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Bedrock Geologic Map of the Seattle 30' by 60' Quadrangle, Washington

by

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INTRODUCTION

The Seattle 30' by 60' quadrangle, situated in the central Puget Lowland, bridges the Tertiary volcanic arc of the Cascade Range and the accreted sediments and volcanic rocks of the Olympic Mountains. The intervening Puget Lowland is covered by thick glacial, fluvial, and marine deposits of Quaternary age that make interpretation of the structural and stratigraphic configuration of the Tertiary rocks difficult. However, the Seattle quadrangle affords one of the few places where "stepping stones" of Tertiary bedrock protrude above the extensive blanket of Quaternary debris. This map, an interpretation of the distribution of Tertiary rock, is based on these outcrops and geophysical and subsurface geologic data.

This map is one of a series of bedrock and surficial geologic maps (Pessl and others, 1988; Whetten and others, 1988) that are meant, in part, to serve as a framework for earthquake-hazards related research in the Puget Sound region. The field work necessary for the preparation of this map was carried out intermittently between 1978 and 1983 and was supported by the Earthquake Hazards Reduction Program of the U.S. Geological Survey.

Our understanding of the geology of the region has been enhanced by our discussions with Parke Snavely, Rowland Tabor, Jim Minard, Ray Wells and Virgil Frizzell of the U.S. Geological Survey. Dave Engebretson of Western Washington University and Paul Heller of the University of Wyoming have shared information about the region gathered by themselves and their students. Weldon Rau of the Washington Division of Geology and Earth Resources kindly identified foraminifera and determined biostratigraphic stages for samples from the study area. Marty Flores (1978), Frank Salter (1979), and Glenn Dembroff (1982) ably assisted with the field work.

PREVIOUS WORK WITHIN AND NEAR THE QUADRANGLE

Willis (1886, 1897, 1898) made some of the earliest observations of the quadrangle's lithologies and geologic structure, as part of an evaluation of coal resources in the Puget Lowland. During these studies he recognized the association of the coal beds with the micaceous arkosic sandstones later termed "Puget group" by White (1889). Willis (1898) made detailed observations of the coal workings at two locales between Newcastle and Issaquah, along Coal Creek in the first instance and on the west side of Tibbetts Creek in the second.

Early workers recognized that the rocks of the Seattle area and those exposed in the northwestern portion of the quadrangle contained abundant molluscan faunas. Zonations of rock units in western Washington, based on their fossil associations were first proposed by Arnold (1906), Weaver (1912), Arnold and Hannibal (1913), Weaver (1916), and Weaver (1937). Although mainly biostratigraphic in nature, these studies introduced many of the "formational" names assigned to rocks within the quadrangle. Subsequent work in the Restoration Point area (Teglund, 1933) and on the Quimper Peninsula (Durham, 1942, 1944) refined the biostratigraphic zonations in those regions. Historical reviews of the development of the stratigraphic nomenclature applied to the rocks of Puget Sound and the Olympic Peninsula can be found in Armentrout (1975) and Addicott (1981).

Theses, principally by students at the University of Washington, have contributed significantly to the understanding of the bedrock geology of the Seattle quadrangle. Allison (1959), Thoms (1959), Sherman (1960), Hamlin (1962), and Ansfield (1972) contributed studies of the rocks west of Hood Canal. Reeve (1979) investigated the igneous rocks near Gold Mountain, on the Kitsap Peninsula. Fulmer (1975) refined the stratigraphy of the Blakeley Formation in the Bainbridge Island area.

Commodity-based studies (oil, gas, or coal investigations) by the U.S. Geological Survey added a great deal to the understanding of the rocks within and near the quadrangle. Brown and others

(1956), Brown and Gower (1958), and Brown and others (1960) refined the stratigraphy of the peripheral rocks of the northern Olympic Peninsula. Mapping of areas within or near the southeast part of the quadrangle was carried out by Warren and others (1945), Waldron (1962), and Mullineaux (1965a,b,c). Summary reports that clarified stratigraphic relations in these areas were produced by Wolfe and others (1961), Wolfe (1968), Vine (1969), and Mullineaux (1970).

Recently, map compilations of the area surrounding the Seattle quadrangle have been completed as part of ongoing regional geologic and earthquake hazard studies. Tabor and Cady (1978a) contributed an important map of the Olympic Peninsula. Tabor and others (1982) and Frizzell and others (1984) have published preliminary compilations of 30' by 60' quadrangles that adjoin the Seattle quadrangle on the east and southeast (Skykomish River and Snoqualmie Pass quadrangles). Whetten and others (1988) recently completed compilation of the 30' by 60' quadrangle lying to the north of the Seattle quadrangle (Port Townsend quadrangle).

GENERAL DESCRIPTION OF ROCKS AND THEIR DISTRIBUTION

Surficial Deposits

The Seattle quadrangle has been covered at least four times in the past two million years by ice lobes advancing out of the Coast Range Mountains of Canada and the mountains of Vancouver Island (Crandell and others, 1958; Waitt and Thorsen, 1983). Most of the quadrangle is covered by a complex mantle of till and gravelly to sandy outwash (*Qg*) that was deposited during the advance and retreat of the Puget Lobe during the last (Fraser) major glaciation of the region, some 10,000 to 16,000 years ago (Waitt and Thorsen, 1983). Areas along major rivers and streams are covered by alluvium (*Qal*) that was deposited after the retreat of the Puget Lobe as the modern fluvial drainage reestablished itself. These glacial and alluvial sediments cover older glacial and non-glacial sediments of Quaternary age that typically outcrop along the bases of sea cliffs and major fluvial valleys within the quadrangle. No attempt is made on this map to distinguish between these older deposits and the deposits of the last glaciation. A companion map (Yount and others, in preparation) delineates the various facies of both the Fraser and older glacial deposits as well as the distribution of Holocene and Pleistocene fluvial and lacustrine deposits and Holocene marsh, beach, and landslide deposits. Only landslide deposits (*Ql*) that involve bedrock units are shown on the present map.

Rocks west of Hood Canal

By chance, the western limit of the Seattle quadrangle nearly coincides with a major geologic boundary within the rocks of the Olympic Peninsula, that being the separation of deformed early Eocene through Oligocene metasediments of the Olympic core from the less-deformed unmetamorphosed early Eocene through Miocene volcanic and sedimentary rocks that make up the eastern periphery of the Olympic Peninsula (Tabor and Cady, 1978a). The rocks within the quadrangle, that outcrop west of Hood Canal, form a crudely ENE-dipping sequence on the nose of the east-plunging Olympic orogen. Tabor and Cady (1978b) demonstrate that the core rocks within the central portion of the Olympic Mountains are comprised of rather coherent slices of metamorphosed marine sediment that consistently top away from the center of the range, yet appear to young, from slice to slice, toward the west. Although the paleontologic data from the metasediments are sparse (Tabor and Cady, 1978b), it appears that such patterns are consistent with the emplacement of the core rocks by subduction along the early Eocene through Oligocene continental margin of North America (Tabor and Cady, 1978b, p. 23-24).

Crescent Formation

The Crescent Formation of Arnold (1906) consists of basalt flows and interbedded basaltic pyroclastic and sedimentary rocks exposed at Crescent Bay on the south shore of the Straits of Juan de Fuca. The term Crescent Formation has been applied to the basalt flows, pillow basalts, basaltic breccias, mudflows, and conglomerates that ring the core of deformed sedimentary rocks on the Olympic Peninsula (Tabor and Cady, 1978a) and that make up the base of the section exposed in the Seattle quadrangle. The Crescent Formation has been divided into upper and lower members in the eastern portion of the Olympic Peninsula (Cady and others 1972a, 1972b) with the upper member consisting of massive and columnar jointed basalt flows and minor interbedded sandstone and limestone and the lower member being dominated by pillow basalt, diabase flows and sills, basaltic mudflow breccia and minor interbeds of variegated argillite and red limestone. Glassley (1974) has proposed that the geochemistry of the upper member shows chemical affinities similar to hot-spot derived oceanic islands or seamounts, while the composition of the lower member indicates eruption at an oceanic ridge crest or intraplate seamount (Glassley, 1976). Lyttle and Clarke (1975 1976) present an alternative view that the rocks of the Crescent Formation accumulated in an oceanic island arc setting. The Crescent Formation is early and middle Eocene in age (Penutian and Ulatisian foraminiferal stages) (Rau, 1964; Armentrout and others, 1983).

The Crescent Formation exposed within the Seattle quadrangle consists almost entirely of massive and columnar-jointed basalt flows (*Tev*) and belongs entirely in the upper member of Cady and others (1972a, 1972b) and Glassley (1974). Exposures east of West Valley often show pronounced red interflow weathered zones indicating that the flows were erupted under subaerial conditions. Minor marine siltstone interbeds containing Ulatisian foraminifera are found between flows at Olele Point (FL-30; table 2). A small amount of basaltic conglomerate (*Tevc*) outcropping east of Port Discovery has been included in the Crescent Formation. This well-rounded cobble and boulder conglomerate appears to represent local reworking of Crescent basalt flows, perhaps in a nearshore environment.

Aldwell Formation and related rocks

The Aldwell Formation (Brown and others, 1960) consists of dark gray and dark green siltstone and minor thin-bedded fine- and medium-grained sandstone and conglomerate in its type area around Lake Aldwell, approximately 43 km west of the Seattle quadrangle. Within the Seattle quadrangle, the Aldwell Formation is composed of olive gray well-indurated siltstone with thin interbeds of fine- and very fine-grained sandstone (*Ta*). The unit contains upper Ulatisian to lower Narizian foraminifera (FL-25; table 2), in agreement with the faunas present in the type area (Rau, 1964). The Aldwell Formation crops out as a narrow belt of rocks overlying the Crescent Formation along the east side of the Quilcene Range. The unit appears to thin to the north, but poor exposure makes it impossible to tell if this thinning represents depositional onlap on the Crescent basalt or comes about from erosion at the base of the overlying Lyre Formation.

Lithic and feldspathic sandstones (*Teu*) crop out south of Maynard and along Salmon Creek that lie on or close to Crescent basalt, in a stratigraphic position similar to that of the Aldwell Formation. These rocks are grouped separately from the Aldwell Formation, in part, because they are coarser grained and thicker bedded, but also because the fossils contained within these isolated exposures span a greater range of ages than usually is attributed to the Aldwell Formation. The foraminifera at Maynard (FL-1, FL-2; table 2) range from no older than upper Ulatisian to Narizian in keeping with the accepted age of the Aldwell Formation. But, north of the quadrangle, in the Port Townsend area, lithologically identical rocks ranged in age from Ulatisian to possibly Penutian (Gower, 1980). We believe that these rocks are equivalent to the upper Eocene rocks described by Durham (1944), the Scow Bay Formation of Allison (1959) and Thoms (1959), and the unnamed Eocene unit of Armentrout and Berta (1977) from the Quimper Peninsula north of the quadrangle.

Lyre Formation

The Lyre Formation (Weaver, 1937, later restricted by Brown and others, 1956) is composed of approximately 400 m of massive, subround pebble and cobble conglomerate and flaggy to massive fine- to coarse-grained sandstone at its type section along the Lyre River, approximately 58 km west of the Seattle quadrangle. The Lyre Formation appears to be middle to early late Eocene in age, chiefly on the basis of the ages of overlying and underlying units (Brown and others, 1956; Rau, 1964) Ansfield (1972) reports that much of the Lyre Formation accumulated during the lower Narizian stage based on foraminifera recovered from thin shale interbeds within the unit. Both Brown and others (1956) and Ansfield (1972) state that the Lyre Formation displays conformable contact relations with the underlying and overlying sedimentary units.

The Lyre Formation within the Seattle quadrangle is subdivided into 4 informal units as well as being portrayed as undifferentiated (*Tl*) in the Big Skidder Hill area. East of Port Discovery, the Lyre Formation is composed mainly of massive to thin-bedded, fine- to medium-grained sandstone with minor pebbly conglomerate and siltstone interbeds (*Tlu*). These sediments appear to rest depositionally on the Crescent basalt and possibly on Crescent basaltic conglomerate west of Moon Lake. Massive, thick-bedded pebble and cobble conglomerate (*Tluc*) and interbedded thick-bedded pebble conglomerate and thin- to thick-bedded sandstone and minor siltstone (*Tll*) outcrop along the north end of the Quilcene Range from the northeast flank of Mt. Zion to the Little Quilcene River. Locally, the Lyre Formation is composed of angular to rounded basalt clasts (*Tllv*) derived from underlying Crescent basalt flows. These local lag deposits of Crescent basalt and the apparent truncation of the Aldwell Formation north of the Little Quilcene River suggest that the Lyre Formation may rest unconformably on older rocks in this area.

Twin River Formation

The Twin River Formation was originally defined by Arnold and Hannibal (1913), later abandoned and referred to as Blakeley Formation by Weaver (1937), and subsequently resurrected and enlarged in scope by Brown and Gower (1958). The type locality for the redefined Twin River Formation at Deep Creek, located approximately 75 km west of the Seattle quadrangle, exposes approximately 5000 m of interbedded fine- to medium-grained, thin- to thick-bedded sandstone and massive to laminated concretionary mudstone. The formation generally fines upward, with the lower portion consisting of interbedded sandstone and siltstone and with the upper portion made up of massive mudstone. The lower contact of the Twin River Formation with the underlying Lyre Formation appears gradational as does the upper contact of the Twin River Formation with the overlying Clallam Formation (Brown and Gower, 1958). The Twin River Formation contains Narizian to Zemorrian foraminifera (Rau, 1964; Addicott, 1976) and the upper 500 m of the unit contains Matlockian (lower Oligocene) mollusks (Addicott, 1976).

The Twin River Formation (*Ttr*) mapped in the Seattle quadrangle consists of feldspathic, fine-grained, thin- to thick-bedded sandstone and massive concretionary siltstone. The unit crops out stratigraphically above the Lyre Formation between Quilcene and Lake Leland. Good exposures of the Twin River Formation are found along Snow Creek, north of Little Skidder Hill. The Twin River Formation has yielded numerous fossils in this part of the quadrangle (FL-5 through FL-12, FL-14 through FL-24, and FL-26, table 2). Foraminifera fall within the range of lower upper Ulatisian to Refugian and nannofossils and mollusks are consistent with this range. Thus, the Twin River Formation may be somewhat older in this portion of the Olympic Peninsula than at the type area, although most of the section in the quadrangle is Narizian. Based on lithology and contained fossils, it appears that the upper part of the type Twin River Formation is missing from this portion of the Olympic Peninsula. The Twin River Formation rests on Lyre conglomerate at Snow Creek, yet rests on Aldwell Formation along the west shore of Quilcene Bay. As with the underlying Lyre Formation, unconformable relations are more common in this portion of the Olympic Peninsula than in the area to the west. The Twin River Formation in the Seattle quadrangle is, in part, equivalent to and most likely grades into the Townsend Shale of Durham (1944) and the Townsend Shale Member of the Lyre Formation as described by Armentrout and Berta (1977) to the north and northeast on the Quimper Peninsula.

Quimper Sandstone of Durham (1942)

The Quimper Sandstone was named by Durham (1942, 1944) for light brown to light gray, medium-grained, massive sandstone that lies in angular unconformity atop the Townsend Shale on the Quimper Peninsula. The type section is located approximately 5 km north of the Seattle quadrangle, along the west shore of Marrowstone Island, where roughly 300 m of massive light brown sandstone is exposed. Marine mollusks and foraminifera both indicate a Refugian age for the Quimper Sandstone (Durham, 1944; Thoms (1959); Armentrout and Berta, 1977) The Quimper Sandstone is unconformable on the Lyre Formation and the Crescent Formation on the Quimper Peninsula and grades upward into the overlying Marrowstone Shale with apparent conformity (Thoms, 1959).

Exposures of the Quimper Sandstone (*Tq*) in the Seattle quadrangle are limited to the west shore of Oak Bay. Here, the Quimper Sandstone is unconformable on Crescent basalt flows (*Tev*). Durham (1942, 1944) reports Refugian mollusks from two locations along Oak Bay (FL-28, FL-29; table 2).

Unnamed Conglomerate East of Port Discovery

Massive, moderately- to poorly-sorted cobble and pebble conglomerate (*Tc*) is exposed immediately east of Port Discovery between Moon Lake and City Lake. The conglomerate dips slightly to the east or is horizontal and unconformably overlies steep east-dipping Lyre Formation (*Tlu*). Both this upper conglomerate and the Lyre conglomerate contain abundant dark chert and light quartz clasts making separation of the units difficult. It is likely that many of the clasts in the upper conglomerate have been derived from underlying or nearby Lyre conglomerate outcrops. But the marked angular discordance between the two units south of Moon Lake makes it possible to map the two units separately, at least locally (Gower, 1980). In addition to overlying the Lyre Formation, the unnamed conglomerate also rests on Crescent basalt flows (*Tev*) and basaltic conglomerate (*Tevc*) northeast of City Lake. The relationship between the upper conglomerate and the Quimper Sandstone or the Marrowstone Shale is not known. We found no fossils or radiometrically-datable material that would directly determine the age of this conglomerate.

Rocks of the Gold Mountain-Bremerton Area

Significant bedrock exposure can be found in the south central part of the Seattle quadrangle between Gold Mountain and the east shore of Bainbridge Island at Restoration Point. The rocks consist of a mafic and silicic volcano-plutonic complex of probable early Eocene age in the Gold Mountain region and a sequence of deep-water marine and nonmarine(?) sediments ranging in age from late Eocene to early Miocene(?) that outcrop along the inlets and passages between Bremerton and Restoration Point. The contact relations between the volcano-plutonic rocks and the marine sediments are not exposed within or anywhere outside the quadrangle. However, based on geophysical evidence, we suggest that these two sequences are separated by a west to west-northwest trending fault.

Mafic to Silicic Plutonic and Volcanic Rocks of the Green Mountain Area

The plutonic and volcanic rocks that make up Gold Mountain and Green Mountain (sometimes referred to as the Blue Hills) west of Bremerton have been described and mapped by Reeve (1979). We generalize some of his map units in the vicinity of Green Mountain and add a silicic volcanic unit (*Tsv*) at the north end of the area of outcrop.

The association of clinopyroxene-bearing gabbro (*Tg*), mutually intrusive (sheeted dikes?) basalt and diabase (*Tdb*), and minor bodies of iron-rich tonalite (*Tt*) which intrude the gabbro and basalt-diabase units is suggestive of oceanic lower crustal rocks (Fox and Stroup, 1981). These lower crustal rocks are juxtaposed against subaerial extrusive basalts by faults that apparently have considerable throw. In particular, the east-trending fault, running between Green Mountain and Gold Mountain, separates at least 300m of subaerial flows on the south from rocks on the north that might have formed at depths of a few kilometers. The extrusive rocks consist mainly of massive to columnar jointed amygdaloidal basalt flows (*Tbv*), commonly exhibiting red, weathered contacts between flows. A minor amount of extrusive, flow-banded rhyolite (*Tsv*) appears to cap the mafic intrusive rocks on the north side of the area of outcrop. The rhyolite may represent a late-stage extrusion of differentiated material associated with the lower crustal melting, but no evidence has been found that would clarify its relationship to the extrusive basalts to the south. Numerous hornblende-bearing andesite dikes cut both the intrusive rocks and the extrusive basalts. It is also possible that the minor extrusion of rhyolite is somehow related to this later volcanic activity.

Duncan (1982) reports $^{40}Ar/^{39}Ar$ total fusion ages of 51.7 and 55.3 my and a $^{40}Ar/^{39}Ar$ incremental heating age of 55 my for the basalt flows exposed along the north shore of Sinclair Inlet (RD-4; table 1). Snavely (written comm., 1976) reports a whole rock K-Ar age of 45.2 my for an andesite dike cutting these basalts south of Kitsap Lake (RD-3; table 1). Thus, it appears that the extrusive basalts are equivalent in age to the basalts of the Crescent Formation.

Blakeley Formation

The Blakeley Formation consists of interbedded marine volcaniclastic sandstone, siltstone, shale, and conglomerate composed of basalt, andesite, and tuff clasts. The Blakeley Formation was defined by Weaver (1912), although Arnold (1906) and Dall (1909) had previously reported fossils from these sediments. Weaver's (1912) type locality includes the sections exposed along the shore around Restoration Point and along Rich Passage to the vicinity of Waterman Point. The rich fossil content of the Blakeley Formation has made it one of the most studied units in the Seattle quadrangle. The most recent stratigraphic study is that of Fulmer (1975), and contained therein is an excellent review of the history of investigations of the litho- and biostratigraphy of the Blakeley Formation. McLean (1977) has recently described the lithofacies associations within the Blakeley Formation and has concluded that the unit was deposited as part of a submarine fan complex accumulating in a borderland basin environment.

Fulmer (1975) divides the Blakeley Formation into a lower coarse-grained sandstone and conglomerate member (the Orchard Point member) and an upper fine-grained sandstone and siltstone member (the Restoration Point member). On the present map we do not show these members separately, but delineate the Blakeley Formation as a single unit (*Tb*). The faunas obtained from the Blakeley Formation range in age from late Eocene through Oligocene (Refugian and Zemorrian) (FL-30 through FL-56; table 2).

Blakeley Harbor Formation of Fulmer (1975)

Fulmer (1975) described, in some detail, the massive, unfossiliferous basaltic conglomerate that outcrops on the north side of Blakeley Harbor and that made up the uppermost part of the Blakeley Formation of Weaver (1912). Fulmer named the conglomerate unit the Blakeley Harbor Formation. The Blakeley Harbor Formation (Tbh) appears conformable on the marine siltstones of the Blakeley Formation on the south side of Blakeley Harbor. The presence of thin coal partings between conglomerate beds and the lack of fossils led Fulmer to conclude that the Blakeley Harbor Formation was nonmarine (Fulmer, 1975, p. 222).

Rocks of the Seattle-Newport Hills Area

Eocene volcanic and arkosic sedimentary rocks, Oligocene shallow marine to nonmarine sedimentary rocks, and possible Miocene nonmarine sedimentary rocks crop out on the flanks of the broad west and west-northwest trending anticlines that make up the Newport Hills in the southeast portion of the Seattle quadrangle. Exposures continue to the east along the nose of the structure into the southern portion of Seattle. Willis (1898) made some of the earliest observations of rocks in the Newport Hills as part of a coal resource study. White (1889), Arnold and Hannibal (1913), Weaver (1912, 1916, 1937), Durham (1942, 1944), and McWilliams (1971) described and correlated fossils in the region, paying particular attention to the rich faunas exposed near the Duwamish River at the southern boundary of the quadrangle. The general stratigraphic framework for the rocks in this region comes from work done south and southeast of the quadrangle. Vine (1962, 1969) described lower Eocene through middle Oligocene volcanic and sedimentary rocks that adjoin the Seattle quadrangle in the Tiger Mountain area, as well as the rocks further south exposed along the Green River. Waldron (1962) defined some of the formations currently in use in the region during his mapping in the Des Moines quadrangle, immediately south of Seattle. Mullineaux (1965a, b, c, 1970) extended the stratigraphic studies into the Renton, Auburn, and Black Diamond areas.

Puget Group

White (1889) first used the term Puget Group for the fossiliferous rocks outcropping along the Duwamish River south of Seattle. Willis (1897) applied the term to the coal-bearing arkosic sandstones and interbedded volcanic rocks that were exposed east and south of Seattle from the Newport Hills to the Carbon River. Waldron (1962) formalized the distinction between the arkosic sandstones and the volcanic rocks by subdividing the Puget Group into the lower volcanic-rich Tukwila Formation and the upper arkosic Renton Formation. The Tukwila Formation, in its type area approximately 3 km south of the Seattle quadrangle, consists of upper and lower volcaniclastic sandstone and siltstone units containing minor volcanic conglomerate separated by a middle arkosic sandstone unit that is indistinguishable from the overlying Renton Formation. The type area of the Renton Formation, near the town of Renton immediately south of the Seattle quadrangle, exposes medium- to fine-grained, cross-bedded to massive arkosic sandstone with minor shale and coal. The Renton Formation contains coal of sufficient quality and quantity to be of economic importance both near the type area at Renton and in the Black Diamond area to the southeast.

We retain the subdivision of the Puget Group into the Tukwila Formation (*Ttv*) and the Renton Formation (*Tpr*) within the Seattle quadrangle. The Tukwila Formation is exposed along the crest of the large anticline that makes up Squak Mountain at the southern edge of the quadrangle. The unit is composed mainly of tuffaceous sandstone, siltstone, and andesitic conglomerate and locally contains small porphyritic andesite intrusive bodies. Fisson-track and K-Ar ages of 41.3 my and 42.3 my (average of 3 K-Ar ages) have been obtained from andesite breccia in the upper part of the Tukwila Formation southwest of Newcastle (Turner and others, 1983; RD-1, table 1). Thus, at least some portion of the Tukwila Formation is as young as late middle Eocene.

The Renton Formation appears to conformably overlie the Tukwila Formation south of Coal Creek. The Renton Formation contains fine- to medium-grained, massive to cross-bedded arkosic sandstone with distinctive large muscovite flakes. No fossils or radiometrically-datable materials were recovered from the unit, but possible Refugian foraminifera exist in the overlying unnamed sedimentary unit (FL-65, FL-69; table 2). Thus, the Renton Formation must be late Eocene in age.

Volcanic and Sedimentary Rocks of Late Eocene and Oligocene Age

Marine and nonmarine tuffaceous sandstone and siltstone and minor volcanic conglomerate (*Tss*) overlie the Puget Group rocks along the north side of the Newport Hills. These rocks are lithologically and stratigraphically similar to rocks referred by Mullineaux (1970) to the Lincoln Creek(?) Formation (Beikman and others, 1967) from the Renton area. The sedimentary rocks apparently interfinger with basalt and basaltic sandstone (*Tv*) north of Issaquah.

Abundant megafossil and microfossil assemblages yield late Eocene and Oligocene ages for the unit (FL-58 to 69 and FL- 76 to 82; table 2). No contact relations with the underlying Renton Formation were observed, but the strike of the unit is generally conformable with the underlying rocks. These unnamed late Eocene and Oligocene rocks correlate with the Blakeley Formation to the west and to the Oligocene sedimentary rocks of Snohomish County to be discussed later.

Miocene Nonmarine Sedimentary Rocks

Tuffaceous, friable, poorly-sorted sandstone and weakly cemented conglomerate (*Tu*) outcrop on both sides of Lake Sammamish, stratigraphically above the Oligocene marine sediments. The unit is unfossiliferous, but contains a number of hornblende-bearing air-fall tuff beds. K-Ar ages of 9.3 and 14.7 my have been obtained from hornblende extracted out of one tuff bed exposed to the west of Lake Sammamish (RD-2; table 1).

No contact relations were observed between these Miocene sediments and the underlying Oligocene rocks. However, southeast of Eastgate the Miocene rocks appear to be faulted against the Oligocene. These rocks may be equivalent in age to the Blakeley Harbor Formation to the west, but they are lithologically dissimilar. The Miocene sediments are lithologically more similar to the Hammer Bluff Formation of Glover (1941) (also see description by Mullineaux, 1970, p. 24-26), a nonmarine clayey, quartzose sandstone unit, that contains volcanic ash beds, exposed approximately 30 km southeast of the Seattle quadrangle in the Green River area. The rocks also appear similar in age and lithology to the Ellensburg Formation outcropping on the eastern flanks of the Cascade Range (Tabor and others, 1982b, 1987)

<u>Oligocene Sedimentary and Volcanic Rocks of Snohomish County</u>

Minard (1985a, b, c, d) has mapped intrusive and extrusive mafic rocks (*Tvu*) and overlying feldspathic and volcaniclastic sandstone, siltstone, and shale (*Ts*) throughout the northeast corner of the Seattle quadrangle. The mafic rocks consist of basalt, diabase, and gabbro, with minor amounts of volcanic conglomerate. These rocks may correlate with the volcanic rocks of Mount Persis exposed east of the quadrangle (Tabor and others, 1982a), but they lack the intermediate and felsic lithologies characteristic of the Mount Persis rocks.

The sedimentary rocks are made up of shale, siltstone, and sandstone, with minor to abundant organic debris. The sandstones are micaceous and siderite concretions are common. To the north, in the Port Townsend 30' by 60' quadrangle, these sediments are thought to be late Eocene and Oligocene in age based on contained megafossils (Whetten and others, 1988). Minard (1985a,b,c,d) considered the sediments correlative with the Blakeley Formation of Weaver (1937). These sediments are also equivalent to the unnamed late Eocene and Oligocene sediments (*Tss*) exposed on the north flank of the Newport Hills.

MAJOR STRUCTURAL FEATURES

The extensive cover of glacial debris covering the bedrock within the quadrangle makes detailed interpretation of structural relationships difficult. However, the available gravity, aeromagnetic, and seismic reflection coverage for the region supplements the outcrop information sufficiently to make some generalizations possible. Most of the major faults and folds interpreted from geophysical data from within the quadrangle have been described previously (e.g. Danes and others, 1965; Rogers, 1970; Gower and others, 1985), but here we refine the locations of some structures based on better outcrop control than was used previously.

Proceeding from north to south the principal structures within the quadrangle are 1) a northwest-trending feature, interpreted to be a fault, extending from southeast of Murphy's Corner through the southern portion of Whidbey Island; 2) an east-trending fold whose axis extends from Port Gamble beneath Puget Sound to the north of Edmonds and continues east beneath glacial cover to the Alderwood Manor area; 3) an east-trending fault extending from Eagle Harbor on Bainbridge Island, east beneath Seattle, and continuing east beneath the southern end of Lake Sammamish; 4) an east-trending fault lying subparallel to and south of (3) that extends from Bremerton beneath Puget Sound and White Center and into the Newport Hills, where the fault nearly merges with (3) at the south end of Lake Sammamish. In addition, a major north-trending structure, presumed to be a fault, lies beneath Hood Canal, coming onshore at the head of Dabob Bay and continuing to the north beneath the glacial and alluvial cover of West Valley. The evidence for interpreting and locating each of these structures will be presented in the discussion that follows.

The northwest-trending structure beneath Whidbey Island has been termed the southern Whidbey Island fault by Gower and others (1985). It is expressed by a linear magnetic high (Plate 4) and lies at the base of the southern boundary of a pronounced gravity low (Plate 3). The gravity low to the north of the fault trace and the dramatic thickening of the Quaternary section to the north of the trace (Yount and others, 1985) indicate that the sense of movement is northeast side down. No faulting is seen in section B_1-B_1' where the fault is projected to cross the seismic line, but faults with the appropriate sense of movement have been interpreted from the seismic data both a few kilometers northeast and southwest of the fault's position as inferred from the gravity and aeromagnetic data. More extensive seismic profiling may permit better location of this structure, but with only one seismic line presently available for interpretation we are unable to determine the trend for any of the faults seen on that line. High resolution seismic profiling in the waters west of Whidbey Island to the north of the Seattle quadrangle has demonstrated displacement of Holocene sediments on faults that lie on trend with the southern Whidbey Island fault as located by gravity and aeromagnetic data (Wagner and Wiley, 1980).

The east-trending fold north of Edmonds is defined by the east-trending gravity high present in the area (Plate 3) and by a pronounced thinning of the Quaternary section over that gravity high (Yount and others, 1985). The shape of the gravity high suggests an east plunge to the structure. A broad arching of the Tertiary section is also visible on sections B_1-B_1' and B"-B'" although the apparent axis of folding does not coincide exactly with the crest of the gravity high.

The east-trending fault extending beneath Seattle is located (Plate 3) at the base of one of the steepest gravity gradients in the United States (Danes and others, 1965; Gower and others, 1985). In addition, it also coincides with the straight southern boundary of the basin beneath Seattle as defined by the thick Quaternary section present there (Yount and others, 1985). Conspicuous steepening of Tertiary strata to dips near vertical or even overturned to the south can be found at both the east and west ends of the fault. The displacement along the fault is down to the north.

The subparallel east-trending fault to the south of the fault beneath Seattle is located along the northern boundary of a large magnetic high (Plate 4). The fault appears to separate the Eocene volcanic rocks from the Oligocene and younger sedimentary rocks in the Bremerton and Seattle areas. The sedimentary rocks to the north of the structure dip more steeply than the older volcanic rocks to the south indicating a structural discontinuity that is consistent with a fault with down to the north movement. In the Newport Hills the evidence for faulting is less abundant, but steepening of dip to near vertical over short distances is observed along the projected trace of this fault in some of the Eocene and Oligocene sedimentary rocks (*Tss*) outcropping southwest of Lake Sammamish.

The structure beneath Hood Canal is defined and located by the base of the steep north-trending gravity gradient (Plate 3) that marks the eastern edge of the gravity high located over the Olympic Mountains. The transition from steeply east-dipping Eocene volcanic rocks (*Tev*) west of the structure to more gently dipping Eocene volcanic rocks (*Tbv*) near Gold Mountain could be accomplished by sharp flexure as well as by faulting. But along the northern projection of the structure north of Dabob Bay the strong gravity gradient terminates. Still, relatively flat-lying Eocene volcanic rocks (*Tev*) in the Port Ludlow area contrast with the steeply dipping Crescent basalt of the Olympic foothills, suggesting the presence of some sharp flexure or fault in the region between. We have mapped the northern continuation of the Hood Canal structure as a fault extending beneath West Valley located along the west margin of the weak gravity high centered over Port Ludlow (Plate 3).

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Table 1: Table of Radiometric Dates from Within and Near the Seattle 30' by 60' Quadrangle

K-Ar Ages

Map Locality (Map Unit)	Sample Number	Rock Type	Mineral Dated	Mean % K_2O	Radiogenic ^{40}Ar moles/g x 10^{-11}	% Radiogenic Ar	Age my $\pm 2\sigma$	Reference
RD-1 (Ttv)	VF78-115	Andesite	Hornblende	0.175	1.003	13.7	39.4 ± 2.4	Turner and others, 1983
					1.167	22.6	45.7 ± 2.7	
					1.063	17.3	41.7 ± 2.4	
RD-2 (Tu)	JY81-9	Air Fall Tuff	Hornblende (Green)	0.251	0.535	29.3	14.7 ± 1.8	This Report
			Hornblende (Brown)	0.234	0.314	8.0	9.3 ± 0.9	
RD-3 (Tah in Tbv)	S75-16	Andesite	Hornblende	0.337	2.237	45.2	45.6 ± 3.2[a]	Parke Snavely, USGS written comm., 1976
RD-4 (Tbv)	D80-CV-24	Basalt	Whole Rock	0.283[b]	1.786[c]	49.0	43.3 ± 0.5[de]	Duncan, 1982
					1.980[c]	46.3	46.9 ± 0.6[de]	
	D80-CV-25	Basalt	Whole Rock	0.264[b]	1.893[c]	55.9	49.2 ± 0.6[de]	
	D80-CV-26	Basalt	Whole Rock	0.280[b]	1.812[c]	64.6	45.2 ± 0.5[de]	
off map[1] (Tav)	RWT-66-72	Andesite	Hornblende	0.201	1.499	32.7		Engels and others, 1976
					1.256	27.3	42.1 ± 7.1[f]	
					1.109	24.1		
off map[1] (Tav)	RWT-66AB-72	Andesite	Hornblende	0.188	0.997	19.0	36.4 ± 1.3[g]	Engels and others, 1976
off map[2] (Tev)	TC-65-627-A1	Diorite xenoclast	Hornblende	0.470	3.759	47.0	54.8 ± 2.7[h]	Engels and others, 1976

Table of Radiometric Dates Continued

$^{40}Ar/^{39}Ar$ Total Fusion Ages

Map Locality (Map Unit)	Sample Number	Rock Type	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{36}Ar$	$^{37}Ar/^{40}Ar$	% Radiogenic Ar	Age my ± 1σ	Reference
RD-4 (Tbv)	D80-CV-24	Basalt	385.48	323.57	0.0499	8.7	51.7 ± 2.4	Duncan, 1982
RD-4 (Tbv)	D80-CV-26	Basalt	319.07	319.07	0.0484	7.4	55.3 ± 3.1	

$^{40}Ar/^{39}Ar$ Incremental Heating Age

Map Locality (Map Unit)	Sample Number	Rock Type	$^{40}Ar/^{39}Ar$	$^{40}Ar/^{36}Ar$	$^{37}Ar/^{40}Ar$	% Radiogenic Ar	Age my ± 1σ	Reference
RD-4 (Tbv)	D80-CV-25	Basalt	14905	298.10	0.0048	<1	48.4 ± 18	Duncan, 1982
			105.48	412.31	0.0714	28.3	54.9 ± 1.3	
			118.35	386.54	0.1080	23.6	51.8 ± 2.0	
			104.24	443.87	0.1624	33.4	64.8 ± 1.9	
			128.93	379.79	0.3645	22.2	57.0 ± 3.6	
			132.7	356.22	0.8067	17.0	52.7 ± 2.4	
					Recalculated Total Fusion Age		55.0 ± 0.9	
					Isochron Age		55.4 ± 3.2	

Table of Radiometric Dates Continued

Map Locality (Map Unit)	Sample Number	Rock Type	Mineral Dated	Fission-Track Age: Spontaneous Tracks Density $\times 10^6/cm^2$	Induced Tracks Total Counted	Thermal Density $\times 10^6/cm^2$	Total Counted	Neutron Dose $\times 10^{15}/cm^2$	Age my $\pm 2\sigma$
RD-1 (Ttv)	VF-78-115	Andesite	Zircon	6.38	781	8.66	5.35	0.939	41.3 ± 2.3[i]

[a]Original reported age of 44.4 my multiplied by 1.026 to correct to new K-Ar constants following Dalrymple, 1979

[b]Originally reported as % K; converted to % K_2O by multiplying by 1.205

[c]Originally reported as cm^3/g radiogenic ^{40}Ar; converted to moles/g by multiplying by 4.462×10^{-5}

[d]error is for 1σ

[e]Argon loss suspected

[1]Immediately west of west quadrangle boundary, 47 55.2'N, 123 00.4'W

[f]Original reported age of 41.0 my multiplied by 1.026 to correct to new K-Ar constants following Dalrymple, 1979

[g]Original reported age of 35.5 my multiplied by 1.026 to correct to new K-Ar constants following Dalrymple, 1979

[2]Approximately 8 km west of west quadrangle boundary, 47 50.0'N, 123 04.9'W

[h]Original reported age of 53.4 my multiplied by 1.0258 to correct to new K-Ar constants following Dalrymple, 1979

[i]Turner and others, 1983

Table 2: Table of Fossil Localities Within the Seattle 30' by 60' Quadrangle

Map Locality (Map Unit)	Sample No.	Fossil Types	Reported Series/ Stage/Zone	Age[1]	Reference	Comments
FL-1 (Teu)	UW-A-217	Foraminifera	No older than upper Ulatisian	No older than early middle Eocene	Thoms, 1959	Also collected and reported fossiliferous but undiagnostic samples along Salmon Creek
FL-2 (Teu)	USGS-M2294	Mollusks, echinoid brachiopods	Upper Eocene	Late Eocene	USGS written comm., 1965	
		Foraminifera	Narizian	Middle Eocene		
FL-3 (Tun)	A-3705	Mollusk	Upper Eocene	Late Eocene	Durham, 1944	
FL-4 (Tev)	USGS-M2873	Mollusks, brachiopods	Eocene	Eocene	USGS written comm., 1966	
FL-5 (Ttr)	G-79-93 G-79-105	Foraminifera "	Middle Narizian Narizian?	Middle Eocene Middle Eocene?	This report	
FL-6 (Ttr)	G-79-100	"	Narizian?	Middle Eocene?	"	
FL-7 (Ttr)	G-79-79	"	Upper Eocene?	Late Eocene?	"	
FL-8 (Ttr)	UW-A-1202	"	Narizian	Middle Eocene	Sherman, 1960	
FL-9 (Ttr)	UW-A-1201	"	"	"	"	

(Paleo Table Continued)

FL-10 (Ttr)	UW-A-1204 to UW-A-1241	"	"	"	"	
FL-11 (Ttr)	G-79-82	"	Upper Eocene?	Late Eocene? or older	This report	
FL-12 (Ttr)	UW-A-1242	"	Narizian	Middle Eocene	Sherman, 1960	
FL-13 (Ta)	UW-A-1506 to UW-A-1508	"	Upper Eocene?	Late Eocene?	Hamlin, 1962	
FL-14 (Ttr)	UW-A-1509 to UW-A-1513	"	Lower Narizian	Middle Eocene	"	
FL-15 (Ttr)	USGS-M2876	Mollusks	Upper Eocene	Late Eocene	USGS written comm., 1966	
FL-16 (Ttr)	UW-A-1514 to UW-A-1519	Foraminifera	Lower Narizian	Middle Eocene	Hamlin, 1962	
FL-17 (Ttr)	UW-A-1520 to UW-A-1523	"	"	"	"	
FL-18 (Ttr)	UW-A-1526 to UW-A-1531	"	"	"	"	
FL-19 (Ttr)	UW-A-1532 to UW-A-1535	" Nannofossils (1533)	" Refugian	" Late Eocene	" Worsley and Crecelius, 1972	
FL-20 (Ttr)	UW-A-1536 and UW-A-1537	Foraminifera	Lower Narizian	Middle Eocene	Hamlin, 1962	
FL-21 (Ttr)	G-79-62 G-79-62A	" "	Upper Narizian? Middle and upper Eocene	Late middle Eocene? Middle and late Eocene	This study	
FL-22 (Ttr)	353	Mollusks	Upper Eocene	Late Eocene	Weaver, 1937	

(Paleo Table Continued)

FL-23 (Ttr)	UW-A-1501 to UW-A-1505	Foraminifera Nannofossils (1501, 1505)	Lower upper Ulatisian Middle Narizian	Early middle Eocene Middle Eocene	Hamlin, 1962 Worsley and Crecelius, 1972	
FL-24 (Ttr)	USGS-M2875	Mollusks	Eocene?, Oligocene?	Eocene?, Oligocene?	USGS written comm., 1966	
FL-25 (Ta)	USGS-M2899 QS-66-13 & 13A	Mollusks, coral Foraminifera Foraminifera	Upper or middle Eocene Upper Ulatisian Upper Ulatisian to lower Narizian	Middle or late Eocene Late middle Eocene Late middle Eocene to early late Eocene	"	
FL-26 (Ttr)	USGS CR 6 & 6A	Wood Foraminifera	Refugian	Early Tertiary Late Eocene	USGS written comm., 1961, 1964	
FL-27 (Tev)	USGS-M2874	Mollusks	Upper Eocene	Late Eocene	USGS written comm., 1966	
FL-28 (Tq)	A-1824	Mollusks, coral	Lower Oligocene	Early Oligocene	Durham, 1944	
FL-29 (Tq)	A-1808	Mollusks, echinoids, coral, brachiopods	Lower Oligocene	Early Oligocene	Durham 1942, 1944	
FL-30 (Tev)	G-79-60	Foraminifera	Ulatisian	Late late to early middle Eocene	This report	
FL-31 (Tb)	B-9022 D-273 B-9033 D-274 D-283 D-290	Foraminifera "	Zemorrian Refugian	Oligocene Late Eocene	Fulmer, 1975	D-283 shown as B-283 on original map
FL-32 (Tb)	A-1812	Mollusks, echinoids, coral	Upper Oligocene	Late Oligocene	Durham, 1942, 1944	

(Paleo Table Continued)

FL-33 (Tb)	D-291	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	
FL-34 (Tb)	304	Mollusks	Middle Oligocene	Middle Oligocene	Weaver, 1916, 1937	
FL-35 (Tb)	A-3210	Mollusks, echinoid, coral	Upper Oligocene	Late Oligocene	Durham, 1942, 1944	
FL-36 (Tb)	B-8809	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	Shown as B-8819 on original map
FL-37 (Tb)	B-8802 B-8803 B-8798	"	"	"	"	
FL-38 (Tb)	A-1804	Mollusks, brachiopod, echinoids, coral	Upper Oligocene	Late Oligocene	Durham, 1942, 1944	
FL-39 (Tb)	B-8785 B-8797	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	
FL-40 (Tb)	B-8783 B-8784	"	"	"	"	
FL-41 (Tb)	B-8819	"	"	"	"	
FL-42 (Tb)	B-8824	"	"	"	"	
FL-43 (Tb)	305	Mollusks	Middle Oligocene	Middle Oligocene	Weaver, 1916, 1937	
FL-44 (Tb)	A-1807 A-3211	Mollusks, echinoids, crinoids, coral Mollusks, coral	Upper Oligocene "	Late Oligocene "	Durham, 1942, 1944	

(Paleo Table Continued)

FL-45 (Tb)	B-8825	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	
FL-46 (Tb)	B-8858	"	"	"	"	
FL-47 (Tb)	A-3671	Mollusks, echinoids	Upper Oligocene	Late Oligocene	Durham, 1944	
FL-48 (Tb)	A-3672	Mollusks	"	"	"	
FL-49 (Tb)	B-8943	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	
FL-50 (Tb)	681	Mollusks, echinoids, coral	Upper Oligocene	Late Oligocene	Durham, 1942, 1944	
FL-51 (Tb)	A-1806	Mollusks	"	"	Durham, 1944	
FL-52 (Tb)	B-8981	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	
FL-53 (Tb)	B-9003	"	"	"	"	
FL-54 (Tb)	B-9013 to B-9019	"	"	"	"	
FL-55 (Tb)	13 & 154	Mollusks	Upper Oligocene	Late Oligocene	Weaver, 1916, 1937	
FL-56 (Tb)	103	"	"	"	Arnold and Hannibal, 1913	
FL-57 (Tb)	B-9020 B-9021	Foraminifera	Zemorrian	Oligocene	Fulmer, 1975	

(Paleo Table Continued)

FL-58 (Tss)	10	Mollusks	Upper Oligocene	Late Oligocene	Weaver, 1916, 1937	
FL-59 (Tss)	48	"	"	"	Arnold and Hannibal, 1913	
FL-60 (Tss)	A-1805	"	"	"	Durham, 1944	
FL-61 (Tss)	A-1803	"	"	"	"	
FL-62 (Tss)	207	"	Oligocene	Oligocene	Weaver, 1916, 1937	
FL-63 (Tss)	9	"	Upper Oligocene	Late Oligocene	"	
FL-64 (Tss)	49	Mollusks	Upper Oligocene	Late Oligocene	Arnold and Hannibal, 1913	Location uncertain
FL-65 (Tss)	G-79-124	Foraminifera	Refugian? to Zemorrian?	Late Eocene? to Oligocene?	This study	
FL-66 (Tss)	172	Mollusks	Oligocene	Oligocene	Weaver, 1916, 1937	
FL-67 (Tss)	206	"	Upper Oligocene	Late Oligocene	Arnold and Hannibal, 1913	
FL-68 (Tss)	173	"	Oligocene	Oligocene	Weaver, 1913, 1937	
FL-69 (Tss)	G-79-6	Foraminifera	Refugian	Late Eocene	This study	
FL-70 (Ttv)	475	Mollusks	Upper Eocene	Late Eocene	Weaver, 1937	

(Paleo Table Continued)

FL-71 (Ttv)	A-3207	Coral	"	"	Durham, 1942	
FL-72 (Ttv)	UW-A-229 UW-A-3420 UW-A-3421	Mollusks	Narizian	Middle Eocene	McWilliams, 1971	
FL-73 (Ttv)	11	"	Upper Eocene	Late Eocene	Weaver, 1916, 1937	
FL-74 (Ttv)	UW-A-1050	"	Narizian	Middle Eocene	McWilliams, 1971	
FL-75 (Ttv)	A-3208	Coral	Upper Eocene	Late Eocene	Durham, 1942	
FL-76 (Tss)	261	Mollusks	Upper Oligocene	Late Oligocene	Arnold and Hannibal, 1913	
FL-77 (Tss)	155	"	"	"	Weaver, 1913, 1937	
FL-78 (Tss)	696	Mollusks?	Upper Eocene?	Late Eocene?	Weaver, 1937	Only shown on Plate 10
FL-79 (Tss)	695	"	"	"	"	"
FL-80 (Tss)	157	Mollusks	Oligocene or lower Miocene	Oligocene or early Miocene	Weaver, 1916, 1937	Location uncertain
FL-81 (Tss)	156	"	Upper Oligocene	Late Oligocene	"	
FL-82 (Tss)	A-3708 to A-3710	"	"	"	Durham, 1944	

(Paleo Table Continued)

FL-83 (Ts)	12	"	Middle Oligocene	Middle Oligocene	Weaver, 1916, 1937	
FL-84 (Ts)	228	"	"	"	"	
FL-85 (Ts)	A-3707	"	Upper Oligocene	Late Oligocene	Durham, 1944	Location uncertain

[1]Foraminiferal stages are assigned ages following Armentrout and others, 1983

Table 3: Table of Rock Chemistry from Within the Seattle 30' by 60' Quadrangle

Map Locality {Original Sample No.[ref.]} (Map Unit)	RC-1 {JY-81-65[1]} (Tev)	RC-2 {JY-81-67[1]} (Tev)	RC-3 {JY-81-64[1]} (Tev)	RC-4 {43[2]} (Tev)	RC-5 {40[3,4]} (Tev)	RC-6 {43[3,4]} (Tev)	RC-7 {38[3,4]} (Tev)
MAJOR ELEMENTS							
SiO_2[5]	46.2	47.6	46.2	50.7	45.4	49.1	46.6
Al_2O_3	14.3	14.3	14.5	16.0	14.0	14.4	13.4
TiO_2	1.81	1.99	1.79	1.9	1.9	1.2	2.0
Fe_2O_3	6.23	5.94	6.03		3.3	3.1	5.4
FeO	6.37	7.46	5.87	6.8[6]	10.8	8.5	9.2
MgO	6.78	6.29	7.67	7.7	6.2	7.5	6.0
CaO	9.24	11.80	9.72	11.4	10.0	12.7	10.0
Na_2O	3.26	2.27	3.63	3.8	2.4	2.3	3.6
K_2O	0.23	0.24	0.12	0.4	0.07	0.18	0.11
P_2O_5	0.19	0.2	0.17		0.18	0.11	0.26
MnO	0.15	0.19	0.26	0.1	0.21	0.22	0.22
CO_2					0.05	0.06	0.3
H_2O[7]					4.5	1.0	3.1
TOTAL	94.76	98.28	95.96	98.8	99.0	100.4	100.2

Rock Chemistry Table continued

TRACE ELEMENTS

	RC-1	RC-2	RC-3	RC-4	RC-5	RC-6	RC-7
Ce[8]				30.0	21.1	13.3	22.3
Nd				n.d.[9]			
Sm				n.d.	4.67	2.84	5.61
Eu				1.27	1.48	1.09	1.91
Tb				0.48	1.22	0.58	1.31
Yb				1.45	3.58	2.65	4.83
Lu				0.45	0.88	0.35	0.89
Ta				1.32			
Hf				4.9			
Cr				280.			
Sc				37.0			
Th				n.d.			
La				n.d.	7.70	4.76	7.52
Zr					100.0	63.0	122.0
Y					42.0	26.0	54.0

Rock Chemistry Table continued

Map Locality	RC-8	RC-9	RC-10	RC-11	RC-12	RC-13	RC-14
{Original Sample No. ref.}	{34[2]}	{35[2]}	{40[2]}	{36[2]}	{37[2]}	{38[2]}	{39[2]}
(Map Unit)	(Tev)	(Tev)	(Tev)	(Tev)	(Tev)	(Tev)	(Tev)
MAJOR ELEMENTS							
SiO_2	49.0	51.0	50.8	52.1		49.0	47.5
Al_2O_3	14.0	14.7	14.2	14.6		14.6	12.6
TiO_2	1.8	2.2	1.9	1.7		2.1	4.1
Fe_2O_3							
FeO	10.4[6]	7.3[6]	9.1[6]	5.2[6]		10.6[6]	15.2[6]
MgO	7.6	6.8	7.2	8.0		7.2	5.4
CaO	10.3	12.8	11.4	11.9		11.8	10.2
Na_2O	3.1	3.0	3.4	3.2		2.9	2.8
K_2O	0.3	0.2	0.1	0.2		0.2	0.6
P_2O_5	0.1	0.2	0.2	0.1		0.1	0.4
MnO	0.4	0.5	0.3	0.3		0.4	0.4
CO_2							
H_2O							
TOTAL	97.0	98.7	98.6	97.3		97.3	99.2

Rock Chemistry Table continued

TRACE ELEMENTS

	RC-8	RC-9	RC-10	RC-11	RC-12	RC-13	RC-14
Ce	29.6	n.d.	14.0	n.d.	n.d.	16.4	60.9
Nd	11.1	24.4	10.3	10.0	18.1	24.4	47.4
Sm	3.9	6.4	3.5	4.0	5.5	6.0	9.2
Eu	0.54	1.6	n.d.	1.23	2.10	1.11	2.57
Tb	n.d.	0.6	n.d.	n.d.	n.d.	n.d.	n.d.
Yb	1.95	3.30	1.95	2.30	2.30	3.07	3.82
Lu	0.32	0.51	0.31	n.d.	0.38	0.49	0.60
Ta	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.4
Hf	1.5	4.5	1.4	3.0	2.1	2.4	4.3
Cr	n.d.	109.0	112.0	291.0	284.0	112.0	68.0
Sc	31.0	45.0	29.0	46.0	39.0	45.0	34.0
Th	n.d.	n.d.	n.d.	n.d.	0.73	n.d.	1.15
La	5.2	8.3	3.8	5.1	11.8	8.2	23.4
Zr							
Y							

Rock Chemistry Table continued

Map Locality {Original Sample No.[ref.]} (Map Unit)	RC-15 {JY-81-79[1]} (Tbv)	RC-16 {JY-81-77[1]} (Tbv)	RC-17 {JY-81-74[1]} (Tbv)	RC-18 {JY-81-62[1]} (Tbv)	RC-19 {JY-81-81[1]} (Tbv)	RC-20 {JY-81-82[1]} (Tbv[10][Tah])	RC-21 {JY-81-84[1]} (Tbv)
MAJOR ELEMENTS							
SiO_2	48.5	47.4	48.0	47.1	48.0	60.8	47.8
Al_2O_3	14.3	14.4	13.6	14.6	14.1	16.8	13.9
TiO_2	1.68	1.55	2.19	1.58	2.03	0.44	1.93
Fe_2O_3	4.39	5.47	6.50	5.41	6.04	2.45	5.15
FeO	8.51	7.23	7.70	7.09	7.96	1.23	8.75
MgO	6.72	7.71	6.65	6.80	6.41	2.51	6.38
CaO	11.6	10.6	8.32	9.76	11.5	5.58	10.5
Na_2O	2.32	2.87	3.80	3.14	2.45	3.10	2.87
K_2O	0.33	0.13	0.18	0.47	0.26	1.36	0.76
P_2O_5	0.16	0.13	0.22	0.16	0.21	0.11	0.21
MnO	0.20	0.23	0.26	0.20	0.21	0.05	0.22
CO_2							
H_2O							
TOTAL	98.71	97.72	97.42	96.31	99.17	94.43	98.47

Rock Chemistry Table continued

Map Locality {Original Sample No.[ref.]} (Map Unit)	RC-22 {JY-81-88[1]} (Tbv)	RC-23 {JY-81-53[1]} (Tbv)	RC-24 {JY-81-60[1]} (Tbv)	RC-25 {JY-81-87[1]} (Tdb)	RC-26 {JY-81-86[1]} (Tbv)	RC-27 {JY-81-44[1]} (Tg[11])	RC-28 {JY-81-52[1]} (Tt[12][Tah])
MAJOR ELEMENTS							
SiO_2	49.4	47.6	47.6	47.0	45.8	70.7	57.3
Al_2O_3	14.1	13.6	14.3	13.0	13.9	12.7	18.8
TiO_2	1.88	2.01	1.82	2.63	2.56	0.35	0.46
Fe_2O_3	10.16	6.77	5.4	7.87	6.76	4.75	3.26
FeO	1.64	7.23	7.30	7.93	8.94	1.84	1.41
MgO	4.38	6.48	7.10	5.87	6.07	0.42	3.46
CaO	9.92	11.3	12.4	9.51	11.5	0.92	3.49
Na_2O	3.07	2.39	2.20	3.46	2.56	5.42	6.74
K_2O	0.24	0.17	0.18	0.57	0.25	1.21	1.38
P_2O_5	0.18	0.20	0.18	0.25	0.28	<0.05	0.12
MnO	0.13	0.20	0.23	0.24	0.23	0.07	0.06
CO_2							
H_2O							
TOTAL	95.10	97.95	98.71	98.33	98.85	98.43	96.48

Rock Chemistry Table continued

Map Locality	RC-29	RC-30	RC-31	RC-32	RC-33	RC-34	RC-35
{Original Sample No. ref.}	{JY-81-46[1]}	{JY-81-34[1]}	{JY-81-28[1]}	{JY-81-4[1]}	{JY-81-25[1]}	{JY-81-10[1]}	{JY-81-11[1]}
(Map Unit)	(Tsv)	(Tg)	(Tdb)	(Tg)	(Tsv)	(Tt)	(Tt)
MAJOR ELEMENTS							
SiO_2	76.1	48.6	43.2	44.5	72.7	64.7	62.3
Al_2O_3	12.4	17.2	11.3	12.9	13.5	14.7	15.0
TiO_2	0.18	1.61	3.63	3.31	0.21	0.79	0.93
Fe_2O_3	1.64	5.05	10.83	7.83	2.75	6.45	5.95
FeO	1.24	6.15	10.37	10.47	0.15	1.29	3.14
MgO	0.24	5.77	7.10	6.22	0.36	0.53	1.04
CaO	0.14	10.7	11.9	10.7	0.36	1.18	2.07
Na_2O	5.39	2.89	1.9	2.51	4.37	4.90	5.76
K_2O	0.91	0.58	0.12	0.46	2.31	2.02	1.63
P_2O_5	<0.05	0.11	0.06	0.09	<0.05	0.17	0.22
MnO	0.07	0.16	0.25	0.22	<0.02	0.12	0.21
CO_2							
H_2O							
TOTAL	98.36	98.82	100.66	99.21	96.78	96.85	98.25

Rock Chemistry Table continued

Map Locality {Original Sample No.[ref.]} (Map Unit)	RC-36 {JY-81-24[1]} (Tsv)	RC-37 {JY-81-16[1]} (Tdb[13][Tg])	RC-38 {JY-81-40[1]} (Tdb)	RC-39 {JY-81-12[1]} (Tg)	RC-40 {JY-81-22B[1]} (Tsv[14][Tt])	RC-41 {JY-81-5[1]} (Tg)	
MAJOR ELEMENTS							
SiO_2	77.9	46.6	49.5	47.8	66.7	47.7	
Al_2O_3	12.0	14.3	19.2	14.9	12.7	16.5	
TiO_2	0.19	2.31	1.42	2.25	0.67	1.65	
Fe_2O_3	1.27	5.50	2.63	6.79	6.33	3.92	
FeO	0.17	9.50	6.11	6.71	0.66	7.18	
MgO	0.16	5.31	4.41	4.98	0.26	6.72	
CaO	0.22	9.88	9.87	9.64	2.50	12.6	
Na_2O	3.69	2.79	2.96	3.97	4.83	2.42	
K_2O	1.76	0.65	0.88	0.38	1.55	0.30	
P_2O_5	<0.05	0.24	0.16	0.27	0.14	0.16	
MnO	0.03	0.25	0.11	0.18	0.12	0.17	
CO_2							
H_2O							
TOTAL	97.44	97.33	97.25	97.87	96.46	99.32	

[1]This study
[2]Glassley, 1974
[3]Lyttle and Clark, 1975
[4]Lyttle and Clark, 1976
[5]Expressed as weight percent
[6]Total Iron
[7]Total Water

Rock Chemistry Table continued

[8]Concentration in parts per million

[9]n.d., means original report indicates that value was not determined

[10]Andesite dike (Tah) within unit Tbv, too small to show at map scale

[11]Alkelai granite outcrop within unit Tg, too small to show at map scale

[12]Andesite dike (Tah) within unit Tt, too small to show at map scale

[13]Gabbro outcrop (Tg) within unit Tdb, too small to show at map scale

[14]Tonalite (Tt) or diorite outcrop within unit Tsv, too small to show at map scale