Locality 59.)

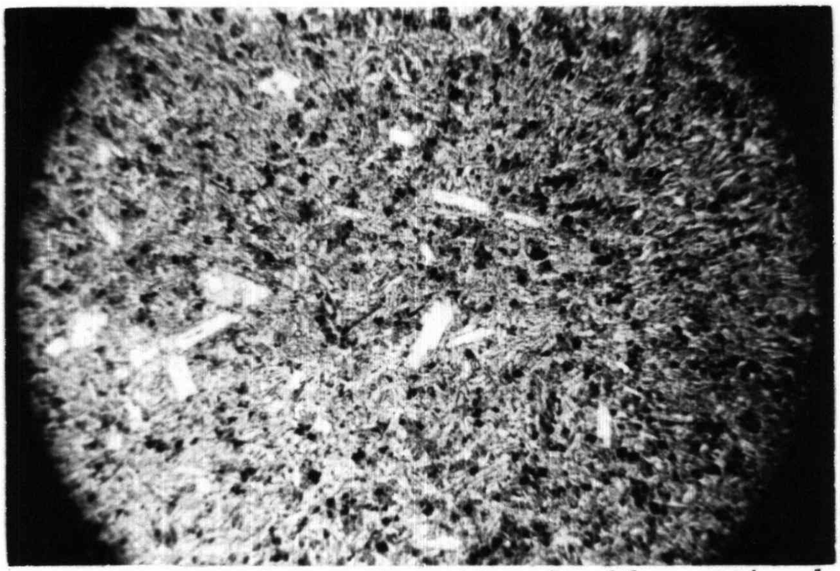


Figure 40. Photomicrograph, weathered basalt with occasional phenocrysts, Columbia River Group, Scofield Surface. (Locality 53.)

1 mm

The most probable explanation of these relationships is that the dikes of basalt in the quarries on the Scofield Surface are feeders to lava flows similar to those mentioned by Warren and Norbisrath (1946, p. 233) in their description of the area to the north, while the patches of basalt and the brick-red soils and cobbles on the Scofield Surface are remnants of flows which were derived from the feeder dikes. A problem exists when we consider that Columbia River Group rests upon topography carved in the Scappoose Formation east of the Scofield Surface, whereas the flows on the Scofield Surface rested upon the Pittsburg Bluff Formation.

Two explanations might account for this. It is possible that the flow, or flows, on the Scofield Surface are older than the Scappoose Formation. Warren and Norbisrath believed that there was a period of uplift and erosion prior to the deposition of the Scappoose Formation upon the Pittsburg Bluff (1946, p. 232). The basal conglomerate which rests on the Pittsburg Bluff Formation along the S. P. and S. Railroad, north of Buxton, would seem to sustain this interpretation (see page 73, this report).

Comparison of petrographic analyses of cobbles from the conglomerate at the base of the Scappoose Formation along the S. P. and S. Railroad, north of Buxton (sample 283, Figure 41 and Table 16, Appendix D) and cobbles on the Scofield Surface indicate that the two basalts are identical. The texture and mineral composition are also

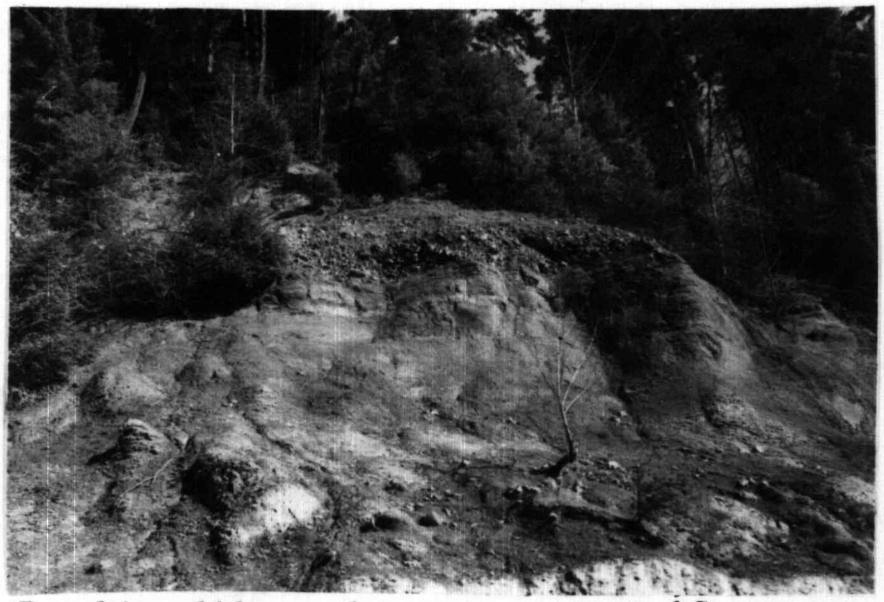


Figure 41. Basaltic cobble conglomerate, contact of Scappoose Formation with underlying Pittsburg Bluff Formation, S. P. and S. R. R., 2 miles north of Buxton.

very close to those of the basalts of the Columbia River Group (see Figure 24).

No angular discordance between the Pittsburg Bluff and the overlying Scappoose Formation is apparent along the S. P. and S. Railroad. The possibility of derivation of the basal conglomerate from the basaltic flows on the Scofield Surface is a very attractive explanation. In this case the basalts on the Scofield Surface would not be equivalent to those of the Columbia River Group but would be local.

A second explanation can be advanced to account for the fact that basaltic lavas which seem to be lithologically equivalent to the Columbia River Group rest on sedimentary strata of two different formations. Warren and Norbisrath believed that uplift and a long period of erosion followed the deposition of the sediments of the Scappoose Formation (1946, p. 232). North and east of Vernonia, and southwest of Buxton the Columbia River Group rests directly upon the Pittsburg Bluff Formation and the younger Scappoose Formation is absent. Throughout the upper Nehalem River basin the thickness of the Scappoose Formation varies widely, from total absence to as much as 1,500 feet. If a period of erosion preceded eruption of the basalts then the lava on the Scofield Surface would be truly equivalent to the Columbia River Group and would be present because the area of Scofield stood as a topographic high during the extrusion of the earlier flows of Columbia River lava. Subsequent weathering and erosion has allowed almost complete removal of this basaltic cover from the Scofield Surface. The very gentle topography there, contrasting markedly with the rugged ravine-laced regions to the north, west and east, is the result of protection of this surface from vigorous down-cutting by streams by the resistant basalt cap.

In view of the great variations in thickness of the Scappoose Formation and its absence in a number of localities the second of these explanations would seem to be the most probable.

PETROLOGY

Methods

Sampling

Altogether 399 samples were taken, many of which represent systematic sampling of nearly continuous sequences of sedimentation. Distribution of these samples by locality is shown in Plate I. Type localities of the Keasey and Pittsburg Bluff Formations, as described by Schenck (1928, p. 36-37), and the Scappoose Formation, as described by Warren and Norbisrath (1946, p. 231), were sampled so that comparisons of rocks in these areas could be made with those cropping out in the area of the present study. The "type localities," of the members of the Cowlitz Formation, described by Warren and Norbisrath, are in the area of the present study, although none of these are the type localities *sensu strictu* of the Cowlitz Formation, described by Weaver in 1912 (p. 13) and 1937, and redefined by Henricksen (1956, p. 35).

Where continuous sequences of beds are well enough exposed each bed of the sequence was sampled. The most detailed sampling of this sort was done in the mudstone member of the Cowlitz Formation where it is exposed upstream along the Nehalem River from the bridge on the Sunset Highway. Complete lists of analyzed samples by formation and locality are given in Appendix C.

Sample Preparation

Preparation for mineralogical and textural analyses was started by breaking whole rock samples in a jaw crusher. If the rock was obviously sandy, a 50 gm split was weighed for disaggregation; if the rock was a siltstone or mudstone, a 100 gm split was separated and weighed. Claystones selected for clay mineral analyses were not weighed. Moisture percentages of the total rock were determined on separate weighed samples and weight corrections made accordingly in the split to be disaggregated. Rocks with carbonate cement were digested in dilute HCl (1:8) overnight at room temperature and the residue washed free of acid without loss of material. No clay mineral analyses were done on samples which had been treated with HCl.

Disaggregation of rocks with such high percentages of fine silt and clay is very difficult to accomplish. As pointed out by Folk (1968, p. 18), in disaggregation of silt and clay fractions of the rock one cannot place too much credence in the amounts of each of the size classes so obtained as these will depend more upon the effectiveness of the method of separation of constituent particles than upon the original size distribution of the detritus. Accordingly, except for sandstones with little matrix and cement, fine-grained mudstones were only separated into three size classes: sand (greater than 62μ), silt (62 to 4μ), and clay (less than 4μ), using the Wentworth (Pettijohn, 1957, p. 19) size classification. To accomplish this, the crushed rock was first placed in a drink mixer cup (fitted with baffles) with distilled water and 15 to 20 ml of Calgon (sodium hexametaphosphate) and stirred for 8 minutes. The sediment slurry was then wet-sieved through a 61μ sieve and all washings were caught in an 8 inch evaporating dish under the sieve. By judicious use of a strong spray, a minimum of water was used and the total volume of washings could generally be kept to less than 2 liters so that reduction to 1 liter for pipette analysis of silt and clay would not be too time consuming.

After initial wet sieving, the sand-sized fraction was placed in a 250 ml beaker with about 150 ml of distilled water and 15 to 20 ml of Calgon and cleaned with ultrahigh frequency sound (20,000 cps) in a Biosonic cleaner which utilized a metal probe, giving a very high intensity of vibration. Samples were simultaneously stirred with a magnetic stirrer to keep the sediment in suspension and to allow a maximum of vibration to reach each grain. Following 5 minutes of sonic cleaning, the sand fraction and suspended fines were re-sieved through a 61μ sieve and the washings caught and added to previous material less than 61μ.

Very friable sandstones could be disaggregated and sand-sized grains cleaned free of adhering clay with one or two such treatments.

Sandstones with much clay matrix and all siltstones had to be run through as many as five cycles of sonic cleaning and sieving before sand grains came out cleaned of clay. Ten treatments were necessary only rarely.

This procedure of disaggregation has been described in detail because of the success which was obtained with it. Mudrocks (such as the majority of those involved in this study) have undoubtedly been so infrequently studied in detail because of difficulties encountered in getting clean separation of components. It was found in this study that it is possible to effectively separate clean grains of medium silt-sized material if one persists in the sequence of treatment described above.

A total of 122 rock specimens were thus disaggregated and analyzed for mineral composition. Of these, 94 were selected for textural analyses. If a rock had more than 1/3 sand-sized material by weight, the sand fraction, after drying, was sieved using Tyler A. S. T. M. Standard sieves with a size interval of $1/4\phi$ and a Rotap machine. The amount of silt and clay-size material was determined by pipette analysis, using methods and sedimentation times outlined by Folk (1968, p. 37-40).

The volume of the less than 62μ fraction was reduced to less than 1 liter either by letting the suspension settle and flocculate and then drawing off the clear supernatant, using a J-shaped tube attached to an aspirator, or by using a Mandler filter candle attached to an aspirator. The silt- and clay-size fractions were stored in tightly capped quart jars for further treatment.

Following withdrawal of 20 ml aliquot determination of the amount of clay-sized material present (less than 4μ) and withdrawal of a 50 ml aliquot to be used for X-ray determination of clay-minerals present, the suspension and the sedimented portion were washed through a 38μ sieve. The sediment caught on the sieve was subsequently dried and weighed and stored for further study of the components of the coarse silt fraction. The amount of silt (62 to 4μ) was determined by subtraction of the weight of clay and sand from the total weight.

Thin sections were cut and analyzed, mainly for textural relationships, but also to check results of mineralogical analyses of disaggregated components. Generally, it was found that disaggregation, microscopic and X-ray study of minerals and other components were more successful and reliable than thin section determination of components, chiefly because of the high ratio of matrix to framework grains in these mudrocks. A few of the "cleaner" sandstones were just as easily studied in thin section. Thin sections were cut of all rocks containing volcanic rock fragments because of the susceptibility of the rock components to destruction during the disaggregation treatments. It is noted in Appendix C whether determination of components and texture were made in thin section or from disaggregated material.

Mineral Separation

Accessory minerals were separated from major constituents by centrifuging with tetrabromoethane (Sp. G. 2.96 at 20°), according to methods suggested by Rittenhouse and Bertholf (1942, p. 85-89). Except for a few sandstones the heavy minerals were separated from the total size fraction greater than 43μ. With such fine material, no method other than that using the centrifuge was feasible. An attempt was made to further fractionate the heavy minerals by use of a Frantz magnetic separator, but this proved impractical because of the fineness of the grains. Too much material hangs up in the chutes due to electrostatic charges on the grains and the machine.

Light Minerals

Two splits of the light fraction were mounted on slides in Lakeside 70; one of these was covered, the other was polished with 400 grit to expose the grains. Subsequently the uncovered mounts were etched using modification of a method described by Bailey and Stevens (1960, p. 1020 - 1025). It will be useful to report here upon some of the techniques that are necessary to ensure reliable results, since it was found through painful experience that different types of sedimentary material respond in slightly different manners to the acid etching and the staining techniques suggested by various workers. The type of feldspar, the condition with respect to weathering and/or deuteric alteration, the grain size and probably the orientation of the feldspar grains--all influence the effectiveness of staining. Methods suggested for rock slabs are not suitable for grains or for sedimentary rock thin section with much matrix. In the latter case, the matrix also responds to the stain and obscures mineral grains. It was found that little difficulty in staining potash feldspar grains was encountered, providing the time of etching in fumes of hydrofloric acid is at least 30 seconds. Etching times of up to 60 seconds were sometimes necessary, especially with fresh feldspar. The problems in staining detrital feldspars arise with the plagioclase grains. The critical step in the plagioclase staining procedure is the replacement of Ca by Ba in the barium chloride solution. At least 10 percent solution must be used and in many cases a saturated solution of $BaCl_2$ is more satisfactory. Immersion of the slide being stained should be for at least 20 seconds and no longer than 40 seconds. Longer periods in the barium chloride solution tend to remove the color of the potash stain (canary yellow) from the K-spar grains. Bailey and Stevens suggest the use of potassium rhodizonate (1960, p. 1022) for the plagioclase stain. It was found that the rhodizonate stain invaded the stained potash feldspar grains also and masked the canary yellow color imparted to them. A more satisfactory method involved the use of amaranth, which is the material of ordinary red food coloring, as suggested by Laniz and others (1964, p. B152). This method of staining plagioclase was very successful and time of immersion in the amaranth was not found to be critical. Periods of up to 3 minutes can be used, if necessary.

The covered grain mount slides of both the heavy and the light mineral fractions were examined with the petrographic microscope, using both transmitted and reflected light. In the light mineral fraction types of quartz, volcanic and metamorphic rocks, composite grains, and other debris were identified and an estimate of their relative abundance noted. Chert, chalcedony and types of silica other than quartz were noted. Species of feldspar were determined, using indices of refraction, or extinction angles on polysynthetic twins. Volcanic glass was identified by isotropism and morphology. In the case of samples with appreciable numbers of rock fragments, thin sectioning had to be resorted to in order to ascertain the variety of rocks.

Relative percentages of light minerals were determined by line counting of 300 to 500 grains. A few counts of 200 grains were made. Lines of count were spaced 2 mm apart so that traverses counted would cover the entire mount. The number of grains counted depended upon their abundance in the mount.

Heavy Minerals

Using a microsplitter, a sample was taken from the heavy mineral fraction and was mounted in Lakeside 70 on slides. The mount was examined to identify all heavy minerals present, both opaque and non-opaque, and an estimate of abundance was made. Varieties of different mineral species and any other distinctive characters were observed and recorded.

Selective sorting of mineral grains, especially heavies, takes place according to size, shape and specific gravity of individual grains of different mineral species (Pettijohn, 1957, p. 561; Krumbein and Pettijohn, 1937, p. 474). Accordingly, it was felt that mounting a split of the heavy minerals greater than 43μ in size would tend to minimize variations caused by hydraulic factors operating on the aforementioned grain properties. Van Andel (1959, p. 156) points out that

> while a test of grain size control is always necessary, it may be concluded that only rarely will this factor seriously impair the interpretation of heavy mineral distributions in terms of source areas and source area characteristics.

He further mentions, in support of this, the lack of difference of heavy mineral content between sandy and clayey deposits of the

Mississippi River delta.

Initial, cursory examination of heavy minerals from the Tertiary strata of the upper Nehalem River basin revealed that three distinct assemblages or suites appeared to be present. It was decided that ranking heavy minerals according to certain pre-set abundance categories would as readily reveal the relative prominence of the three assemblages, the volcanic, the igneous plutonic and the metamorphic, as would detailed grain counts. Griffiths (1967, p. 214) has pointed out that assemblages are most commonly of greater significance than individual species. The errors inherent in sampling, splitting and counting are reviewed by Griffiths (p. 213), just as they have been so discussed by many others (Milner, 1962, p. 389; Folk, 1968, p. 99; Krumbein and Pettijohn, 1938, p. 469-473). Milner, quoting F. Smithson (1964, p. 389), points out that

> so long as a petrologist always employs the same procedure it is probably safe for him to compare his estimates one with another. But if he changes his methods or compares his estimates with those of petrologists who use different methods of operation, erroneous conclusions may easily result.

Since no other published heavy mineral analyses of these Tertiary strata in northwest Oregon exist the problem of comparison does not arise in this present work.

In the present heavy mineral studies the abundance ranking chosen was as follows:

Rank	Value (percentage of total grains)
1	greater than 50 percent
2	25 to 5 percent
3	5 to 1 percent
4	less than 1 percent
5	trace (only one or two grains detected)

The last rank represents an actual count since a mineral would fall into this class if no more than one or two grains were seen in examination of the entire heavy mineral mount. After placing the minerals in their proper abundance rank by visual estimate the frequency of each abundance rank for each mineral was calculated in terms of percentage of samples of a given formation. The results of these calculations are given in Table 8 and Figure 59.

Description of Minerals

Quartz

Monocrystalline

Clear. Single crystal fragments, without inclusions. With less than 5^{o} variation in extinction position ("non-undulose.") Always angular to subangular, anhedral, more or less equant.

Clear, Undulose. As above, except indefinite extinction position.

With Inclusions. Single crystal fragments, with liquid inclusions, rod-shaped microlites (apatite, tourmaline, rutile) scattered or aligned (e. g. "bubble-trains"), non-undulose extinction, angular to subangular, equant, anhedral, always with very few inclusions. Folk (1968, p. 71) regards monocrystalline anhedral quartz as derived from plutonic source rocks, either granitic or gneissic but Blatt (1967, p. 1039) points out that in medium- and fine-grained sand-sized quartz, an igneous or metamorphic source is not distinguishable since these small grains are probably derived from larger monocrystalline or polycrystalline grains by chipping. In the present study, quartz of this type, which is always the most abundant (85-90 percent) of all quartz present in the silt to sand-sized fractions, will be interpreted as coming from plutonic rocks, meaning granitic or gneissic.

Clear, Non-undulose, Euhedral. Single crystals or the major part of a single crystal. Folk (1968, p. 70-71) regards this type of quartz as of volcanic origin. This is exceedingly rare in these Tertiary sediments, but has been found. (See Table 4.)

Polycrystalline

Macrocrystalline, Non-undulose. Composite grains with straight grain-boundaries, equant grains, no cement. Folk (1968, p. 72) regards this as recrystallized metamorphic quartz.

Macrocrystalline, Undulose. Composite grains with sutured to indefinite grain-boundaries, "stretched" grains with strongly undulose (indefinite) extinction, often sutured grain-boundaries.

Cryptocrystalline

Fibrous. Chalcedony, may be brownish or colorless. This is quite rare.

Granular. Chert; counted with rock fragments.

Feldspar

Plagioclase

Plagioclase feldspar ranges from albite (rare) to labradorite, with 60 to 70 percent falling in the oligoclase-andesine range. Zoning is common, especially where volcanic glass and volcanic rock fragments are also present. Much of the plagioclase is quite unaltered, but some clay alteration is commonly present. Twinning is generally the albite type, although pericline twinning is seen. Although present in only one sample, potassic oligoclase is found in the Scappoose Formation. Barth (1969, p. 44) remarks about this type of plagioclase, which can have up to 35 percent $KAlSi_3O_8$ and is, according to him, well known.

Potash-Feldspar

Potassium feldspars include microcline, identified by characteristic "grid" twinning and index of refraction lower than 1.54, and orthoclase, simple twins or untwinned with index of refraction lower than 1.54. Some sanidine is present in several samples, but it is rare. Staining was used to differentiate K-feldspar from plagioclase so that relative percentages of orthoclase and microcline were not determined. Their presence was merely noted in thin section or grain mount. Potash feldspar is present in considerable amounts in all rocks sampled, with the exception of one or two volcanic sandstones. In a number of rocks, potash feldspar is equal in amount or exceeds plagioclase feldspar, especially in the Cowlitz Formation and the Scappoose Formation.

Mica

Muscovite and biotite, both green and brown, are ubiquitous. In some rocks their abundance is noteworthy but in most, the total was between 1 and 10 percent. The Cowlitz Formation is the only one with mica exceeding 10 percent and most such rocks are the arenites.

Chlorite

Large flakes of green detrital chlorite are commonly present, though rarely abundant enough to warrant counting. They are recognized by their extremely low birefringence.

Rock Fragments

Rock fragments are nearly always present, even in the fine sand-sized fractions. Volcanic porphyries are more abundant than all other types of rocks combined, with the basaltic to andesitic types being the most common. The andesitic or dacitic types are commonly vitrophyric. Strong oxidation of the glassy groundmass of basalt fragments produces a red-brown matrix in which the phenocrysts are often unaltered.

Chert

Cryptocrystalline silica in the form of chert is common in most samples. This is recognized by the fine mosaic texture evident between crossed polars.

Microgranitic

Composite grains made up of quartz and feldspar are found in many samples of all formations, but are much more common in the sandstones of the Cowlitz Formation. Types of rocks present include granitic, dioritic and doleritic types.

Metamorphic Rocks

Phyllitic and schistose rock fragments consisting of foliated mica and quartz are found in some sandstones. Metaquartzites with "stretched" and sutured quartz grains are fairly common. Amphibole fragments are found in one or two samples.

Sedimentary Rocks

Since some lumps of undisaggregated rock are always present, it is not possible to differentiate true detrital sedimentary rock fragments from those parts of the rock being analyzed.

Glauconite

Dark green furrowed pellets of glauconite are present in many of these sediments. In a few sandstones glauconite may account for as much as 65 to 70 percent of the sand-sized fraction. In addition to the furrowed pellets, dark green lumps are also noted and regarded as glauconite. In some cases these could be nontronite, which is common as an alteration product of some of the volcanic rock fragments. Glauconite is more widely present in the Pittsburg

Bluff Formation than in any other of the Tertiary sediments of this area. In that formation it constitutes not much more than 1 percent, except in the sandstones of the lower part. Since the glauconite pellets are soft, it is probable that some are lost in the disaggregation process and therefore it may be present in the grain mounts studied in amounts less than that originally present in the rock. Most thin sections of the Pittsburg Bluff Formation showed glauconite present.

Heavy Minerals

Minerals with specific gravity greater than 2.96 (Tetrabromoethane) constitute from as little as 0.01 weight percent to as much as 7 weight percent of the sediments of the upper Nehalem River basin. The average heavy mineral percentage is around 1.0 percent.

The relative abundance of different species of heavy minerals varies markedly from one formation to another and from one part of a formation to another. Although allowance generally needs to be made for the hydraulic factor (Folk, 1968, p. 89) when considering relative abundance of heavy minerals, lack of any consistent lateral correlation between outcrops makes such a determination unnecessary in this present study.

The minerals described below are considered in order of general over-all abundance. Interpretation with respect to relative abundance of different species is given under the discussion of the lithology of each separate formation.

Amphiboles

Green to yellow-green or yellow-brown pleochroic hornblende, sometimes etched, is the most common amphibole. Deer and others (1963, p. 307) interpret blue-green hornblende as coming from a metamorphic source. Basaltic hornblende (oxyhornblende or lamprobolite) is characterized by its deep red-brown to brown pleochroism and small extinction angle. Occasionally colorless hornblende is found. Common hornblende is regarded as acidic to intermediate plutonic or metamorphic in origin. Basaltic hornblende comes from mafic igneous rocks (Blatt, 1967, p. 1037). Other amphiboles include tremolite, actinolite, and glaucophane, with tremolite by far the most common of the three. These minerals are certainly from metamorphic source rocks. Although glaucophane and actinolite might be considered to occur in a different facies (blueschist or greenschist) than tremolite it is probable that no such fine distinction can be drawn (Deer and others, 1966, p. 165-166).

Pyroxene

Augite is the commonest pyroxene and is easily recognized by its large extinction angle, high interference colors and lack of pleochroism. Gray-green types are the most common. It is among the commonest heavy minerals of some beds but rare in others. Hypersthene is the next commonest pyroxene. It is recognized by its parallel extinction, low order interference colors and, generally, strong pleochroism. Grains of either hypersthene or augite may be deeply etched, leaving only spinose fragments. Both minerals are commonly found as subrounded, subhedral prisms, although this is more common in hypersthene. Enstatite, diopside and hedenbergite are found rarely so that their identification, dependent as it is upon one or two grains, is never without question.

Augite is derived from mafic igneous rocks in general while hypersthene may come from andesitic to basaltic igneous rocks. Enstatite would be derived from ultramafic igneous rocks and the diopside-hedenbergite series minerals can be derived from either calcareous metamorphic assemblages or from some basaltic types of igneous rocks (Deer and others, 1966, p. 117, 119).

Epidote Group Minerals

Of the epidotes, yellow-green epidote is the most common. It is frequently accompanied by zoisite and clinozoisite. Epidote grains are generally all polycrystalline grains. Occasionally, the purplish manganese epidote, piedmontite, is found. In one sample, another form of zoisite, termed "beta zoisite" (Tröger, 139b, 1959,

p. 39) is encountered.

Sources for the epidote group of minerals include metamorphic rocks of the threshold between the greenschist facies and the epidote-amphibolite facies, and deuterically altered basic and intermediate igneous rocks. Deer and others (1966, p. 67) state that piedmontite is characteristic of lower grade metamorphics such as glaucophane schists and greenschists proper.

Sphene

Sphene occurs as pale to deep yellow or honey-colored anhedral grains (and, rarely, colorless grains) and chips which range from angular to well-rounded, with occasional euhedral crystals. It may be surprisingly common. In some beds of the Cowlitz Formation, sphene may be one of the most abundant two or three mineral species.

Notable abundance of sphene is usually regarded as indicative of authigenic origin (Milner, 1962, p. 192, vol. 2) but in that case most of the grains should be euhedral. Occurrences of large amounts of sphene in the Paso Robles Formation (Pliocene), California, are explained by Galehouse (1967, p. 960) as simply the contributions of heavy minerals from adjacent plutonic rocks which have very high percentages of sphene in their accessory mineral fractions. Sphene in amounts up to 60 percent was found in

Cretaceous rocks of the Sacramento Valley, California, by Ojakangas (1964, p. 79) and was regarded as derived from plutonic source rocks of the Yosemite region of the Sierra Nevada Mountains.

Thus high percentages of sphene do not necessarily require that the mineral be of authigenic origin. Sphene is generally considered to be most common in acid to intermediate plutonic igneous rocks, although it may be derived from calc-silicate metamorphics and from some gneisses and schists (Deer and others, 1966, p. 20).

Zircon

Several different types of zircon are found. The most common are euhedra, broken prisms and some doubly terminated prisms showing either a simple first order tetragonal dipyramid termination, or occasionally, combinations of first and second order tetragonal dipyramids. Generally these euhedra are free of inclusions. The most striking thing about the euhedra is the length-width ratio. Ordinarily this ranges from about 2:1 to 5:1 in plutonic rocks (Poldevaart, 1954, p. 535). Most zircon crystals found in these Tertiary sediments fall within this range. But in a number of the sandstones, siltstones and mudstones of the Cowlitz Formation, acicular zircon crystals are found with length-width ratios of from 6:1 to as high as 13:1 (see Figure 42). There seem to be few reports of such long crystals in the literature on zircons excepting

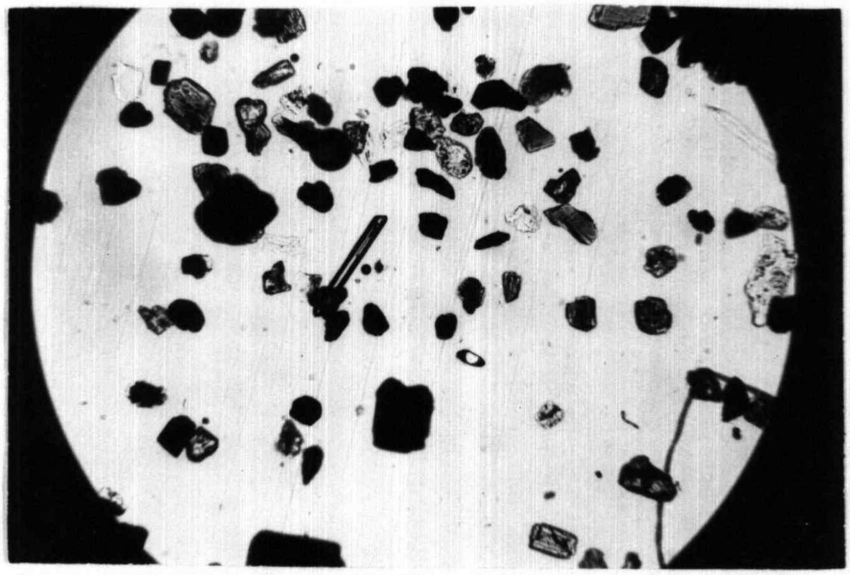


Figure 42. Photomicrograph, acicular zircon (center) in heavy minerals of mudstone member, Cowlitz Formation.

0.5 mm

some of Taubeneck's work on the Bald Mountain Batholith (1957, p. 214-221) in which length-width ratios of 8:1 and 9:1 are noted and in the Pend Oreille tonalite, where Poldevaart reports length-width ratios up to 32:1.

Generally euhedra of zircon are considered to be derived from acid to intermediate plutonic source rocks (Krumbein and Sloss, 1963, p. 140). In a few samples, however, euhedra of zircon were found with adhering volcanic glass which proves a volcanic (pyroclastic) source. Folk (1968, p. 97) also mentions euhedra of zircon as being indicative of a volcanic source. It is possible that most of the zircon crystals in sediments which have volcanic detritus are of volcanic origin. It is possible also that authigenesis is responsible for some of the euhedral zircons, as also suggested by Folk. This could explain the acicular types of zircon with very large length-width ratios.

Beside perfectly euhedral zircons subangular to very well rounded grains are found. These are commonly present with euhedra and indicate a reworking of older sedimentary rocks. Colors of zircons include colorless (most common), pale yellow, pale pink, rose, and lavender. Some worn grains may be dusky brown or tan. The grains most well-rounded are generally pink.

Apatite

Although not commonly abundant, apatite is present in nearly all the rocks of this area. Euhedra, generally colorless, are often seen but subrounded to rounded prisms and broken crystals are most common. Beside colorless grains, dusky gray and yellow are also common. Some pleochroic apatite is found, but is quite rare. Etched grains are present occasionally. Baker (1941, p. 388) states that the dusky types of apatite are derived from a volcanic source. Otherwise apatite is generally considered to indicate acid to basic igneous source rocks. The most well-rounded grains probably come from pre-existing sedimentary rocks.

Tourmaline

Strongly pleochroic brown, yellow, green and pink grains of tourmaline are as common as apatite. The green tourmalines predominate and are generally broken euhedral prisms. Most grains exhibit only slight rounding and some are quite angular, apparently a function of the extreme durability of tourmaline, as pointed out by Folk (1968, p. 97). Although nearly always present with zircon, some of which is commonly very well-rounded, tourmaline is from a strictly volcanic provenance, along with euhedral zircon, while the rounded zircons come from sedimentary rocks which were poor in tourmaline.

Garnet

Garnets, like zircon, apatite and tourmaline, are present in nearly all these sediments. They are generally present as angular to subangular chips which may be colorless, pink, yellow or rose colored. Occasional dodecahedra are seen, generally of the pink variety. In sandstones of the Scappoose Formation, pink chips of garnet up to 0.3 mm in size are found. Although garnets are present in many plutonic igneous rocks, they are especially common in schists, gneisses and metamorphosed carbonate rocks.

Alumino-silicates

Kyanite, staurolite and andalusite are found in trace amounts (two or three grains) in a number of the sediments of the upper Nehalem River basin. They are always angular to subangular which suggests that they are of first cycle derivation, coming from metamorphosed pelitic sedimentary rocks, such as schists. Kyanite generally indicates a higher grade of metamorphism than does andalusite or staurolite and all may be formed in contact aureoles around igneous intrusions as well as in regionally metamorphosed argillaceous rocks (Deer and others, 1966, p. 40, 44).

Rutile

Deep brown to red brown elongate prisms and broken euhedra of rutile are often present in trace amounts (two or three grains), although in a few rocks rutile may be more noticeable. One geniculate twin of rutile was observed in the sandstones of the middle part of the Cowlitz Formation. Although not abundant, rutile is widely distributed in most of these sediments of the upper Nehalem River basin. One grain of brookite, the orthorhombic polymorph of TiO_2, was identified in siltstone of the lower part of the Keasey Formation.

Deer and others (1966, p. 417) state that rutile is widely distributed in plutonic igneous rocks. It is also found in some metamorphic rocks and may be formed authigenically in the diagenesis of argillaceous sediments. Because of its rather widespread occurrence in rocks of many types, rutile is probably not too useful as an indicator of provenance.

Miscellaneous

Monticellite (related to olivine), $CaMg(SiO_4)$ and idocrase were found in one mudstone of the Cowlitz Formation. Both minerals are found in metamorphosed magnesian carbonate rocks. Their presence in these Tertiary sedimentary rocks is certainly rare, but perhaps indicative of one type of source rock.

Olivine was tentatively identified in several samples but its presence is questionable. It might be expected along with some of the other ferromagnesian rock-forming minerals, but owing to its chemical instability it is considered very rare in sediments (Folk, 1968, p. 97).

Opaque Minerals

Magnetite

Magnetite is generally the most abundant allogenic opaque mineral. It may be present in anhedral fragments or in perfectly euhedral octahedrons.

Ilmenite

In most samples ilmenite could be distinguished by its purplish-black color in reflected light. Ilmenite in the opaque fraction, where determined, may exceed 15 percent. Leucoxene generally always accompanies ilmenite.

Hydrated Iron Oxides ("Limonite," Goethite)

Due to the weathered nature of most rock samples no special note was made of the presence of red-brown oxidized "lumps." Many of these may be thoroughly oxidized basic volcanic rock fragments.

Pyrite

Authigenic pyrite is present in large amounts in the opaque fraction of most of the mudrocks of this region, especially those of the Cowlitz and lower Keasey Formations. The form most commonly seen is fine sand-sized aggregates of octahedral crystals, in discoidal or spheroidal shapes, referred to as "framboidal" (Deer and others, 1966, p. 449). Individual cubes and octahedra are also seen. Occasionally pyrite occurs as inclusions in chlorite, biotite and muscovite, where it is presumed not to be authigenic. Occasionally pyrite occurs filling the tests of foraminifera, such as Plectofrondiculria.

Carbon

Dark brown to black, nearly opaque. Common in many siltstones and mudstones.

Rock Classification and Nomenclature

Folk's (1968, p. 144-152) classification seems to best allow for expression of the provenance, climatic and tectonic factors, mineralogic character, dispersal and factors dependent upon the environment of deposition. This nomenclature provides a relatively simple but thoroughly descriptive name which expresses as many as possible of the criteria used in classifying the rock. The relative merits of sandstone classification, which are legion, have been ably reviewed by Klein (1963). In this review article, Klein pointed out, in conclusion, that in his opinion the classifications of Folk (1954) and Van Andel (1958) recognized the independence of texture and mineralogy by proposing separate terms for grain size, textural maturity, and composition (p. 572). He had previously in the same paper (p. 572) raised some doubts with respect to Folk's choice of end members because of the difficulties connected with distinction between the provenance of different sorts of polycrystalline quartz, the placing of all igneous rock fragments at the arkose pole with feldspar, and the lack of provision for rock fragments of unknown provenance. In the 1968 edition of Folk's "Petrology of Sedimentary Rocks," (p. 120-123) he reviews the evolution of his scheme of classification and points out that he has revised it to provide three ternary diagrams whereby the rock clan (for example, arkose) can be determined by:

1. Neglecting clay matrix, cement, glauconite, micas and so forth and calculating essential components (<u>all</u> types of quartz, metaquartzite, <u>excepting</u> chert) (Q); all single grains of feldspar, plus granite and gneiss (F) and all rock fragments (R) to 100 percent.
2. Recalculating all rock fragments to 100 percent and plotting

on a ternary diagram allowing for sedimentary, volcanic and metamorphic rock fragments at the three poles respectively.

3. Recalculating the sedimentary rock fragments to 100 percent and plotting on a ternary diagram allowing for sandstone-shale, carbonate and chert rock fragments at the three poles respectively.

In this present study Folk's grain-size nomenclature is used (Figure 43) and his classification and nomenclature of sandstones, siltstones and mudstones (Figure 48) have been adopted with one modification. Feldspathic (granitic and gneissic) rock fragments are only found in significant percentages in the Cowlitz Formation sandstones. Here rock fragments include chert, schist, and microgranitic types and virtually no volcanic rock fragments. Of these types, feldspathic rocks make up only a few percent and total rock fragments make up no more than 10 percent (except in one out of 14 samples). In all other formations, feldspathic rock fragments constitute much less than 1 percent of the total sample; the overwhelming majority of rock fragments are vitrophyres and other volcanics. Hence, it was felt that including all rock types under "rock fragments" (R) and not determining relative abundance of each type would not seriously alter the rock name. Classification of rocks of the upper Nehalem River basin is given in Figures 44-47, 50-53.

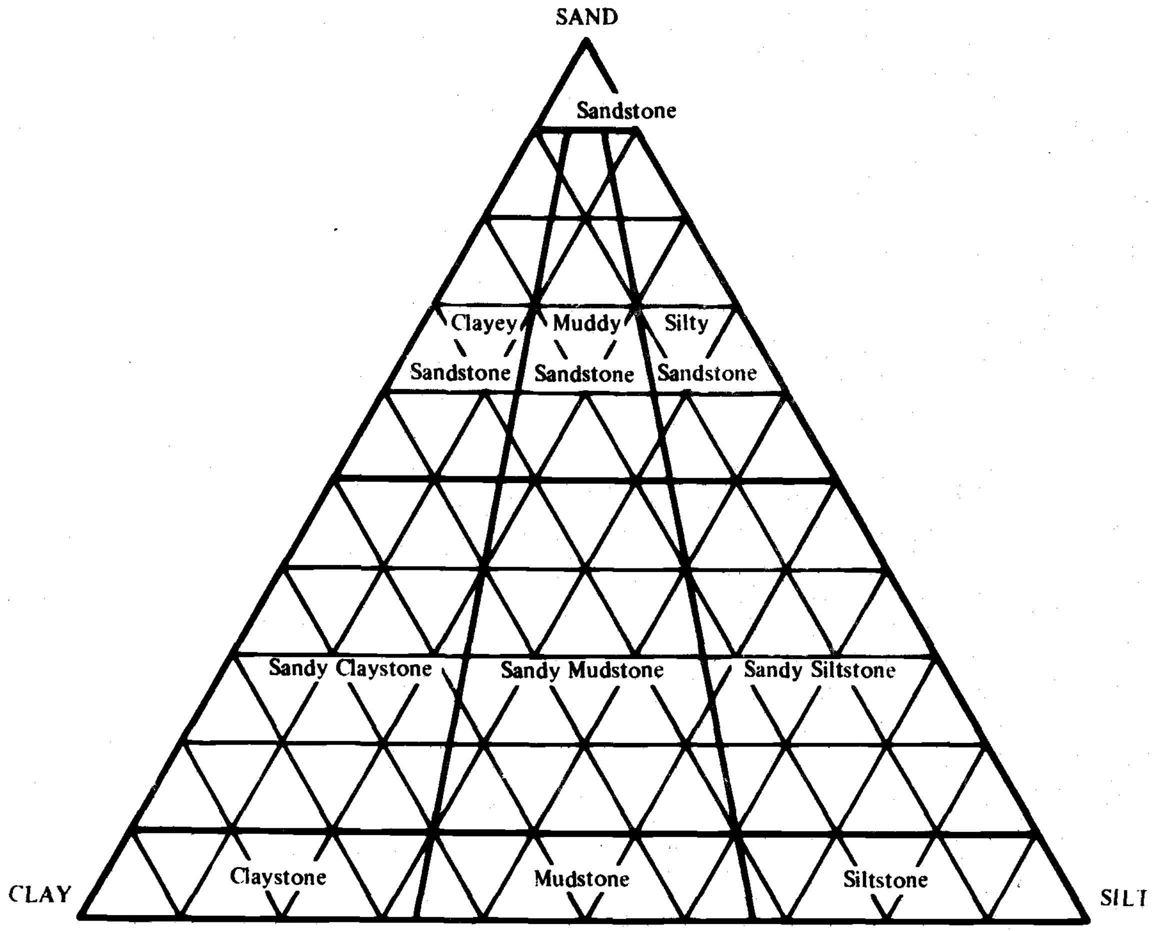


Figure 43. Size classification and nomenclature of clastic rocks (after Folk, 1954)

By way of comparison, if these sediments were to be classified according to Gilbert's scheme (1954, p. 292-293) (Figure 49) they would be termed either arkosic or lithic wackes or arenites, depending upon whether the percentage of matrix (clay and silt) was equal to or was less than 10 percent, respectively. According to Pettijohn's classification (1957, p. 291) the rocks with over 15 percent argillaceous matrix and no cement would be classified as feldspathic graywackes or lithic graywackes, depending upon whether feldspar or rock fragments were dominant. Rocks with less than 15 percent matrix would be either arkose or subgraywackes, dependent upon whether feldspars or rock fragments are predominant.

Sandstones

Sandstones are found in each of the four lower Tertiary formations of the upper Nehalem River basin but are much more common in the lower Cowlitz, the uppermost Pittsburg Bluff and in the Scappoose Formations. In the majority of cases, according to Folk's classification (see Figures 43 and 48), they range from very silty to slightly silty arkose, lithic arkose and some feldspathic volcanic litharenites (see Figures 44, 52 and 53). In the Cowlitz Formation which crops out in the area west of the Nehalem River, light yellowish micaceous arkose beds are about equal in number to

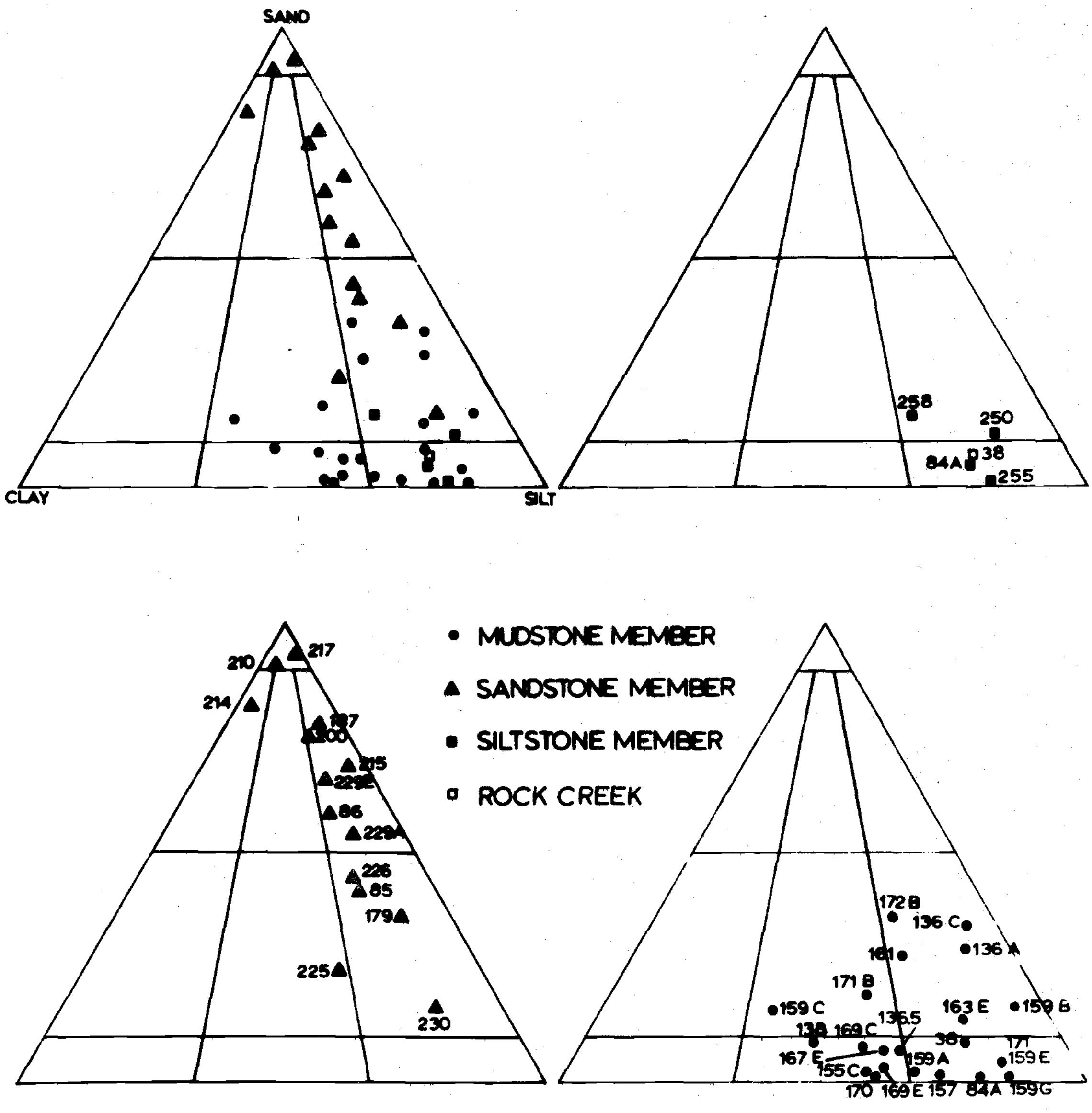


Figure 44. Size classification, Cowlitz Formation clastic rocks (after Folk, 1954).

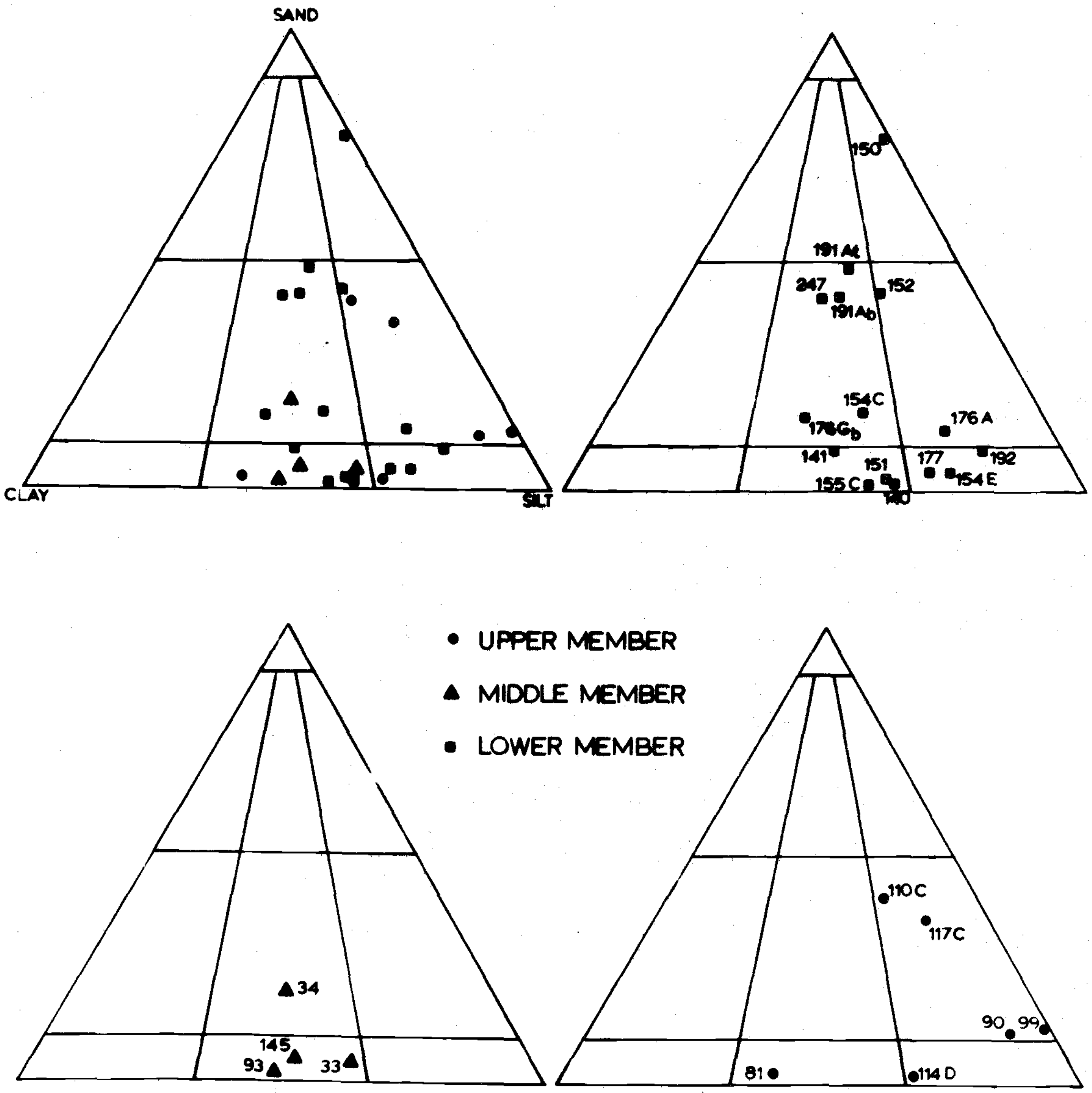


Figure 45. Size classification, Keasey Formation clastic rocks (after Folk, 1954).

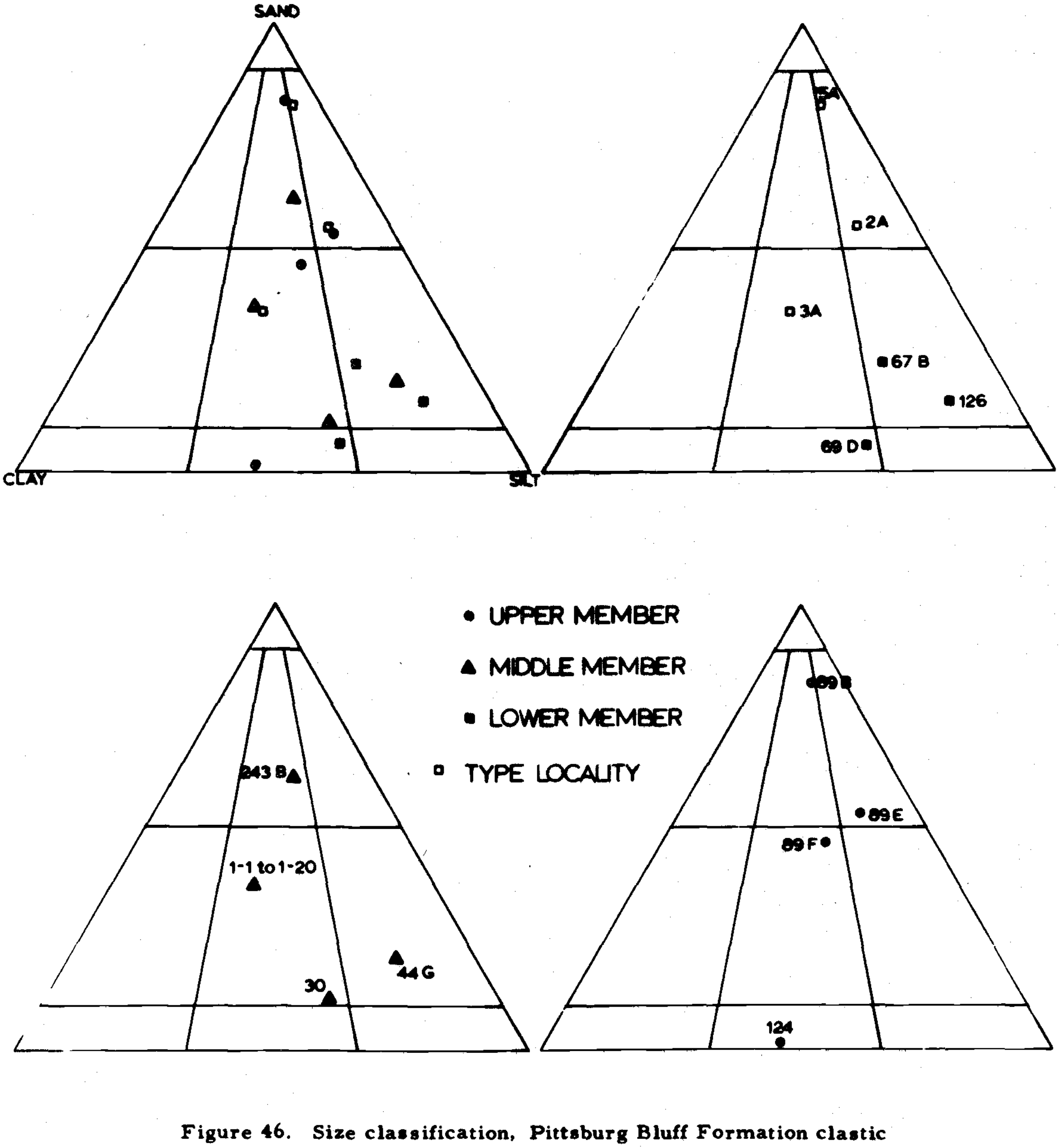


Figure 46. Size classification, Pittsburg Bluff Formation clastic rocks (after Folk, 1954).

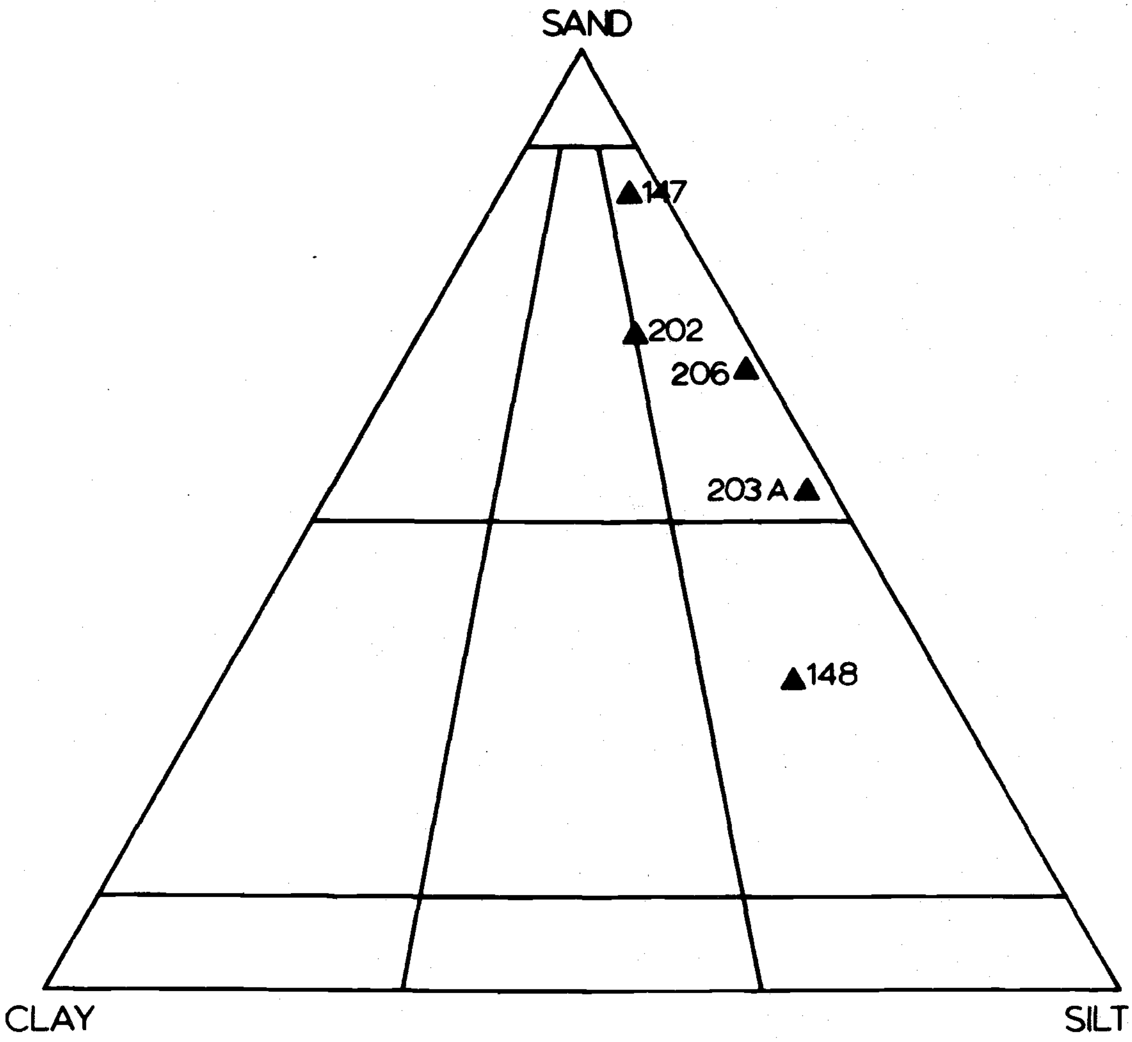


Figure 47. Size classification, Scappoose Formation clastic rocks (after Folk, 1954).

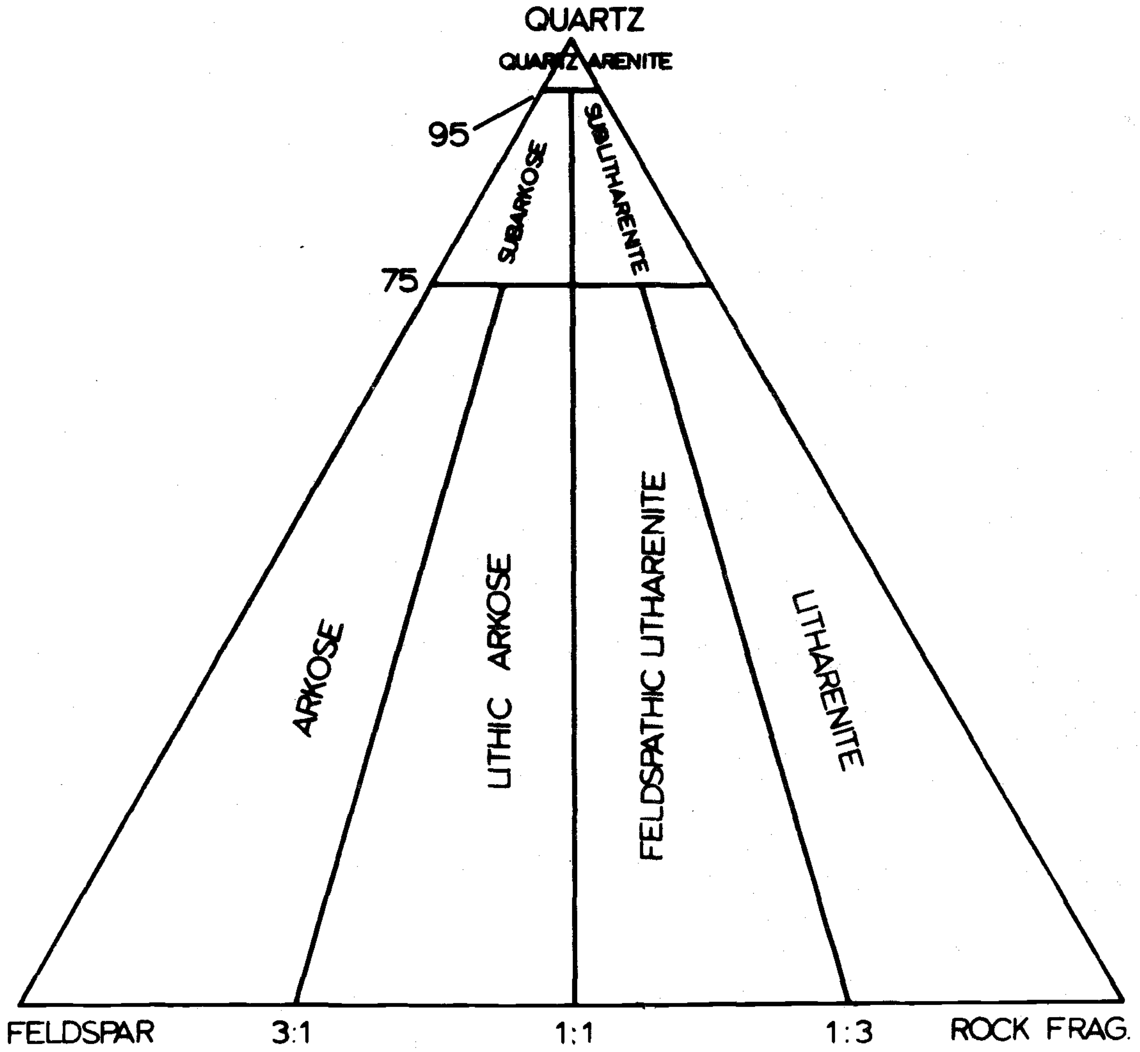


Figure 48. Classification of sandstones according to Folk (1968, p. 124).

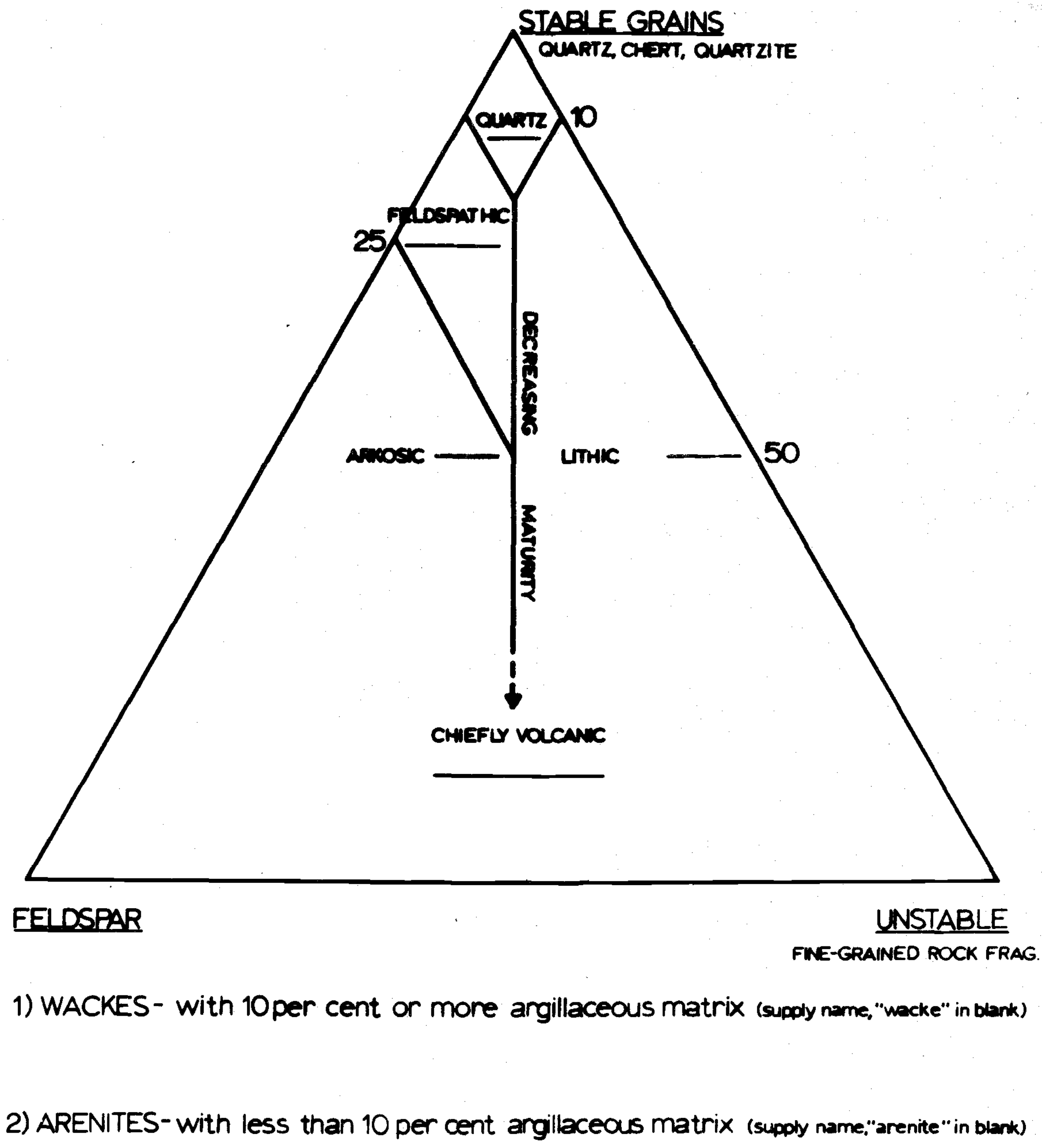


Figure 49. Classification of sandstones according to Gilbert (1954, p. 292).

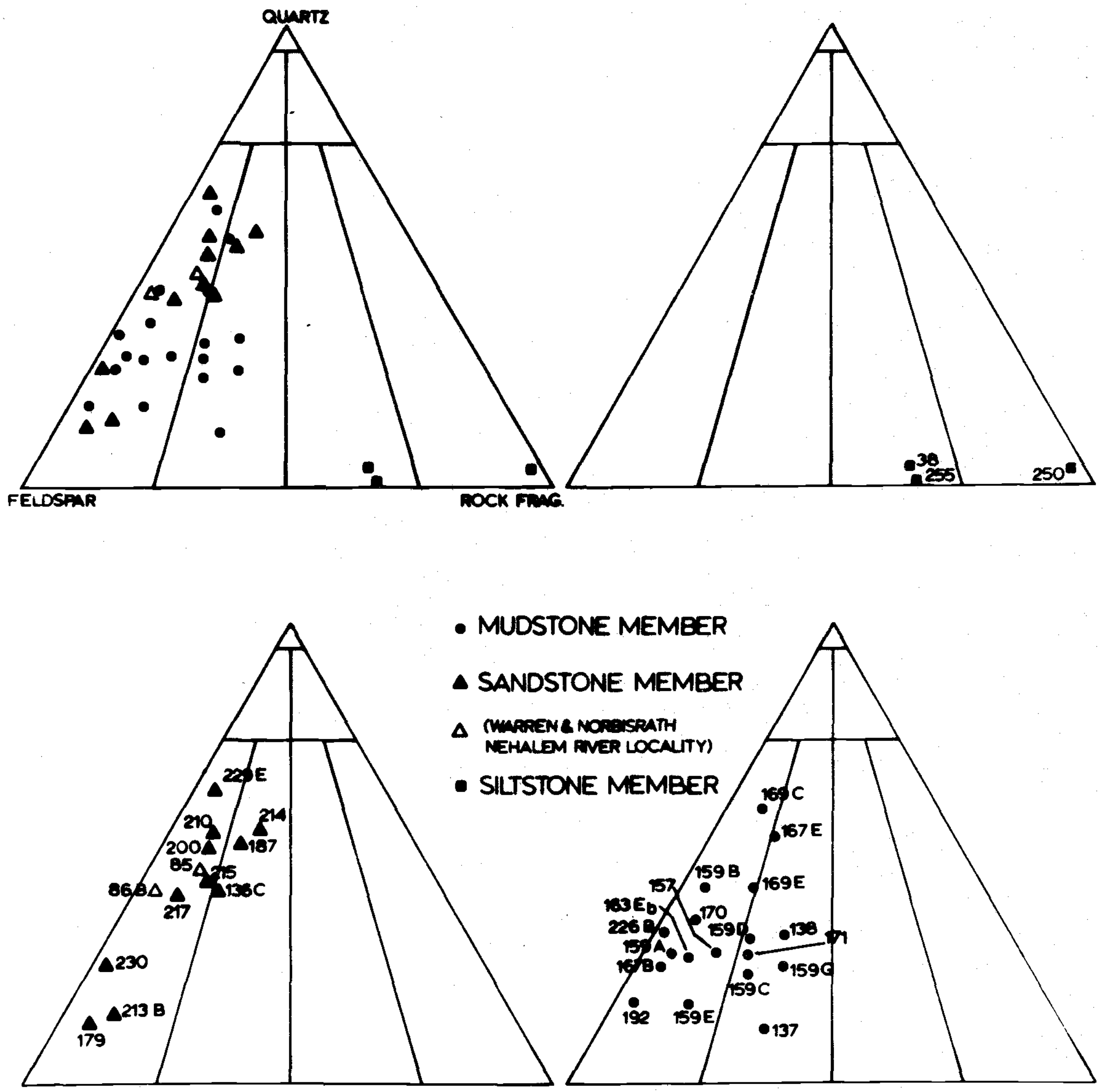
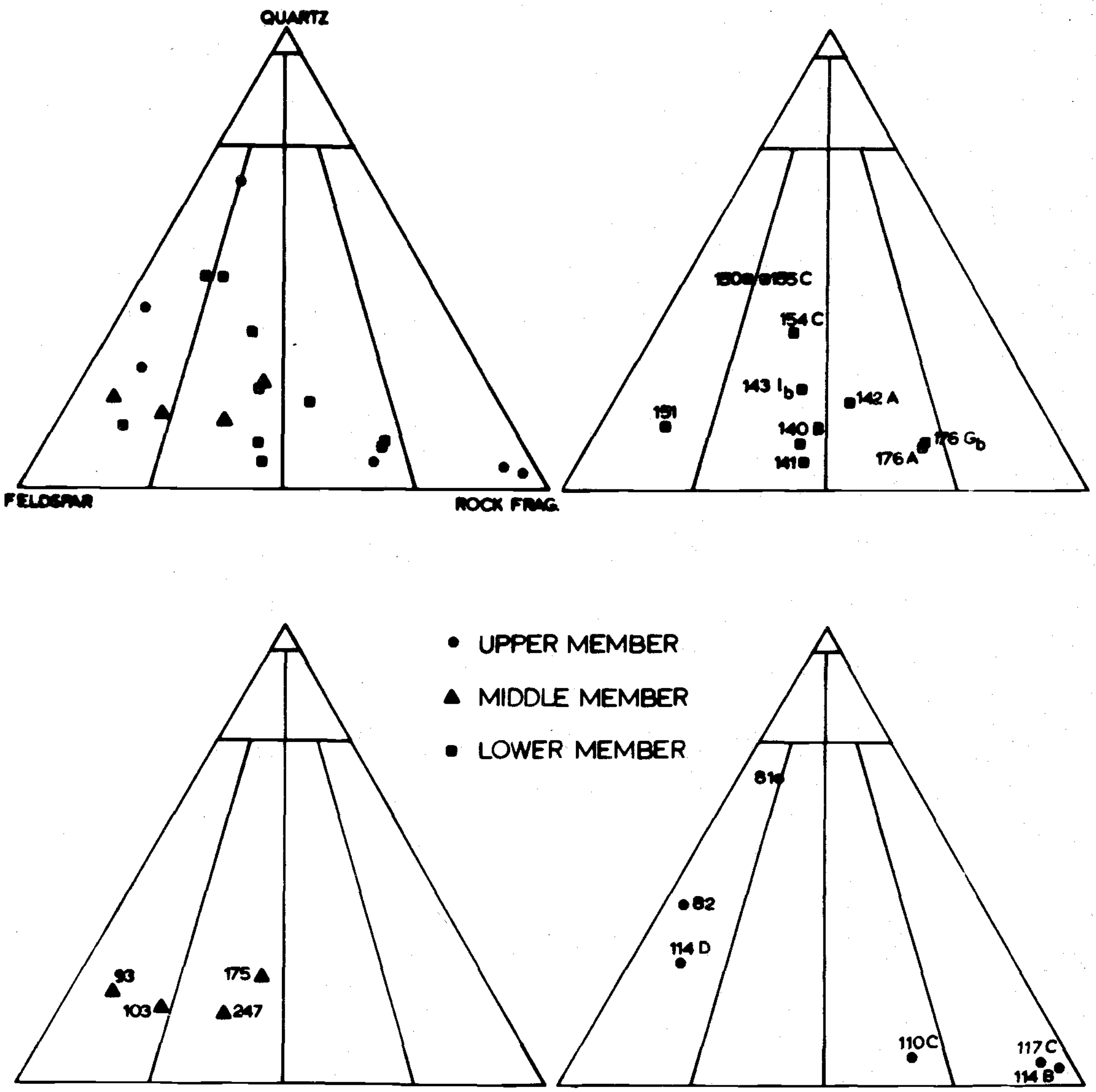


Figure 50. Classification of sandstones, siltstones and mudstones, Cowlitz Formation (after Folk, 1968).



NOTE: All samples plotting as lithic arenites are vitric arenites.

Figure 51. Classification of sandstones, siltstones and mudstones, Keasey Formation (after Folk, 1968).

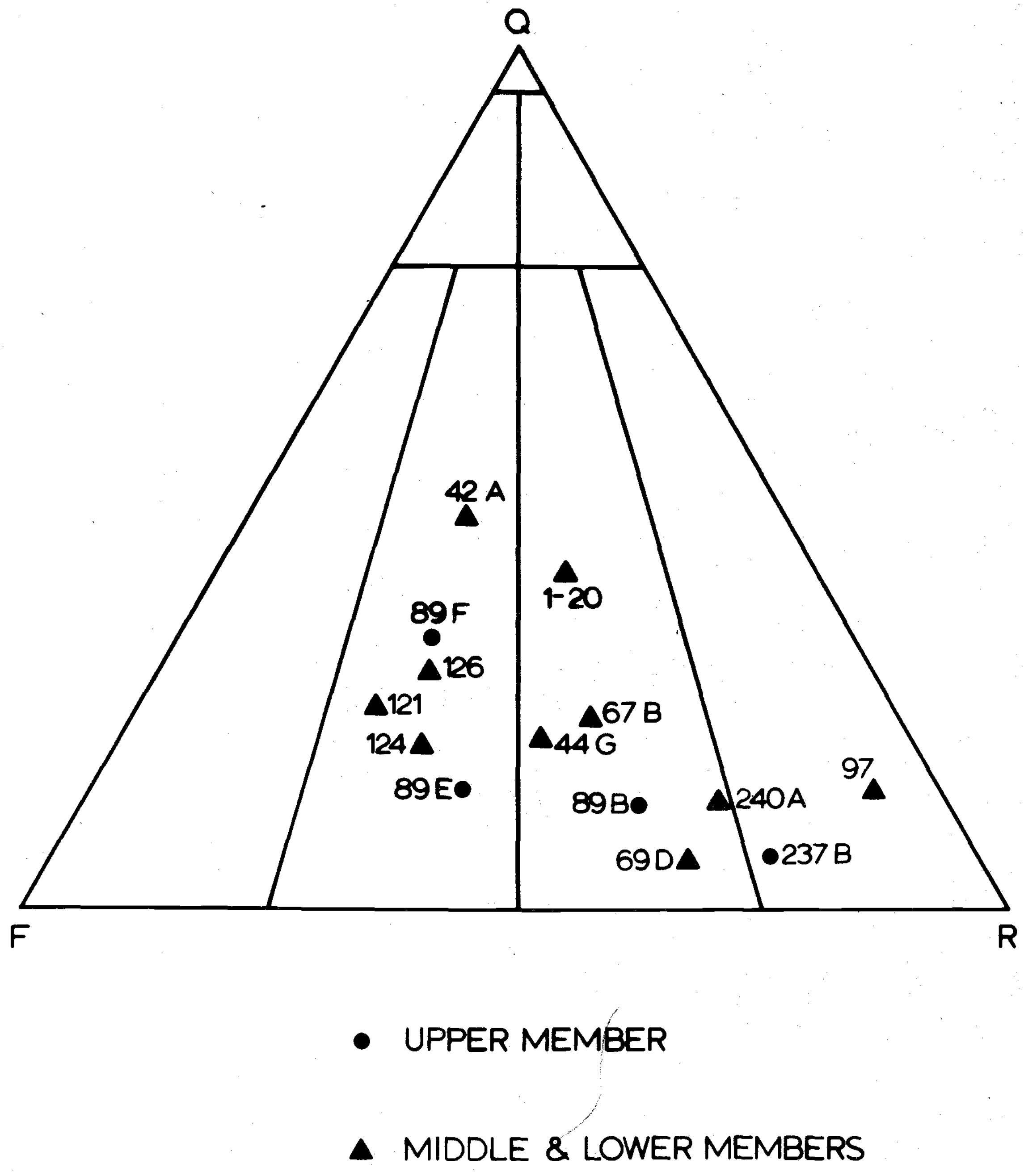


Figure 52. Classification of sandstones, siltstones and mudstones, Pittsburg Bluff Formation (after Folk, 1968).

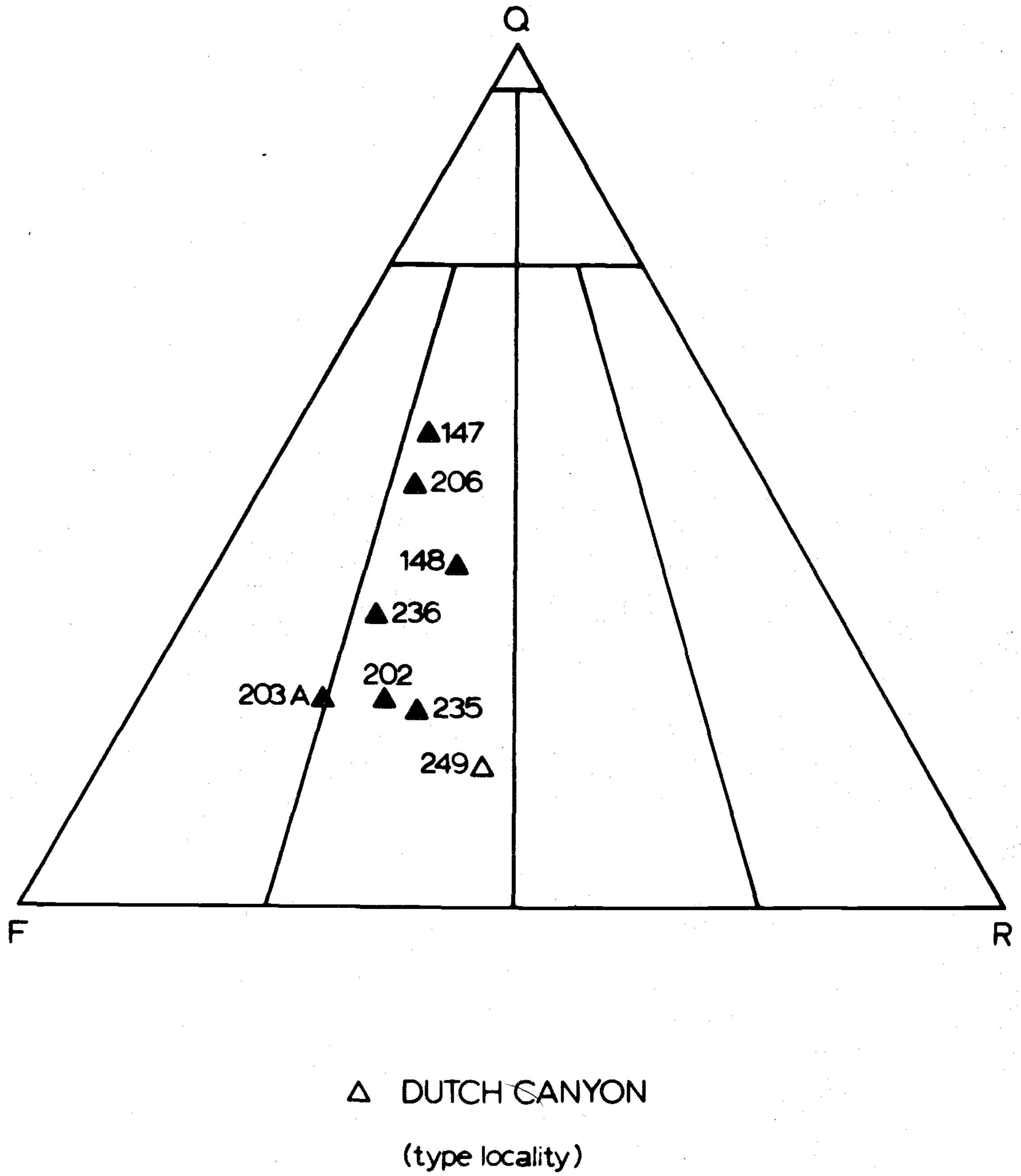


Figure 53. Classification of sandstones and siltstones, Scappoose Formation (after Folk, 1968).

interbedded sandy arkosic siltstones and mudstones. Beds range in thickness from 6 inches to as much as 8 feet. A typical interbedded sequence of sandstone, siltstone, mudstone and claystone is shown in Figure 54.

Immediately south of Keasey, 8-feet thick beds of light gray, cross laminated silty micaceous arkose with less than 10 percent clay matrix are exposed in many roadcuts. In the same area, along Fall Creek, just southeast of Keasey, similar micaceous sandstones crop out in beds 2 to 3 feet thick.

In the mudstone member of the Cowlitz Formation, exposed along the Nehalem River, occasional 4 to 6 inch beds of coarse, dark green, calcareous, volcanic litharenite to volcanic pebbly lithic sandstone are interbedded with dark gray arkosic siltstones and mudstones. In the lowermost part of the Keasey Formation one yellowish silty arkose bed is found. This was described in some detail under the discussion of the stratigraphy of the lower member of the Keasey Formation. Coarse, dark green, calcareous, volcanic litharenite to pebbly sandstone beds nearly identical to those in the mudstone member Cowlitz Formation are also found in the lower member of the Keasey Formation.

The only sandstones in the Pittsburg Bluff Formation in the southern part of the upper Nehalem River basin are restricted to the uppermost part, exposed along the S. P. and S. Railroad 1 mile

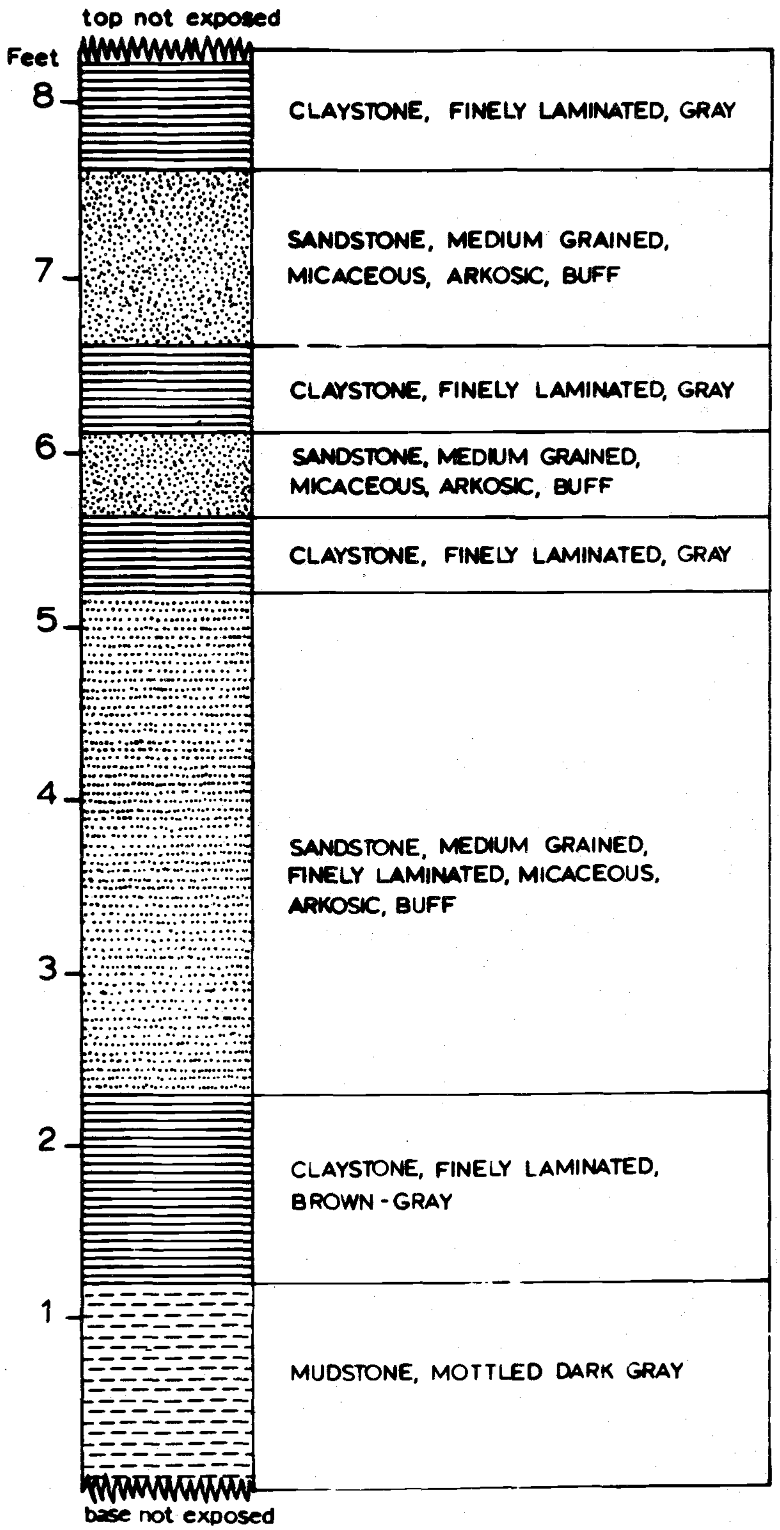


Figure 54. Typical sequence of sandstone, siltstone and claystone beds, sandstone member, Cowlitz Formation (location 200).

north of Buxton. These beds are gray to brownish gray, cross-laminated, silty, pumiceous, carbonaceous, lithic arkosic sandstone interbedded with dark gray, sandy, arkosic mudstone. The sandstone beds are from 3.5 to 25 feet in thickness and become coarser grained and more carbonaceous as the top of the sequence is approached. They are overlain by beds of pebble to boulder conglomerate believed to be at the base of the Scappoose Formation (Warren and Norbisrath, 1945, p. 229).

The Scappoose Formation is characterized by yellowish, silty, cross-laminated, micaceous, carbonaceous, lithic arkose beds from less than 1 foot to over 10 feet thick. These are interbedded with some dark gray, arkosic siltstones and a few 6 inch- to 3 feet-thick beds of feldspathic litharenite (see Figure 34).

Texture

The framework grains in all but the coarsest sandstones or pebbly sandstone beds are angular to subangular. Grains in very coarse volcanic litharenites are subrounded to rounded. Some species of heavy minerals, such as zircon and apatite, may have very well-rounded grains together with subangular to angular grains of the same species. Statistical size parameters, calculated according to Folk's graphic methods (1968, p. 44-47), are summarized in Table 1 and given in detail in Table 13, Appendix B. Sorting in

Table 1. Summary of Size Parameters

Formation	$Md\phi$*	σ_i*	Sk_i*
Scappoose	1.55-3.9ϕ	1.45-2.80ϕ poorly to very poorly sorted	0.58-1.80 strongly to very strongly sorted
Pittsburg Bluff			
upper member	2.68-4.1ϕ	1.53-3.14ϕ	0.59-0.64
middle member	3.98-5.65ϕ		
Type Locality (1 sample)	3.5ϕ	1.3ϕ poorly to very poorly sorted	0.62 strongly fine-skewed
Keasey			
lower member (3 samples)	2.9-4.7ϕ	1.33-2.7ϕ poorly to very poorly sorted	0.6-2.3 strongly fine-skewed
Cowlitz			
sandstone member	2.5-4.1ϕ	0.73-2.28ϕ moderate to very poor	0.28-0.72 fine to strongly fine-skewed

*Folk's graphic size parameters (1968, p. 44-47).

all sandstones except those of the Cowlitz Formation is poor to very poor. A few of the Cowlitz sandstones are moderately sorted. All of the sandstones are strongly fine-skewed except a few of those in the Cowlitz Formation. The median grain size of all sandstones ranges from 1.55ϕ (medium sand, 0.41 mm) to 4ϕ (finest sand, 0.064 mm).

Folk (1951, 1968) and other workers (for example, Pettijohn, 1957), have developed the concept of textural maturity. Folk's criteria are given in Table 2. According to his scheme all of the

Table 2. Criteria for Determination of Textural Maturity (Adapted from Folk, 1968, p. 102)

Stage	Clay Matrix	Sorting	σ_i (Folk sorting)	Rounding	ρ (Powers, 1953)
Immature	over 5%	poor	over 1.0ϕ	not well-rounded	under 3.0
Submature	under 5%	moderate to poor	over 0.5ϕ	not well-rounded	under 3.0
Mature	little or none	well sorted	under 0.5ϕ	not well-rounded	under 3.0
Super-mature	none	well sorted	under 0.5ϕ	sub-rounded to well-rounded	over 3.0

sandstones in these Tertiary formations are immature, except some of those of the sandstone member of the Cowlitz Formation and the Scappoose Formation which rank as submature owing to their lack of clay matrix. A listing of the textural and mineralogical maturity of various rocks of the upper Nehalem River basin is given in Table 14, Appendix C. The mineralogical maturity of these rocks will be discussed in the next section. The sandstone which crops out on Robinson Creek, near the base of the Keasey Formation, also classifies as texturally submature, but, compared to all other rock types in the Keasey beds, it is unique.

Mineral and Rock Components

The framework grains of the sandstones consist of varying proportions of feldspar, quartz, rock fragments, volcanic glass and micas (biotite and muscovite), commonly with authigenic glauconite and from as much as 5 percent to as little as a few tenths of a percent heavy minerals, most of which are opaque minerals. Detailed lists and summaries of the composition of rocks sampled in this study are given in Table 15, Appendix C. Descriptions of the species and varieties of mineral and rock fragment components of the sedimentary rocks of the upper Nehalem River basin are given on page 96 and following pages.

Feldspar

The abundance of feldspar grains is generally equal to or exceeds that of quartz, rock fragments and volcanic glass, except in the sandstone member of the Cowlitz Formation where quartz exceeds feldspar in abundance by a small amount.

The potash feldspar is predominantly orthoclase but microcline is almost always present. In the sandstones of the sandstone member of the Cowlitz and uppermost Pittsburg Bluff Formations

Figure 55. Photomicrograph, arkosic sandstone, sandstone member, Cowlitz Formation. Note perthitic microcline, right center; plagioclase, upper left; chert, stippled, lower and upper left. Crossed polars. (locality 200.)

0.5 mm

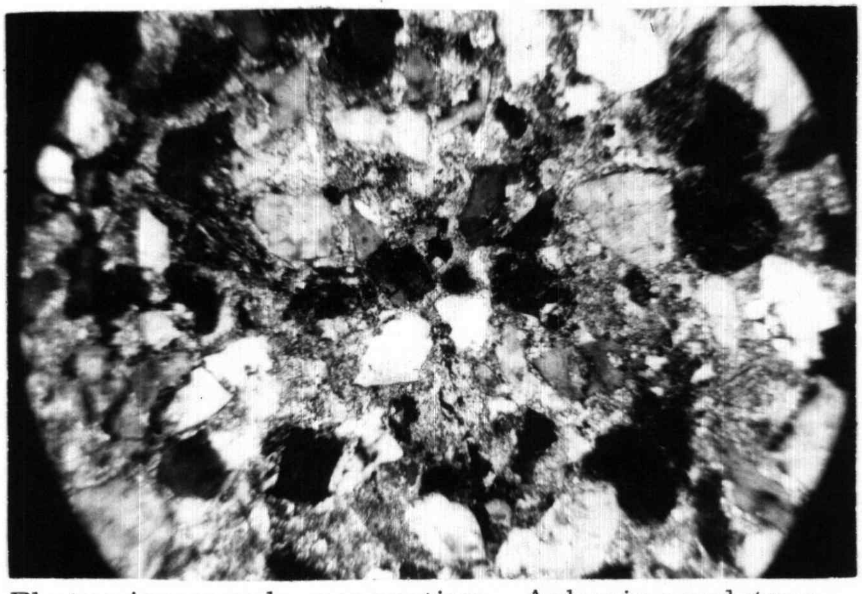


Figure 56. Photomicrograph, concretion. Arkosic sandstone, lower member, Keasey Formation. Note sutured polycrystalline quartz, gray, lower right of center; zoned plagioclase, upper left margin; calcite cement. Crossed polars. (locality 150, Robinson Creek.)

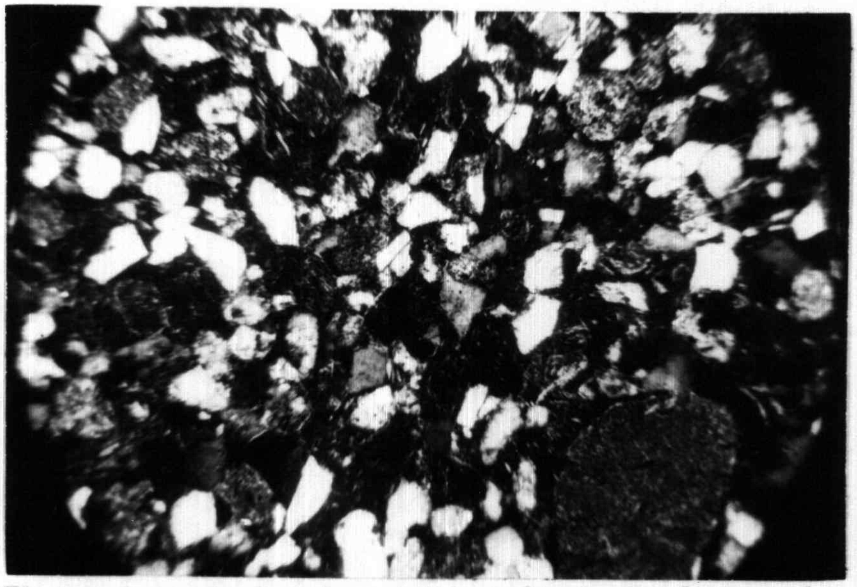


Figure 57. Photomicrograph, glauconitic arkosic sandstone, lower member, Pittsburg Bluff Formation, type locality near Pittsburg, Oregon. Note large glauconite grain, lower right; quartz, white; plagioclase and potash feldspar, gray. Crossed polars. (locality 5A.)

0.5mm

Figure 58. Photomicrograph, lithic arkose, Scappoose Formation. Stippled grains of chert, upper left of center; foliated metamorphic rock, lower left; quartz with undulose extinction and microcline, lower right of center; plagioclase, upper right. Other grains include sutured polycrystalline quartz, and volcanic rock fragments (black). Cement is calcite. Crossed polars. (locality 201A.)

1mm

microcline is present in all rocks which were sampled. Sanidine is present in the uppermost Pittsburg Bluff Formation. Potash feldspar is more abundant than plagioclase in 58 percent of the sandstones of the sandstone member of the Cowlitz Formation and in 45 percent of the sandstones of the Scappoose Formation.

Plagioclase feldspar varies in composition from albite to labradorite, with each sandstone containing plagioclase of two or three different compositions. Albite was found in 31 percent of the sandstones of the Cowlitz Formation but in only 11 percent of the sandstones of the Pittsburg Bluff Formation. All sandstones of the Cowlitz Formation have oligoclase but none of the samples studied have labradorite. In the sandstones of the Scappoose Formation andesine is the most common type of plagioclase and is present in 60 percent of the rocks sampled. A summary showing the percentage of rocks sampled which contain the various types of plagioclase discussed here is given in Table 3. The specific types of plagioclase identified in a particular sample are given in Table 15, Appendix C.

Feldspar grains are almost all angular to subangular and both fresh and altered grains are present in nearly every rock sampled. Weathering of these porous sandstones has undoubtedly decreased the original feldspar content somewhat but the presence of unaltered grains in almost all samples indicates that loss due to weathering must be negligible.

Table 3. Frequency Percentage* of Feldspar Types

	Plagioclase, An Content				Potash Feldspar		
Formation	0-10	10-30	30-50	50-70	K$\overline{>}$P	Micro-cline	Sani-dine
Scappoose	--	40	60	20	45	75	--
Pittsburg Bluff							
middle and upper members	11	46	46	11	--	100	12
lower member	--	20	60	60	--	60	--
Keasey							
middle and upper members	--	27	45	64	25	66	11
lower member	--	33	75	42	27	46	--
Cowlitz							
mudstone member	13	50	42	13	28	66	6
sandstone member	31	100	38	--	58	100	--

*Percentage of samples in which type of feldspar was identified

Quartz

All types of quartz, except chalcedony, are found in the sandstones of the Cowlitz Formation. More samples (58 percent) have monocrystalline non-undulose quartz with inclusions than other types, while 42 percent had polycrystalline undulose quartz with sutured contacts. In the Pittsburg Bluff Formation 60 percent of the samples have polycrystalline sutured quartz. Fewer sandstones of the Scappoose Formation have polycrystalline sutured quartz.

Clear grains of non-undulose quartz are by far the most abundant of all types in all of the sandstones. The distribution of the various types of quartz identified does not appear to present a very significant pattern (see Table 4).

Table 4. Frequency Percentage* of Various Types of Quartz

	Monocrystalline				Polycrystalline		
Formation	Clear	Clear und.	With incl.	Euhed.	Non-undul.	Undul.	Chalced.
Scappoose	66	--	33	--	25	17	--
Pittsburg Bluff							
middle and upper members	70	--	20	--	10	60	10
lower member	75	--	25	--	25	75	--
Keasey							
middle and upper members	93	--	20	--	20	--	7
lower member	100	--	8	--	8	33	17
Cowlitz							
mudstone member	90	20	40	--	--	60	10
sandstone member	42	17	58	8	25	42	--
siltstone member	100	50	--	--	--	--	--

*Percentage of samples in which quartz types were identified

Volcanic Glass

Glass present in the sandstones of these Tertiary sediments is of both the clear, colorless acidic and the brown basaltic varieties. In the sandstone member of the Cowlitz Formation volcanic glass is virtually absent. Every sandstone sampled has less than 1 percent. The same holds true for the sandstone in the lowermost Keasey Formation. By contrast, the sandstones in the uppermost Pittsburg Bluff Formation and the Scappoose Formation have higher percentages of glass, ranging from a few percent to as much as 12 percent in the Pittsburg Bluff and 18 percent in the Scappoose sandstones. Forty-four percent of the sandstones of the Scappoose Formation have greater than 10 percent glass. The relatively low content of clay matrix militates against accounting for low glass content in the Cowlitz sandstones because of destruction by weathering. In the Cowlitz Formation sandstones volcanic glass is present in such small amounts that any reference to such rocks as being "tuffaceous" is in error.

Rock Fragments

In most of the sediments of the upper Nehalem River basin vitrophyres and volcanic porphyries are the most abundant of all rock fragments present. However, in the sandstone member of the Cowlitz Formation vitrophyric rock fragments are exceedingly rare; only one sample contains a few volcanic rock particles. Foliated metamorphic rock fragments are found more frequently in the sandstone member than in other parts of the Cowlitz Formation. In the Pittsburg Bluff Formation only 33 percent of the sandstones sampled contain any type of metamorphic rock fragments. A similar frequency of occurrence is found in the sandstones of the Scappoose Formation.

Chert is commonly found in rocks of all size classifications. Microgranitic rock fragments are more frequently found in the sandstones than in other rocks, except for the Cowlitz Formation in which microgranitic rock particles are nearly equal in frequency of occurrence in both the sandstone and the mudstone members. Table 5 gives a summary of volcanic glass and rock fragments in these sediments.

Mineralogic Maturity

The mineralogic maturity of clastic sediments has been discussed at length by Pettijohn (1957, p. 287; 508-510). He suggests the ratio: quartz plus chert/feldspar plus rock fragments, as a suitable, "measure of the approach of a clastic sediment to the stable end type toward which it is driven by the formative processes operating on it." (p. 508). This involves intensity of weathering, the relief and the provenance under which the sediments were originally generated. Included also would be the question of whether sediments were derived from primary crystalline rocks or from other sedimentary rocks.

Although Pettijohn does not suggest a scale of maturity, he

Table 5. Frequency Percentages* of Glass and Rock Types. Glass: x = most abundant type of glass; (x) = present, < 10%

Formation	>10% Glass			Vitro-phyre	Volc. porph.	Foliated meta.	Chert	Micro-granitic
		clrl	brn					
Scappoose	44	x	x	50	50	30	70	80
Pittsburg Bluff								
middle and upper members	88	x	x	56	56	33	89	66
lower member	60	x	x	80	40	60	60	20
Keasey								
middle and upper members	80	x	x	73	40	--	40	7
lower member	75	x	x	47	67	20	40	27
Cowlitz								
mudstone member	28	x	x	43	36	14	93	64
sandstone member		(x)	(x)	--	8	45	85	62
siltstone member		(x)	(x)	--	100	--	66	33

*Percentage of samples in which glass or rocks were identified uses an index number calculated from the ratio given above. He gives several such indices for different clastic rock types, as shown in Table 6.

Table 6. Pettijohn's Maturity Indices for Different Types of Clastic Rocks (1957, p. 509)

Rock Type	Quartz + chert: feldspar + rock fragments
Average Arkose	1.1
Average Graywacke	1.2
Average Lithic Sandstone	2.3

Since most rocks involved in this present study have significant amounts of volcanic glass as well as vitrophyric rock fragments, which are generally considered as unstable components (Folk, 1968, p. 139), it was felt that these should be added to the feldspar and other rock fragments. On that basis the maturity indices were calculated for these Tertiary sediments and are reported in Table 14, Appendix C.

The sandstones of the Cowlitz Formation have a mean maturity index of 0.83, which would indicate that they are very immature according to Pettijohn (see Table 6). The majority of Cowlitz rocks classified in this manner have indices close to this value but a few have indices greater than 1.00. These latter might be thus regarded as immature to submature since the percentage of quartz and chert was as great or greater than the unstable components.

The sandstone in the lower Keasey Formation also has a maturity index of 0.83, but the indices of the sandstones of the uppermost Pittsburg Bluff and those of the Scappoose Formation are as low as 0.26 (mean) and 0.58 (mean) respectively. They can be considered very immature, which is because of their volcanic glass content.

Heavy Minerals

Minerals with specific gravity greater than 2.96 make up from a few tenths of a percent to about 1.5 percent of the sandstones of the Cowlitz, Keasey, and Pittsburg Bluff Formations. In the Scappoose Formation heavy minerals are more abundant, comprising up to 5 percent of the total weight of the rock. Heavy mineral content of each sample analyzed is given in Table 15, Appendix C. The method of evaluating relative abundance rank of heavy minerals in each of these sandstones is summarized on page 96.

Hornblende, augite and epidote group minerals (epidote, zoisite, clinozoisite) are most frequently the predominant heavy minerals, except for rare individual beds in which apatite or sphene may be the most abundant. The green and olive brown varieties of

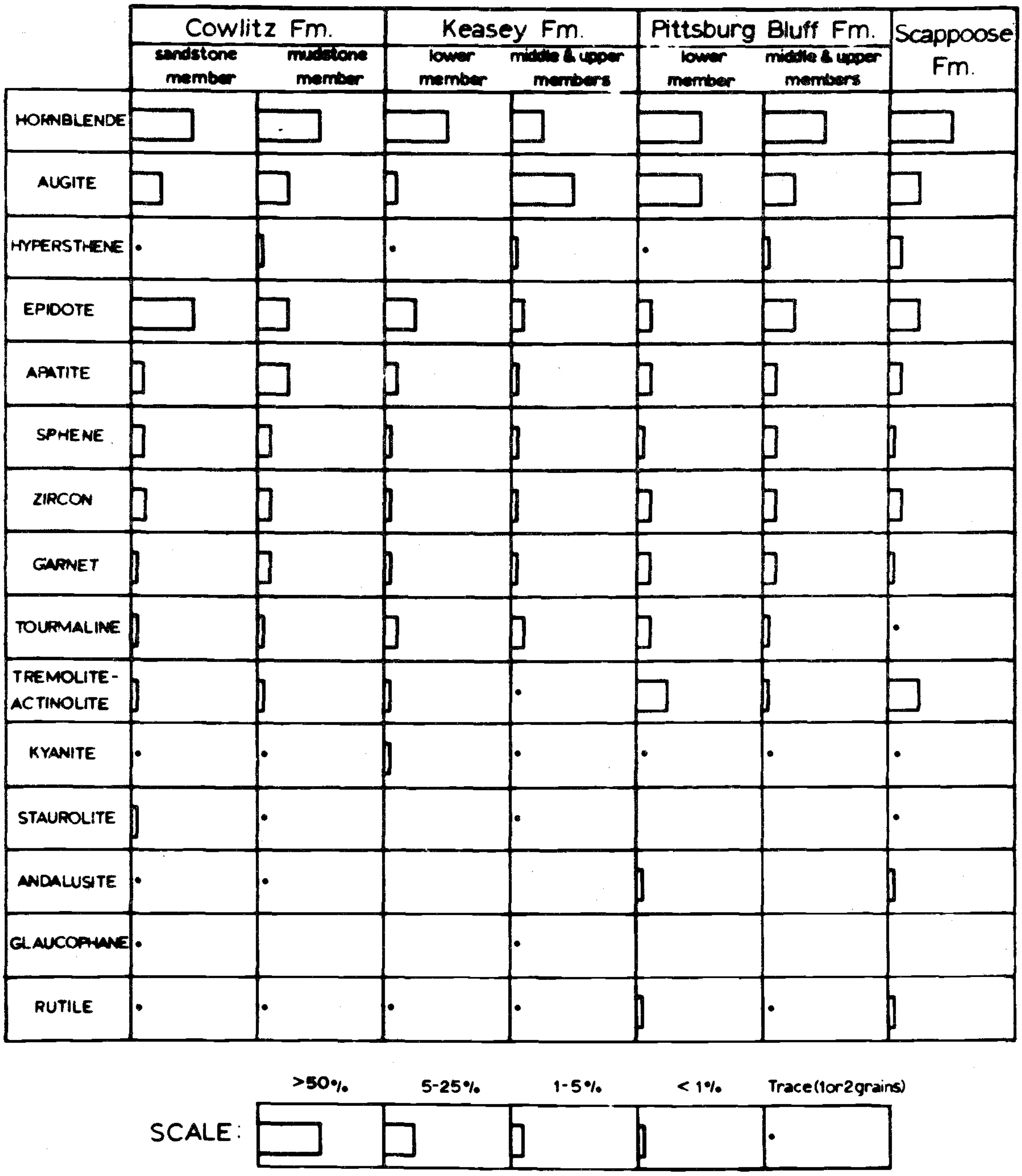


Figure 59. Most frequent abundance-rank of heavy minerals.

Table 7. Frequency Percentage of Abundance-Rank of Heavy Minerals. Percentage of samples with given rank of abundance (see p. 96)

Formation	Abundance Rank	Pyroxene: Augite	Pyroxene: Hypersthene	Pyroxene: other: E-Ens Diop., hed.	Apatite	Hornbl: brown, green	Hornbl: Oxyhornblende	Sphene	Zircon	Tourmaline	Garnet	Epidote group	Tremolite-Actin	Glaucophane	Kyanite	Andalusite	Staurolite	Rutile (B-brookite)
Scappoose Formation	1	27	-	-	-	91	-	-	-	-	-	-	-	-	-	-	-	-
	2	36	45	-	-	9	18	-	9	-	-	36	36	-	-	-	-	-
	3	18	9	9E	27	-	45	27	27	18	9	27	18	-	-	-	-	-
	4	9	18	-	18	-	9	55	18	18	45	18	-	-	18	27	-	18
	5	-	-	9D	9	-	-	-	9	36	18	-	18	-	18	-	9	10
Pittsburg Bluff Fm. Upper & Middle	1	40	-	-	-	100	-	-	-	-	-	-	-	-	-	-	-	-
	2	40	30	-	-	-	-	20	-	-	10	40	30	-	-	-	-	-
	3	20	40	-	50	-	-	40	70	20	50	40	20	-	-	-	-	-
	4	-	10	-	30	-	60	10	30	30	40	20	40	-	10	-	-	20
	5	-	-	9D	9	-	-	-	9	38	18	-	18	-	18	-	9	10
Pittsburg Bluff Fm. Lower	1	40	-	-	-	67	-	-	-	-	-	17	-	-	-	-	-	-
	2	17	-	-	-	17	-	17	17	17	17	17	17	-	-	-	-	-
	3	17	-	-	100	17	33	-	33	17	33	50	-	-	-	-	-	-
	4	-	-	-	-	-	33	33	33	17	-	-	-	-	17	17	17	33
	5	-	17	17D	-	-	33	17	-	-	17	-	-	-	17	-	-	17
Keasey Fm. Upper & Middle	1	64	-	9D	-	27	-	-	-	9	-	9	-	-	-	-	-	-
	2	18	9	-	9	27	-	-	-	-	-	18	-	-	-	-	-	-
	3	-	27	-	18	-	9	9	27	18	18	27	9	-	-	-	-	-
	4	-	18	-	45	9	45	27	36	18	27	18	-	-	-	-	-	9
	5	-	18	-	-	18	18	9	9	-	-	-	18	27	-	-	9	36
Keasey Fm. Lower	1	22	-	-	-	78	-	11	-	-	-	22	-	-	-	-	-	-
	2	22	-	-	-	11	11	-	11	-	11	45	-	-	-	-	-	-
	3	33	-	-	22	-	11	11	22	11	-	11	22	-	-	-	-	-
	4	-	-	11H	22	11	11	56	44	22	45	-	22	-	22	-	-	-
	5	-	22	-	-	-	45	-	-	11	22	-	-	-	-	-	-	22
Cowlitz Fm. Upper Mudstone	1	21	4	-	4	58	-	-	-	-	-	37	-	-	-	-	-	-
	2	29	4	-	54	17	4	46	16	-	8	42	-	-	-	-	-	-
	3	4	4	-	20	13	-	50	42	23	62	13	8	-	-	-	-	17
	4	37	37	-	17	13	-	4	29	38	25	8	27	-	-	-	14	R42
	5	-	8	8D	4	-	54	-	4	8	-	-	8	-	25	17	14	B4
Cowlitz Fm. Sandstone Member	1	8	-	-	-	54	-	8	-	-	-	69	-	-	-	-	-	-
	2	31	-	-	83	23	-	15	8	-	-	15	-	-	-	-	-	-
	3	15	-	-	23	-	-	61	38	29	38	15	8	-	-	-	-	-
	4	15	-	-	31	15	-	-		58	46	-	23	-	15	-	15	-
	5	-	23	4B	-	-	46	-	23	4	-	-	15	4	23	8	15	31

hornblende are present most commonly, but blue-green hornblende is also present, mostly in the sandstones of the Cowlitz Formation and in the Scappoose Formation. Oxyhornblende is most frequently found in the Pittsburg Bluff and Scappoose sandstones. Table 8 summarizes the frequency of the various types of hornblende.

Table 8. Frequency Percentage* of Hornblende Types

Formation	Green, olive brown	Blue-green	Oxyhornblende	Etched
Scappoose	100	20	90	10
Pittsburg Bluff				
middle and upper members	100	--	80	--
lower member	100	--	83	--
Keasey				
middle and upper members	80	10	70	--
lower member	100	--	67	--
Cowlitz				
mudstone member	100	37	58	--
sandstone member	100	23	54	15
siltstone member	100	25	50	--

*Percentage of samples in which type was identified

A number of different types of apatite are found and Table 9 summarizes the frequency of occurrence of these.

In the sandstones of the Cowlitz Formation epidote alone makes up over 50 percent of the heavy minerals in three of the rocks analyzed, and in most of the rocks both hornblende and

Table 9. Frequency Percentage* of Apatite Types

Formation	Dusky	Euhedr.	Rdd-sbrd.	Yellow	Pink
Scappoose	--	--	30	10	--
Pittsburg Bluff					
middle and upper members	10	--	30	--	--
lower member	33	33	33	--	--
Keasey					
middle and upper members	20	--	30	--	--
lower member	11	11	22	--	--
Cowlitz					
mudstone member	37	29	67	17	17
sandstone member	15	8	31	--	--
siltstone member	50	--	60	--	--

(rdd-sbrd. = rounded to subrounded)
*Percentage of samples in which type was identified

epidote are the most abundant heavy minerals, together making up over 50 percent of the total. Augite exceeds hornblende and epidote minerals in the middle and upper members of the Keasey Formation, and in the lower part of the Pittsburg Bluff Formation augite and hornblende together comprise over 50 percent of the heavy mineral fraction.

Commonly apatite, sphene, zircon, tourmaline, garnet and tremolite-actinolite each make up from 5 percent to less than 1 percent of the heavy minerals in the sandstones of the upper Nehalem River basin. In the Cowlitz sandstones apatite, sphene and zircon each make up 1 to 5 percent of the heavies most commonly. Garnet, tourmaline and tremolite-actinolite each most frequently make up less than 1 percent. Apatite and sphene each make up from 5 to 25 percent of the heavy mineral fractions of some rocks and sphene, together with epidote, in one sample (187) was found to make up over 50 percent.

In the sandstones of the uppermost Pittsburg Bluff Formation apatite, sphene, zircon and garnet each most commonly account for 1 to 5 percent of the heavies but in one sandstone (89F) sphene makes up from 5 to 25 percent, as does tremolite-actinolite in two samples (89E, 89F). Zircon and garnet are less abundant, generally. Sandstones of the Scappoose Formation may have 5 to 25 percent tremolite-actinolite present, apatite 1 to 5 percent, zircon and garnet less than 1 percent each, and tourmaline only in trace amounts.

Zircon occurs in both euhedra and well-rounded grains. The rounded grains may be yellow or pink but the pink grains are always very well-rounded. These are most frequently found in the uppermost sandstones of the Pittsburg Bluff Formation and in the Scappoose Formation. Colored zircons are not common in the Cowlitz Formation. Acicular euhedra with length-width ratios greater than 6:1 are found in most of the sandstones but are least common in the Cowlitz sandstones. Euhedra with attached volcanic glass are found in 20 percent of the sandstones of the Scappoose Formation but were not detected in any other sandstones. Table 10 summarizes the frequency of occurrence of different types of zircon.

Table 10. Frequency Percentage* of Zircon Types

Formation	Euhedral 1:1-5:1	L:W 6:1	Rdd-sbrd.	Pink	Yellow	With volc. glass
Scappoose	70	20	50	20	40	20
Pittsburg Bluff						
middle and upper members	40	--	30	20	10	--
lower member	33	17	33	17	33	--
Keasey						
middle and upper members	50	20	20	10	10	20
lower member	33	--	33	--	--	--
Cowlitz						
mudstone member	54	29	71	54	13	4
sandstone member	61	15	38	8	--	--
siltstone member	25	25	25	--	--	--

(Rdd-sbrd. = Rounded to subrounded)
*Percentage of samples in which type was identified

Kyanite is found only in trace amounts in all of the sandstones, except those in the lower member of the Keasey Formation where kyanite amounts to about 1 percent. Staurolite ranks less than 1 percent in the sandstones of the Cowlitz Formation and is found only in trace amounts in the Scappoose sandstones. It was not detected in the Keasey or Pittsburg Bluff sandstones. Glaucophane was detected in trace amounts in the Cowlitz sandstones. Rutile is present in amounts less than 1 percent or only as a trace in all formations.

Mudrocks

Textural and Mineralogical Classification

Of the 83 rocks sampled and analyzed for size classification, 76 percent are siltstones and mudstones. According to Folk's classification about half of these are "sandy" (see Figures 44 to 47). Mudrocks are present in every part of the Tertiary section of the upper Nehalem River basin; even the sandstone member of the Cowlitz Formation and the Scappoose Formation have interbedded sandy siltstone. All of these rocks have greater than 5 percent clay matrix and therefore, according to Folk's scheme of textural maturity, they classify as immature (see Table 14, Appendix C). The few samples for which granulometric analyses were made are poorly to very poorly sorted and strongly fine-skewed, according to Folk's statistical parameters and related verbal scales (1968, p. 45-47).

The range in composition of the mudrocks extends from arkose to litharenite, with the feldspathic mudrocks being the most common. In the Cowlitz Formation mudrocks are arkoses or lithic arkoses

(Figure 50), just like the sandstones, except for those which are intercalated with the Goble Volcanics along the Sunset Highway and near Keasey. There the mudrocks are volcanic litharenites, owing to the large percentage of volcanic rock fragments.

In the Keasey Formation most of the mudrocks are arkoses to lithic arkoses but a few in the lowermost Keasey along the Nehalem River are feldspathic litharenites and some in the uppermost Keasey, just at the contact with the Pittsburg Bluff Formation, are volcanic litharenites.

In the Pittsburg Bluff Formation some lithic arkose mudrocks are found but most of the rocks analyzed classified as feldspathic litharenites or volcanic litharenites, because of rather larger percentages of volcanic rock fragments and/or glass (see Table 15, Appendix C). The siltstones from the Scappoose Formation are lithic arkoses and have the same general composition as the sandstones of this formation.

Mineral and Rock Components

Feldspar

The most outstanding difference between the feldspar content in mudrocks as compared to the sandstones is in the general predominance of plagioclase over potash feldspar and in the fact that basic (labradoritic) plagioclase is much more common in the mudrocks. In the mudstone member of the Cowlitz Formation labradorite is found in 13 percent of the rocks analyzed, whereas it is not found in the sandstone member of the Cowlitz Formation. The most frequent types of plagioclase feldspar in the Cowlitz Formation mudrocks are oligoclase and andesine. Albite is quite rare. For a summary of feldspar types, see Table 3.

In the Keasey and Pittsburg Bluff Formations andesine and labradorite are present most frequently. Few rocks in the Keasey Formation (only 27 and 25 percent in the lower member and in the middle and upper members, respectively) have potash feldspar exceeding plagioclase in abundance and no rocks in the Pittsburg Bluff Formation are found with more potash feldspar than plagioclase. All mudrocks in the upper and middle members of the Pittsburg Bluff Formation contain microcline but only half the rocks analyzed in the lower member of the Keasey Formation and two-thirds of the rocks in the mudstone member of the Cowlitz, upper member of the Keasey and lower member of the Pittsburg Bluff Formations have microcline. Sanidine is found in the Keasey Formation.

Quartz

No outstanding differences in content of different types of quartz can be detected, except for the greater prevalence of undulose, polycrystalline quartz grains in the mudrocks as compared to the sandstones of the upper Nehalem River basin. Chalcedony is found infrequently in the mudrocks whereas it is not found in the sandstones. The summary of the frequency of occurrence of different types of quartz is given in Table 4.

Volcanic Glass and Rock Fragments

The high volcanic glass content of the mudrocks makes a striking contrast to the lack of glass in the sandstones of the Cowlitz Formation. Some of the mudrocks of the Keasey and Pittsburg Bluff Formations have glass making up as much as half of the framework grains larger than 43μ. In a few rocks glass constitutes from 75 to 95 percent of the rock. Tuffaceous sediments are more common in the upper member of the Keasey Formation than in any other formation (Figure 61). The mudstones of the upper member of the Cowlitz Formation do not as frequently contain abundant volcanic glass. Only 28 percent of the rocks analyzed had more than 10 percent glass. From 60 to 88 percent of the mudrocks of the Keasey and Pittsburg Bluff Formations had greater than 10 percent glass (see Figure 62).

The proportion of the volcanic rock fragments in the mudrocks of these Tertiary formations parallels the volcanic glass content: sediments with high glass content also have large quantities of

Figure 60. Photomicrograph, pebbly calcareous volcanic sandstone, lower member, Keasey Formation, Nehalem River. Note vesicular basaltic rock fragments with devitrified palagonite lining vesicles. Sparry calcite cement. (locality 143B.)

0.5mm

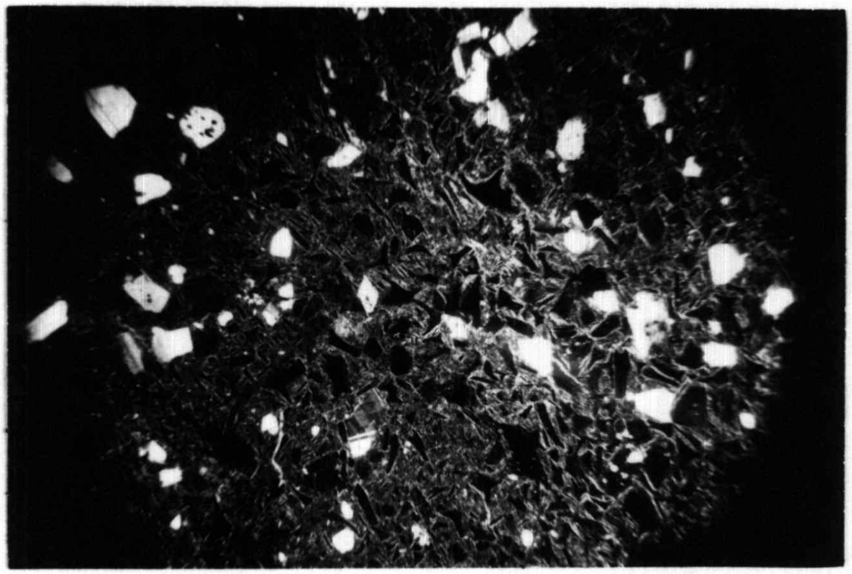


Figure 61. Photomicrograph, tuffaceous arkosic siltstone, upper member, Keasey Formation. Note glass shards (black), quartz (white), plagioclase (lower center, twinned) and clay matrix. Crossed polars. (locality 114, S. P. and S. R. R., north of Tophill.)

1mm

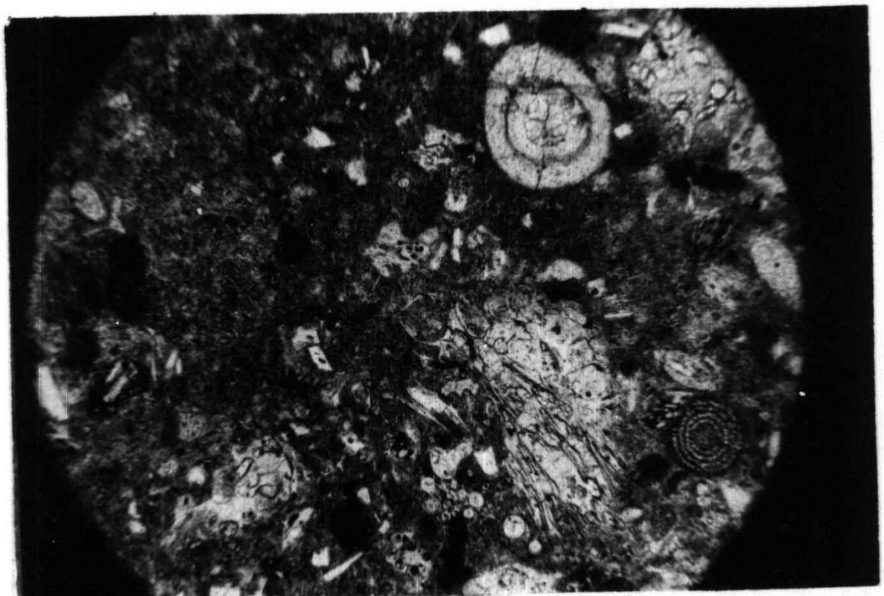


Figure 62. Photomicrograph, tuffaceous, glauconitic mudstone, upper member, Keasey Formation. Note glauconite pellets (black), glass shards and pumice (white, moderate negative relief), quartz (white), foraminifer test (upper right) and diatom (lower right). (locality 70, S. P. R. R., near Timber.)

0.5 mm

vitrophyre and other volcanic rock fragments. Judging from a few determinations of anorthite content of phenocrysts, these volcanic rock fragments range from andesitic to basaltic in both the Keasey and the Pittsburg Bluff Formations. The same is true of the mudstone member of the Cowlitz Formation. The index of refraction was determined by use of immersion oils for glass from unweathered mudstone of the middle member of the Pittsburg Bluff Formation along the Sunset Highway just above Staley's Junction. Microvesicular, colorless glass was found to have an index of refraction of 1.510. Colorless, fluted glass has an index of 1.514. According to the graph of index of refraction against SiO_2 content, by W. O. George (cited in Williams, Turner and Gilbert, 1954, p. 28), this corresponds to a silica content of 70 and 68 percent, respectively, which would make the glass rhyolitic (acidic; Williams and others, 1965, p. 27). In both the lower member of the Keasey and lower member of the Pittsburg Bluff Formations brown basaltic glass is the most abundant type.

Microgranitic rock fragments are found only half as frequently in the Keasey and Pittsburg Bluff mudrocks as in the sandstones of these formations but were found as commonly in the mudrocks of the Cowlitz Formation as in the sandstones. The frequency of occurrence of foliated metamorphic rocks does not seem to follow the frequency of the microgranitic rock in the mudrocks as closely as it does in the sandstones. In the lower member of the Pittsburg Bluff Formation especially, foliated metamorphic rock fragments are found in three times as many samples as are the microgranitic rock fragments. Chert is as commonly found in the mudstone member of the Cowlitz Formation and in the Pittsburg Bluff Formation as in the sandstones of either of these two units, but is less common in the Keasey Formation.

The most clear-cut patterns of association are found in the comparison of volcanic components with metamorphic and granitic components in the Keasey Formation where the abundance of these latter rock types is markedly lower and the abundance of the volcanic rock fragments is higher than in any other formations of the Tertiary sediments of the upper Nehalem River basin. The summary of frequency of glass and various rock types is given in Table 5.

Mineralogical Maturity

A comparison of maturity indices (Pettijohn, 1957, p. 509) in Table 14 reveals that the mudrocks of the Keasey and Pittsburg Bluff Formations have a much lower mineralogic maturity than those of the Cowlitz Formation. The mean index of the former rocks is only about half that of the latter. Comparison of the maturity of these rocks with those given by Pettijohn (see Table 6, page 142, this report) reveals that these rocks are exceedingly immature, judging from the opinion that graywackes and arkoses are generally immature sediments (Williams and others, 1954, p. 290).

Heavy Minerals

The composition of the heavy mineral fraction of the mudrocks of all formations is generally like that of the sandstones, except in the relative proportions of certain of the most abundant components (see Table 7 and Figure 59). Hornblende, augite and epidote are the most abundant of all heavy minerals. In the middle and upper members of the Keasey Formation hornblende is less abundant than augite, which makes up over 50 percent of the heavies. In the lower member of the Pittsburg Bluff Formation augite and hornblende together make up 50 percent of the heavy mineral fraction, but epidote commonly comprises only 5 percent. Hypersthene makes up more than 50 percent of the heavies in a few of the mudrocks of the mudstone member of the Cowlitz and up to 25 percent in some of the mudrocks of the middle and upper members of both the Keasey and the Pittsburg Bluff Formations. Generally hypersthene makes up less than 1 percent. In the lower members of the Keasey and Pittsburg Bluff Formations hypersthene is not present in more than trace amounts. In one sample from the upper member of the Keasey Formation pigeonite was found to make up the entire non-opaque heavy mineral fraction.

The frequency of occurrence of various types of hornblende is summarized in Table 8. Whereas blue-green hornblende is present in a good percentage of the mudrocks of the Cowlitz and Scappoose Formations, it is absent in nearly all the mudrocks of the Keasey and Pittsburg Bluff Formations. Oxyhornblende is present in about half of the samples analyzed from the Cowlitz Formation but is present in from 67 to 83 percent of the rocks of the Keasey and Pittsburg Bluff Formations, in which it may make up as much as 25 percent of some heavy mineral fractions. Most commonly, however, oxyhornblende makes up only 5 to less than 1 percent of the heavy mineral fraction of the mudrocks.

Apatite is present in 54 percent of the mudrocks of the mudstone member of the Cowlitz Formation in amounts from 5 to 25 percent. In the other formations apatite is most commonly present in amounts from 5 to less than 1 percent. A "dusky" type of apatite is present in most of the mudrocks, whereas it is not at all common in the sandstones (see Table 9).

The frequency of occurrence of sphene and garnet is nearly the same in the mudrocks as in the sandstones.

Zircon is as common in the mudrocks as in the sandstones of these Tertiary sediments. Subrounded to well-rounded zircons and colored zircons are more common in the Cowlitz mudrocks than in the sandstones, but rounded grains are just about as common in the Keasey and Pittsburg Bluff Formations as in the Cowlitz sandstones. Colored zircons are much more common in the mudstone member of the Cowlitz Formation than in any of the other formations. Zircons with adhering volcanic glass are found in the mudrocks of the Cowlitz and Keasey Formations but not in the Cowlitz sandstones.

Tremolite-actinolite is present in amounts up to 25 percent in the Pittsburg Bluff mudrocks but is less common in the Cowlitz and Keasey Formations, although it is always present.

Kyanite is always present in the mudstones at least in trace amounts, just as it is in the sandstones, but staurolite and andalusite are not found in the lower Keasey Formation and the middle and upper Pittsburg Bluff Formation mudstones. These latter minerals and glaucophane are not universally present.

Opaque Minerals

Magnetite and ilmenite are the most abundant detrital heavy minerals in the mudstones, with magnetite being by far the more abundant of the two. Leucoxene, hematite and "limonite" are always present. Frequency percentages from grain counts of a few representative samples are given in Table 15, Appendix C. The most abundant opaque mineral is authigenic pyrite, which is present in irregular grains, euhedral crystals (cubes and octahedra) and/or framboidal aggregates of microcrystals. Authigenic pyrite is far more common in the mudrocks of the Cowlitz and Keasey Formations than it is in the Pittsburg Bluff Formation. In the latter rocks, pyrite seldom makes up more than a few percent of the opaque minerals.

Authigenic Minerals

In the coarse silt to sand fractions of the rocks of the area of this study glauconite was the only authigenic mineral other than pyrite. In fine-grained sandstone concretions of the lower Pittsburg Bluff Formation near the type locality along the Nehalem River near Pittsburg, Oregon, authigenic analcime is found as a cement. Examination of thin sections of concretions from the area of this study failed to find any analcime, although the presence of large quantities of volcanic glass could have encouraged the diagenic formation of zeolites (Hay, 1966, p. 21).

The types of glauconite present in these sediments are described in Table 11. In most of these Tertiary formations from one-half to one-third of all rocks examined contained glauconite, except in the Cowlitz Formation where only 7 percent of the rocks were found to be glauconitic. Mudrocks of the lower and upper members of the Keasey Formation (Figure 62) and the lower member of the Pittsburg Bluff Formation contain glauconite much more commonly than do the rocks of the middle and upper members of the same formations. In disaggregation of the mudrocks, as has already been pointed out, soft pellets of glauconite were possibly destroyed; hence, examination of the coarse silt and sand-sized fractions failed to reveal much glauconite.

Table 11. Frequency Percentage* of Glauconite

Formation	Frequency (%)
Scappoose	45
Pittsburg Bluff	
middle and upper members	30
lower member	43
Keasey	
middle and upper members	27
lower member	53
Cowlitz	
mudstone member	39
sandstone member	7

*Percentage of samples with glauconite

Clay Mineralogy

Methods

As mentioned in discussion of disaggregation and size fractionation of these sedimentary rocks, 50 ml of the less than 4μ size class was saved from the pipette analysis for study of the clay mineralogy of these sediments. It is customary (Brindley, 1961, p. 40) to use the less than 2μ size class for X-ray study of clays, but in order to simplify the number of size separations, it was felt that no great problem would be encountered in using slightly coarser material. That this was justified is borne out by the results which, for the purposes of this study, were satisfactory. In addition, it was noted that other workers do use sediments as coarse as this and even coarser (up to 16μ) (Klug and Alexander, 1954, p. 290-305). Furthermore, it has been pointed out by Jenne (1966, p. 2) that coarsely crystalline clays, such as kaolinite, may be concentrated in the coarser size fractions. Since Calgon (sodium hexametaphosphate) was universally used as a dispersant, both in rock disaggregation and in the pipette analysis, all clay had an opportunity for sodium saturation. Samples were washed free of excess Calgon before mounting for X-ray identification.

It is noted that a great number of workers commonly use sodium hexametaphosphate, sodium carbonate, sodium hydroxide, sodium citrate, sodium hydrosulfite, and/or sodium bicarbonate at various stages in the treatment of clays for dispersion and for removal of iron compounds (Brindley, 1961, p. 41; Hathaway, 1956, p. 8; Jenne, 1966, p. 4; and many others). It has been pointed out by MacEwan (1961, p. 185) that the use of sodium to obtain full dispersion and optimum orientation has little effect upon the results of treatments with organic complexes, such as glycerol or ethylene glycol, and there seems to be no evidence that sodium saturation has any effect upon heat treatments used in identification procedures. It is commonly held that sodium and calcium smectites are those occurring most frequently in soils and sediments (Grim, 1968, p. 231). It is recognized, however, that sodium saturation is not the most desirable because ordered d-spacings are not as good in clays so treated. Also, the spacing is very dependent upon the relative humidity of the air during X-ray analysis. MacEwan (1961, p. 185) does not recommend the use of sodium ions with solvation treatments. In light of these points, the probability of sodium saturation of the clays during dispersion in the analyses of this present report raises doubts with respect to some of the interpretations of X-ray diffractograms, especially those involving mixed-layer clays.

Clay samples were mounted for X-ray diffraction study on porous ceramic tiles, according to the method suggested by Kintner and Diamond (1956). A number of refinements and variations of this technique are used by various workers, and it was found that some adaptations were necessary for material used in this present study.

Unglazed porous ceramic tiles, 45x19x2 mm, were placed on a filter tube with a fritted glass disc 60 mm in diameter, ground smooth on the top surface and fitted with a rubber gasket with two rectangular cut-out holes, slightly smaller than the tiles. The filter tube is mounted on a 500 ml filtering flask attached to a vacuum pump.

By arranging two or more such set-ups, it is possible to mount several specimens at one time. Preparation of the tiles was as follows: 10-20 mg/ml of the clay sample was thoroughly suspended and disaggregated by placing a sonic cleaner probe in the sample container at maximum intensity for 3 minutes. The suspension was then placed on the ceramic tile by means of a bulb-type syringe ("eye-dropper"), covering the surface of the tile with as much suspension as could be contained by the surface tension without overflow. Two tiles of each sample could be prepared on one filter tube and thus there was no risk of contamination. In this technique there is some risk of size segregation with larger particles on the bottom and smaller particles on the top of the tile. One tile was X-rayed untreated and then re-X-rayed after exposure to ethylene glycol vapor, by suspending the tile over glycol in a covered evaporating dish for 12 hours at 60°C. The second tile was heated to 550°C in a furnace for 1 hour, after which the tile was removed, cooled a short time and then placed in a dessicator with anhydrous $CaCl_2$ to prevent any rehydration.

Thus for each sample, three diffractograms were run, one untreated, one glycolated and one heated to 550°C, as has been suggested by Brindley (1961, p. 44). Samples suspected of having chlorite were placed in dilute (1:5) HCl at $80^{\circ}C$ for 12 hours; washed free of acid, mounted on tiles. An untreated tile and one heated to $550^{\circ}C$ for 1 hour were re-X-rayed to distinguish between chlorite and kaolin, as suggested by Brindley (1961, p. 264). Quite satisfactory results were obtained by these methods, as verified by several re-runs of samples which reproduced the diffractograms of first runs. Although some chlorites are not dissolved by this treatment, it was felt that the procedure gave definitive results in the samples studied.

The following criteria, given in Table 12, based upon procedures as noted in the references given, were used to identify the clay minerals present in samples studied.

Interstratified (Mixed-layer) Clay Minerals

According to MacEwan and others (1961, p. 431 and following) diffractograms of regularly interstratified clays show "an integral sequence of 001 reflections" which is caused by a regular periodicity representing the sum of the layer thickness of the components. Irregularly (randomly) interstratified clay minerals do not show a periodicity representing the sum of layer thicknesses. Reflections of layers with long spacings (greater than 30Å) are generally always present in both regularly and irregularly interstratified clays.

In this study, mixed-layer clay minerals very likely are more

Table 12. Criteria for Identification of Clay Minerals (Basal Spacings in Angstrom Units)

Clay Mineral (Most intense reflection)	Untreated	Glycolated (12 hrs. at 60°C)	Heated to 550°C, 1 hr.	Treated in dilute (1:8) HCl, 12 hr., 80°C
Kaolin[1] (001)				
Jenne, 1966, p. 6				
Brindley, 1961, p. 84-88	7.15-7.2	7.15-7.2	Destroyed	7.15-7.2
Chlorite (Fe-rich)(002)				
Jenne, 1966, p. 20-22				
Brown, 1961, p. 260-266	7.0-7.2 (14.0-14.3-001-weaker)	7.0-7.2 (14.0-14.3-001-weaker)	7.0-7.3 weaker 14.0-14.3-001-enhan.	Most chlorites destroyed (especially chlorites rich in Fe and fine-grained)
Smectite[2] (001)				
Jenne, 1966, p. 11				
MacEwan, 1961, p. 183-202	12.6-14.2	16.9-17.1	9.9-10.0	Destroyed
Mica (Illite?)(001)				
Jenne, 1966, p. 19				
Bradley and Grim, in Brown, 1961, p. 238	9.9-10.1	9.9-10.1	9.9-10.1	9.9-10.1
Vermiculite (001)				
Walker, in Brown, 1961, p. 311-320	12.3-12.6 Na^+ sat.	to 14.3	10.0	

[1] Kaolin Group: No differentiation of species of 7Å clays in the group is made in this study.

[2] Smectites: Grim (1968, p. 41) points out that the name "Smectites" is becoming more widely accepted as a name for the group of clay minerals with expanding lattices, excepting vermiculite, while the name formerly used more commonly, "Montmorillonite," is now being applied to a species of the Smectites in which there is high alumina content, "some slight replacement of Al''' by Mg" and substantially no replacement of Si'''' by Al'''." Since in this study no effort was made to positively identify the species of smectite, this name will be used for the group. It is probable, however, that most of the expanding lattice 14Å clay found in these sediments is montmorillonite. This assumption will be further justified later in this report.

common than is reported. In a few samples, peaks in diffractograms due to spacings greater than 20Å suggest the presence of interstratified clay minerals. Some of the broad peaks in the 10Å to 14Å region could be caused by inequally interstratified montmorillonite-chlorite. However, since Na was used as a saturating ion and the relative humidity was not controlled during X-ray diffraction, the results could be due to different amounts of adsorbed H_2O between the layers. Beyond these generalized observations no further effort is made in this study to identify the interstratified clay minerals. The presence of these clay minerals is not especially interpreted, although they certainly can be. In the study of the mineralogy of recent clays in the Atlantic Ocean, Biscaye (1964, p. 824) regarded the presence of mixed-layer clays as indicating a continental source for the sediments, rather than diagenetic, while Berry and Johns (1966, p. 192) found that abundant mixed-layer clays seemed to be clearly related to diagenetic alteration of expandable clays derived from continental areas. Weaver (1956, p. 178-179) cites a number of workers who find mixed-layer clays related to depth of burial, as in Miocene sediments of the Gulf Coast, the upper Mississippian of Oklahoma and the Cretaceous of California. Despite the probability of useful interpretations made possible by the careful identification of different mixed-layer clays, the choice of sodium saturation and the lack of sure stratigraphic control in location of most samples in this study seemed to militate against the practicability of such work. Instead, the major clay mineral groups have been used for interpretation of provenance, diagenesis, and, to a very limited extent, environment of deposition.

Smectite

A total of 47 samples were examined for clay mineral content by X-ray diffractometer methods (Table 17, Appendix E). In practically all samples studied in each of the formations, smectites are the dominant group. No effort was made to determine the species of smectites. In one series of samples (159A to 159G, mudstone member, Cowlitz Formation) which was subjected to digestion in 1:8 HCl in order to distinguish between chlorite and kaolinite, all smectite clay was destroyed in the process, which suggests, according to MacEwan (1961, p. 186), that the species in these samples is nontronite. Although no quantitative analysis of diffractograms was done, relative heights of peaks in diffractograms of the majority of samples indicate that smectites constitute from 60 to nearly 100 percent of most clay-size material in the rocks studied.

There seems to be a general agreement among students of clay minerals that the presence of smectites in sedimentary rocks can be accounted for either by detrital contributions from continental environments in which rock weathering under conditions of moderate to low rainfall and leaching of soils is rather incomplete (Grim, 1968, p. 517-518; Milne and Earley, 1958, p. 328), or by diagenesis of sediments rich in volcanic detritus deposited in environments of high pH, such as a marine environment (Weaver, 1958, p. 302; Hay, 1966, p. 81; Grim, 1958, p. 252). Owing to the relatively high proportions of volcanic glass present in the Pittsburg Bluff and Keasey Formations, the very high percentage of smectite in these rocks is best explained in terms of diagenesis. It is possible that some of these rocks contain mixed-layer illite-montmorillonite, which is revealed by some diffractograms showing very broad, low peaks between 11Å and 14Å. However, these could possibly be caused by the degree of hydration in the untreated sodium-saturated sample. If mixed-layer clays are present they could be accounted for by diagenetic changes in montmorillonite to mixed-layer illite-montmorillonite upon deeper burial, as was observed in Gulf Coast Miocene sediments by a number of workers cited by Grim (1958, p. 178-179). Depths of burial stated in this reference range from 10,000 to 15,000 feet. Judging from this and from the fact that clay present in many rocks of the Tertiary formations of the upper Nehalem River basin is entirely smectite, it would seem that the depth of burial of these rocks did not exceed this, if it even approached it. Stratigraphic evidences bear out this conclusion also.

In the Cowlitz Formation smectites are as prominent as in the other Tertiary formations of this area, although very little volcanic glass is associated with it. Here again, diagenesis is the probable explanation for most of the smectite and would account also for the lack of glass, which has been completely altered to form the clay matrix of these argillaceous rocks.

Smectites are not especially prominent in the Scappoose Formation, although some volcanic glass is present. The fact that the Scappoose Formation is predominantly arenaceous and contains very little clay matrix and few mudstone units would account for this. It is more likely that the smectite in the Scappoose Formation is largely of detrital origin, although this present study was not thorough enough to prove this.

One occurrence of smectitic clay is of interest. At one locality (Plate I, sites 132, 133) atop a ridge of Pittsburg Bluff mudstone, a brick-red soil contains enough smectitic clay to be visibly expandable when placed in water. The soil has a "popcorn" texture due to the alternate swelling and shrinking upon wetting and drying. The red coloration is due to concentration of hydrated iron-oxides by downward migration of ground water from once-overlying flows of the Columbia River Group (see discussion of general stratigraphy, Scofield Surface, p. 78). Modal analyses of thin sections from the underlying mudstones of the Pittsburg Bluff Formation exposed along U.S. Highway 26 (Sunset Highway) reveal the presence of large amounts of fresh, unaltered volcanic glass. The original cut at this locality was made in 1945. A count of 200 grains (sample 8-64) 43μ and larger revealed 30.5 percent glass shards. As was pointed out earlier in this paper, in 1965 the Sunset Highway was widened and the face of the road cut was moved back some 20 feet, exposing fresh essentially unaltered rock. A new sample (1-9-8-65) taken at the same locality as sample 8-64 and a count of 200 grains 43μ and larger revealed 50 percent glass shards. It is probable that even within a few years' time normal weathering has decreased the amount of volcanic glass. Thus the swelling soil might be accounted for by the weathering of this highly tuffaceous mudstone of the Pittsburg Bluff Formation at this locality.

In every characteristic this soil resembles bentonite. Grim (1968, p. 569), however, flatly states that bentonite is not formed by a weathering process. He considers that ash accumulation in water is necessary for the formation of bentonite. Since much bentonite is found in sequences of marine sedimentary rocks, it is supposed that alteration takes place in sea water soon after or possibly contemporaneously with accumulation of the volcanic ash. Thus bentonite would be formed syndiagenetically, to use the term of Bissell, cited and explained by Larsen and Chilingar (1967, p. 33).

The swelling soil was not noted at other exposures of the Pittsburg Bluff mudstones over the Scofield Surface, many of which lie at the same topographic and stratigraphic elevations. For the most part, other brick-red soils on the Scofield Surface seem to be the products of weathering of basalt of the Columbia River Group and are not swelling. (See discussion of the Scofield Surface, page 78). Although the one occurrence of swelling clay discussed above may be the remnant of a particular bed, it seems unusual that it is not found cropping out in nearby exposures of the Pittsburg Bluff Formation.

One other sample (174) was found upon disaggregation to be highly swelling. Other than this rock sample (174) and the soil discussed above, no other swelling material is found in the area of this study.

Kaolin

Criteria for identification of kaolin are given in Table 12. Methods of sample preparation when kaolin and chlorite occur together are given on page 166.

The only sediments in which kaolin is found are those of the Cowlitz Formation. In the claystones, mudstones and siltstones of the Cowlitz Formation, there appears to be a definite correlation between the presence of kaolin and the abundance of smectite in the sedimentary rock (see Appendix E). In the samples studied for clay mineral content, those sediments with large amounts of smectitic clays tend to have little or no kaolin (9 out of 12 samples) while kaolin is generally always present in sediments with only moderate amounts of smectites (9 out of 11 samples). In the sandstone member of the Cowlitz Formation this correlation does not appear and in one of the three samples studied both kaolin and smectite are very abundant.

One relationship of kaolin to overall lithology of the mudstone member of the Cowlitz Formation at locality 159, on the Nehalem River, is of interest. Beds of mudstone alternate with beds of calcareous pebbly volcanic muddy sandstone. The pebbly sandstones, samples 159B and 159D, both contain sparry calcite which has replaced much of the matrix so that volcanic rock fragments and other framework grains are "floating" in calcite cement. The absence of kaolin in these calcareous beds can be explained in two ways. Larsen and Chilingar (1967, p. 105) state that illite and kaolin are particularly susceptible to flocculation by Ca^{+2} ions and thereby will take up less interstitial space in some sandstones, allowing the remaining pore space to be filled with precipitated carbonate. Reactions between the clay and the carbonate, as proposed by Eades and Grim (1962, p. 168):

$$\text{Kaolinite or illite} + Ca^{+2} \longrightarrow \begin{array}{l}\text{calcium silicate hydrate or}\\ \text{calcium aluminum hydrate}\end{array}$$

would then destroy any kaolin present. It must be noted that mica (illite?) is present in these samples, but this could be explained by pH conditions around 8, at which kaolin is considered unstable while illite can be stable. The second possible explanation is that these beds accumulated at very slow rates so that kaolin was being altered to chloritic or illitic mica, a process which Grim (1968, p. 530) believed to be taking place in the Gulf of California at the present. The thinness (from 0.5 to 1.0 foot, see Appendix A) of these beds, lack of laminations and other structures indicative of slow sedimentation and the presence of rather uniform bottom to top grading would seem to militate against this second explanation. Furthermore, the abundance of kaolin in subjacent and superjacent beds of the same series which are not appreciably calcareous, probably due to lack of initial pore space and very low permeability, would favor the first explanation. Additional evidence in favor of carbonate replacement of kaolin is afforded by the presence of a white residue from acid (HCl) digestion of the carbonate cement in samples 159B, D, and F. This was not identified but in all probability it is a hydrated calcium aluminum silicate. Very probably other similar sedimentary sequences in the mudstone member of the Cowlitz Formation can be expected to have the same clay mineral-carbonate relationship.

Grim (1968, p. 541) regards the presence of kaolin in ancient sediments as definitely reflecting a kaolinitic source area, because kaolin, according to him, "is not found in the sea." Furthermore, he regards kaolin as indicative of rather rapid accumulation of sediments so that syndiagenetic alteration is not as likely to occur. The fact that in the Cowlitz sediments of this present study kaolin does not seem to be present in rocks with high smectite content could possibly be explained on the basis of diagenetic alteration to chlorite, which is generally present in those beds with large amounts of smectite.

In the Cowlitz Formation near Castle Rock, Washington, 35 miles northeast of the locality of this present study, a high-alumina clay deposit which is rich in kaolin is known and was mined for many years. Allen and Nichols (1943, p. 1823) describe this deposit as,

> resting on a water-laid breccia on which a weathering profile developed before deposition of the clay. The high-alumina clay is of sedimentary origin. It is in part a stream deposit, in part a swamp deposit, and some of it, especially, the fine-grained facies, is lacustrine. Some of the clay may have been derived from the weathering profile, developed on the breccia.

They regard much of the clay as developed outside the depositional area and later transported to it. A concentration such as this would argue for detrital clay in other parts of the Cowlitz Formation, such as in the area of this present study.

The absence of kaolin in the Keasey, Pittsburg Bluff and Scappoose Formations and the presence of very large amounts of volcanic detritus would suggest the lack of kaolin in the source areas of these sediments. This would be true of a provenance with a high calcium content, which, according to Grim (1968, p. 518), favors the formation of smectite and defeats the formation of kaolin. A greater amount of rainfall and poor drainage also will favor the formation of smectites in preference to kaolin (Grim, 1968, p. 518).

Mica (Illite?)

Weaver (1956, p. 205) points out that the largest part of illite in ancient sediments is of the 2 M variety, which is simply one of the structures of ordinary muscovite (Deer and others, 1966, p. 201) and must have been derived from high temperature (metamorphic) muscovite. Deer and others (1962, p. 223) point out that although Dietz and others have held that illite might be produced from montmorillonite in diagenesis by the absorption of potassium from sea water, this would require some extensive redistribution of ions in octahedral and tetrahedral lattice sites. Considering the general feeling of many, for example Biscaye (1965, p. 828), that clay mineral species found in marine sediments most commonly have a detrital origin and the fact that these Tertiary sediments of the upper Nehalem River basin have large amounts of megascopic muscovite, it seems unnecessary to make a distinction between finely comminuted muscovite (clay-size) and the clay mineral illite. For that reason, it would probably be best to simply refer to this as mica.

No special interpretation is made of this mica (illite?) which is common in all formations of this study.

Chlorite

Chlorite, like the 10Å clay material, appears in nearly all samples studied (Table 17, Appendix D). No attempt was made to identify the polymorphic form of the chloritic clay. Chloritic material in micaceous flakes is commonly present in the greater than 43μ size-fraction and is obviously detrital. Therefore, it is probable that much of the chlorite in the clay-size fraction of these sediments is also detrital. This is further supported by the presence of actinolite and epidote in a great many of the heavy mineral fractions, indicating a low grade metamorphic provenance as one of the sources for these minerals. Some of the chlorite is probably formed by diagenetic alteration of smectitic clays, as noted by Larsen and Chilingar (1967, p. 144) or by alteration of degraded illite, a weathering product, as mentioned by Grim (1968, p. 545).

Non-Clay Minerals in Clay-Size Fraction

In addition to clay minerals, some non-clay minerals are found in the clay-size fractions of these Tertiary sediments. Quartz is ubiquitous and produces pronounced 4.26Å and 3.343Å peaks in diffractograms. It is sometimes as abundant in the clay-size fraction as some of the clay minerals themselves. Feldspars, both of the potash and plagioclase species, are nearly always present, as revealed by strong diffractogram peaks at 3.24Å (potassium feldspar, Jenne, 1966, p. 31) and 3.22 to 3.17Å (Brown, 1961, p. 471). Since both types of feldspar are included in the study of the light mineral fraction of framework grains, no special note is made of either in the clay-size fraction other than their presence. In some samples plagioclase is definitely more abundant than potash feldspar, but for the most part the two types are about equally abundant.

A number of samples from all formations except the Scappoose show the presence of zeolite minerals (Table 17, Appendix D). Using data given by Mumpton (1960, p. 356) and Deer, Howie and Zussman (1963, vol. 4, p. 412), all but one of these were identified as either clinoptilolite or heulandite on the basis of the persistence of the 9Å peak after heating to 550°C. Mumpton (p. 359) states that heulandite, which has very similar d-spacings, being, according to Hay (1966, p. 11), simply a member of an ion exchange series involving Ca, Na and K, with a Si/Al ratio of from 2.7 to 5.0, is unstable above 350°C and becomes amorphous. One sample of fine sandstone from the Keasey Formation contains stilbite; clinoptilolite is found in seven samples and heulandite in one sample.

Origin of the Zeolites

Hay (1966, p. 81) points out that clinoptilolite is a characteristic zeolite formed in marine tuffs from diagenetic alteration of glass of rhyolitic composition, although he also reports clinoptilolite in some tuffs of intermediate composition (1966, Table 5). He also notes the common association of clinoptilolite and montmorillonite (1966, p. 217) in his montmorillonite subfacies of the clinoptilolite facies in the John Day Formation of Oregon. Smectite is very abundant in all samples in which clinoptilolite occurs in rocks of this present study. Biscaye (1964, p. 824), in his studies of the 2μ to 20μ size-fraction of two pre-Recent cores and of Recent deep-sea clay of the Atlantic Ocean and adjacent seas and oceans reports the presence of a 9Å zeolite which he assigns to the clinoptilolite-heulandite series, although he found no conclusive evidence to account for its presence either by diagenetic reactions, submarine volcanic action, or terrigenous sediment contribution.

In the Pittsburg Bluff and Keasey Formations there is an abundance of volcanic glass and mineral detritus, much of which is of intermediate to acidic composition, so that the most plausible origin for clinoptilolite in the clay-size fraction of the sediments of these formations is through diagenetic alteration of the glass. The universal presence of quartz in the clay-size fraction also supports the diagenetic origin of zeolites. Larsen and Chilingar (1967, p. 140) point out that large amounts of silica are released in the transformation of glass to zeolites. Stilbite in sample 110C could also be of diagenetic origin, because, according to Kostov (1960, as quoted by

Deer, Howie and Zussman, 1963, p. 354-355), the energy index of stilbite is inversely related to the energy of formation and Al:Si ratio. Because of this it is possible that stilbite could form at temperatures associated with diagenesis almost as easily as could clinoptilolite.

In the Cowlitz Formation, however, the presence of clinoptilolite is not so easily explained in terms of diagenesis. Where volcanic detritus is present, it all appears to be of basaltic to intermediate composition. In one sample, 172B, clinoptilolite is present in a sandstone of the mudstone member which is overlain by a submarine basaltic lava flow. In the lower siltstone of the Cowlitz Formation, which is known to be interbedded with basaltic flow rocks, clinoptilolite is probably present also. In the sandstone of the Cowlitz Formation, neither heulandite nor clinoptilolite is present. The presence of clinoptilolite in the Cowlitz Formation could be explained more easily in terms of detrital contributions rather than by diagenetic reactions, although the association of clinoptilolite-bearing sediments with submarine basalts is puzzling.

It is probable that a more concerted study of the 2μ to 20μ size-fraction by X-ray techniques might reveal a wider distribution and greater amount of zeolite minerals than was detected in this study. Due to the wider scope of mineralogic study undertaken in this present work, this was not attempted.

Summary of Mineralogy of the Clay-Size Fractions

Tertiary sediments of the portion of the upper Nehalem River basin studied in this present work include smectite, illite, chlorite and mixed-layer clays, probably most illite-montmorillonite in the Cowlitz, Keasey and Pittsburg Bluff Formations. Smectites dominate all other clay-minerals in the sediments of these formations. Kaolin is restricted to the Cowlitz Formation; it is much more abundant in sediments with lower smectite content and is frequently absent from sediments where smectite forms the majority of all clay present.

Non-clay minerals in the clay-size fraction include quartz, potash feldspar, plagioclase feldspar, and, in tuffaceous mudstones with large amounts of smectite, clinoptilolite. This zeolite is diagenetically formed from volcanic glass.

SEDIMENTATION

During late Eocene the region of the upper Nehalem River basin was receiving sediments from both volcanic and plutonic source rocks. Much of the volcanic detritus was derived from areas immediately adjacent, such as volcanic islands. A few current directions which were ascertained in the Cowlitz Formation indicate some source area to the south, which would agree with the opinion of Snavely and Wagner (1963, p. 11-14) that volcanic islands and islands of uplifted sedimentary rocks of the Tyee Formation existed in the north-central part of what is now the Coast Range of Oregon during the late Eocene. Interbedded with the mudstones and siltstones of the lowermost Cowlitz Formation are basaltic breccias, submarine flows of the Goble Volcanics and conglomerates derived from the volcanics indicating that some of the centers of volcanic activity lay within the western margin of the upper Nehalem River basin. Almost all the detritus in the muddier sediments of the lowermost Cowlitz Formation is derived from volcanics and basaltic intrusions west of the Nehalem River all contain mudstone inclusions.

Volcanism was intermittent. The arkosic sandstones of the lower part of the Cowlitz Formation are almost entirely free of volcanic rock fragments and glass. Sediments from plutonic igneous and metamorphic source areas, along with some derived from older sedimentary rocks were supplied to the region of the upper Nehalem River basin from the northeast. These were probably derived from the Rocky Mountains and brought to the upper Nehalem River basin by the ancestral Columbia River. They constitute a much greater quantity than the sediments derived from erosion of the volcanic islands to the south of the upper Nehalem River basin. The Columbia River today carries arkosic sediments. In reaches east of the present Cascade Mountains, the Columbia River sediments are rich in quartz, and potash feldspar is equal to or exceeds plagioclase (Whetten and others, 1969, p. 1158). It is probable that the volcanic islands may not have stood very high above sea level and that they might have been rapidly eroded to sea level in much the same manner as some modern volcanic islands of the western Pacific or the North Atlantic oceans. A great volume of the Siletz River Volcanics and the younger Goble Volcanics is considered to have been submarine. If centers of volcanic action were never built very high above sea level then sediments derived from these areas would not be spread outward for any great distance or for any long period of time.

The fact that many of the sandstone beds of the Cowlitz Formation are considered texturally submature (see Table 14, Appendix C) due to lack of clay matrix indicates that these sediments were deposited at a lower rate and subjected to higher energy conditions than the muddier sediments of the mudstone member of the Cowlitz

Formation. The less mature siltstones and mudstones of the uppermost Cowlitz commonly show less stratification than the well-laminated sandstones of the sandstone member of the Cowlitz Formation.

During the time of deposition of the mudstone member of the Cowlitz Formation and the lower member of the Keasey Formation there was renewed basaltic and andesitic volcanic activity. Palagonitic detritus in the pebbly, muddy sandstone beds of these two formations suggests that much of the volcanic activity was submarine. Although large volumes of volcanic sediments were available there was still a considerable amount of detritus contributed by the ancestral Columbia River from acidic to intermediate igneous plutonic and volcanic rocks and from medium rank metamorphic rocks, from a Rocky Mountain provenance northeast of the upper Nehalem River basin. Some of the arkosic sediment present in the mudstones and sandstones of the upper Cowlitz and lower Keasey Formations was probably supplied from the southwest where islands exposing arkosic sandstones of the Tyee Formation existed during the late Eocene. Intertonguing siltstones, mudstones and pebbly, muddy sandstones of the Cowlitz and Keasey Formations were deposited in a shallow shelf environment with variation in sediment supply both in time and place.

Although the submature arkosic sandstone and the ripple-laminated siltstones and mudstones of the lower member of the Keasey Formation show that sedimentation rates slowed somewhat and energy available for moving and reworking the sediment increased, the conditions of deposition and the sediment supply must have been nearly the same as those during the deposition of the mudstone member of the Cowlitz Formation. Lithologically there is little justification for separating the mudstone member of the Cowlitz and the lower member of the Keasey into two rock-stratigraphic units. It would be best to include them both in the lower member of the Keasey Formation.

During the Oligocene deposition continued in essentially the same type of environment that existed during the late Eocene in the region of the upper Nehalem River basin except that there were no centers of basaltic volcanic activity. The thickness of most sedimentary units of the middle members of the Keasey and the Pittsburg Bluff Formations indicate a greater volume of sediments supplied to the region than the volume supplied during deposition of the lower Keasey Formation. The massive character of tuffaceous mudstone beds and load deformation structures show that rates of sedimentation must have been high and the deposits must have been thixotropic. The thinner, better stratified rocks of the uppermost Keasey and the lower member of the Pittsburg Bluff Formation suggest lower rates of sedimentation than rates during deposition of the middle members.

The provenances of Keasey and Pittsburg Bluff sediments still included basaltic volcanics to the southwest and the acidic and intermediate igneous plutonic rocks and the metamorphic rocks of the Rocky Mountain region to the northeast, just as in the late Eocene. However, rhyolitic and andesitic or dacitic volcanic detritus was added to the sediments being deposited. This latter material was probably derived from the region of the Cascade Mountains and from central Oregon to the east. Beds composed almost entirely of rhyolitic to dacitic volcanic ash and pumice indicate that periodic outbursts of pyroclastic activity dominated the sediment supply from the east during the time of deposition of the upper member of the Keasey Formation. Because of the rapid sedimentation during the deposition of the middle member of the Keasey Formation water depths were decreased. Local conglomerate (locality 117), pebbly, muddy sandstone beds and well-stratified siltstones show that the sediments in the uppermost Keasey Formation and the base of the overlying Pittsburg Bluff Formation were deposited at or near wave base. The fact that sediments of the Pittsburg Bluff Formation in the northern part of the upper Nehalem River basin, in the type locality, are coarser than sediments in the southern part of the basin suggests that the direction of sediment transport was from the north or northeast toward the south or southwest.

Subsidence of the shelf area and rapid rates of deposition for the middle member of the Pittsburg Bluff Formation are shown by the thick massive character of these beds. Influx of highly tuffaceous, clay-sized rhyolitic to andesitic volcanic sediments took place intermittently. Load compaction in the rapidly accumulating debris caused disruption of clay interbeds. Rapid sedimentation rates did not, however, prevent the existence of an active burrowing fauna which continually stirred the tuffaceous muds.

Cessation of subsidence with continuing high rates of sedimentation caused a shallowing of the water during deposition of the upper member of the Pittsburg Bluff Formation. Coarser sediments, intermixture of plant debris, local conglomerates, and slump structures, such as intraformational breccias, indicate that the environment of deposition during the late Oligocene was changing from shallow shelf to deltaic. The sediments of the Scappoose Formation are part of a large delta system of the ancestral Columbia River, although in the areas of this present study the sediments of the Scappoose Formation were deposited on the outer fringes of the deltaic environment. Increased amounts of arkosic debris and greater mineralogic maturity suggest that the sediments of the Scappoose Formation were derived from the Rocky Mountain plutonic and metamorphic provenance of moderate to low relief to the east. Volcanic activity to the east of the region of the upper Nehalem River basin is shown by the persistence of andesitic and basaltic glass and rock fragments in the sediments.

Following deposition of the sediments of the Scappoose Formation emergence and deformation of the region of the upper Nehalem River basin brought about the development of a topography of moderate relief upon which basaltic lavas of the Columbia River Group were extruded from local vents. The same deformation caused faulting which brought about uplift of the Rocky Point area, allowing the Nehalem River and its immediate tributaries to remove the Scappoose, Pittsburg Bluff and Keasey Formations and most of the mudstone member of the Cowlitz Formation in the vicinity of Rocky Point.

CONCLUSIONS

Physiography

The present topography of the southern half of the upper Nehalem River basin has been carved in an older surface. West of the Nehalem River, accordant ridge summits at about 1, 200 feet suggest a temporary base level and development of an accordant topographic surface. East of the Nehalem River, in the drainage of the West Fork of Dairy Creek, remnants of this accordant surface dip gently to the southeast, forming a cuesta-like dip slope. The Keasey, Pittsburg Bluff and Scappoose Formations now exposed in this eastern area were once buried by flows of the Columbia River Group. Red lateritic soils and remnant patches of the basalt, together with feeder dikes of basalt exposed in several quarries, give clear evidence of the former covering of lava which probably retarded erosion. The stripped or structural plain developed on the resistant flows of the Columbia River Group in the region east of the divide between the Nehalem River and the Dairy Creek-Tualatin River drainage systems I propose to call the "Scofield Surface," after the hamlet of Scofield located thereon.

Stratigraphy

Cowlitz Formation and Goble Volcanics

Cowlitz Formation

Careful study of the sandstones and siltstones of the Cowlitz Formation in the upper Nehalem River basin indicate that their lithology is essentially the same as that of the type Cowlitz in the Stillwater Creek and Olequah Creek area 35 miles to the north. Deacon's name "Rocky Point Formation," proposed in 1954 for beds of the Cowlitz age along Rock Creek and Nehalem River should therefore be abandoned.

Mudstones, siltstones and pebbly, muddy sandstones which crop out along the Nehalem River were divided by Warren and Norbisrath (1946) on the basis of paleontological evidence into the upper shale member of the Cowlitz Formation and the lower member of the Keasey Formation. There is some lithologic basis for this division in that the beds which have been included in the lower Keasey member have more primary structures (ripple laminations, cross-laminations, graded bedding, load deformation and structures produced by burrowing organisms). However, there seems to be no other justification for separation of the upper series of beds of this sequence along the Nehalem River and the Sunset Highway from the underlying uppermost Cowlitz beds. Paleontological evidence does not demand separation of the lower part of the Keasey into a new unit if one follows the arguments of Kleinpell and Weaver (1963) regarding the lag in evolutionary change with regard to physical changes in the depositional environment.

In view of this evidence it would seem logical to include all of the mudrocks and pebbly, muddy sandstones exposed along the Nehalem River and Sunset Highway in the Keasey Formation. The siltstones and sandstones west of the Nehalem River would then constitute the Cowlitz Formation.

Goble Volcanics

The lowermost siltstones and sandstones of the Cowlitz Formation interfinger with basaltic lava flows and breccias which are part of the Goble Volcanics. Pebble to boulder conglomerates occur locally where these volcanic rocks and the sediments are found together and submarine lava flows and intrusions were penecontemporaneous with sedimentation. At Rocky Point large masses of Goble Volcanics are clearly intrusive into Cowlitz sandstones and siltstones.

Warren and others (1945) named the upper Eocene basaltic rocks of this western part of the upper Nehalem River basin the Tillamook Volcanic Series. However, the interbedded and interfingering relationship between the Cowlitz Formation and the basaltic rocks in this area make it appear more logical to refer to them as the Goble Volcanics Member of the Cowlitz Formation.

Pittsburg Bluff and Scappoose Formations

The division of the beds in the vicinity of Buxton into the Pittsburg Bluff Formation and the Scappoose Formation by Warren and Norbisrath (1946, p. 231) on the basis of faunal evidence is also amply justified on the basis of lithology. Almost all the rocks of the Scappoose Formation are silty sandstones and sandy siltstones whereas the underlying Pittsburg Bluff Formation consists of much muddier sediments.

Columbia River Group

Basaltic lava flows of the Columbia River Group once covered the area of the Scofield Surface. These basalts probably also covered the area just to the west of the Scofield Surface, since basaltic cobbles and pebbles of Columbia River lithology are found along the eastern tributaries of the Nehalem River.

"Nehalem Group"

Since the sedimentary rocks of the Cowlitz, Keasey, Pittsburg Bluff and Scappoose Formations are so much alike in texture and composition it is proposed that they be given group status. The name "Nehalem Group" seems appropriate considering the typical exposures of these formations in the upper Nehalem River basin. Deacon previously suggested (1954, p. 60) the name "Nehalem Formation" for parts of the Keasey Formation, but for reasons stated on page 55 of this report, there seems so little justification for this subdivision that the name is not considered to have valid priority.

Structure

Uplift, warping and faulting of the rocks of the upper Nehalem River basin caused mild deformation of these Tertiary strata. In general, the strata strike northeast and dips range from a few degrees to as much as 20° southeast. Siltstones and sandstones of the Cowlitz Formation west of the Nehalem River strike northwest and dip southwest in the Clear Creek and Lousignont Creek areas. In the region of Fall Creek, on the northeast flank of Rocky Point, these same beds dip northeast, due to up-faulting of the Rocky Point ridge area (see Plate II). The regional trend of faulting is northwest throughout most of the area.

Petrology

Sandstones

A typical sandstone of the Nehalem Group is a silty immature arkose or lithic arkose (Folk, 1968). Potash feldspar may equal or exceed plagioclase feldspar in abundance in about 50 percent of any sandstones sampled. Some very thin sandstone beds are muddy volcanic litharenites.

Mudrocks

The largest volume of sediments of the upper Nehalem River basin consists of tuffaceous arkosic mudrocks, sandy mudstones and siltstones. Except for the lower parts of the Keasey and Pittsburg Bluff Formations, most mudstone and siltstone beds are several feet thick and apparently massive. Extensive "stirring" of these sediments by burrowing organisms accounts for the massive character of the strata. Interbeds of tuffaceous claystone a few inches thick are almost universally found in the mudstone and siltstone sequences throughout the area.

Warren and Norbisrath and other workers have consistently referred to these mudrocks as "shales," even so naming members of formations, for example the upper shale member of the Cowlitz

Formation (Warren and Norbisrath, 1946, p. 224). None of these mudrocks are shales, however, since they show almost no fissility or tendency to split along bedding planes. According to Twenhofel (1936-37, p. 98), Williams and others (1954, p. 326), Pettijohn (1957, p. 341), and various other authorities, the term shale should be applied only to those rocks with the tendency to split along bedding planes.

Clay Mineralogy

Smectites are the dominant clay minerals in nearly all of the sedimentary rocks of the upper Nehalem River basin. Mixed-layer clays, mostly illite-montmorillonite are commonly present. Kaolinite is restricted to the Cowlitz Formation where it is of detrital origin, having been formed where feldspathic rocks were weathered under conditions of moderate rainfall and good drainage. Clinoptilolite has been formed in the clay-sized fraction of many of the tuffaceous sediments.

Sedimentation

The sediments of the upper Nehalem River basin were accumulated in an environment which changed from shallow marine flanking volcanic islands during late Eocene time to shallow continental shelf during Oligocene time. The uppermost strata (Scappoose Formation) probably was deposited in the outer fringes of a delta system of the ancestral Columbia River. Basaltic to andesitic volcanic activity during the late Eocene was intermittent. Arkosic sediments from a plutonic and metamorphic provenance to the northeast were at times supplied to the region in greater volume than volcanic detritus. During the early and middle Oligocene, however, rhyolitic and andesitic volcanics in the mainland area to the east contributed most of the sediments (see Figure 63). By the end of the Oligocene, volcanic sediments from the east and sediments from plutonic and metamorphic provenances to the northeast were supplied in about equal volumes.

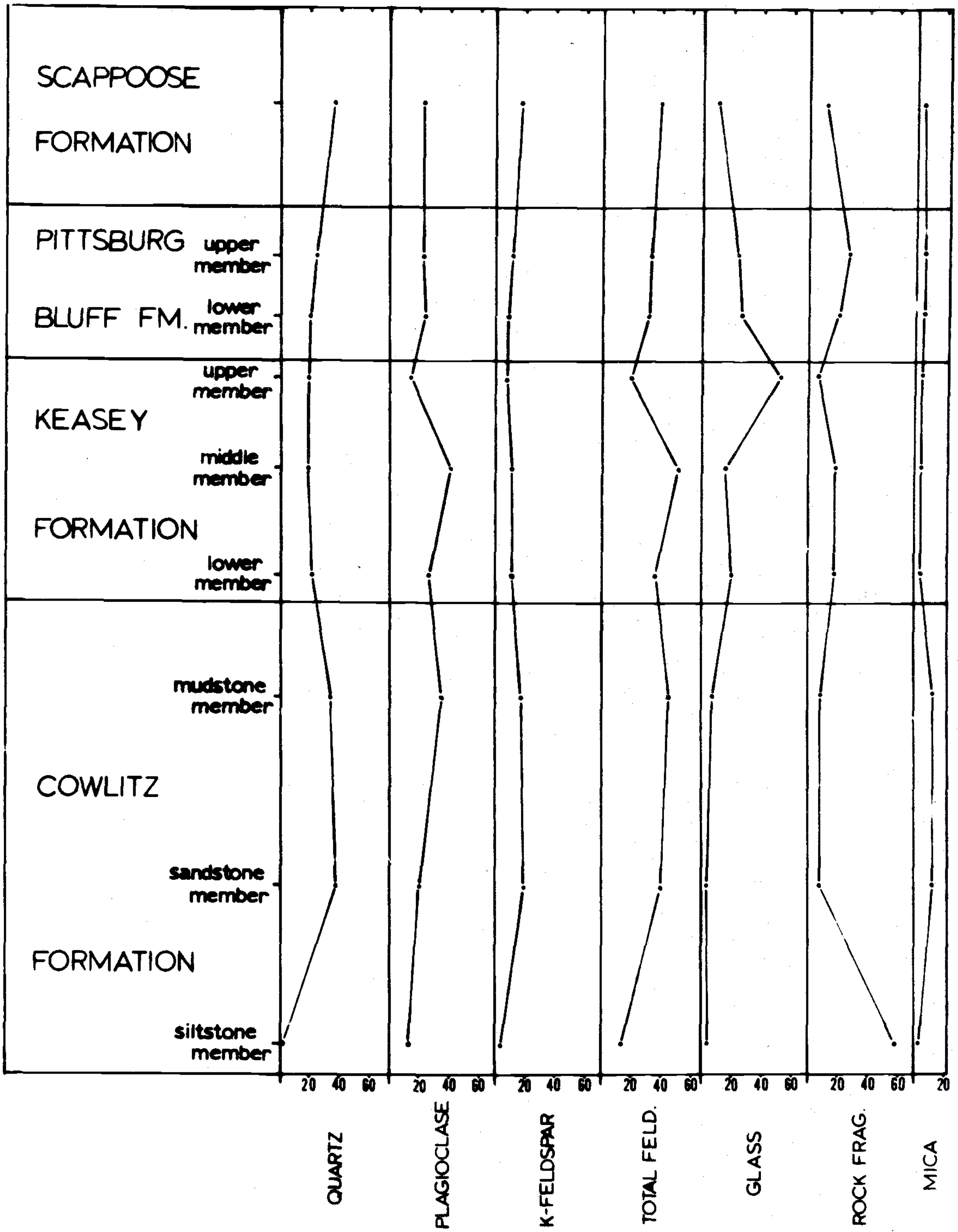


Figure 63. Variation in lithologic composition (based on formation and member averages).

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APPENDICES

Appendix A

NEHALEM RIVER SECTION

Unit Number	Description	Thickness (feet)
	Keasey Formation Lower Member	
72	Dark gray mudstone with 2-4 inch greenish volcanic sandstone and one 2 inch bed of highly glauconitic volcanic sandstone ("greensand")	10. 0
71	Greenish gray coarse-to-medium-grained muddy volcanic sandstone	2. 5
70	Dark gray coarse-to-medium-grained muddy volcanic sandstone. Groove casts oriented N. 10° E.(current direction)	3. 0
69	Dark gray coarse-to-medium-grained muddy volcanic sandstone. Graded bedding	1. 2
68	Greenish gray coarse-to-medium-grained muddy volcanic sandstone. One inch mudstone interbed with coarse sand mixed in top of mudstone. Graded bedding. Flame structure (?) at top of bed	1. 2
67	Greenish gray pebbly muddy pumiceous glauconitic volcanic sandstone. Graded bedding with upper 0. 2 foot sandy mudstone. Sole marking?	1. 0
66	Dark gray pebbly muddy pumiceous volcanic sandstone graded to dark gray glauconitic mudstone with upper 2 inches coarsely to finely laminated	1. 3
65	Dark gray compact calcareous mudstone. Fossils: <u>Delectopectin</u> (sp?), foraminifera. Indistinctly laminated	0. 15

Unit Number	Description	Thickness (feet)
64	Dark gray-green pebbly muddy volcanic sandstone with scattered claystone clasts (intraformational breccia?) graded to dark gray siltstone and mudstone. Upper portion of bed is glauconitic and fossiliferous, with Delectopectin (sp?) and foraminifera	1.2
63	Dark gray pebbly muddy pumiceous volcanic sandstone graded to very dark gray-green calcareous muddy siltstone to mudstone	4.0
62	Dark gray mudstone with a few 1-2 foot pumiceous muddy volcanic sandstone interbeds. Small "ball-bearing" concretions, fossils, abundant Natica, Dentalium, foraminifera, crustacea in concretions. Pronounced jointing striking N. 24° E. Some burrower holes filled with silt, and indistinct lamination, cross-lamination and flame structure showing possible current direction N. 10°E. in lower 25 feet	(estim.) 189
61	Dark gray micaceous mudstone with clots of silt and coarse muscovite and biotite flakes (up to 3 mm in diameter)	44
60	Dark gray finely laminated carbonaceous micaceous mudstone. Laminae composed of light gray silt and coarse muscovite and biotite (2-3 mm diameter), carbon, finely comminuted wood and other plant debris	4
59	Dark gray laminated to thin-bedded micaceous carbonaceous mudstone. Burrower holes filled with gray silt. Weathers buff to yellow-brown	6
58	Dark gray sandy mudstone, mottled with clots of light gray silt. Appearance of having been "stirred" by burrowing organisms	16

Unit Number	Description	Thickness (feet)
57	Gray mudstone with light gray thinly laminated siltstone interbeds 1 to 6 inches thick. Mudstone interbeds show flame structures and loadcasts and compaction deformation at contact with siltstone beds. Current direction from flame structures, NE	10
56	Dark gray discontinuous claystone laminae and beds, 5 to 15 mm thick interbedded with light gray ripple laminated siltstone	10.0
55	Gray non-indurated siltstone	0.25
54	Dark gray mudstone with thin light buff siltstone interbeds. Upper 4 feet is siltier and shows ripple laminations and cross laminations	42.0
	base of Keasey Formation ----------- conformable (?) contact --------- top of Cowlitz Formation	
53	Dark green pumiceous glauconitic calcareous coarse-grained muddy sandstone. Graded bedding	5.5
52	Dark gray glauconitic concretionary calcareous sandy siltstone. Basal 1 inch non-indurated and sandier. Resistant ledge-forming bed	2.5
51	Dark gray sandy mudstone. Scattered clots of sandy pumiceous material. Fossiliferous	1.5
50	Gray pumiceous, calcareous sandy siltstone. Sparry calcite cement with large (1 to 2 cm) calcite crystals	0.5
49	Dark gray massive mudstone. Weathers into a flaky dark yellow-brown material	3.2
48	Dark gray calcareous sandy siltstone. Concretionary and resistant ledge-forming bed	1.25

Unit Number	Description	Thickness (feet)
47	Dark gray massive mudstone	2.1
46	Dark gray calcareous fine-to-medium-grained muddy sandstone. Concretionary and ledge-forming. Distinct knife-edge contact with unit 45 below	0.75
45	Dark gray micaceous massive mudstone	1.5
44	Greenish-black calcareous muddy volcanic sandstone. Graded from pebbly muddy sandstone at base to medium sandstone at top. Concretionary and ledge-forming	0.6
43	Dark gray micaceous concretionary mudstone. Top has load casts of pebbly volcanic sandstone from unit 44 above. Resistant and ledge-forming	73.0
42	Dark gray micaceous pumiceous massive silty sandstone. Sparse spherical to lensoid calcareous concretions	1.5
41	Dark gray pumiceous siltstone to mudstone, graded in lower portion of bed	1.5
40	Dark gray pumiceous siltstone to mudstone, graded	0.6
39	Dark gray massive mudstone. Siltier in upper part of bed	22.2
38	Gray calcareous, concretionary siltstone. Resistant, ledge-forming	0.5
37	Dark gray massive mudstone	17.2
36	Gray, calcareous concretionary siltstone. Resistant, ledge-forming	0.5
35	Dark gray micaceous pumiceous sandy siltstone. Fossiliferous (gastropods)	31.6

Unit Number	Description	Thickness (feet)
34	Dark gray calcareous, micaceous silty sandstone. Concretionary, ledge-forming	0.5
33	Dark gray micaceous, pumiceous muddy siltstone. Fossiliferous	1.5
32	Gray calcareous, pumiceous, silty sandstone. Concretionary, resistant ledge-forming	0.5
31	Dark gray, pumiceous muddy siltstone	31.8
30	Dark gray faintly laminated calcareous siltstone	1.5
29	Dark gray, laminated calcareous pebbly siltstone	2.5
28	Dark green-gray calcareous, glauconitic pebbly sandstone to coarse-grained sandstone. Indistinct contact with unit 27 below	0.5
27	Dark gray massive mudstone	1.0
26	Dark greenish gray calcareous, glauconitic pebbly sandstone. Contact with unit 25 below is sharp, except for occasional load casts and stringers of pebbly sandstone in mudstone below	0.5
25	Dark gray calcareous mudstone	0.8
24	Poorly exposed. Dark gray mudstone	26.0
23	Dark greenish-gray calcareous pebbly muddy sandstone	1.0
22	Dark gray siltstone	2.0
21	Gray calcareous siltstone	0.5
20	Dark gray sandy siltstone	88.0
19	Interbedded thin dark gray mudstone, siltstone and greenish-gray calcareous pebbly muddy sandstone	5.15

Unit Number	Description	Thickness (feet)
18	Poorly exposed. Dark gray calcareous sandy siltstone to mudstone. Concretionary	88. 0
17	Dark gray calcareous, concretionary siltstone. Resistant, ledge-forming	0. 75
16	Dark gray siltstone	2. 5
15	Dark gray, calcareous, concretionary siltstone. Resistant, ledge-forming	0. 75
14	Covered	2. 0?
13	Dark gray calcareous, concretionary siltstone. Resistant, ledge-forming	0. 67
12	Covered	1. 0?
11	Gray calcareous, concretionary siltstone	0. 25
10	Dark gray, pebbly muddy sandstone	0. 25
9	Poorly exposed. Dark gray, massive, micaceous sandy siltstone. Partly concretionary. Sparsely fossiliferous	640
8	Dark gray, micaceous concretionary mudstone	20. 0
7	Dark gray calcareous sandy siltstone	0. 4
6	Dark gray micaceous silstone	0. 55
5	Dark greenish-gray calcareous pebbly muddy sandstone. Resistant, ledge-forming	1. 0
4	Dark gray sandy mudstone	1. 0
3	Dark gray calcareous, concretionary sandy siltstone. Resistant, ledge-forming	0. 5

Unit Number	Description	Thickness (feet)
2	Dark gray, micaceous, sandy siltstone	9.1
1	Poorly exposed. Dark gray, massive mudstone base not exposed	?
	Total thickness	1115.4

Appendix B

Table 13. Size Analysis of Disaggregated Samples. Sand + Silt + Clay = 100%. Statistical Parameters after Folk, 1968. (Samples in Approximate Stratigraphic Order)

Sample	Sand	Silt	Clay	Mdϕ	Mz	σ_i	Sk_i
SCAPPOOSE FORMATION							
206	66%	32%	2%	3.15	3.62	1.70	1.80
203A	53	44	3	3.9	4.23	1.45	0.40
202	70	20	10	3.5	4.08	1.92	0.73
147	84	12	4	1.55	2.62	2.80	0.58
148	33	52	15				
PITTSBURG BLUFF FORMATION							
89F	53%	35%	12%	3.87	4.76	2.15	0.59
89E	48	31	21	4.10	5.37	3.14	0.64
89B	83	11	6	2.68	3.01	1.53	0.60
124	1	46	53	--	--	--	--
1-1	30	34	36	5.20	--	--	--
1-2	50	25	25	3.98	--	--	--
1-3	32	34	34	5.00	--	--	--
1-4	32	33	35	5.05	--	--	--
1-8	35	31	34	4.9	--	--	--
1-10	38	23	39	4.5	--	--	--
1-12	38	20	42	4.5	--	--	--
1-13	36	30	34	4.5	--	--	--
1-15	32	22	46	5.65	--	--	--
1-16	32	24	44	5.65	--	--	--
1-20	37	28	35	4.7	--	--	--
243B	62	23	15	--	--	--	--
30	11	55	34	--	--	--	--

Table 13. continued

Sample	Sand	Silt	Clay	Mdϕ	Mz	σ_i	Sk_i
PITTSBURG BLUFF FORMATION (continued)							
44G	20%	64%	16%	--	--	--	--
67B	24	54	22	--	--	--	--
126	15	71	14	--	--	--	--
69D	7	60	33	--	--	--	--
2A	55	33	12	--	--	--	--
5A	81	12	7	3.5	3.8	1.3	0.62
KEASEY FORMATION							
114D	2%	67%	31%	--	--	--	--
81	2	40	58	--	--	--	--
117C	35	52	13	4.7	5.06	2.4	2.3
99	13	86	1	--	--	--	--
90	12	80	8	--	--	--	--
110C	41	41	18	--	--	--	--
93	1	48	51	--	--	--	--
247_1	42	28	30	--	--	--	--
145	4	50	46	--	--	--	--
143K	--	--	43	--	--	--	--
143B	--	--	16	--	--	--	--
155C	1	58	41	--	--	--	--
151	2	60	38	--	--	--	--
154C	17	48	35	--	--	--	--
154E	4	71	25	--	--	--	--
152	44	38	18	4.2	5.32	2.7	0.74
150	77	22	1	2.90	3.37	1.33	0.6
141	9	47	44	--	--	--	--
140	2	62	36	--	--	--	--

Table 13. continued

Sample	Sand	Silt	Clay	Mdφ	Mz	σ_i	Sk_i
KEASEY FORMATION (continued)							
191At	49%	30%	21%	4.2	--	--	--
191Ab	43	31	26	4.85	--	--	--
192	9	75	16	--	--	--	--
176Gb	16	38	46	--	--	--	--
176A	14	65	21	--	--	--	--
177	4	68	28	--	--	--	--
34	19	41	40	--	--	--	--
33	3	61	36	--	--	--	--
COWLITZ FORMATION, MUDSTONE MEMBER							
226	45%	40%	15%	4.30	5.0	2.6	0.42
138	9	44	47	--	--	--	--
136.5	5	62	33	--	--	--	--
171	3	82	15	--	--	--	--
171b	18	49	33	--	--	--	--
170	1	60	40	--	--	--	--
169E	4	58	38	--	--	--	--
169C	7	54	39	--	--	--	--
167E	5	59	36	--	--	--	--
163E	?	?	7	--	--	--	--
163Eb	13	?	?	--	--	--	--
163A	16	?	?	--	--	--	--
161	28	51	21	--	--	--	--
157	1	72	27	--	--	--	--
159G	1	84	16	--	--	--	--
159E	3	82	15	--	--	--	--

Table 13. continued

Sample	Sand	Silt	Clay	Mdϕ	Mz	σ_i	Sk_i
COWLITZ FORMATION, MUDSTONE MEMBER							
159D	?%	?%	35%	--	--	--	--
159C	15	33	52	--	--	--	--
159B	15	78	7	--	--	--	--
159A	2	66	32	--	--	--	--
172B	36	45	19	4.90	5.37	2.85	0.43
COWLITZ FORMATION, SANDSTONE MEMBER							
136C	34%	50%	6%	--	--	--	--
136A	29	62	9	--	--	--	--
86B	58	29	13	--	--	--	--
85	42	43	15	4.7	--	--	--
225	24	49	27	5.30	6.50	3.45	0.35
200	75	17	8	2.50	3.20	1.99	0.69
229E	64	26	10	2.9	3.90	2.28	0.72
229A	54	36	10	3.80	4.70	2.10	0.65
230	16	71	13	4.80	5.28	2.30	0.41
210	91	6	3	2.70	2.70	0.87	0.27
215	69	28	3	3.30	3.70	1.45	0.48
214	82	16	2	3.0	3.20	1.10	0.5
213B	23	58	19	--	--	--	--
211A	43	23	34	--	--	--	--
179	36	54	10	4.1	4.60	1.70	0.71
187	78	18	4	3.2	3.4	1.18	0.67
217	93	6	1	2.5	2.50	0.73	0.28
84A	5	75	20	--	--	--	--
258	15	61	24	--	--	--	--

Table 13. continued

Sample	Sand	Silt	Clay	Mdϕ	Mz	σ_i	Sk_i
COWLITZ FORMATION, SANDSTONE MEMBER (continued)							
255_3	1%	81%	19%	--	--	--	--
250	11	78	11	--	--	--	--
38	8	73	19	--	--	--	--

Appendix C

Table 14. Mineralogical and Textural Maturity of Sandstones and Siltstones. (Samples in Approximate Stratigraphic Order)

Sample	Mineralogical Maturity (Pettijohn, 1957) $\frac{Q}{F+G+R}$ [a]	Index	Textural Maturity (Folk, 1968) % Clay	σ_i [b]	ρ_Q [c]	Stage
SCAPPOOSE FORMATION						
206	46/48	0.96	2	1.70	3.0	Submature
203A	22/64	0.34	3	1.45	3.0	Submature
202	24/69	0.35	10	1.92	3.0	Immature
147	54/42	1.29	4	2.80	3.0	Submature
148	38/54	0.70	15			Immature
235	21/71	0.30				
236	30/59	0.51				
249	11/53	0.21				
Mean		0.58				
Mean, #147 excluded		0.48				
PITTSBURG BLUFF FORMATION						
89F	31/65	0.48	12	2.15	3.0	Immature
89E	12/82	0.15	21	3.14	3.0	Immature
89B	12/79	0.15	6	1.53	3.0	Immature
124	19/80	0.24	53			Immature
Mean 1-20	39/58	0.67	36			Immature
42A	45/54	0.83				
44G	19/78	0.24	16			Immature
109a	2/98	0.02				

Table 14. continued

Sample	$\frac{Q}{F+G+R}$ [a]	Index	% Clay	σ_i [b]	ρ_Q [c]	Stage
PITTSBURG BLUFF FORMATION continued						
97	13/85	0.15				
67B	19/68	0.28	22			Immature
121	23/59	0.39				
126	26/70	0.37	14			Immature
69D	3/76	0.04	33			Immature
Mean		0.28				
KEASEY FORMATION						
81	61/30	2.03	58			Immature
82	37/60	0.62				
70B	5/23	0.22				
114D	27/65	0.42	31			Immature
114B	5/99	0.05				
117C	5/90	0.06	13	2.4	3.0	Immature
110C	6/93	0.06	18			Immature
103	15/83	0.18				
93	20/76	0.26	51			Immature
175	22/69	0.32				
247_1	15/80	0.19	30			Immature
143Ib	16/58	0.10				
143Bt	2/92	0.02	16			Immature
155C	43/33	1.30	41			Immature
151	16/76	0.21	38			Immature
154C	28/52	0.54	35			Immature
150	45/54	0.83	1	1.33	3.0	Submature
142A	21/81	0.26				

Table 14. continued

Sample	$\frac{Q}{F+G+R}$ [a]	Index	% Clay	σ_i [b]	ρ_Q [c]	Stage
KEASEY FORMATION continued						
141	8/86	0.09	44			Immature
140B	9/72	0.13	36			Immature
176Gb	9/83	0.11	46			Immature
176A	9/91	0.09	21			Immature
Mean		0.37				
Mean, #81, 155C excluded		0.24				
COWLITZ FORMATION, MUDSTONE MEMBER						
226	8/51	0.16	15			Immature
138	31/69	0.45	47			Immature
171	27/65	0.42	15			Immature
170	32/57	0.56	40			Immature
169E	40/56	0.71	38			Immature
169C	53/36	1.47	39			Immature
167E	52/45	1.16	36			Immature
167B	26/70					
163E	27/71	0.38	7		3.0	Immature
157	28/70	0.40	27			Immature
159G	20/63	0.32	16			Immature
159E	11/73	0.21	15			Immature
159D	29/66	0.44	35			Immature
159C	21/70	0.30	52			Immature
159B	42/56	0.75	7			Immature
159A	28/65	0.43	32			Immature
172B			19	2.85	3.0	Immature
Mean		0.51				
Mean, #169C, 167E excluded		0.40				

Table 14. continued

Sample	$\frac{Q}{F+G+R}$ [a]	Index	% Clay	σ_i [b]	ρ_Q [c]	Stage
COWLITZ FORMATION, SANDSTONE MEMBER						
86B	36/52	0.69	13			Immature
85	41/46	0.89	15			Immature
200	45/45	1.00	8	1.99		Immature
229E	60/35	1.71	10	2.28		Immature
230	12/35	0.34	13	2.30		Immature
210	47/40	1.16	3	0.87	3.0	Submature
215	38/48	0.79	3	1.45		Submature
214	42/32	1.31	2	1.1		Submature
213B	10/60	0.17	19			Immature
187	48/46	1.04	4	1.18		Submature
217	37/56	0.66	1	0.73	3.0	Submature
179	11/68	0.16	10			Immature
Mean		0.83				
COWLITZ FORMATION, SILTSTONE MEMBER						
84			20			Immature
258			24			Immature
255_1	0/93	0.00	19			Immature
250	2/98	0.02	11			Immature
38	1/31	0.03	19			Immature

[a] Q = quartz; F = feldspar; G = volcanic glass; R = rock fragments

[b] σ_i = Folk's inclusive graphic standard deviation, in phi units (1968, p. 46)

[c] ρ_Q = Roundness of quartz, Power's scale

ABREVIATIONS USED IN TABLE 15

GENERAL TERMS

alt-altered
anh-anhedral
bcca-breccia
b-g-blue-green
blk-black
brn-brown
chp-chips
clr-clear
crl-colorless
cs-coarse
do-ditto
dsk-dusky
dus-dusty
ech-etched
eu-euhedral
fibrs-fibrous
fr-fresh
frc-fractured
GM-grain mount
grn-green
gry-gray
liq-liquid
lrg-larger than median
lt-light
olv-olive
pk-pink
plbrn-pale brown
ple-pleochroic
pr-prism
rx-rock
stchd-stretched
suh-subhedral
TS-thin section
ylw-yellow

MINERAL AND ROCK TERMS

Quartz
- chal-chalcedony
- incl-inclusions
- mono-monocrystalline
- polyx-polycrystalline
- sut-sutured
- und-undulose

Feldspar
- micr-microcline
- or-orthoclase
- per-perthitic
- sndn-sanidine

Plag. Feldspar (P-spar)
- andes-andesine
- lab-labradorite
- olig-oligoclase
- + k-potassic olig.

Glass
- fltd-fluted
- palag-palagonitic
- pmc-pumice
- rhy-rhyolitic
- shds-shards
- vesc-vesicular

Rocks
- ampb-amphibolite
- chrt-chert
- diab-diabase
- fol-foliated
- gr-granitic
- mcgr-micro granitic
- meta-metamorphic
- porp-porphyritic
- qtzt-quartzite

Rocks (cont.)
- sed-sedimentary
- vlc-volcanic
- vtph-vitrophyre

Glauconite
- celad-celadonite
- pell-pellets

Opaques
- hem-hematite
- ilm-ilmenite
- leuc-leucoxene
- mag-magnetite
- pyr-pyrite

Amphiboles (amph)
- act-actinolite
- glp-glaucophane
- trm-tremolite
- ox-oxyhornblende

Pyroxenes
- aeg-aegerine
- dio-diopside
- en-enstatite
- hed-hedenbergite
- pid-piedomontite

Epidote Group
- clz-clinozoisite
- ep-epidote
- pie-piedomontite
- zoi-zoisite

Zircon
- + gl-with adherring volcanic glass

Tourmaline
- sch-schorolite

Al Silicates
- al-aluminum
- and-andalusite
- ky-kyanite
- st-staruolite

Other
- brk-brookite
- ido-idocrase
- mtc-monticellite
- spinl-spinel

Roundness
- RR-very well-rounded
- R-well-rounded
- r-sub-rounded
- a-sub-angular
- A-angular

TABLE 15. MINERALOGY OF SAND AND COARSE SILT
(Samples in approximate stratigraphic order)

SCAPPOOSE FORMATION

	LIGHTS								HEAVIES												
									Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type	Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmal'ne	Garnet	Al-Silic	Other
209 TS	clr		An_{59} lab	75% brn bs	vtph sltst	musc bio			1+ grn												
206 GM	46% clr incl	13% micro or?—	20% An_{28} olig	2% vesc	13% sed (ss) gr	6% bio (musc)		mag ilm leuc pyr	2 grn ox		2	2 ech		2 ep grn	3	2 5:1 R eu crl pk ylw		5	5 pk anh (eu)	5 ky	5 rut
203A GM	22% clr incl	16% micr or	33% An_{30} An_{33} andes olig	5% clrl micr vesc fltd	10% mcgr vlc sed chrt	11% bio musc	<1% grn pell	mag ilm leuc pyr	2 grn brn b-g	5 trm	3 ech	2 ech & not	· dio	3 ep zoi	3	4 eu +gl crl	4 crl	5	4 pk crl		5 rut
202 TS GM	24% polyx	17% micr or	31% An_{33} andes	3% clr brn	18% vlc mcgr chrt	5% bio	1% pell	mag leuc	3 grn brn ox	2 trm	2 ech	2 ech & not	dio	4 ylw-grn zoi	4 ech	5 r eu crl anh	3 A-R crl	5 grn	4 crl		
147 GM	54% clr sut	14% micr or	16% znd An_{28}-An_{45} olig-andes	7% clr plbrn vesc fltd	5% phll mcgr vlc vtph chrt	2%		mag ilm leuc	2 brn grn		1 ech	1		2 ep ylw grn	3				1 pk cs	4 ky cs	4 rut

Table 15 (Continued)

	LIGHTS								HEAVIES														
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar AnX	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
148 TS GM	38% clr	17%	16% znd An_{60} lab	18% clrl brn vesc pmc chrt	3%	5% musc bio		mag pyr ilm leuc		1 grn ox	3 act trm	2 ech	2 eu suh	3 en aeg	3 ep ylw grn	4	3 r-a eu R pk crl ylw	3 crl ylw r-R	3	3 crl pk	4 and	
201D TS 201B TS	clr polyx clr do 201A	micr lrg	do	sample pmc	201A vtph dlrt		alt rx celad			1 grn ox		1										
201A TS	clr polyx	micr lrg	An_{33}- An_{49} andes znd	shds clrl	vtph mcgr ampb gr chrt					1 grn cs		1 cs									4 and	
235 GM	21% clr	25% per	20% An_{30}- An_{31} andes olig	16% brn clr	10% vtph mcgr chrt	5% bio musc	1%			1 ech grn ox b-g	2 trm	2	3	dio	2 ep zoi clz	4 ylw	3 eu crl ylw A-r	3 crl a-R	4 eu brn	4 crl pk A-a	5 ky	
236 GM	30% clr incl sut	29% micr or	14% +K- olig	1% brn clr vesc	15% vlc mcgr sed chrt meta	9% bio musc chl	none seen			1 grn brn ox	2 trm	4	4 ech		2 ep zoi	4	3 eu brk 6:1	5 crl	4 grn	5 crl	5 ky st	

Table 15 (Continued)

Sample	LIGHTS: Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type	HEAVIES	Amph: Hnblde	Amph: Other	Pyroxene: Augite	Pyroxene: Hypers	Pyroxene: Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
249 GM Dutch Cnyn Type Loc.	11% clr incl	9%	20% An_{33} andes fr, alt	18% crl brn fltd vesc	6% sed mcgr vlc chrt	musc	28% gry-grn pell	mag ilm leuc		1 grn ox	5 trm	2 ech	2		4 ep zoi	4	4 6:1 +gl	4 crl		4 pk		
87 GM						bio brn musc		mag ilm leuc hem pyr		1 grn ylw ox	3 trm act	3 frc	4 suh prm		3 ep clz	4 ylw	3 R eu ylw brn pk 6:1		3 grn ylw	4 crl anh	4 and ky	4 rut
PITTSBURG BLUFF FORMATION																						
124 GM	19% mono non-und polyx und sut	20% micr per	29% An_{41}-An_{43} andes znd	12% clr fltd brn	19% chrt mcgr ss fol meta	2% bio brn musc				1 grn brn	4 trm	2	4 lrg brn		2 ep zoi clz	3 ylw eu chp	3 R eu ylw crl brn	4 r	4 ylw brn grn	4 chp ylw crl pk	5 ky	5 rut
237B TS	7% mono liq incl	6% micr	14% An_{30}-An_{25} olig	51% plbrn crl fltd brn fltd	18% vtph chrt qtzt	4% bio olv brn				1 grn olv-grn	2 trm	2 ech	2		3 ep zoi	3	3 a-A crl dsk		4	3 crl		5 rut

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar Anx	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
240A GM	11% mono non-und polyx und	5% micr per or 4xMd	16% An_{46} An_{41} An_{32} 5xMd	19% crl-fl fltd brn vesc	39% vtph chrt mcgr	10% bio olv-brn				1 grn olv-grn	3 trm	1 ech lrg	2 ech a-r lrg		2 ep zoi	3	3	3 one 16:1		3		5 rut
89F GM	31% clr polyx und sut	17% sndn micr	23% An_{10}-An_{30} Albit	8% crl fltd vesc shds	17% ss vlc chrt	4% bio brn musc				1 grn brn ox	2 trm	3 pid	3	dio	3 ylw grn	2	3 R eu crl pk	3 crl dus	3 ylw grn	3 pk crl ylw		4 rut
89E GM	12% clr polyx	16% micr lrg	30% olig An_{32} andes	12% brn fltd rhy	24% mcgr vlc meta chrt	5% bio brn musc				1 grn ox	2 trm act	3	3		3 ylw grn	3 ylw crl	3 R pk crl	3 r-a ech crl	3 sch brn	3 A crl pk ylw	4 ky	4 rut
89B GM	12% clr mono non-und polyx	10% micr lrg	19% olig An_{45} znd	10% crl fltd vesc dus	40% meta mcgr vtph chrt wacke vlc porp	8% bio brn musc		mag ilm leuc (pyr)		1 brn grn ox	3 trm	1+	2 ech		3	5	4 4:1 eu anh crl		5 ylw brn	4 A pk		5 rut ol?

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
1-1 TS	46%		26%	23%	6%																	
1-8 TS	36%		26%	33%	5%					1 grn ox	4 trm	1	3		4 ep zoi		4	4		4		
1-10 TS	35%		26%	26%	13%																	
1-12 TS	40%		27%	27%	5%					1 grn ox	4	1	3		4 ep zoi		4	4		4		
1-16 TS	40%		38%	13%	8%																	
1-20 TS	37%		23%	33%	7%																	
42A GM	45% clr polyx und	10% micr <u>or</u>	22% An_{47} andes znd	1% crl fltd vesc	21% vtph vlc cht mcgr	1%	<1%	mag ilm leuc		1 grn olv brn ox	5 trm	2 cs ss (.9)			2 ep zoi	2 ylw crl	3 crl A-a		4	2 ylw red pk		5 rut
44G GM	19% clr polyx und sut	7% micr	30%	21% crl brn	20% chrt vlc mcgr meta fol	2%		mag		1 grn brn	4 trm	2			2 ep	4 anh eu	3 crl	3 r-a crl		3 crl ylw pk		

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
109A GM	2% chalc		10%	41% pmc crl brn	47% vlc- porp vtph- porp		2% pell ylw- grn															
97 GM	10- 15% clr incl		5-10% znd	75- 80% crl fltd brn vesc				pyr														
67B GM	19% clr polyx und sut	7% micr per	20% An_{30}- An_{31} znd	23% crl brn	18% chrt mcgr meta fol	2%	11% dk- grn pell			1 grn ox	trm	2 frc	1 ech	5 en	2 ep ylw grn zoi	5	3 R ylw eu	3 R crl dsk	4 eu blk	3 crl pk 3x Md	4 and ky	5 rut
121 GM	23% clr polyx und	20% micr or	27% An_{37}	5% brn crl fltd incl	17% vtph chrt vlc	8% bio musc chl				1 grn brn					3 ep zoi		3	3 eu	3	3		
126 GM	26% clr polyx und	10% micr or	33% An_{37} An_{33}	4% brn fl	23% vtph vlc meta fol	5% bio musc				3 grn ox	2 trm	3 ech	ech		1 ep zoi	2	2 11:1 r-R pk ylw crl	3 crl dsk r	2 crl grn ylw grn	2 pk crl ylw	5 ky	4 rut

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_X	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
69D GM	3%	4%	20%	16%	36% vtph chrt	3%	17%			2 grn ox		1 A	4 a					3 crl eu		pk 3-4 xMd		4 rut
3C GM		or		crl brn						1 grn ox		1	2		3	4	4	3				
5A GM		or								1 grn ox		1	2		3 ep	4	4	3		5		
KEASEY FORMATION																						
81 GM	61% clr polyx	12%	11%	6% fltd	1% chrt mcgr	9% bio brn				2 brn grn		4			3 ep grn		3 eu R crl ylw		1 grn ylw brn			4 eu 10:1
82 GM	37% clr	20%	35% An_{39}	2% fltd vesc	2% vtph	4%				grn		ech					a crl eu	R crl prm				
70B	5%		3% lab	17% shds tube vesc	3% chrt vlc		11% fil'd vesc pell celad															

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnble	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
114E GM	clr		olig andes	82%																		
114D GM	27% clr	28% micr or	29% olig	5% brn crl	3% chrt	6%		pyr carbn		1 grn ox		2	3		2 ep clz	4	3	2	3	3 ylw pk	5 ky st	5 rut
114B GM	5% clr vlc	1% micr	4% znd An_{36} An_{64}	87% clr brn small	7% sed vlc gbbro	1% bio grn brn musc		mag		grn ox												
74B TS	clr		An_{29}	>40% fltd shds clr brn	bsalt vlc vtph																	
117C GM	5% clr		6% An_{60}	68% bsalt	16% vtph chrt	3%	1%			5 ox	5 trm	1	2		3			3 r crl				
H2 (est)	clr		<1%	99% brn clr		<1% bio lrg							5 dio									
99 GM	clr incl	micr	99%+ An_{52}-An_{70}	brn crl	vlc vtph					5 eu		1	3				4 eu	3 crl				

Table 15 (Continued)

Sample	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar Anx	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
99C GM	polyx		cs znd	to50%	porp gbbro					4 grn ox		1 suh	3 suh				4 ech	3				
90 GM	clr incl			99%+ pmc	vtph	bio grn musc				2 grn ox	trm glp	1	4 r		1 ep zoi clz	4	3 9:1 crl pk eu R	4 r crl	3	3 RR crl pk		5 rut
110C GM	6% clr		30% An_{53}-An_{60}	30% crl to dk brn	33% vtph	2% bio				4 grn		1 90-95%	4		4			4 crl				
103 GM	15%	1%	64% znd	9% ylw brn clr	9% vtph gbbro	2% bio								1 pid 99%		5						
93 GM	20% clr incl chal polyx	27% micr or sndn	41% olig andes	5% clr brn	3% vtph porp chrt	1% bio musc	2% celad pell			1 b-g grn ox	3 trm	2	5		2 ep zoi clz	3	4 crl +gl eu	4 R-r ple crl dsk	4	4 crl pk A		5 R

Table 15 (Continued)

	LIGHTS								HEAVIES														
										Amph		Pyroxene											
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
175 GM	22% clr	13% micr or	25% znd basic	9% brn crl	22% vtph chrt porp	5% bio musc	1%			2 grn ox	5 glp	1			3 ep zoi		4 A crl	4 dsk ple crl		4		5 rut
247 GM	15% clr lrg	11% micr	39% znd	19% brn crl	11% vlc vtph	5%		mag		1 grn ox		1	3		4	4	4 8:1 +gl	4	4 crl ylw	4 eu pk crl		
143Ib GM	16% clr chal	1%	32% An_{56} znd lab	11% palag	14% vlc bsalt	1%	23% pell ox			1 grn ox		1						4 eu crl r dsk		5 R		
143B1 TS 143B TS	1.5%		15% An_{48} An_{52}	63% palag 98- 99% palag	14% palag tuff bcca 1-2% vlc porp bsalt An_{56}	1.5%		pyr														
155C GM	43% polyx und non- und	14% micr or	24% An_{24} olig	13% brn incl vesc fltd	3% chrt mcgr	3% brn high Ti Chl	pyr frags	mageu pyr ilm leuc		4 grn brn ox	4 act	4 ech	3 ech ple	4 hed	1 ep ylw grn	1 eu anh ylw	3 RR eu 4:1 r-a	2 R-a crl RR	3 eu pk grn		4 ky	5 rut

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
151 GM	16% clr polyx meta sut	42% micr or	28% An_{35}	<1%	5% chrt mcgr meta fol	9% bio musc chl		pyr		2 grn	trm	2	5		1 ep zoi	3 R	3 R crl	3 A-a crl	4 ylw grn crl	4 crl		
154C GM	28% polyx clr incl stchd	13% micr	18% An_{25}- An_{48}	.5%	20% chrt gr meta vlc porp	2%	18% dk grn pell			1 grn	4 trm	3 ech			2 ep zoi clz	4	4 R crl		4 ylw blk	2 A pk crl ylw 2-3 xMd		5 rut
150 GM	45% clr polyx sut stchd	22% micr per myrm or	21% An_{26}- An_{31} olig andes	<1%	10% chrt vlc porp mcgr meta	1% bio				1 grn ox	3 trm	3	5		2 ep zoi	4	4 crl eu			4 ylw	4 ky	
142A GM	21% clr	2% micr or	34%	11% vesc fl	34% vtph vlc porp																	

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_X	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
141 GM	8% clr	11% micr or	37% An_{28}, 38, 49, 60	15% clr plbrn	23% vtph chrt pmc vlc diab	5%	1% pell															
140B GM	9% clr chal	5%	36%	12%	19% vtph chrt	4%	16% (one sample 64%)	pyr		1 brn		1										
176Gb GM	9% clr	7% or	24%	46% brn	12% vtph mcgr	2%	5%	pyr 80% of heavy mins		1 grn ox		2			2	4		4 crl		4 crl pk		
176A GM	9% clr	1% or	27% An_{42} An_{57}	33% dus	30% vtph vlc porp		1%			1 grn ox		1 ech			2 ep zoi	4	4 crl	4 crl		4 crl		
177 GM	clr	micr	An_{31}	brn	vtph vlc porp			pyr ilm		1+ grn brn ox		3 grn 2x Md	5		3 ep grn ylw	4	4 eu	3 a-r pk	5	5 pk		

Table 15 (Continued)

COWLITZ FORMATION																						
	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
226b GM	32%	15% micr per	37% An22 An37	2%	8%	7% bio 4% musc				1 grn brn	3 trm	4			2 ep	3	4 r-R crl	3 R dsk crl	3 ylw blk	3 crl pk	5 ky	5 rut
138 GM	31% liq incl clr	13%	30% An20- An24 An40- An47	10% micro vesc clr chps brn fltd	16% chrt vtph vlc mcgr	1% bio musc	<1%	45% mag 20% pyr 17% ilm 9% leuc 6% hem		1 olv brn grn b-g ox	4 trm		4 4x Md ple		2 ep grn ylw	2 R-a ylw	3 A-R eu anh pk crl	2 anh eu R-r crl ylw	3 A-a brn eu suh	3 A-R crl pk ylw		
137 GM	9%	20%	27%	24%	1% mcgr	19% bio red- brn grn- brn	mageu ilm hem			1 grn b-g ox		4	3 eu- suh ech		2	2	3 eu A- RR pk	2 eu- anh crl dsk A-R	3 eu	3 a-r crl pk eu		
136.5 GM						bio brn chl		mag pyr		3 grn ox			4	en	1 ep ylw grn	2	4 R crl	2 R dsk	4 ylw grn	3 pk crl R-A		

Table 15 (Continued)

Sample	LIGHTS								HEAVIES														
										Amph		Pyroxene											
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
191At GM										1 grn		2			2 ep	3	3 r	3 R	4	A	5 ky	
192 GM	18% polyx sut clr	41% micr sndn myrm	31% An_{8} An_{14}- An_{22} An_{35}	$<$ 1% micro vesc crl rough brn	3% chrt mcgr	6% bio musc chl		mag ilm pyr		4 grn ox		2 ech	2		1 ep clz ylw grn	3 crl ylw		3 eu- suh R-a	ylw olv grn brn- blk	4 crl pk A		rut brk ol
171 GM	27%	11%	36% An_{30} An_{60}	14%	4%	5% bio brn		mageu ilm leuc pyr		2 grn b-g ox	4 trm		5 suh eu		4 zoi ep	3 Md ylw tan	4 10:1 crl pk eu R	crl	4 eu pk brn	3 A-r pk		rut eu
170 GM	32%	13% micr	39% An_{16}- An_{25} An_{35}	1%	4%	7% bio brn rut incl	4%	pyr mag ilm leuc		1 grn b-g	4 trm	4 ech 3x Md	4 ech	dio	2 ep zoi grn ylw clz	2 ylw crl	3 ylw 10:1 4:1	2 crl ylw pk	3 eu A	3 eu- anh pk ylw crl		4 mtc R-a ido
169E GM	40% clr polyx und sut	26% micr or	17% An_{6} An_{20} An_{30}	2% plbrn fltd fl	11% mcgr chrt vtph meta fol	4% bio musc	$<$ 1%	mag ilm hem leuc		1 grn	4 trm	2	4 2-3 xMd		1 ep zoi	3	3 A pk- red crl	2 r-R crl dsk	4 ylw brn grn	4 pk A	4 st and pk ylw	5 rut

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
169C GM	53%	14% micr	15% An_{20}-An_{32}	1%	6% chrt	14% bio chl	4%	mag ilm leuc pyr		1 grn ox	5 trm	4			1 ep zoi	3 crl	3 pk crl 13:1	2 crl brn	4	3 suh pk ylw	5 and ky	4 rut eu ol
167E GM	52%	17%	16% An_{15}-An_{25}	4%	8% chrt mcgr	5% bio brn grn	2% w/mag	pyr mag ilm leuc		1 grn ox	4 trm	4 A	5 r-a		1 ep grn ylw zoi	3	3 A-R eu-anh crl pk-red	2 crl ylw dus eu r	3 grn ylw eu	3 ylw pk A	5 ky	4 rut eu
167B GM	26%	8%	62%			4% bio brn red		pyr mag ilm leuc		4 grn		1 ech	1		4 ep	4 ylw	4 a	4		4 ylw A		5 rut
163Eb GM	27%	15% micr	47% An_{30}-An_{40}	1%	8% chrt mcgr	2% bio olv brn chl		pyr ilm leuc mag		1 grn b-g ox	4 trm	2 some 10x Md	4 pr		2 ep grn clz	3 ylw eu R	3 R eu ylw RR-R crl A-r 7:1	4 crl eu r	3 eu r ylw brn olv grn	3 crl ylw pk	5 and ky	4 rut eu, spinl ol

Table 15 (Continued)

Sample	LIGHTS: Quartz type	K-Spar	P-Spar An_X	Glass type	Rocks	Mica	Glauconite	Opaque type	HEAVIES	Amph: Hnblde	Amph: Other	Pyroxene: Augite	Pyroxene: Hypers	Pyroxene: Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
163A GM										2 b-g grn		1 75- 80%		en	3 ep	2	4 A-r eu	4	4	3 pk		
161 GM										1 grn ox	5 trm	4			1 ep zoi	3	2 R crl pk dsk	2 r-R	4 pk grn	3 crl ylw		4 rut
157 GM	28% clr	10% micr	47% An_{24}	3% mag incl	10% chrt	2% bio brn musc chl	1% dk grn fibrs	pyr mag ilm		1 b-g grn brn ox	5 glp	4	4		2 ep grn ylw	2 crl ylw eu- anh	3 a-r eu ylw crl	2 eu r crl dus	3 eu ylw brn olv	3 ylw crl eu- anh		5 rut eu
159G GM	20% mono non- und polyx und	15% micr or	25% olig	2-3% clr vesc	20% chrt vtph mcgr meta fol	15% bio				2 grn b-g ox		2			1	3	4 crl eu	2 crl A-r	4 pk ylw	4		
159E GM	15% clr non- und polyx sut	25% micr or	36% An_{30}	1% clr fltd brn fltd	11% vtph vlc porp chrt mcgr	11% bio musc	1% grn pell			1 grn ox	trm	2			1 ep zoi clz	2	3 2:1 eu r	2 ylw R	4	3 crl		5 rut

Table 15 (Continued)

	LIGHTS								HEAVIES	Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar Anx	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
159D GM	29% clr dus incl	7%	41% An_{20} An_{30} An_{58} znd	9% clr fl clr fltd	9% chrt vlc porp vtph	5% bio red- brn				3 grn olv brn	4 trm	1			3 ep	2	4 7:1 crl eu	3 crl R tan r	4 pk blk	4 crl A		
159C GM	21% clr incl chal	28% micr per	22% An_{8} An_{23}- An_{25}	9% crl vesc crl fltd crl fl	11% chrt qtzt mcgr	10% bio brn musc				2 grn 10- 15 xMd		3	5		2 ep zoi clz	2	4 pk R	2 crl r	4 ylw brn	2 pk crl eu		5 rut
159B GM	42% clr und polyx und	12% micr	39% An_{16} An_{28}	1% fltd brn	4% chrt vlc porp	2% bio brn chl musc				1 grn ox	3 trm	4			2 ep zoi	3 ylw	3 R pk A crl	4 crl R	4 grn	3 crl pk eu A-R	5 st	5 rut
159A GM	28% clr incl polyx und	25% micr or	37% An_{23}- An_{27}	1% tubes brn	2% chrt	7% bio musc chl		mag ilm pyr		3 grn		1 lrg	4 ech	5 en	1 ep grn ylw clz	2 ylw anh a	3 4:1 eu dus brn	2 R-r eu dus brn	4 ylw grn pk	2 crl pk ech A-r	5 and ky	
172B GM		---no	slide---					pyr mag ilm leuc		1 grn b-g ox	4 trm	2 ech	4	5 dio	2 ep zoi	3	3 eu RR pk +gl	3 dus 2-3 xMd	4	3 pk crl A-a		

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
174 GM								ilm mag leuc pyr		4 grn		4			3 ep zoi	2	4 8:1 eu	1 pr		4		
136A GM	8%		21%	2%	19%	1%	48%	mag hem ilm leuc		2 grn b-g ox		1 ech		5 dio	3 ep		4 A eu	4 R				
86B GM	36%	28%	20%		4%	6% bio musc				2 grn		2			1 ep	3	3 a eu	3	4 ylw blk	3 ylw pk crl	ky st and	
85 GM	41%	15% micr or	23% olig		8% chrt	7% bio musc				1 grn ol	3 trm	2			1 ep zoi	3	3 eu 10:1 R-a	2 a-r eu-suh	4 sch grn	3 ylw pk	4 st	5 rut
200 GM	45% clr incl polyx	21% micr or per	15% An_{25}	<1% crl fl shds	8% chrt mcgr	6% bio musc		carbn		1 ylw grn brn ech	4 trm act	4			2 grn ylw	2 brn ylw crl ech	3 crl pr 3:1	crl	4 pk brn eu crl	3 ylw red brn eu A	4 ky st	4 ol
229E GM	60% clr polyx und	7% micr or	24% An_{24-28} An_{37-49}	fltd	4% mcgr chrt	2% bio musc				1 grn ox	4 trm	3			3 ep zoi	3		4		4		

Table 15 (Continued)

	LIGHTS								HEAVIES													
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
230 GM	12% clr polyx	14% micr or	20% An_{26}	<1% fl shds	chrt mcgr	18% bio musc chl		36% carbn		1 grn ox					1 ep					crl		
210 GM	47% clr polyx	23% micr per sndn	10% An_{23}- An_{27}		7% chrt felsic	13% bio musc		pyr		2 grn ech ox	trm	3			1 ep zoi	2	4 r	4 dsk r	4 ylw blk	4 ylw crl	5 ky st	
215 GM	38% clr incl und polyx sut	23% micr or	16% An_7 An_{17} An_{33}	crl	9% mcgr meta qtzt	14% bio musc chl				4 grn		2			1 ep zoi	3			3 crl ylw grn	3 crl ylw		
214 GM	42% clr incl dus	12% micr or	9% An_{10} An_{23}	<1% crl fl shds	10% chrt grdio meta sht	20% bio musc				4 grn			5		1 ep zoi	3	3 R crl pk eu	4 crl r	3 ylw pk blk	4 crl a-r		5 rut
213B GM	10% clr incl dus	32% micr per	21% An_9 An_{19} An_{32}	<1% crl chps brn fltd crl fl	6% chrt qz sht meta	26% bio musc		carbn		1 grn ox			5		1 ep zoi	3		3 a crl		4 pk		

Table 15 (Continued)

	LIGHTS									HEAVIES												
										Amph		Pyroxene										
Sample	Quartz type	K-Spar	P-Spar An_x	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
187 GM	48% clr polyx und	18% micr per or	13% olig andes znd	<1% crl fltd brn dus	14% chrt	3% bio brn grn chl		mag ilm leuc pyr		grn brn ox	trm				1+ ep ol pie	1 brn ylw crl	2 eu R crl 10:1	3 R-r crl dus ech	3 pk grn ylw brn	3 pk red A-r		rut ol
217 GM	37% clr incl	17% micr or	31% An_{24} An_{37}	<1% crl	7% vlc chrt grdio meta qtzt	7% bio brn musc				1 grn brn b-g		4			2 ep	3	4 eu crl		4 ylw blk	4 crl pk	5 ky	
179 GM	11% clr und polyx	23% micr sndn myrm	40% An_{10} An_{30}	<1%	4% chrt	16% bio brn musc chl		carbn		1 grn b-g ox	4 trm	2	5 2-3 xMd		1 ylw grn	3	3 r-R crl 4:1	4	5	4 crl A ylw	5 ky	5 rut
84A GM								pyr in forams		2 grn ox		4	5		5 ep	2	2 R eu	1 r pr dsk	2 ylw brn grn	3 ylw crl eu		4 rut
255 GM		4% or lrg	26% An_{57} lab	2.5% clr fltd vesc	60% vlc porp znd P-Spr	8% bio musc				3 grn		1			4 ep		4 eu 7:1	3 crl r	4 crl ylw	4 crl r-A		

Table 15 (Continued)

Sample	LIGHTS								HEAVIES													
										Amph		Pyroxene										
	Quartz type	K-Spar	P-Spar Anx	Glass type	Rocks	Mica	Glauconite	Opaque type		Hnblde	Other	Augite	Hypers	Other	Epidote gp	Sphene	Zircon	Apatite	Tourmaline	Garnet	Al-Silic	Other
250 GM	2% clr	.3% or	3% An51 lab	1% clr fl	93% mcgr chrt vlc bsalt	.6% bio				3 grn		1	4		4 zoi	4		4 dsk				
38 GM	1% clr und	3%	8%	2% fltd	18% chrt vlc porp	<1% bio brn	68% dkgrn pell			3 b-g ox		1 grn lrg	4 12x Md					4				

APPENDIX D

Table 16. Thin Section Analyses of Basaltic Rocks

UNIT	Sample	An_{30-40}	An_{40-50}	An_{50-60}	An_{60-70}	Ferromags. and opaque	Glass	Alteration
COLUMBIA RIVER GROUP (East of West Fork Dairy Creek)	280_1			An_{56} - 33%		augite-10%	56%	nontronite
	280_2			An_{52} - 29%		augite-23%	39%	nontronite-7%
	281			An_{54} - 41%		augite-10%	49%	
	283			An_{54} - 47%		augite-26%	17%	nontronite
(Basalts of Scofield Surface)	53A			An_{54-58}				
	80		phenocrysts An_{48} - 24%			augite pigeonite-14%	black to brown-59%	nontronite zeolite-3%
	90	(non-porph.)		An_{54}				
Goble Volcanics (Rocky Point and Clear Creek)	172A				An_{68} - 28%	augite-19%	palagonite-40%	calcite-3% pyrite nontronite-10%
	212		An_{45} GM		An_{65} - phenocrysts			
	224		An_{48}				5%	
	227			An_{52} GM	An_{62} - phenocrysts	augite	15%-devitrified	
	228	(An_{32}??)	An_{42}? -56%			ilmenite	brown-strg. palagonite? -14%	
	232a			An_{52} - 73%	An_{60} - phenocrysts	augite-24% pigeonite	brown 4% palagonite?	nontronite
	242					pyrite augite-20%		
	252_2			An_{50}		augite (olivine)		
	277			An_{52} GM	An_{62} - phenocrysts	augite	15%-devitrified	
	278		andesine-54%			magnetite-15%	flow oriented	zeolites
	Col. Co.					augite-16%	15%	

Appendix E

Table 17. Clay Mineralogy of Selected Samples. Samples in Approximate Stratigraphic Order. (X = present; XX = abundant; ? = doubtful)

Formation	Sample	Smectite	Kaolinite	Chlorite	Illite (Musc.)	Vermic-ulite	Mixed layer	Zeolites
Scappoose	148	X	?	?	X			
Pittsburg Bluff	89E	X	?	?	X			
	89B	X			X			X
	124	XX			?			
	1-9-8-65	X	?	?	X			Clinoptilolite
	10-64	X	?	X	X			
	44G	XX	?	X	X			
	67B	X		XX				
	126	X		X				Clinoptilolite
	121	XX		X	X			
(Keasey?)	108	XX		X	X			
	109B	X						?
Keasey	69D	X		X	X			
	99	X		X				

Table 17. continued

Formation	Sample	Smectite	Kaolinite	Chlorite	Illite (Musc.)	Vermic-ulite	Mixed layer	Zeolites
Keasey continued	110C	XX		X	X			Stilbite
	111	X					X	
	103	X		?				?
	105	X		X	X		X	
	175	XX		X	?		X	?
	176A	XX		X				Clinoptilolite
	177	XX		?			X	Clinoptilolite
	155C	X		X	X		X	
	154C	XX						Heulandite?
	191Ab	X	X	X	X			
	192	X	X	X				
Cowlitz Mudstone member	174	X	XX	X	X			
	172B	X		?	X			Clinoptilolite
	170	X	XX	?	X			
	169C	X	?	?	X			
	167E	X	X	?	X	X		
	163Eb	?	?	X		X		

Table 17. continued

Formation	Sample	Smectite	Kaolinite	Chlorite	Illite (Musc.)	Vermiculite	Mixed layer	Zeolites
Cowlitz Mudstone member	161	X	?	X	X			
	159G	X	X	X	X			
	159D	XX		?	?			?
	159C	XX	X	?	X			
	159B	XX		?			X	
	159A	XX	XX	X	X			
	157	XX	X	X	X			Clinoptilolite
	138	XX	?	X	X			?
	136E	XX		X	X		X	Clinoptilolite
Sandstone member	229A	X	X	X	X			?
	213A	XX	XX	X	X			
	187	X	XX	X	XX		X	
	255_3	?	X	X				
	250	XX	?		X			
	84A	XX	X	X	X			?
	38	X		XX				