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Provenance study of late Eocene arkosic sandstones in southwest and central Washington

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The purpose of this study is to compare the sandstone composition and trace element geochemistry between samples representing the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations in order to determine if these sediments were all derived from the same provenance, and to determine the composition of the source rocks in hopes to identify the present day location of the source areas.

The light mineral portion of this study reveals that the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations are all

arkosic to lithic arkosic in composition, and were derived from the erosion of a silicic plutonic source terrane. The rather small percentage of K-feldspar (<12%) found in these sandstones suggests that these sediments were not derived from rocks of true granitic composition, but rather from plutonic rocks of lower potassium content. The polycrystalline quartz and rock fragment content indicate a major low grade metamorphic (quartz-biotite schist), and mafic volcanic source rock, contributing sediments to the finer fractions of these rocks.

All four formations are characterized by the heavy minerals epidote, apatite, zircon, garnet, sphene, rutile, tourmaline, hornblende and hypersthene. The Naches, Chumstick, and Carbonado Formations also contain small percentages of zoisite and augite, and the Carbonado Formation contains traces of staurolite. This heavy mineral composition indicates that the coarser fraction of these sediments were derived chiefly from plutonic source rocks.

The Summit Creek sandstone, Chumstick, and Carbonado Formations have a similar geochemical composition indicating a common provenance. The average trace element similarity coefficient existing between these three formations is 0.99, where a 1.0 indicates perfect similarity. The younger Naches Formation has a somewhat unique chemistry, and shows only a 0.72 similarity coefficient with the other three formations. The significantly higher concentration of Cr, and Sc, and the lower concentration of La in the Naches Formation suggests that it contains a larger mafic or ultramafic component to its sediments than the other three formations.

The Mount Stuart area, and the Chelan Mountain terrane are the most likely source areas for these sediments, since they can account for all of the rock types needed to comprise these sediments. Derivation of sediments from these two source areas is also in accordance with southwesterly current directions.

PROVENANCE STUDY OF LATE EOCENE ARKOSIC SANDSTONES IN SOUTHWEST AND CENTRAL WASHINGTON

by

MARK EDWARD BYRNES

A thesis submitted in partial fulfillment of the requirements for the degree of

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TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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I would like to dedicate this thesis to my mom and dad (Elfie and Frank Byrnes) who have always provided me with emotional, financial, and loving support.

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CHAPTER I

INTRODUCTION

PURPOSE OF STUDY

This study concentrates on the Summit Creek sandstone, Chumstick Formation, Naches Formation, and Carbonado Formation in central and southwestern Washington (Figure 1). These deposits are Eocene in age, light gray to pale brown in color, arkosic to lithic arkosic in composition, and all except the Carbonado Formation - which was deposited in a near shore marine environment - were deposited in nonmarine fluvial and braided stream environments (Snavely and others, 1951; Gard, 1968; Gresens and others, 1981; Clayton, 1983; Tabor and others, 1984). The purposes of this study are: 1) to compare these four formations in terms of their light and heavy mineral assemblages and trace element contents, in order to determine if these sediments were derived from the same provenance; and 2) to determine the composition of the source rocks based on the light and heavy mineral assemblages, in hopes of identifying the souce areas.

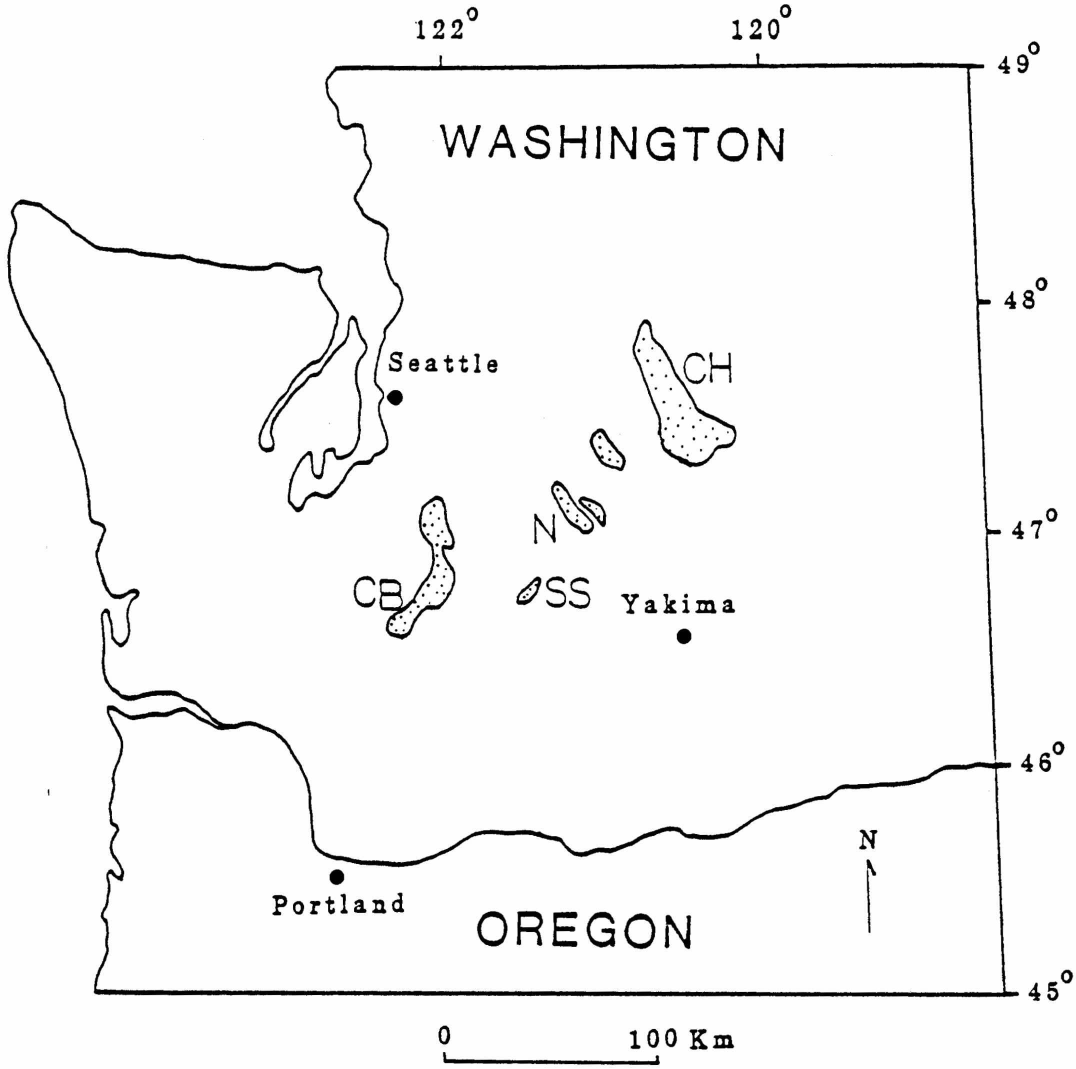


Figure 1. Map of the state of Washington showing the location of the Summit Creek sandstone (SS), Naches (N), Chumstick (CH), and Carbonado Formations (CB).

METHODS OF INVESTIGATION

The fieldwork entailed collecting samples representative of the Summit Creek sandstone, Chumstick Formation, Naches Formation, and the Carbonado Formation. Samples were preferably collected from the basal 1 m of fine-grained, thinly bedded, sandstone units, because Carver (1971) found heavy minerals to be more concentrated in these types of finer grained rocks.

These samples were first dissaggregated using a kerosene and hot water treatment. Samples were soaked in kerosene for several hours, after which time the kerosene was poured off and replaced with boiling water. The boiling water causes the kerosene, still held within the pore spaces of the rock, to expand as it vaporizes. This expansion forces a separation between matrix and clasts and thus disaggregates the sample. This treatment works best to disaggregate samples that are predominantly clay cemented. However, since several samples from each formation were partly cemented with calcite, they were first soaked in a dilute HCl solution before being treated with kerosene and hot water.

The disaggregated samples were then split in half. Half of the sample was prepared for instrumental neutron activation analysis, while the remainder of the sample was used in the light and heavy mineral study.

The samples for the petrographic study were sieved to separate out the 2 to 3 ϕ size fraction, then split into approximately 10 gram samples. These samples were then weighed, placed in 50 ml test tubes, and then centrifuged in tetrabromoethane (sp. gravity 2.96 at 25 C) for 20 minutes. The sediment was stirred once during the centrifuging to make it easier for the finer heavy minerals to settle out. The light and heavy minerals were then mounted on separate petrographic slides in Lakeside 70 cement. The light mineral slides were ground with 400 grit to expose the grains for plagioclase and potassium feldspar staining. This staining procedure required the slides first to be etched in fumes of hydrofluoric acid for up to 1 minute. The slides were then dipped into sodium cobaltinitrate for 30 seconds, dipped in water, and then dried. They were then dipped into barium chloride for 8 to 10 seconds, dried, dipped into red dye #3 for 45 seconds, rinsed in water as before and finally dried. The slides where then point counted using the 'Line Method' (Carver, 1971).

The samples for the geochemical study were first washed, crushed to a powder in a mortar and pestle, split and weighed, and then placed in small plastic polyvials. The samples were then irradiated for 1.0 hours in the TRIGA Mark I reactor at Reed College at 250 kw power. The samples were then counted twice using gamma ray spectroscopy. The first count was run as soon as the dead time fell below 10%. This count was important in detecting elements with short half-lives. The second count was run one month after irradiation, this count avoids interference from elements with relatively short half-lives. From the first and second count data, elemental abundances were determined in terms of percentages and parts per million. This data was then plotted on graphs, and entered into similarity and cluster analysis programs.

LOCATION AND ACCESS

The four study areas can be found on the Packwood, Leavenworth, Easton, and Morton 15' quadrangle maps of the State of Washington (Figure 2).

The Summit Creek sandstone is exposed along Summit Creek which is located approximately 12 miles northeast of the town of Packwood. This section is approximately 900 m thick and can be found in the NE1/4 of section 14 and the NW1/4 and NE1/4 of section 13, T.14 N., R.10 E., of the Packwood 15' quadrangle (Clayton, 1983). Although the base of this section is not exposed, the sandstones overlie Eocene basaltic lava flows. The Summit Creek sandstone is conformably overlain by rocks of the Ohanapacosh Formation.

The Chumstick Formation is well exposed along highway US 2 between the towns of Wenatchee and Winton. This section is 5,800 m thick (Whetten, 1976); it is unexposed at its base and is overlain unconformably by rocks of the Wenatchee Formation.

The upper portion of the Naches Formation is exposed along logging roads in the Quartz Creek drainage, located approximately 25 miles northwest of the town of Naches. This section is approximately 1,500 m thick (Tabor and others, 1984), and is exposed in the NE1/4 of section 21 and the SW1/4 and SE1/4 of section 22, T.18 N., R.14 E., of the Easton 15' quadrangle. This section is underlain by the Rhyolite of Mount Clifty (Tabor and others, 1984), and is overlain by the upper tuff member of the Naches Formation which may be correlative with the Steven Ridge Formation (Hammond, 1980).

The Carbonado Formation is well exposed along Snow Creek which can

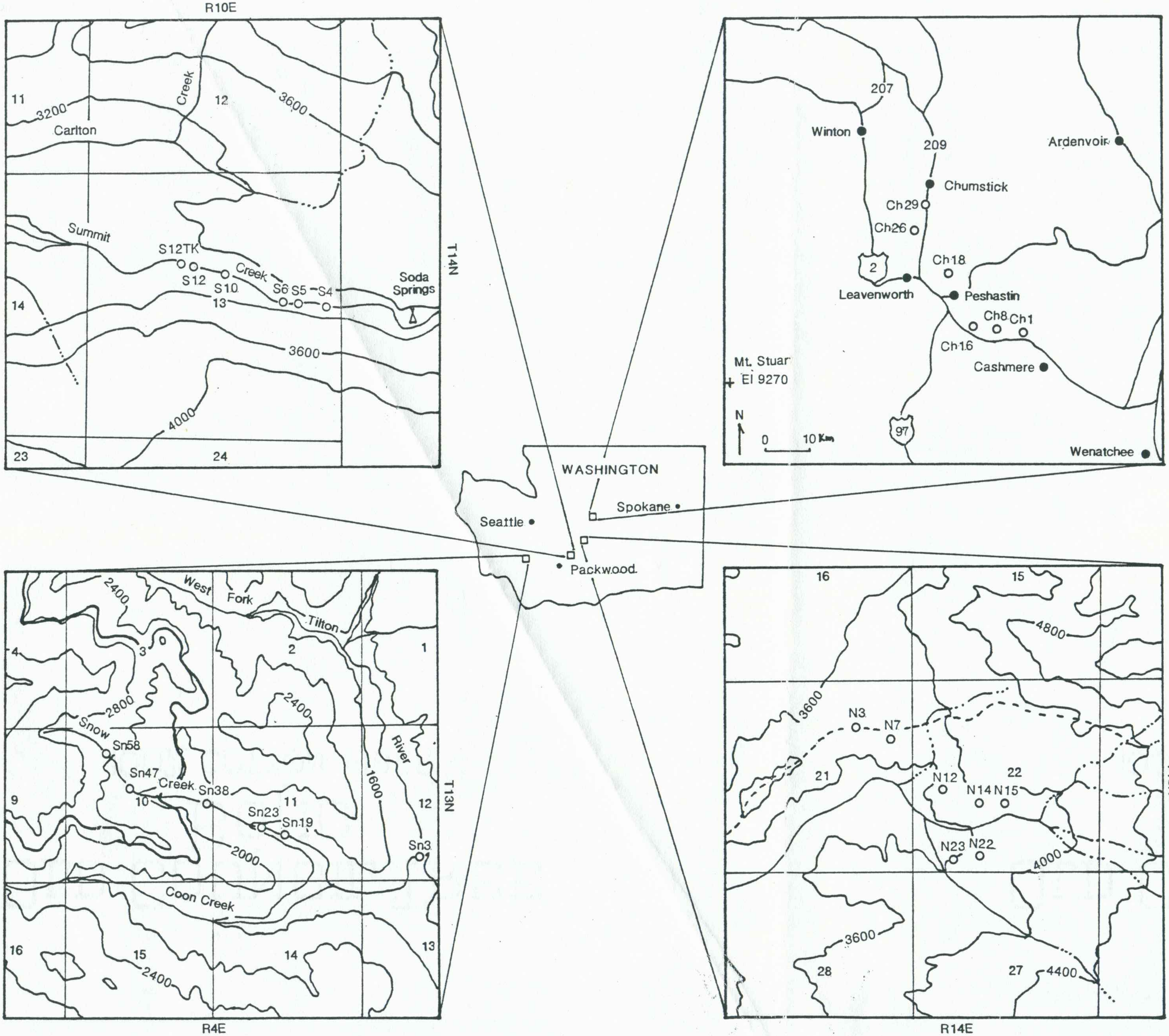


Figure 2. Figure showing sample location sites (o) in the four study areas.

be found in the SW1/4 of section 12, the SE1/4 and SW1/4 of section 11, and in the NE1/4 of Section 10, T.13 N., R.4 E.. The total exposed thickness of this formation is more than 1200 m. It is unexposed at its base and is overlain by volcanic rocks of the Northcraft Formation.

PREVIOUS WORK

Previous workers have mapped a number of Eocene arkosic units in southwest and central Washington, including the Puget Group (Gard, 1968; Buckovic, 1979), Roslyn Formation (Bressler, 1951), McIntosh Formation (Snavely and others, 1958), Carbonado Formation (Gard, 1968), Chumstick Formation (Gresens, 1981), Naches Formation (Frizzell, 1979; Hammond, 1980), Skookumchuck Formation (Snavely and others, 1958), Summit Creek sandstone (Clayton, 1983), Renton Formation (Vine, 1962), Tiger Mountain Formation (Vine, 1962), and the Spiketon Formation (Gard, 1968).

A summary of the characteristics of the four formations is shown in Table 1. The chronostratigraphic relationships between these formations is shown in Figure 3.

Buckovic (1979) summarized the stratigraphic relationships between various Eocene arkosic sedimentary units mapped by previous workers in west-central Washington, including the Puget Group, Renton, Tiger Mountain, Spiketon, Carbonado, Skookumchuck and McIntosh Formations. He believes that the similar arkosic to lithic arkosic composition of these sediments, as well as the dominant westerly current directions collected from the channel sandstone deposits, indicates that these formations represent different facies of one large 'Puget Deltaic System'. He found the majority of the Puget Group to consist of an extensive

TABLE I

DESCRIPTION OF FORMATIONS

FORMATION	SOURCE	AGE	TH	LITHOLOGY
SUMMIT CREEK SANDSTONE	HAMMOND (1980) CLAYTON (1983)	LATE EOCENE TO EARLY OLIG-OCENE	900m (+	Interstratified gray to pale brown micaceous, arkosic sandstone, siltstone, shale, sporadic thin coal beds, and rhyolitic tuff beds.
NACHES FORMATION	FRIZZELL (1979) HAMMOND (1980)	LATE EOCENE	1400 m	Dominantly arkosic sandstones and siltstones near the top, with volcano-clastic sandstones, siltstones, basaltic and rhyolitic lava flows and rhyolitic tuffs interstratified with arkosic rocks in the middle and lower portions of the formation.
CHUMSTICK FORMATION	BUZA (1979) GRESENS (1981) (1983)	MIDDLE TO LATE EOCENE	5800 m	Arkosic conglomeratic sandstone, sandstone, and shale with tuffaceous interbeds.
CARBONADO FORMATION	GARD (1968) HAMMOND (1980)	EARLY TO MIDDLE EOCENE	1370 m	Interstratified gray to pale brown micaceous arkosic sandstone, siltstone, and shale with thin coal beds, interfingered towards the top with volcanic rocks of the Northcraft Formation.

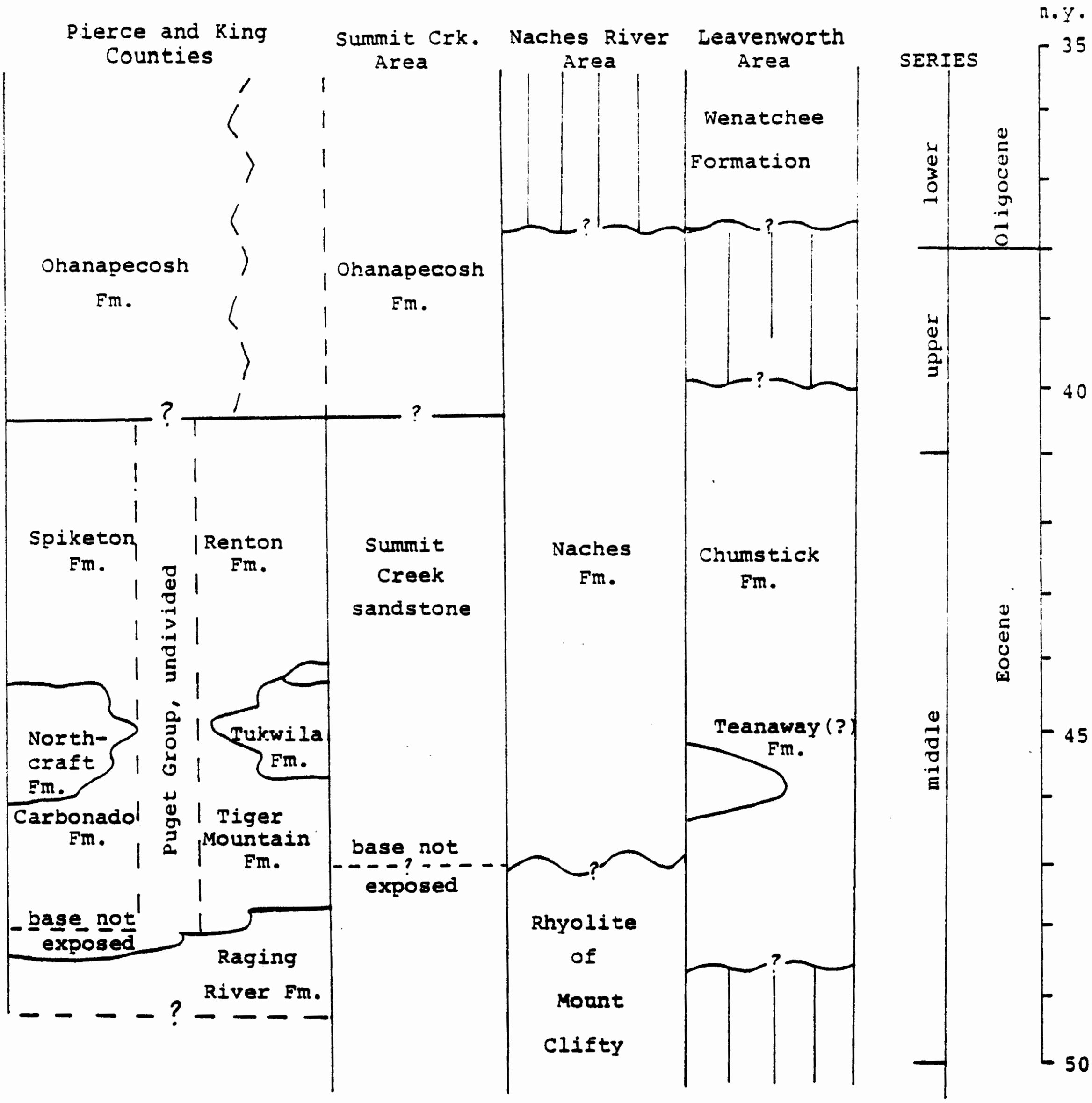


Figure 3. Chronostratigraphic correlation chart (modified after Winters, 1984). Dashed vertical lines between columns indicate lithostratigraphic equivalence; solid line indicates uncertain lithostratigraphic relationship. References for local columns are: 1, Armentrout and others, 1983; 2, Buckovic, 1974; 3, Gard, 1968; 4, Mullineaux, 1970; 5, Vine, 1969; 6, Clayton, 1983; 7, Tabor and others, 1984.

facies of nonmarine sandstone, siltstone, mudstone, and coal. Marginal marine and marine facies are less common, particularly in the lower portions of the Puget sequence. Alternating sandstone, siltstone, mudstone, and coal sequences are interpreted as distributary and interdistributary channel deposits of the delta plain facies. The thin-bedded marginal marine strata of the lower Carbonado Formation and upper Skookumchuck Formations are considered to be lagoon, or bay-like, inter-distributary deposits (Buckovic, 1979). The upper McIntosh Formation and lower Skookumchuck Formation are interpreted as delta front facies, while the lower portion of the McIntosh and the middle part of the Skookumchuck Formations may represent prodelta facies of the Puget Deltaic system. These interpretations were supported with mega- and micro-faunal data.

Frizzell (1979) studied the framework grains of Paleogene non-marine arkosic sandstone units in western Washington. He collected samples from the Puget Group, Chuckanut, Swauk, Chumstick, Manastash, and Naches Formations, and found all six of these sandstone units to be either feldspathic or lithofeldspathic subquartzose in composition (terminology after Dickinson, 1970). Relating his findings to previous work by Dickinson (1970), Frizzell concluded that the total quartz content in these sediments indicates a combination of plutonic and magmatic arc provenances. Winters' (1984) study of the framework grains of the Chambers Creek beds in southwest Washington revealed that these sandstones range in composition from arkose to lithic arkose, and are dominantly composed of subangular monocrystalline quartz and feldspar. Rock fragments comprise from 3 to 19 percent of these rocks, and are dominantly of the metamorphic, and volcanic variety, with smaller amounts of sedimentary and granitic rock fragments. Plotting the results from this study along with results collected from previous workers - on the composition of the Cowlitz, Chumstick, Naches, Renton, Roslyn, Spiketon, Skookumchuck, and Spencer Formations - Winters attempted to compare the provenances between these nine sedimentary units. The results revealed two compositionally distinct, geographically separated groups. The Chumstick, Roslyn, and Naches Formation contain a significant amount of coarsely polycrystalline quartz (Qp/Q=.30) and are relatively low in potassium feldspar (P/F=.85). In contrast the Chambers Creek beds, and the Skookumchuck, Cowlitz, and Spencer Formations all contain very little polycrystalline quartz (Qp/Q<.30), and notable amounts of K-feldspar (P/F=.60).

REGIONAL GEOLOGY

The Cascade Range of Washington can be subdivided into two main geologic provinces, separated along the northwest-trending Olympic-Wallowa lineament near Snoqualmie Pass, east of Seattle. The northern Cascade province consists primarily of a metamorphic-plutonic crystalline core, which is fault-bounded on the east and west by pre-Tertiary marine and continental sedimentary rocks. The crystalline core rocks consist of low to high ranking regionally metamorphosed rocks of pre-middle Devonian to Jurassic age, and plutonic intrusions of late Triassic to Tertiary age (Misch, 1966).

The southern Cascade province consists primarily of Cenozoic volcanic and fine-grained intrusive rocks, Tertiary continental and marine sedimentary and volcanoclastic deposits, and Tertiary granitic plutons.

Additional Tertiary continental and marine deposits, along with Holocene glacial deposits and alluvium, are found west of the Cascade Range in the Puget Lowlands.

The volcanic and sedimentary strata in the four study areas are deformed chiefly along northwest trends. Dips are as steep as 78 degrees overturned in the Summit Creek sandstone area; generally dips range from 20 to 35 (+5) degrees.

CHAPTER II

SEDIMENTARY PETROLOGY

LIGHT MINERALS

The light minerals, which are defined in this study as those minerals which have specific gravities less than tetrabromoethane (specific gravity 2.96 at 25 C), were point counted using the 'Line Method' of Carver (1971). The results from this analysis are listed in Table 2, and are plotted in ternary diagrams in Figures 4A-E.

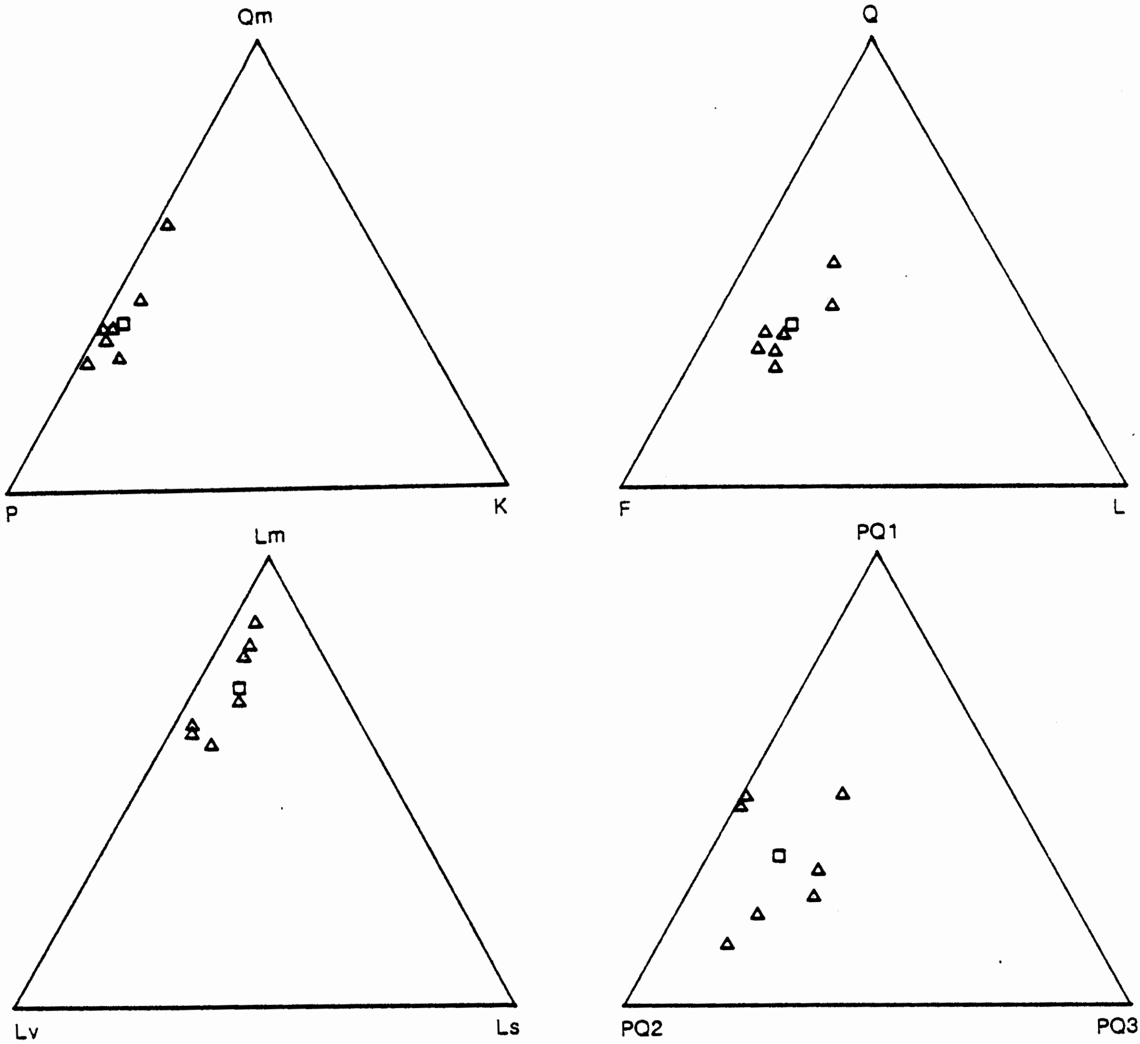
These results indicate that all four of the formations are characterized by sandstones that are arkosic to lithic arkosic in composition, with feldspar being more abundant than quartz. Plagioclase comprises between 30 and 50 percent of these rocks, and thus is the most abundant mineral in all of the formations. Plagioclase is most abundant in the Naches and Chumstick Formations.

Quartz is present in both a monocrystalline and polycrystalline form. Monocrystalline quartz comprise between 15 and 38 percent of these rocks, while the polycrystalline form comprises between 1 and 9 percent. The monocrystalline grains are generally equant in shape and often show strain shadows through 5 degrees of stage rotation. The

TABLE II

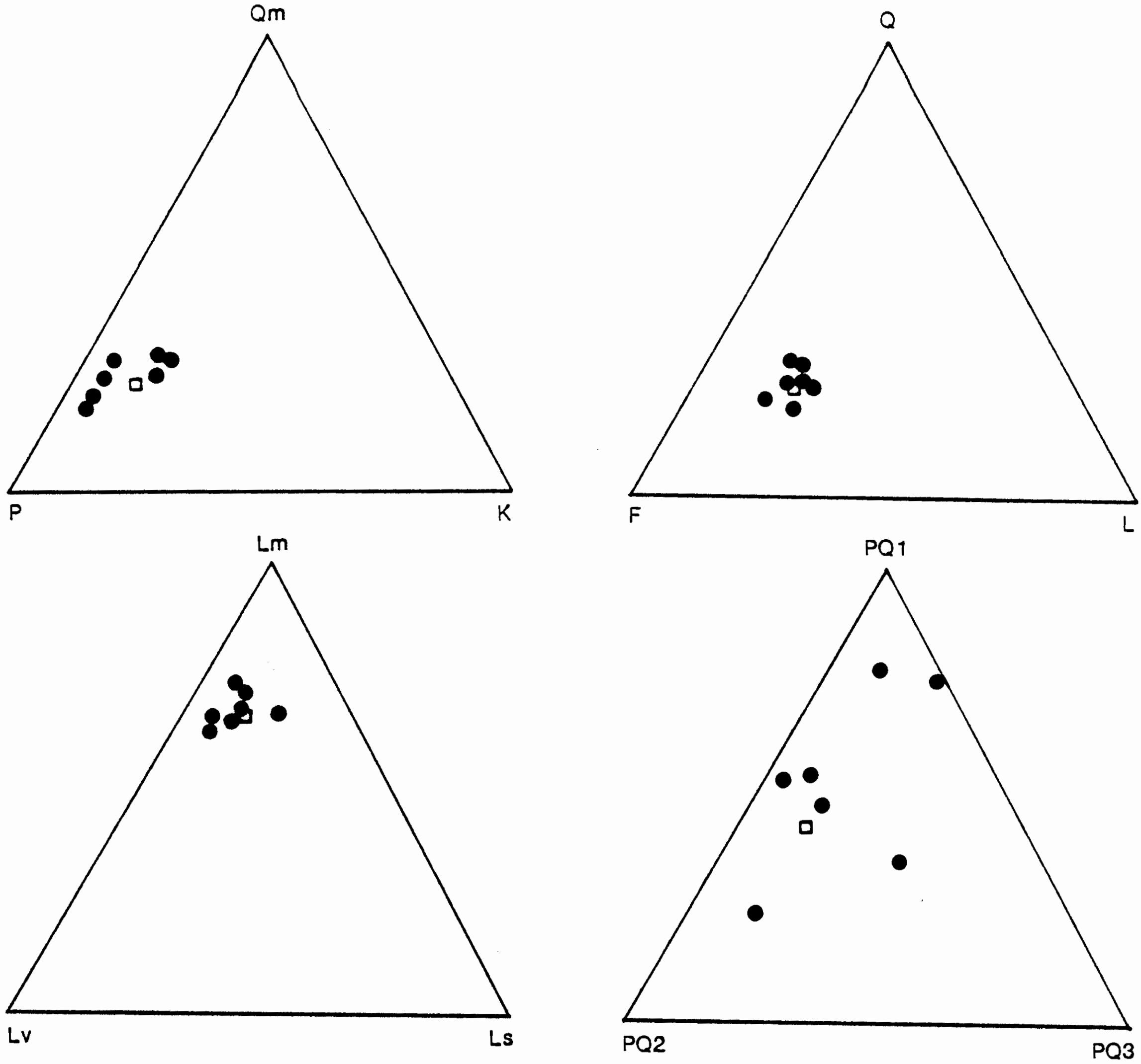
RELATIVE PERCENTAGES OF LIGHT MINERALS

Formation	Sample	Qm	PQ1	PQ2	PQ3	total Q	P	K	total F	Lv	Lm	Ls	total L	Cht	B	M
Carbonado Fm	Sn3	36	2	2	3	43	25	10	35	8	4	2	14	2	2	1
	Sn19	30	1	2	6	39	36	5	41	7	8	1	16	1	3	T
	Sn23	21	1	3	3	28	38	11	49	5	14	T	19	1	2	-
	Sn38	26	1	2	3	32	33	5	38	10	8	T	18	T	7	2
	Sn47	14	2	1	-	17	48	12	60	7	8	T	15	1	6	1
	Sn58	18	2	4	1	25	42	12	54	6	4	T	10	1	11	T
Summit Creek S.S.	S4	30	3	2	1	36	36	3	39	7	13	T	20	T	3	T
	S5	49	1	1	-	51	29	2	31	6	10	T	16	-	2	T
	S6	29	1	2	1	33	50	-	50	4	7	1	12	T	4	1
	S10	27	T	2	T	29	50	2	52	1	10	T	11	1	7	T
	S11	29	1	1	1	32	51	1	52	2	7	1	10	-	5	1
	S12	21	2	2	-	25	48	3	51	2	13	1	16	1	6	2
	S12TK	22	1	4	1	28	49	1	50	2	11	1	14	-	6	2
Naches Fm	N3	21	4	3	T	28	38	11	49	5	11	1	17	T	5	1
	N7	16	2	T	T	18	46	11	57	4	8	1	13	-	12	T
	N12	15	1	1	1	18	48	4	52	5	12	2	19	-	9	T
	N14	20	4	1	-	25	37	9	46	2	10	3	15	-	13	1
	N15	19	2	1	T	22	43	5	48	4	14	2	20	T	9	T
	N22	19	1	4	1	25	47	5	52	3	11	1	15	-	7	T
	N23	18	4	3	1	26	40	10	50	4	13	2	19	-	5	T
Chumstick Fm	Ch1	19	1	4	2	26	44	3	47	9	8	1	18	-	6	2
	Ch8	19	T	3	-	22	48	6	54	3	5	1	9	-	13	2
	Ch16	24	-	1	T	25	37	10	47	5	13	1	19	-	7	1
	Ch18	18	1	4	1	24	54	3	57	4	6	1	11	-	5	1
	Ch26	30	T	5	2	37	36	11	47	2	10	1	13	-	2	T
	Ch29	21	T	1	1	23	43	7	50	5	11	1	17	-	9	T



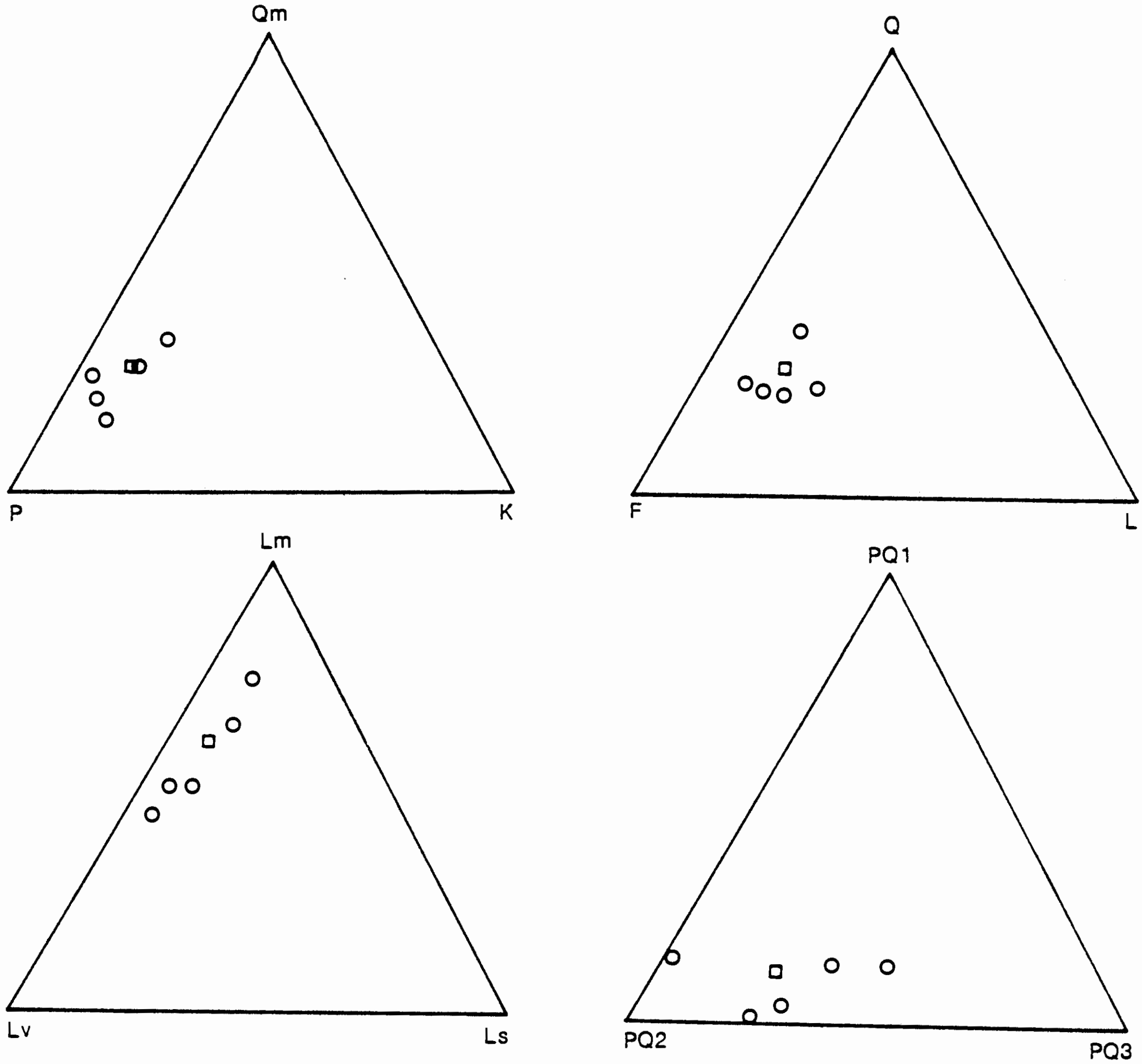
(□) = mean composition

Figure 4A. Ternary diagrams showing the composition of framework grains for seven samples from the Summit Creek sandstone (△). Qm, quartz, monocrystalline; P, plagioclase; F, total feldspar; Lm, lithic fragments, metamorphic; Lv, lithic fragments, volcanic; Ls, lithic fragments, sedimentary; PQ1, quartz, polycrystalline, containing greater than 10 crystals/grain; PQ2, quartz, polycrystalline, containing less than 10 and greater than 3 crystals/grain; and PQ3, quartz, polycrystalline, containing 3 crystals/grain or less.



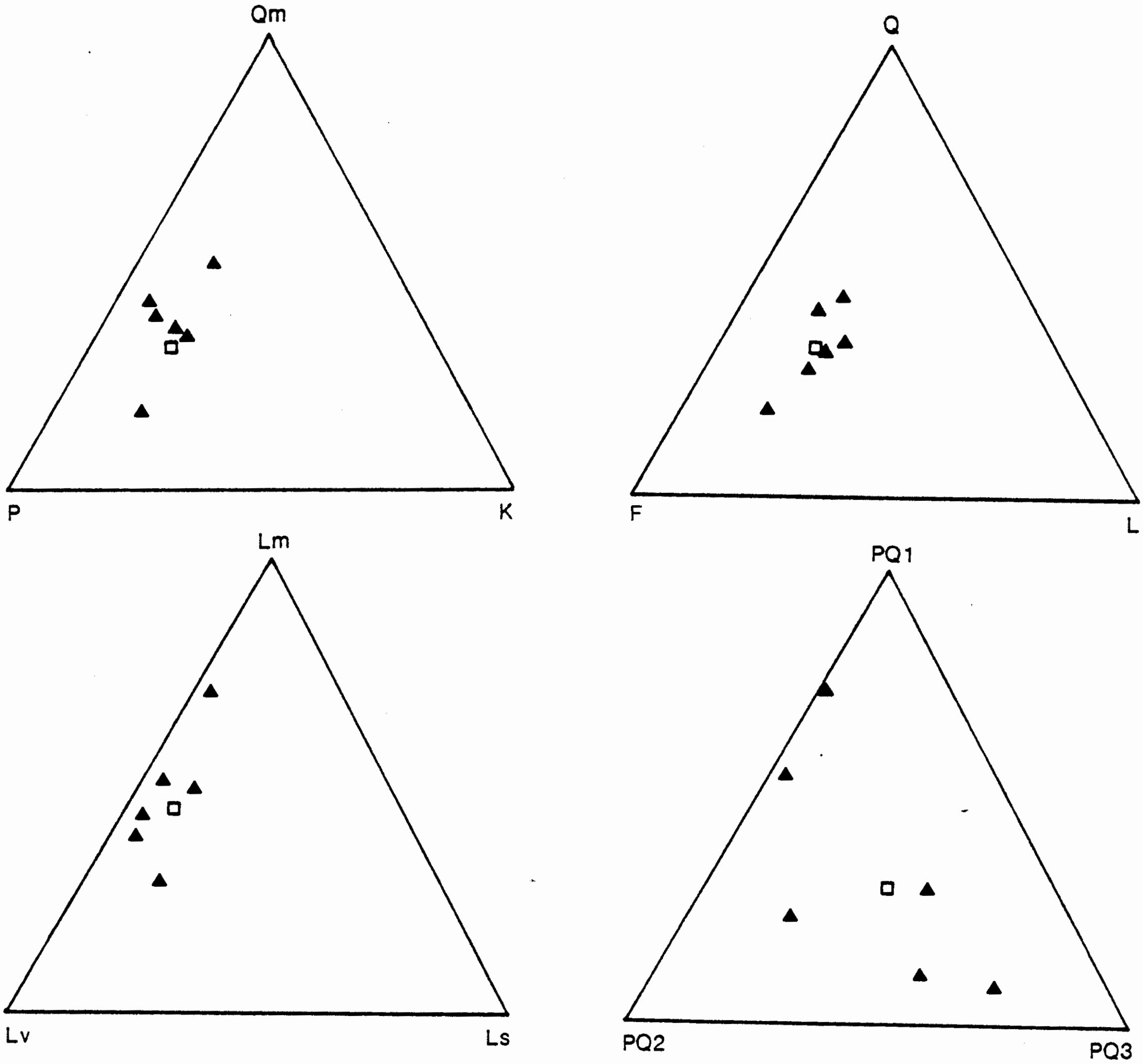
(□) = mean composition

Figure 4B. Ternary diagrams showing the composition of framework grains for seven samples from the Naches Formation (●). (refer to Figure 4A for abbreviations)



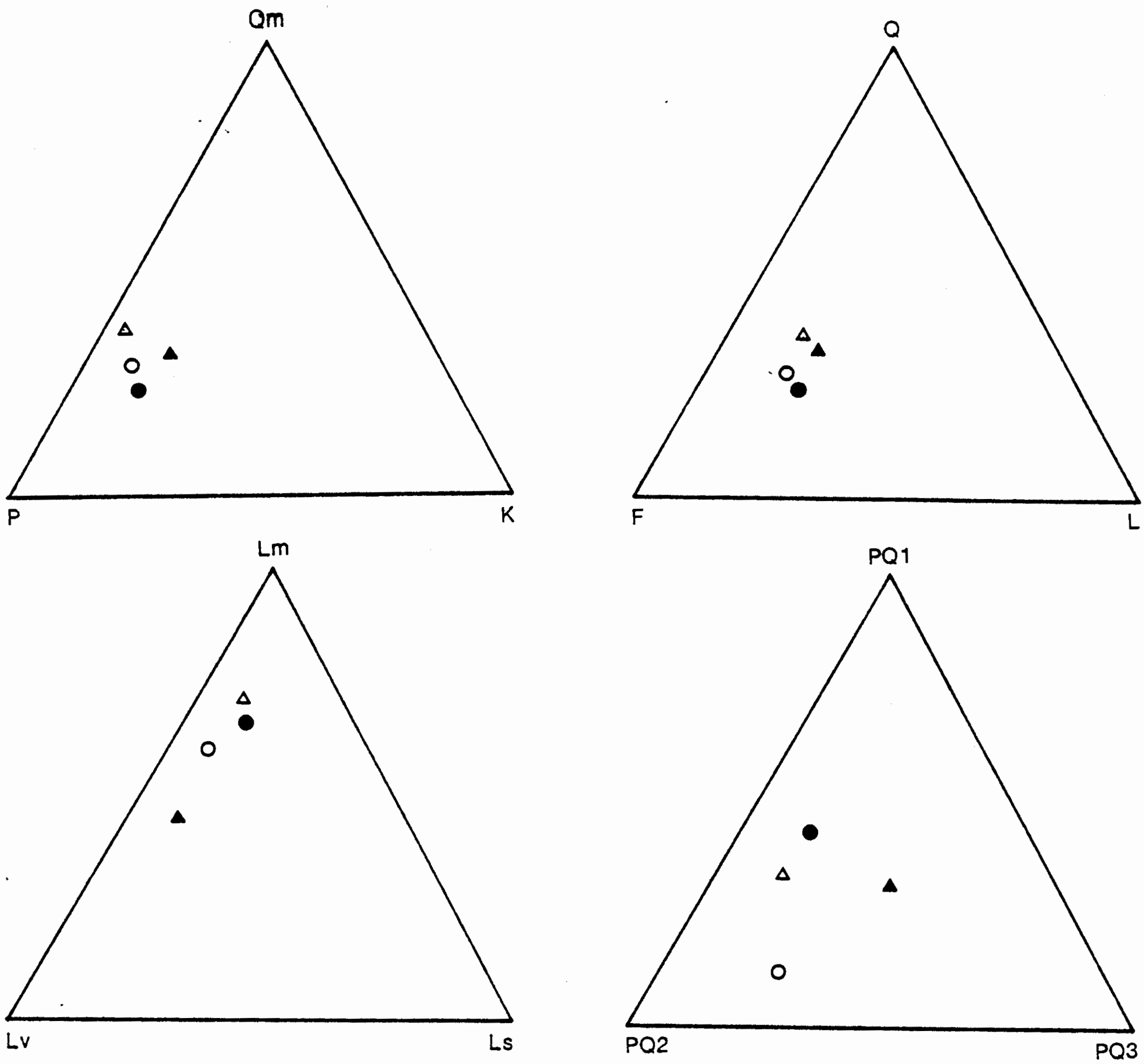
(▫) = mean composition

Figure 4C. Ternary diagrams showing the composition of framework grains for six samples from the Chumstick Formation (o). (refer to Figure 4A for abbreviations)



(▫) = mean composition

Figure 4D. Ternary diagrams showing the composition of framework grains for six samples from the Carbonado Formation (▲). (refer to Figure 4A for abbreviations)



<u>Figure 4E</u>. Ternary diagrams showing the mean composition of framework grains for the Summit Creek sandstone (△), Naches (●), Chumstick (○), and Carbonado Formations (▲). (refer to Figure 4A for abbreviations)

Polycrystalline grains generally show crystal units with polyhedral outlines, smooth crystal-crystal boundaries, and interfacial angles of 120 degrees at triple junctions of crystal boundaries. Only one polycrystalline quartz grain was found to contain distinctly elongated crystal units. PQ1, PQ2, and PQ3 are three varieties of polycrystalline quartz defined by the author. PQ1 and PQ2 identify those polycrystalline quartz grains which contain greater than ten and those less than ten and greater than three crystals/grain, while PQ3 identifies grains which contain 3 crystals/grain or less. PQ2 is the most abundant variety of polycrystalline quartz found in all four formations, followed by PQ1 and PQ3. PQ1 is found most abundant in the Naches formation, whereas PQ2 and PQ3 are found most abundant in the Chumstick and Carbonado Formations. The overall total quartz percentages are slightly higher in the Carbonado Formation, and the Summit Creek sandstone than in the Naches and Chumstick Formations.

Potassium feldspar is found in all of the formations, generally making up between 1 and 11 percent of these rocks, and is dominantly of the orthoclase variety. The Summit Creek sandstone contains the smallest percentage of this mineral at 3 percent or less, where the others contain near equal amounts.

Rock fragments are found to comprise as much as 21 percent of these rocks. The most abundant rock fragments are of the metamorphic quartz-biotite-schist variety. These fragments show a well defined foliation, are fine grained, and can be distinguished from polycrystalline quartz by containing greater than 5 percent mica.

The next most abundant rock fragments are the mafic volcanic variety, which comprise between 1 and 10 percent of these rocks. These fragments have been determined to be mafic on the grounds that they contain no potassium feldspar or quartz. Sedimentary siltstones and mudstones are rare. Biotite is the most abundant phyllosilicate mineral comprising as much as 13 percent of these rocks. Muscovite and chlorite are considerably less abundant making up less than 2 percent and less than 1 percent of these rocks respectively. The biotite found in the Carbonado Formation, and the Summit Creek sandstone is medium-brown to dark-brown in color, while in the Naches and Chumstick Formations, the boitite ranged in color from dark-brown to dark-brown-green to yellow-green in color.

COMPARATIVE MINERALOGY WITH CORRELATIVE ARKOSIC SANDSTONE UNITS

In order to better understand the provenance, the overall size of the depositional basin, and the depositional setting of the four formations under study, the results from this analysis were compared to published modal data from the correlative middle to upper Eocene Chambers Creek beds, Roslyn, and Renton Formations (Winters, 1984; Frizzell, 1979), the Cowlitz, and Spencer Formations of northwest Oregon (Jackson, 1983; Al-Azzaby, 1980), and the Skookumchuck Formation of western Washington (Buckovic, 1974).

The stratigraphic relationships between these formations are shown in Figure 5.

The framework grain compositions of the above mentioned formations were added to ternary and secondary ratio diagrams previously constructed by Winters (1984) (Figures 6 and 7).

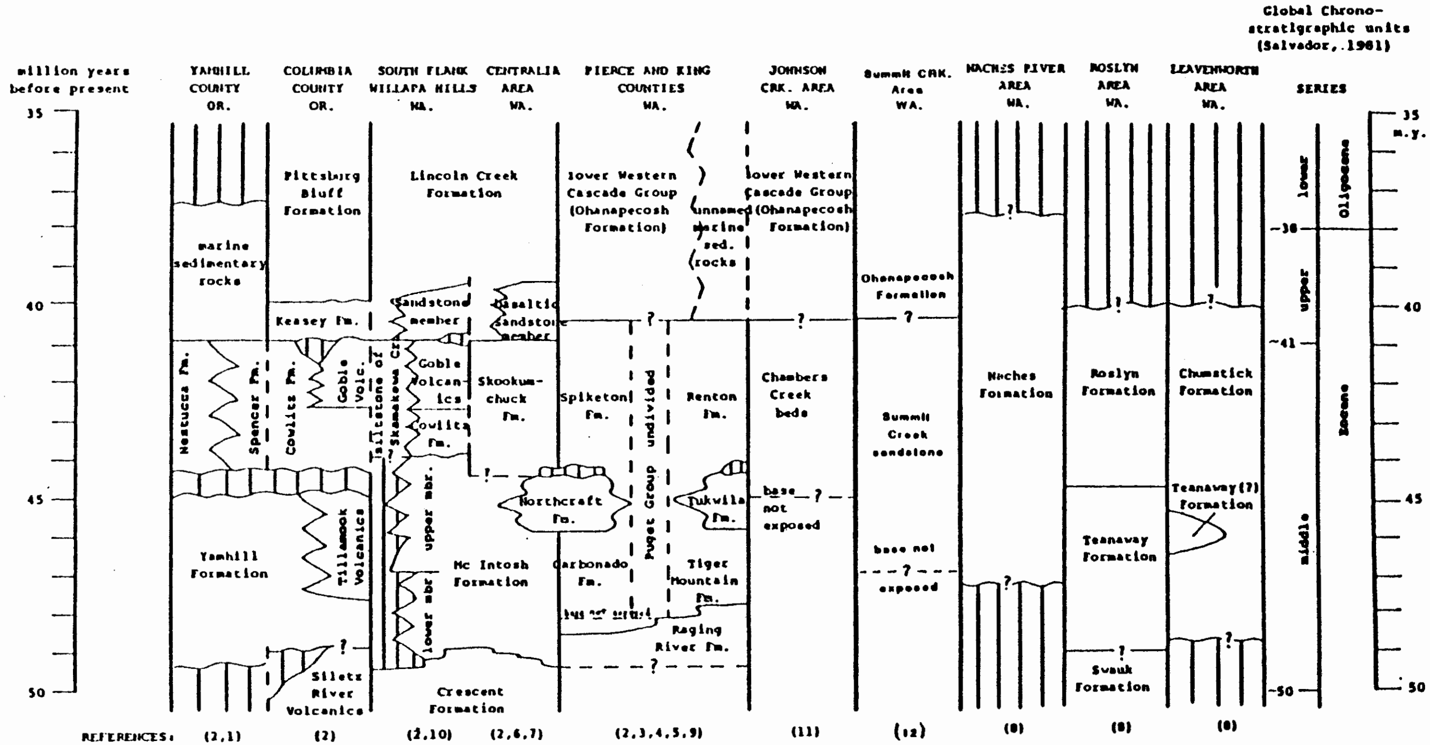


Figure 5. Chronostratigraphic correlation chart (modified after Winters, 1984). Dashed vertical lines between columns indicate lithostratigraphic equivalence; solid line indicates uncertain lithostratigraphic relationship. References for local columns are: 1, Al-Azzaby, 1980; 2, Armentrout and others, 1983; 3, Buckovic, 1974; 4, Gard, 1968; 5, Mullineaux, 1970; 6, Rau, 1981; 7, Snavely and others, 1958; 8, Tabor and others, 1984; 9, Vine, 1969; 10, Wells, 1981; 11, Winters, 1983; 12, Clayton, 1983.

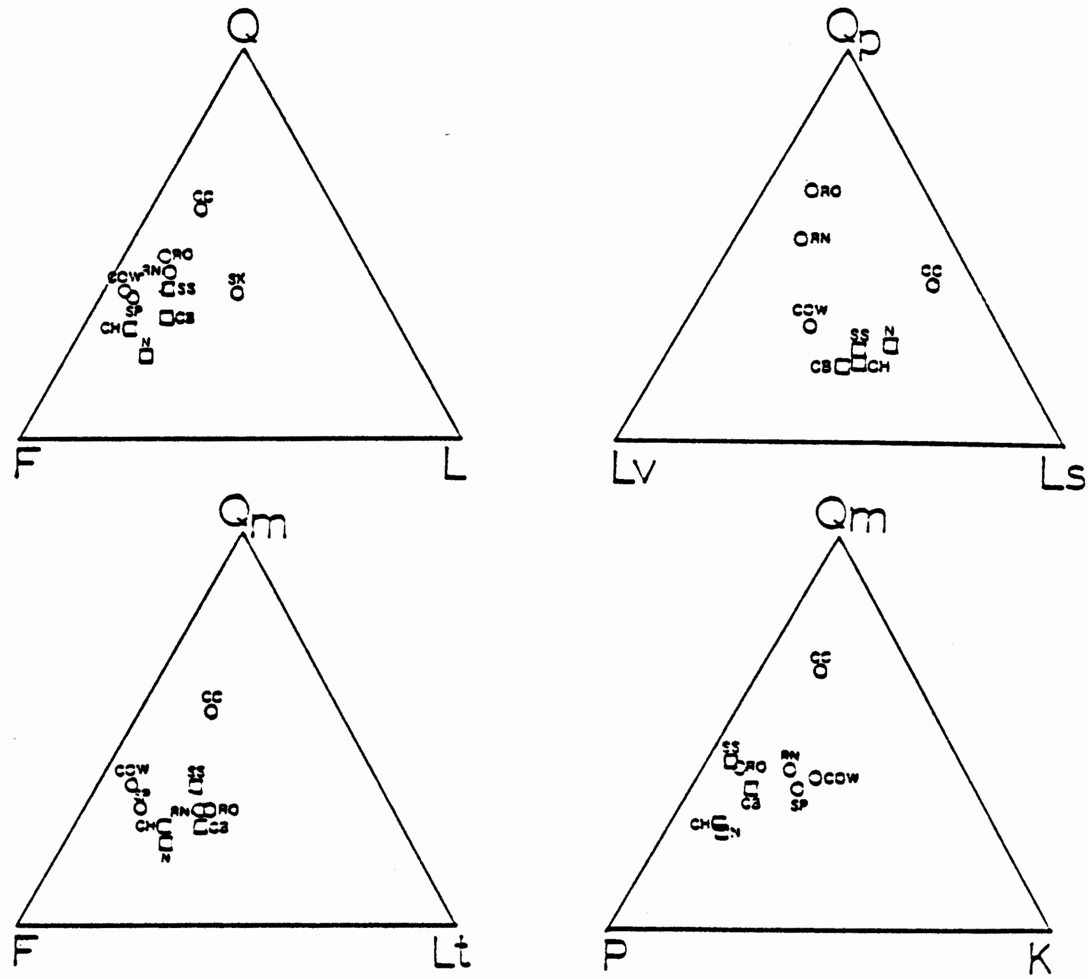


Figure 6. Ternary diagrams showing the mean composition of framework grains between the Chambers Creek beds (CC), Summit Creek sandstone (SS), Carbonado (CB), Chumstick (CH), Cowlitz (COW), Naches (N), Renton (RN), Roslyn (RO), Skookumchuck (SK), and Spencer Formations (SP) (modified after Winters, 1984). Qm, quartz, monocrystalline; Qp, quartz, polycrystalline; Q, total quartz; P, plagioclase; K, potassium feldspar; F, total feldspar; Lv, lithic fragments, volcanic plus metavolcanic; Ls, lithic fragments, sedimentary plus metasedimentary; L, Lv + Ls; Lt, Lv + Ls + Qp.

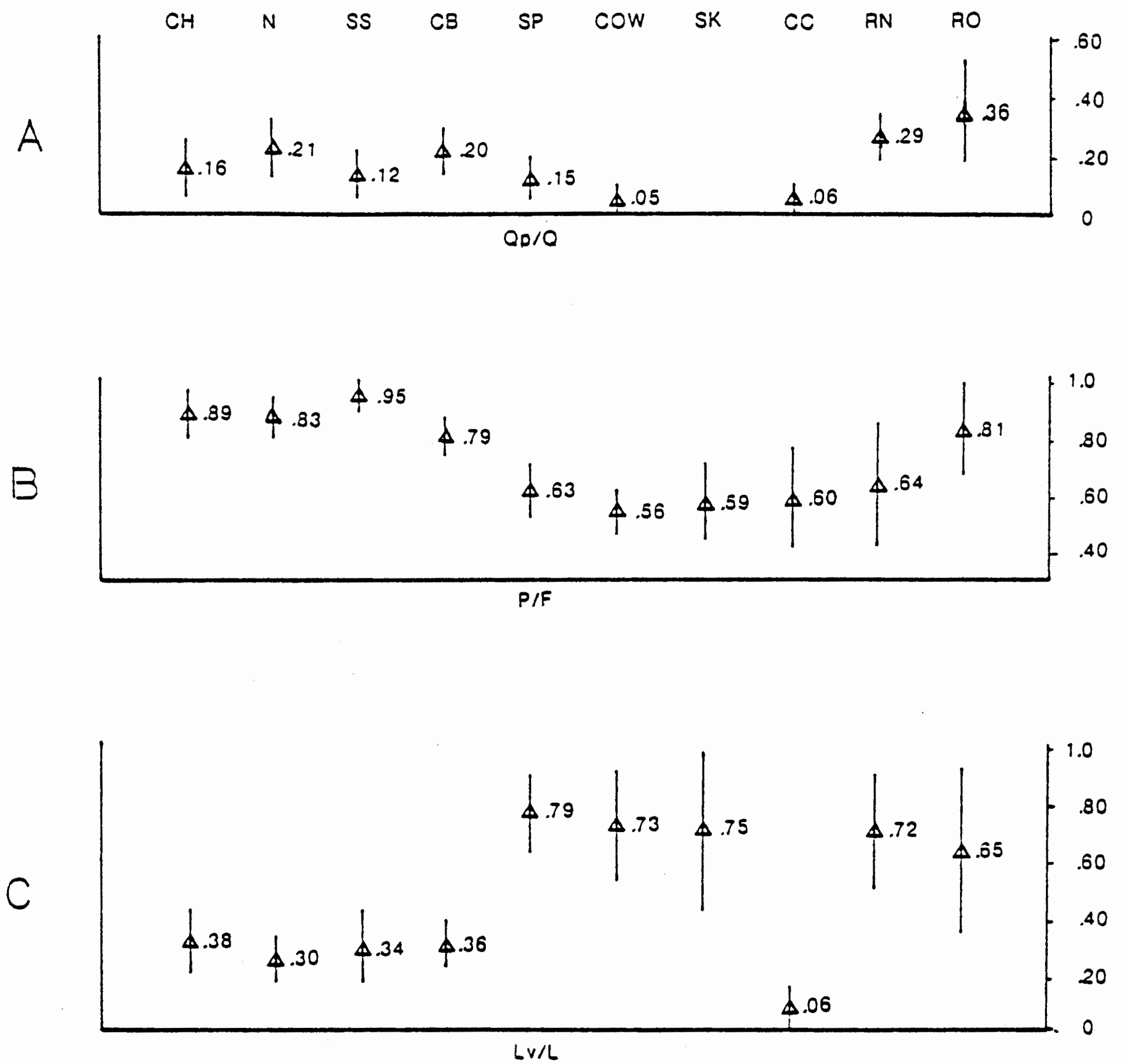


Figure 7. Ratio of polycrystalline quartz to total quartz (Qp/Q), plagioclase to total feldspar (P/F), and volcanic lithic fragments to total lithic fragments (Lv/L) between formations identified on preceding figure. Bars show 80% confidence interval for data (modified after Winters, 1984).

Although the framework grain compositions of the ten formations show a considerable amount of variation between formations, only the QpLvLs diagram in Figure 6 shows an obvious grouping pattern. In this diagram, it appears that the Roslyn, Renton, and Chambers Creek beds contain a significantly larger polycrystalline quartz concentration than the other five formations. On the other hand, the Summit Creek sandstone, Naches, Chumstick, Carbonado, and Chambers Creek beds contain a significantly larger concentration of sedimentary and metasedimentary rock fragments than the other three formations. The Chambers Creek beds and the Skookumchuck Formation are unique in that they respectively contain a considerably larger concentration of total quartz, and total lithic fragments than any of the other eight formations. Plot C, in Figure 7, shows by far the best grouping of formations based on framework grain composition. This plot reveals three distinct populations of samples, The first population, which represents the Spencer, Cowlitz, Skookumchuck, Renton, and Roslyn Formations, is characterized by a relatively high volcanic lithic to total lithic fragment ratios (averaging 0.72). The second population, which represents the Summit Creek sandstone, Chumstick, Naches, and Carbonado Formations, is characterized by intermediate volcanic to total lithic fragment ratios (averaging 0.35), and finally the third population, which represents the Chambers Creek beds, is characterized by very low volcanic to total lithic fragment ratios (averaging 0.06). Plot A, in Figure 7 also reveals three distict populations of samples, although these populations are not as well defined as in Plot C. The first population in Plot A includes the Renton and Roslyn Formations, this population is characterized by a relatively high polycrystalline quartz to total quartz ratio (averaging 0.32 + 0.15). The second population includes the Summit Creek sandstone, Chumstick, Naches, Carbonado, and Spencer Formations, it is characterized by an intermediate polycrystalline quartz to total quartz ratio (averaging 0.16 + 0.1). The third population includes the Cowlitz Formation and Chambers Creek beds, and is characterized by the smallest polycrystalline quartz to total quartz ratio (averaging 0.06 + 0.05). Plot B in Figure 7 shows only two populations of samples. One population contains a relatively high plagioclase to total feldspar ratio, which includes the Summit Creek sandstone, Chumstick, Naches, Carbonado, and Roslyn Formations (averaging 0.85 + 0.1), and the other contains a lower plagioclase to total feldspar ratio (averaging 0.60 + 0.2), and includes the Chambers Creek beds, Spencer, Cowlitz, Skookumchuck, and Renton Formations.

HEAVY MINERALS

The heavy mineral assemblages were characterized by the presence of epidote, apatite, zircon, garnet, sphene, rutile, tourmaline, zoisite, hornblende, augite, hypersthene, and staurolite. The relative abundances of these minerals are shown in Table III.

The results from this analysis indicate that all four formations are basically characterized by the same heavy mineral populations, with only minor variations in percentages between formations.

COMPARATIVE HEAVY MINERALOGY WITH CORRELATIVE ARKOSIC SANDSTONES

The most extensive heavy mineral study done on Eocene sandstones

TABLE III

RELATIVE PERCENTAGES OF HEAVY MINERALS

epidote	apatite	zircon	garnet	sphene	rutile	tourmaline	zoisite	hornblende	augite	hypersthene	staurolite	others	Formation	Sample
7	16	20	8	2	2	6	-	-	2	2	1	34	CARBONADO FORMATION	SN3
4	3	19	14	2	6	10	-	-	2	-	1	39		SN19
10	-	25	23	-	4	6	1	-	-	-	-	31		SN22
18	26	3	1	-	-	-	-	-	-	3	-	49		SN38
10	18	14	10	-	4	-	-	T	8	-	-	36		SN47
19	24	12	5	-	-	-	-	-	-	-	-	88		SN58
19	7	19	9	-	-	2	-	-	-	10	-	34	SUMMIT CREEK S.S.	S4
6	27	13	11	-	9	15	-	-	-	-	-	19		S5
15	20	10	8	3	5	5	-	-	-	-	-	34		S6
11	21	23	11	5	2	6	-	-	-	-	-	16		S10
10	22	17	11	1	3	6	-	1	-	1	-	28		S11
7	24	29	8	6	-	5	-	-	-	-	-	21		S12TK
42	12	7	6	-	4	-	6	1	6	-	-	16	NACHES FORMATION	N3
37	3	16	3	6	4	3	-	-	10	4	-	14		N7
37	6	11	8	8	4	3	1	1	5	1	-	15		N12
46	3	3	3	11	4	1	10	-	-	-	-	19		N15
33	5	2	9	14	-	2	-	-	-	-	-	35		N22
45	5	2	12	11	2	1	1	-	-	-	-	21		N23
26	-	10	11	18	3	2	-	5	-	2	-	23	CHUMSTICK FORMATION	CH1
19	-	10	17	11	1	1	-	11	-	3	-	27		CH8
34	14	3	4	10	3	3	15	5	-	-	-	9		CH16
30	14	-	40	7	1	-	1	-	-	1	-	6		CH18
34	10	6	23	13	1	-	3	-	-	-	-	9		CH26
45	4	4	5	22	3	-	5	-	-	-	-	12		Ch29

in southwest and central Washington, was a study done by Bressler (1951) on the Roslyn Formation. Heavy minerals were also noted in Karachewski's (1983) study of the Oligocene Lincoln Creek Formation in southwest Washington, and in Van Atta's (1971) study of the Cowlitz Formation in northwest Oregon.

Bressler's (1951) petrographic study of the middle to upper Eocene Roslyn Formation in central Washington revealed these sedimentary units to contain heavy mineral assemblages which are dominated by the minerals epidote, clinozoisite, apatite, garnet, sphene, tourmaline, zircon, actinolite, and least abundant rutile. Karachewski (1983) found zircon, garnet, sphene, and apatite in his study of the Lincoln Creek Formation in southwest Washington, while Van Atta (1971) noted apatite, sphene, epidode, tourmaline, garnet, hornblende, augite, actinolite, kyanite, staurolite, rutile, andalusite, and least abundant glaucophane in his study of the Cowlitz Formation of northwest Oregon.

CHAPTER III

GEOCHEMISTRY

Samples for this portion of the study were analyzed using gamma ray spectroscopy. The results from this analysis can be found in Appendix A. The concentrations of the twelve trace elements Ce, Co, Cs Eu, Fe, Hf, La, Na, Sc, Sm, Ta and Th were then entered into a similarity matrix, and then plotted in the cluster analysis shown in figure 8.

The results from this cluster analysis indicate that there are two distinct populations of samples. The first population includes samples from the Summit Creek sandstone, Chumstick, and Carbonado Formations. The samples within this population show trace element compositional similarities averaging 0.99, where 1.0 indicates samples of perfect similarity. The samples within the second population, which represents the samples from the Naches Formation, show an average similarity of 0.95. However, the similarity between the two populations is only 0.72. The results from this analysis were also plotted graphically in Figure 9, in hopes to better illustrate the compositional variation between formations. From Figure 9 and Appendix A, it is evident that relative to the Summit Creek sandstone, Chumstick, and Carbonado Formations, the Naches Formation contains a significantly lower concentration of Ce, La,

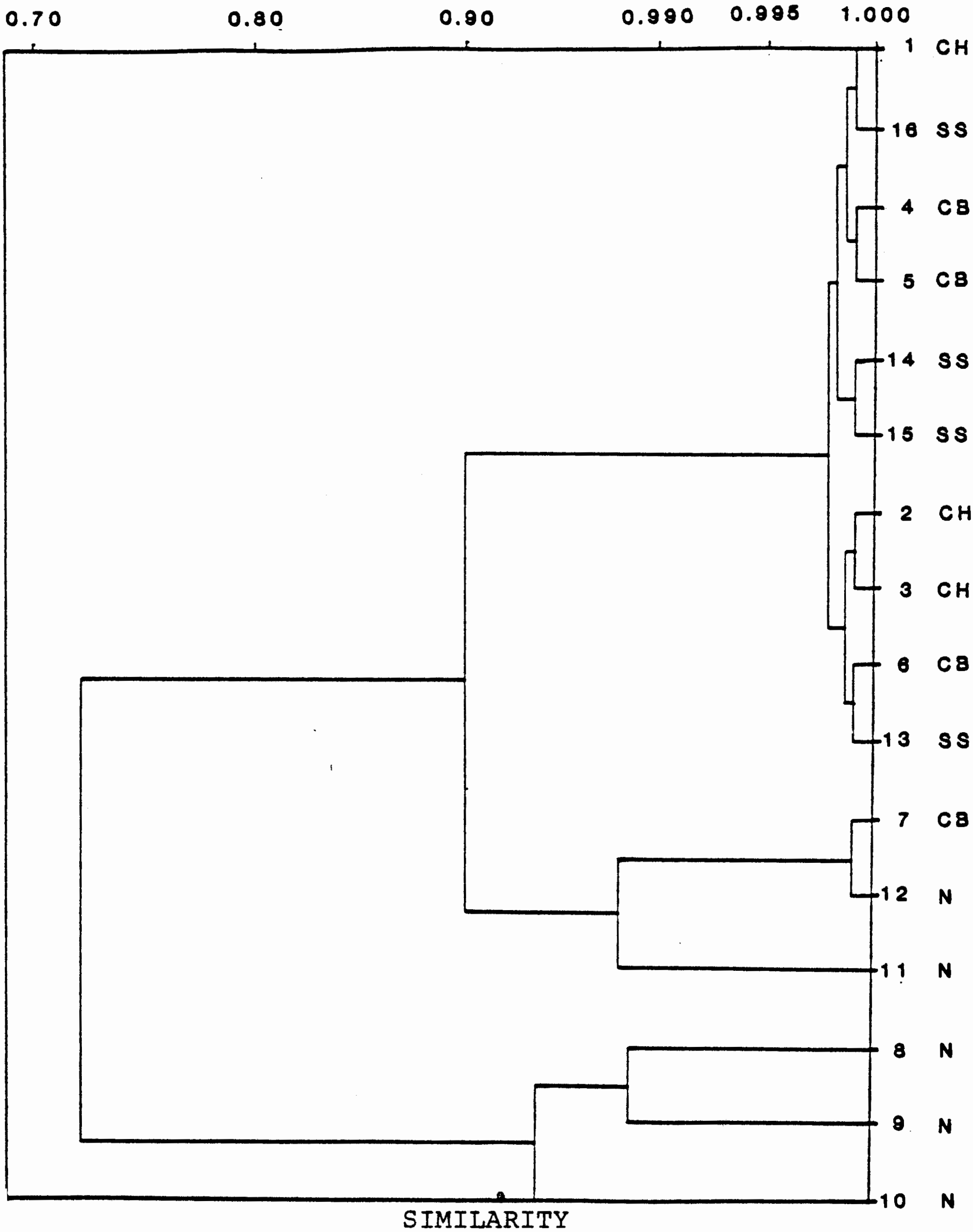


Figure 8. Cluster analysis showing the geochemical similarity between various samples from the Summit Creek sandstone (SS), Naches (N), Chumstick (CH), and Carbonado Formations (CB).

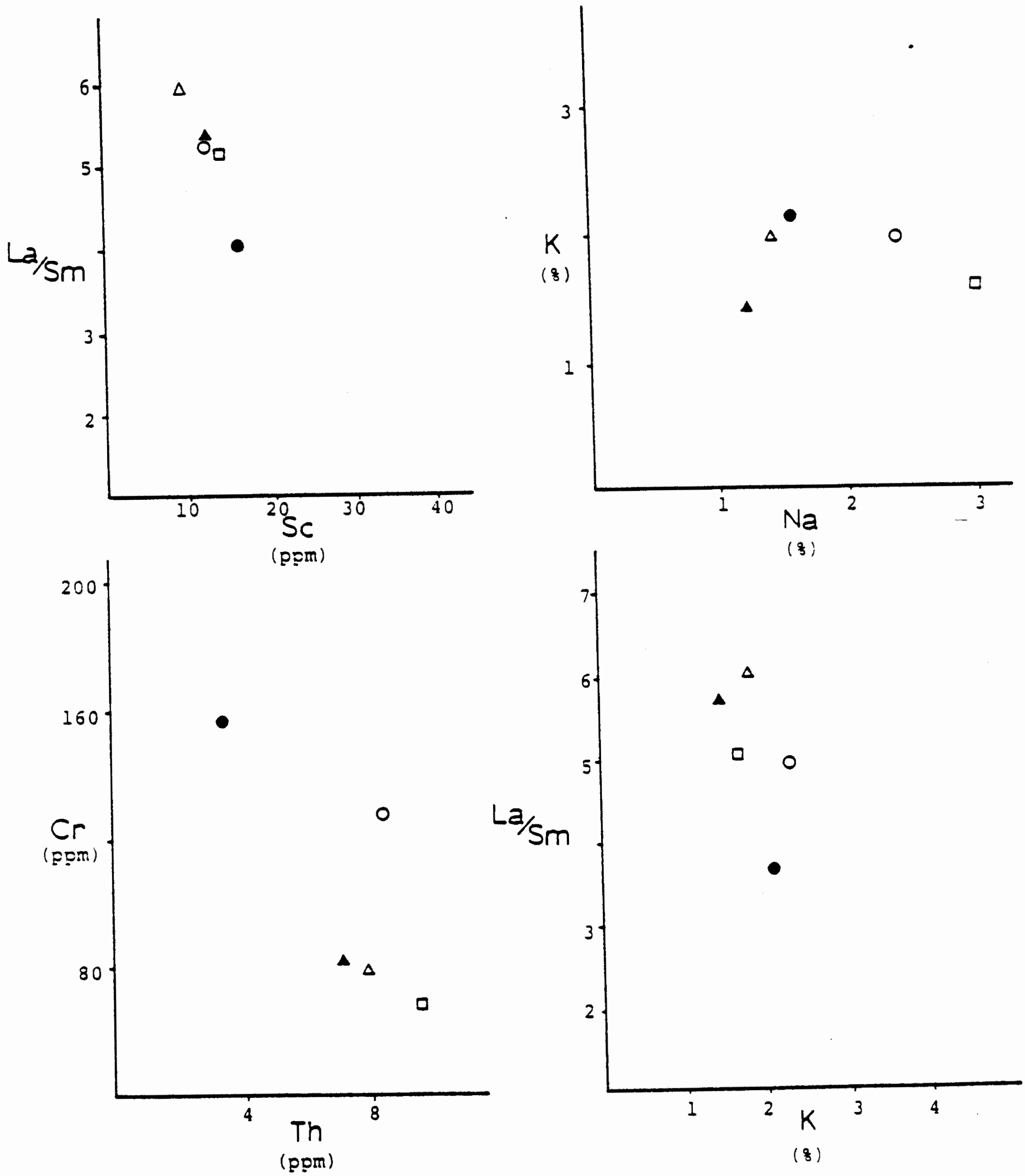


Figure 9. Plots showing the geochemical variation between the Summit Creek sandstone (△), Naches (●), Chumstick (○), Carbonado (▲), and Cowlitz Formations (□).

Ta and Th, and a higher concentration of Co, Cr, Fe and Sc. Of the three more geochemically similar formations, the Chumstick Formation contains a slightly higher concentration of Cr, Sm, and Hf then either the Summit Creek sandstone, or the Carbonado Formation. The Summit Creek sandstone, and the Carbonado Formation are nearly identical in composition.

COMPARATIVE GEOCHEMISTRY WITH CORRELATIVE ARKOSIC SANDSTONES

The trace element data from Kadri's (1982) study of the Cowlitz Formation was also plotted in Figure 9 against the trace element composition of the Summit Creek sandstone, Naches, Chumstick, and Carbonado formations.

The results indicate that the Cowlitz Formation shows similar La/Sm ratios to both the Chumstick, and Carbonado Formations. It also shows similar concentrations of Sc and K to the other four formations. However, the Cowlitz Formation shows considerably larger concentrations of both Na and Th, and a slightly smaller concentration of Cr than do the other three formations.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

LIGHT MINERALS

The results from the light mineral analysis indicate that the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations are virtually identical in composition in terms of their monocrystalline quartz, feldspar, and lithic fragments (Figure 4). There is some degree of variation in the concentration of the three varieties of polycrystalline quartz between formations; however, this variation may, in part, be due to the rather small number of grains to which this plot is based.

The arkosic to lithic arkosic composition of these sediments suggests either a silicic plutonic or metamorphic source terrain. The significantly higher percentage of feldspar than quartz in these rocks, may suggest that the source areas were uplifted and eroded rapidly so as to not allow sufficient time for a significant amount of these minerals to either be physically or chemically broken down.

The rather small percentage of K-feldspar in these rocks leads me to conclude that the majority of these sediments were not derived from rocks of true granitic composition, since granitic rocks typically contain greater than 30 percent K-feldspar (Blatt and others, 1980). This rather low percentage of K-feldspar is more indicative of sediments derived from tonalites, quartz-diorites, or high grade metamorphic gneisses and schists. The lack of twinning in the feldspars may be due in a large part to the fact that in grain mounts, plagioclase grains generally lie on the (010) surface, which is the most common twin plane. The rather small ratio of polycrystalline quartz to total quartz, is common in sedimentary rocks since the numerous grain boundaries in the polycrystalline quartz grains cause them to be less stable. The majority of the polycrystalline quartz grains appear to be of the upper greenschist facies metamorphic variety, since the majority of the polycrystalline quartz contains greater than three crystals per grain (Young, 1976; Blatt and others, 1980).

The rock fragment data also indicates a major medium to low grade quartz-biotite schist, and mafic volcanic source area contributing sediments to the finer fractions of these sedimentary rocks. The small percentage of sedimentary rock fragments is typical of most sedimentary rocks, since they generally are more easily broken down than metamorphic and volcanic rock fragments.

The abundance of brown biotite (titanium-rich biotite), as opposed to green biotite (titanium depleted biotite), in these formations indicates that the majority of the biotite from these formations is derived from a mafic volcanic, as opposed to a silicic plutonic source, since titanium tends to be enriched in these types of rocks. The higher concentration of green biotite in the Naches, and Chumstick Formations may indicate that these sediments are closer to a silicic plutonic source than the Summit Creek sandstone and Carbonado Formation

In summary the light mineral data indicates a tonalite, or quartz-diorite plutonic, or a high grade metamorphic source rock contibuting to the coarser fraction of the sediments, with a medium to low grade metamorphic and mafic volcanic source rock contributing to the finer fraction of these sediments.

HEAVY MINERALS

The results from this portion of the study indicate all four formations under study to be characterized by the presence of the heavy minerals epidote, apatite, zircon, garnet, sphene, rutile, tourmaline, hornblende, and hypersthene. The Naches, Chumstick, and Carbonado Formations also contain small percentages of zoisite and augite, and the Carbonado Formation contains traces of staurolite.

The minerals apatite and zircon are common minerals of plutonic igneous rocks, and granite pegmatites. They are also present although slightly less common in contact and regional metamorphic rocks, and volcanic rocks (Deer and others, 1966).

Rutile and sphene are both common accessory minerals of intermediate to acidic plutonic rocks, metamorphic schists and gneisses rich in ferromagnesium minerals, as well as calc-silicate rocks and skarns (Deer and others, 1966).

Hornblende is one of the most widely distributed minerals in nature, being found in igneous rocks from ultramafic to salic in composition, regional metamorphic schists and gneisses, and volcanic rocks.

However, this mineral is most characteristic of intermediate plutons (Phillips and Griffen, 1982).

Augite is the common pyroxene of mafic igneous rocks, and is especially characteristic of gabbros. This mineral is less common in intermediate and silicic igneous rocks. Augite is an antistress mineral and thus is generally not characteristic of metamorphic rocks (Phillips and Griffen, 1982).

Hypersthene is a common constituent of ultramafic and mafic plutonic igneous rocks, volcanics, and high-grade metamorphic rocks, both regional and contact (Phillips and Griffen, 1982).

The tourmaline found in all four formations was predominantly of the schorl-dravite (iron-rich) variety, evidenced by its common blue and black color. This variety of tourmaline is most common of granitic plutonic rocks, and granite pegmatites (Phillips and Griffen, 1982).

Epidote, staurolite and zoisite are all predominantly metamorphic minerals. Staurolite is a common mineral of medium grade regionally metamorphosed argillaceous sediments, and carbonate rocks. Epidote and zoisite also principally occurs in regional metamorphic rocks where they mark the change from the greenschist facies to the amphibolite facies. They may also form as the result of the hydrothermal alteration of plagioclase (Deer and others, 1966; Phillips and Griffen, 1982).

The garnet found in these rocks is predominantly of the iron-rich almandine variety, evidenced by its reddish-pink color (Phillips and Griffen, 1982). Garnet is predominantly a metamorphic mineral found in upper greenschist through the granulite facies metamorphic rocks. It is typically found in association with staurolite, and kyanite in upper amphibolite and granulite facies rocks. Garnet in most sedimentary rocks is of the almandine variety (Phillips and Griffen, 1982).

From the heavy mineral data it appears that the coarser fraction of these sediments was derived predominantly from plutonic as opposed to high grade metamorphic source rocks. This is evidenced by the absence of strictly high grade upper amphibolite and granulite facies metamorphic minerals such as sillimanite, andalusite, or kyanite. The only minerals found in these sediments which are common in high grade metamorphic rocks are garnet, hornblende, and hypersthene. However, garnet can also be derived from metamorphic rocks with as low of a grade as upper greenschist facies. Hornblende and hypersthene, although they can be derived from high-grade metamorphic rocks, can just as easily be derived from mafic and ultramafic plutonic, or volcanic rocks. The heavy minerals zircon, rutile, sphene, and apatite are common heavy minerals which can be derived from either plutonic, pegmatitic, or greenschist to lower-amphibolite facies metamorphic rocks, and therefore tell us little about the source rocks other than that they were not high-grade metamorphic.

Staurolite and zoisite are both common heavy minerals of regional metamorphic rocks. These minerals are derived from lower amphibolite facies metamorphic rocks. Zoisite may also be derived from upper greenschist facies metamorphic rocks.

In summary absence of strictly high grade metamorphic minerals such as sillimanite, andalusite, or kyanite may indicate that the garnet found in these sediments is derived from rocks of lower metamorphic grade, suggesting then that the coarser fraction of these sediments was derived predominantly from plutonic as opposed to high grade metamorphic source rocks.

GEOCHEMISTRY

The two populations of samples which the cluster analysis clearly defined in figure 8 suggest that the trace element composition of the Naches Formation is significantly different than that of the other three formations. The very strong geochemical similarity, averaging 0.99, between the Summit Creek sandstone, Chumstick, and Carbonado Formations, strongly supports these sediments being derived from the same provenance. The somewhat unique chemistry of the Naches Formation on the other hand may suggest one of several things. Since the Naches Formation is the youngest of the four formations, its unique chemistry may suggest: 1) a changing chemistry of the source rock with time; 2) the unroofing of a new source; 3) some local source rock contributing more sediment to this formation than to the others; or 4) the Naches Formation is part of an entirely different drainage system than the other three formations. The author tends to support the third hypothesis that the rather unique chemistry of the Naches Formation is as a result of some local source rock contributing more sediments to the Naches Formation than to the other three formations, for reasons to be discussed.

Recent studies have shown trace elements to be more concentrated in some minerals as opposed others. By knowing which minerals tend to concentrate which trace elements it is possible to draw generalizations in terms of rock composition from trace element data. This technique is especially useful in attempting to determine the provenance of sedimentary rocks. Important studies by Kaskin and Paster (1979) found that rare earth elements appear to be transferred almost quantitatively into clastic sediments, and that common sedimentary and metamorphic processes do not significantly affect the rare earth element distribution in sedimentary rocks. It has also become accepted that the average rare earth element pattern in sedimentary rocks basically reflects the rare earth element distribution in the continental crust (McLennan and others, 1980).

The concentrations of the various trace elements in the sedimentary rocks in this study reveals a significantly lower concentration of the Ce, La, Ta, and Th, and a significantly higher concentrations of Co, Cr, and Sc in the Naches Formation as compared to the other three formations. The Summit Creek sandstone, Chumstick and Carbonado Formations, as revealed in the cluster analysis, show very similar concentrations of the various trace elements, with the Chumstick Formation containing only a slightly higher concentration of Cr, Sm, and Hf than the near geochemically identical Summit Creek sandstone, and Carbonado Formation. Of these nine elements which show the most variation in concentration between samples, the elements Cr, La, and Sc were selected for this portion of the study because they show the largest amount of variation in concentration between rock types, and they are less mobile than some of the other elements.

The element chromium, Cr, occurs as a trivalent ion, readily substitutes for Fe^{3+} and Al^{3+}, and does not go into solution easily. It is typically precipitated from magmas at an early stage either in the form of spinel, or clinopyroxene, which are minerals common in ultramafic rocks. Cr is typically depleted in less mafic rocks (Smith, 1972).

The element lanthanum, La, occurs in a tripositive oxidation state, and occurs in highest concentration in rare earth minerals that favor light rare earths such as monazite (Kay, 1972). The La concentration in average basalts is 17 ppm, and ranges over a factor of ten. Alkaline oceanic basalts and most continental basalts have more La than oceanic tholeiites and some continental diabases. The La concentration in granites average 84 ppm, a value which is considerably higher although more variable than for basalts (Kay, 1972).

The element scandium, Sc, is also a trivalent ion, which is captured widely as a trace constituent of silicate minerals. The process of magmatic differentiation apparently leads to a maximum concentration of Sc of about 30 ppm in rocks of basaltic composition. In more silicic rocks the Sc content drops off to quite low levels (Curtis (1972)).

From this information, the significantly higher concentration of Cr, and Sc, and a significantly lower concentration of La in the Naches Formation appear to indicate that the Naches Formation has a significantly larger mafic component to its sediments than the other three formations. Although the light mineral study did not reveal this to be the case, it is possible that the finer silt and clay sized fractions of the Naches samples may contain a larger mafic volcanic component than the other three formations. This may explain the slightly darker color of the Naches samples.

In summary, the strong geochemical similarity that exist between samples from the Summit Creek sandstone, Chumstick, and Carbonado

Formations strongly supports these sediments being derived from the same provenance. The somewhat unique chemistry of the Naches Formation may suggest some local source rock is contributing more sediments to the Naches Formation than the other three formations. The significantly higher concentration of Cr, and Sc, and lower concentration of La in the Naches Formation indicates that this formation has a larger mafic component to its sediments than the other three formations.

CHAPTER V

REGIONAL SIGNIFICANCE OF STUDY

In order to better understand the provenance, the overall size of the depositional basin, and the depositional setting of the four formations under study, the results from this study were compared with published data from the time correlative Chambers Creek beds, Roslyn, Renton, Cowlitz, Spencer, and Skookumchuck Formations (Figure 10).

The seven framework grain plots in Figures 6 and 7, when looked at as a whole, appear to indicate that there are three distinct populations of formations. The first population, which shows the strongest similarity in framework grain composition, includes the Summit Creek sandstone, Chumstick, Naches, Carbonado, and Roslyn Formations. These formations all contain relatively large mean concentrations of lithic fragments, relatively small mean concentrations of sedimentary rock fragments, and K-feldspar (Figure 6), and relatively high mean plagioclase to total feldspar ratios (Figure 7). The Summit Creek sandstone, Chumstick, Naches, and Carbonado Formations also contain very similar intermediate mean polycrystalline quartz to total quartz, and volcanic to total lithic fragment ratios. The Roslyn Formation contains a significantly higher mean polycrystalline quartz to total quartz, and volcanic to

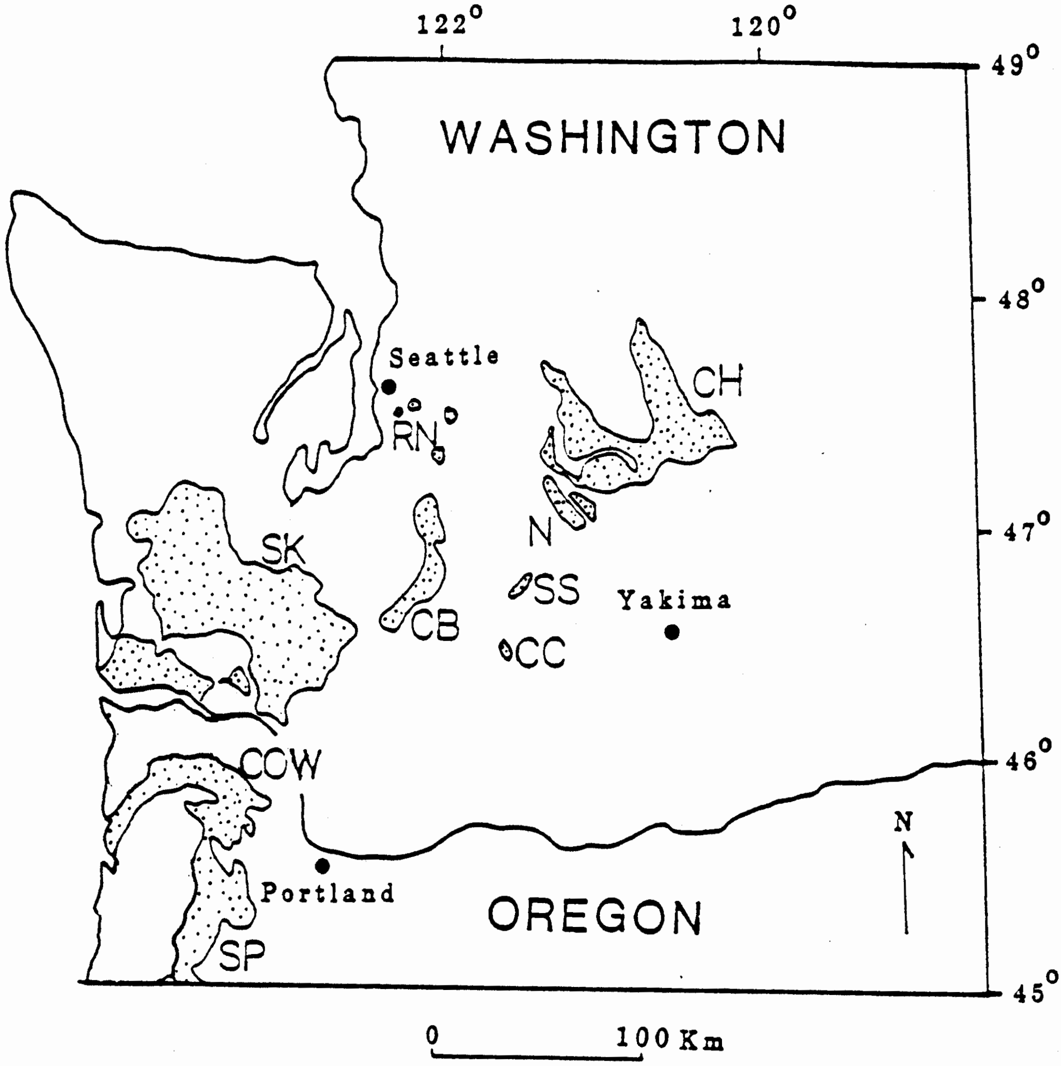


Figure 10. Map showing the location of the Summit Creek sandstone (SS), Naches (N), Chumstick (CH), and Carbonado Formations (CB) from this study, along with the time correlative Chambers Creek beds (CC), Roslyn (RO), Renton (RN), Cowlitz (COW), Spencer (SP), and Skookumchuck Formations (SK). (modified after Winters, 1984)

total lithic fragment ratios than the other four formations; however, the Roslyn Formation also shows the largest variation in concentration of these constituents between samples within this formation.

The second population, which includes the Cowlitz, Skookumchuck, Renton, and Spiketon Formations, is characterized by sediments with relatively small concentrations of lithic fragments, relatively large concentrations of K-feldspar (Figure 6), relatively small ratios of plagioclase to total felspar, and a relatively high ratio of volcanic to total lithic fragments (Figure 7). The only significant difference in composition between these four formations is the relatively large concentration of polycrystalline quartz in the Renton Formation.

The third population contains only the Chambers Creek beds. This population is unique in its relatively large percentage of total quartz, and sedimentary rock fragments, and its relatively small ratios of polycrystalline quartz to total quartz, and volcanic to total lithic fragments.

These three populations appear to indicate that the formations that occur within a population are all derived from the same provenance, while formations between populations are either derived from an entirely different provenances, or there is at least a major source rock contributing sediments to one population and not to the other.

Comparing the heavy mineral data collected in this study with Bressler's (1951) petrographic study of the Roslyn Formation, indicates that these five formations show virtually identical heavy mineral populations. Although the relative percentages of the heavy minerals vary slightly between formations, they are all basically characterized by the presence of epidote, apatite, zircon, garnet, sphene, rutile, and tourmaline. The only minerals found in the Roslyn Formation which are not noted in the other four formations are clinozoisite, and a small amount of actinolite. On the other hand, the only minerals found in the four formations in this study which are not likewise found in the Roslyn Formation are hornblende, hypersthene, augite, zoisite, and a trace of staurolite.

Actinolite, and clinozoisite are both metamorphic minerals common in upper greenschist to lower amphibolite facies metamorphic rocks (Deer and others, 1966). Since these minerals occur in such small concentrations in the Roslyn Formation, it is very possible that these minerals are also present in the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations, and were overlooked. These two minerals are at least consistant with the metamorphic grade of the minerals zoisite and staurolite from this study.

The Oligocene Lincoln Creek Formation, in southwestern Washington, also shows a nearly identical heavy mineral assemblage to the four formations in this study (Karachewski, 1983). The zircon, garnet, sphene, and apatite noted in Karachewski's (1983) study, are all abundant in the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations. Since garnet is the only predominantly metamorphic mineral noted in Karachewski's study, it is not possible to determine the grade of metamorphic rocks contributing sediments to the Lincoln Creek Formation.

The heavy mineral assemblage of the Cowlitz Formation (Van Atta, 1971) is different from the Summit Creek sandstone, Naches, Chumstick, Carbonado, Roslyn, or Lincoln Creek Formations, in that it contains small percentages of kyanite, and andalusite which are high grade upper amphibolite to granulite facies metamorphic minerals. The presence of these two minerals indicates that a high grade metamorphic source rock is contributing to these sediments. The presence of apatite, sphene, epidote, tourmaline, garnet, staurolite, and rutile in the Cowlitz Formation, however, is consistent with the other six formations. This observation may indicate that the Cowlitz Formation is receiving sediments from the same source areas as the Summit Creek sandstone, Naches, Chumstick, Carbonado, Roslyn, and Lincoln Creek Formations, along with sediments from some high grade metamorphic source.

Comparing the trace element composition of the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations, with geochemical data from the Cowlitz Formation (Kadris, 1982), reveals similar La/Sm ratios, as well as Sc and K concentrations in these five formations (Figure 9). However, the Cowlitz Formation shows a significantly higher concentration of Th, and smaller concentration of Cr than the other four formations. The element Th is concentrated in the late stages of magmatic crystallization (Moore, 1972), while Cr is concentrated in the early stages (Smith, 1972), suggesting that the Cowlitz Formation has the smallest mafic and ultramafic component to its sediments.

The results from this portion of the study indicates that the Summit Creek sandstone, Naches, Chumstick, Carbonado, and Roslyn Formations are compositionally very similar and thus are probably derived from the same provenance. The Chambers Creek beds, Renton, Cowlitz, Spencer and Skookumchuck Formations, on the other hand, are compositionally unique from the above formations, indicating that they were at least partially derived from a different provenance.

POSSIBLE SOURCE ROCKS

The Mount Stuart area, the Chelan Mountain terrane, the Pasayten River terrane, and the Idaho batholith are the four most probable source terrains which contributed sediments to the four formations studied (Figure 11).

The Mount Stuart batholith area lies just to the west of Leavenworth, Washington. This batholith intruded the surrounding upper Jurassic ophiolite melange of the Ingalls tectonic complex, and the Chiwaukum Schist, in late Cretaceous time (Miller, 1982; Tabor and other, 1984). Tonalite and granodiorite dominate the composition of this batholith (Erikson, 1977). The southern end of the batholith is surrounded by ultramafic rock of the Ingalls tectonic complex. The contact between these two rock units is marked by a discontinuous zone of chiefly biotite and hornblende schists. In contact with the Mount Stuart batholith to the north is the Chiwaukum Schist which is composed predominantly of garnet and staurolite-bearing graphite-biotite-quartz schist with lesser amounts of siliceous hornblende schist, amphibolite, calc-silicate schist and marble (Page, 1939).

The Chelan Mountain terrane is located in the vicinity of Lake Chelan. This terrain is mainly characterized by migmatitic and tonalitic plutonic rocks, but also contains amphibolite, biotite schist, siliceous schist, and rare light-colored tonalite sills and dikes (Cater and Wright, 1967). Work by Mattinson (1972) revealed a 220 m.y. age for

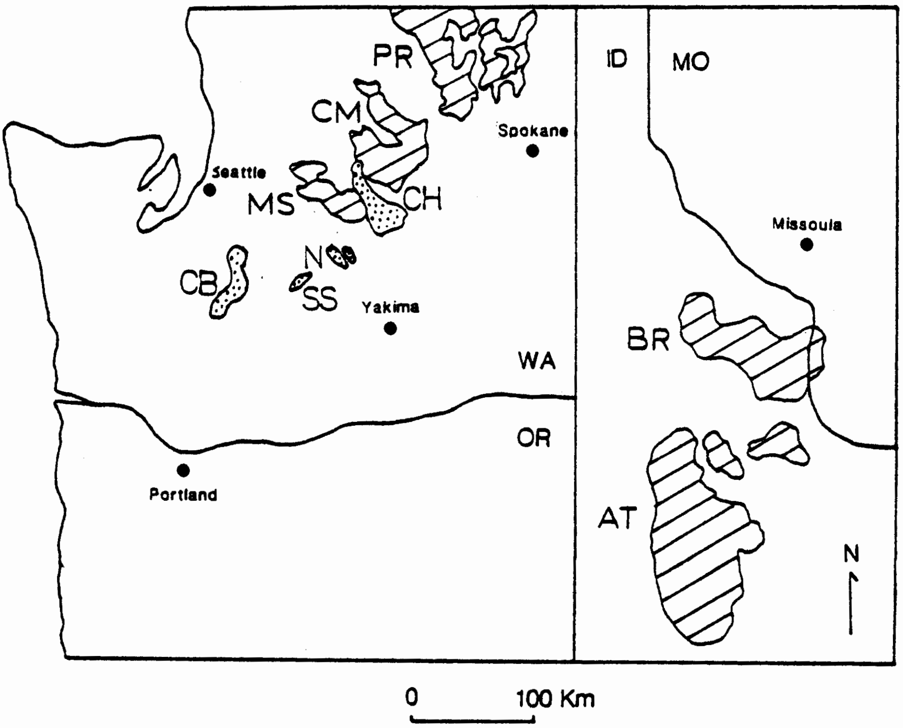


Figure 11. Map showing the location of the Summit Creek sandstone (SS), Naches (N), Chumstick (CH), and Carbonado Formations (CB), in relation to the four most probable source areas: Mount Stuart batholith (MS), Chelan Mountain terrane (CM), Pasayten River Area (PR), and the Idaho batholith (Bitterroot (BR) and Atlanta (AT) lobes).

the plutonic rocks in this area. The Entiat pluton, as described by Waters (1930), represents a facies of the Chelan batholith, and is characterized by medium-grained rocks of granitoid composition. These rocks have a much higher K-feldspar content than other plutonic rocks of the Chelan area. K-Ar age dates on hornblende in the Entiat pluton reveal a 60 to 73 m.y. age for this pluton (Mattison, 1972).

The Pasayten River area studied by Tabor and others (1968) is located in the north central part of the state of Washington. This area contains granitic rocks of the Monument Peak stock, hornblende-biotite granodiorite of the Castle Peak stock, hornblende-biotite-granodiorite and quartz monzonite of the Lost Peak stock, biotite-hornblende quartz diorite to granodiorite of the Pasayten and Rock Creek dikes, along with gneiss, schist and granitoid plutons of the Okanogan Highland crystalline block. These rocks range from 46 to 86 m.y. in age.

The Idaho batholith is located in east-central Idaho. This batholith can be broken down into two lobes, the northern Bitterroot lobe, and the southern Atlanta lobe. The Bitterroot lobe is both the smaller and the younger of the two lobes. It ranges in age from 85 to 66 m.y., and is slightly over half the size of the Atlantic lobe. The Bitterroot lobe is predominantly granodioritic and granitic in composition, and was emplaced into metamorphosed Belt Group and pre-Belt basement rocks during late Cretaceous time (Hyndman and others, 1977). The Atlanta lobe is 63 to 117 m.y. in age and the rocks grade in composition from west to east across the western half of the batholith from fine grained migmatitic gneisses, to biotite-quartz schist, to leucocratic quartz dioritic migmatite, to quartz dioritic gneiss, to leucocratic quartz diorite, to granodiorite, to quartz monzonite, and finally granite at the interior of the batholith (Hyndman and others, 1977).

Comparing the rock composition from the four possible source areas mentioned above, to the framework grain composition of the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations, it appears that the Mount Stuart batholith area, and the Chelan Mountain terrane are the most likely source rocks for these sediments. This conclusion is based on the fact that the four formations under study contain no more than 12% K-feldspar. The Mount Stuart batholith area, and the Chelan Mountain terrane both contain plutonic rocks which are predominantly tonalitic in composition (<10% K-feldspar), with smaller amounts of granodiorite (<35% K-feldspar). The Pasayten River Area, and the Idaho batholith, on the other hand, all contain abundant granite (>35% K-feldspar) and granodiorite (<35% K-feldspar) plutonic rocks. If these sediments had been derived from the Pasayten River Area, or the Idaho batholith area, one would expect higher concentrations of K-feldspar.

The area immediately surrounding the Mount Stuart batholith, and the Chelan Mountain terrane can both account for the rather large percentage of quartz-biotite-schist metamorphic rock fragments found in the four formations. The Mount Stuart batholith area could have supplied these metamorphic rock fragments from the Chiwaukum Schist located just north of the batholith, while the Chelan Mountain terrane could have supplied these metamorphic rock fragments from schists of Twenty-Five Mile Creek.

The Mount Stuart area can also account for the rather large percentage of mafic volcanic rock fragments found in these sediments. These mafic fragments could be derived from the ultramafic Ingalls tectonic complex just south of Mount Stuart. The Ingalls complex contributing to these sediments could account for the rather high Cr concentrations in these sediments. The Naches Formation, which is the closest formation to the Ingalls Complex, has a significantly higher Cr concentration than the other formations, as one would expect.

Paleocurrent direction data collected by previous workers reveals dominantly southwesterly current directions (Winters, 1983; Buckovic, 1979; Buza, 1979) for most of the Eocene sedimentary rocks in the area. These current directions are consistent with a Mount Stuart and Chelan Mountain terrane source rock.

CHAPTER VI

SUMMARY

The purpose of this study is to compare the sandstone composition and trace element geochemistry between samples representing the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations in hopes of identifying if these sediments were all derived from the same provenance, and to determine the composition of the source rocks in hopes to identify the present day location of the source areas.

The light mineral portion of this study revealed the Summit Creek sandstone, Naches, Chumstick, and Carbonado Formations to be arkosic to lithic arkosic in composition, indicating a silicic plutonic source area. The rather small percentage of K-feldspar found in these sediments indicates that these sandstones were not derived from rocks of true granitic composition, since granitic rocks typically contain greater than 30% K-feldspar, but were more likely derived from tonalites, quartz-diorites, or granodiorites. The majority of the polycrystalline quartz appears to be derived from upper greenschist facies metamorphic rocks. The rock fragment data parallels the polycrystalline quartz data by indicating a major low grade quartz-biotite-schist metamorphic source rock, as well as a mafic volcanic source rock, contributing sediments to the finer fractions of these rocks.

All four formations are characterized by the heavy minerals epidote, apatite, zircon, garnet, sphene, rutile, tourmaline, hornblende and hypersthene. The Naches, Chumstick, and Carbonado Formations also contain small percentages of zoisite and augite, and the Carbonado Formation contains traces of staurolite. These heavy minerals appear to indicate that the coarser fraction of the four formations is derived predominantly from plutonic as opposed to high grade metamorphic source rocks, which is evidenced by the absence of upper amphibolite and granulite facies metamorphic minerals such as kyanite, sillimanite, and andalusite.

The cluster analysis constructed from the trace element data reveals two populations of samples. The first population consists of samples representing the Summit Creek sandstone, Chumstick, and Carbonado Formations, while the second population consists of samples from the Naches Formation. The strong geochemical similarity that exists between the Summit Creek sandstone, Chumstick, and Carbonado Formations supports the interpretation that these sediments were derived from the same provenance. The somewhat unique chemistry of the Naches Formation appears to indicate that a local source rock is contributing more to the Naches Formation than to the other three formations.
The significantly higher concentration of Cr, and Sc, and the significantly lower concentration of La in the Naches Formation as opposed to the Summit Creek sandstone, Chumstick, and Carbonado Formations suggests that the Naches Formation has a significantly larger mafic or ultramafic component to its sediments than the other three formations.

Comparing the light and heavy mineral and geochemical data in this study with published data on time correlative units reveals three distinct populations of formations. The first population, which shows the strongest compositional similarity includes the Summit Creek sandstone, Chumstick, Naches, Carbonado, and Roslyn Formations. The second population includes the Cowlitz, Skookumchuck, Renton, and Spiketon Formations, and the third population includes the Chambers Creek beds. The formations within each of the three populations were most likely all derived from the same provenance, while formations between populations are likely being influenced at least partially by unique source rocks.

The Mount Stuart batholith area, and the Chelan Mountain terrane are assumed to be the major source rocks for the Summit Creek sandstone, Naches, Chumstick, Carbonado, and Roslyn Formations based on their light and heavy mineral assemblages, and current directions.

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APPENDIX A

TRACE ELEMENT DATA

MEB THESIS 1ST CT

SAMPLE	BA		CE		CO		FE	
CH8	1000.00	± 200.00	75.00	± 9.00	18.00	± 2.00	4.52	± 0.20
CH16	900.00	200.00	54.00	7.00	14.00	2.00	5.40	0.20
CH29	900.00	200.00	67.00	8.00	15.00	3.00	4.40	0.20
SN17T	610.00	150.00	54.00	7.00	12.20	1.80	5.34	0.18
SN19	680.00	160.00	63.00	7.00	11.20	1.60	4.42	0.15
SN32	780.00	170.00	57.00	6.00	5.40	1.50	5.74	0.16
SN47	640.00	170.00	38.00	6.00	17.80	2.00	5.36	0.18
N3	900.00	200.00	40.00	6.00	20.00	2.00	6.10	0.20
N7	610.00	150.00	37.00	5.00	27.00	2.00	7.50	0.20
N10	470.00	160.00	19.00	5.00	23.00	2.00	7.90	0.20
N12	720.00	170.00	39.00	5.00	15.60	1.70	5.33	0.17
N15	740.00	180.00	37.00	5.00	25.00	2.00	6.01	0.18
S4	600.00	140.00	41.00	5.00	5.70	1.10	6.05	0.16
S10	720.00	170.00	71.00	8.00	10.70	1.60	3.61	0.14
S11	620.00	150.00	65.00	7.00	8.30	1.50	3.53	0.14
S12	750.00	170.00	67.00	7.00	12.80	1.60	4.58	0.16
BQM4	960.00	190.00	72.00	7.00	13.30	1.20	4.38	0.14
GSP1	620.00	120.00	201.00	18.00	3.70	1.10	1.57	0.05
BCR1	680.00	170.00	54.00	7.00	38.00	3.00	13.40	0.30

MEB THESIS 1ST CT

SAMPLE	HF		K		LA		NA	
CH8	6.70	± 1.50	0.00	± 0.00	31.90	± 0.60	2.74	± 0.01
CH16	5.10	1.30	2.30	0.50	24.60	0.60	2.70	0.01
CH29	7.20	1.60	3.40	0.50	26.80	0.60	2.64	0.01
SN17T	4.80	1.10	1.30	0.40	25.00	0.50	1.64	0.01
SN19	3.90	1.00	2.40	0.50	26.70	0.50	1.70	0.01
SN32	3.30	0.90	1.50	0.50	25.60	0.50	1.58	0.01
SN47	3.80	1.00	0.00	0.00	16.50	0.50	2.35	0.02
N3	4.00	1.10	0.00	0.00	16.50	0.50	2.74	0.02
N7	3.70	0.90	0.00	0.00	18.20	0.50	1.75	0.01
N10	4.00	1.00	3.20	0.70	12.70	0.40	2.02	0.02
N12	6.10	1.30	2.00	0.60	17.40	0.40	2.29	0.02
N15	3.90	1.00	0.00	0.00	18.00	0.50	2.32	0.02
S4	3.60	0.80	1.60	0.50	20.00	0.40	1.10	0.01
S10	5.10	1.10	2.50	0.80	31.90	0.60	2.04	0.02
S11	5.00	1.10	2.40	0.60	26.70	0.60	2.15	0.02
S12	6.30	1.30	3.00	0.70	30.90	0.60	2.06	0.02
BQM4	4.60	0.90	3.80	0.60	32.80	0.50	3.10	0.01
GSP1	4.60	0.80	2.90	0.40	70.30	0.80	1.05	0.01
BCR1	4.70	1.10	1.70	0.20	26.00	0.40	3.27	0.01

MEB THESIS 1ST CT

SAMPLE	SC		SM		YB	
CH8	11.18	± 0.18	5.47	± 0.06	1.70	± 0.30
CH16	13.40	0.20	5.01	0.06	2.20	0.30
CH29	12.90	0.20	5.22	0.06	2.50	0.30
SN17T	10.15	0.15	4.52	0.05	2.00	0.20
SN19	10.37	0.16	4.76	0.05	2.30	0.30
SN32	10.28	0.16	4.33	0.05	2.00	0.20
SN47	12.43	0.19	3.40	0.05	1.60	0.30
N3	16.50	0.20	4.18	0.05	2.30	0.30
N7	13.81	0.19	4.11	0.05	2.20	0.30
N10	22.20	0.30	3.79	0.05	1.80	0.30
N12	15.65	0.20	4.28	0.05	2.20	0.30
N15	15.63	0.20	4.23	0.05	2.30	0.30
S4	9.08	0.13	3.61	0.04	1.42	0.19
S10	9.51	0.15	5.08	0.06	2.00	0.20
S11	7.98	0.14	4.32	0.05	2.00	0.20
S12	9.09	0.15	4.97	0.06	2.00	0.20
BQM4	11.00	0.10	4.05	0.03	1.83	0.18
GSP1	2.39	0.04	9.66	0.06	0.65	0.09
BCR1	33.00	0.20	6.60	0.05	3.40	0.30

MEB THESIS 2ND CT

SAMPLE	BA		CE		CO		CR	
CH8	730.00	± 100.00	88.00	± 3.00	12.10	± 0.03	130.00	± 20.00
CH16	610.00	100.00	75.00	2.00	11.70	0.30	140.00	20.00
CH29	760.00	110.00	73.00	2.00	11.40	0.30	114.00	18.00
SN17T	430.00	80.00	77.00	2.00	9.50	0.30	74.00	12.00
SN19	490.00	80.00	73.00	2.00	10.40	0.30	96.00	15.00
SN32	460.00	80.00	66.00	2.00	6.60	0.20	86.00	13.00
SN47	540.00	100.00	44.10	1.70	16.60	0.40	170.00	30.00
N3	630.00	120.00	34.00	1.70	18.80	0.40	170.00	30.00
N7	440.00	90.00	33.50	1.60	23.70	0.40	125.00	19.00
N10	460.00	110.00	21.00	1.90	24.00	0.40	150.00	20.00
N12	500.00	100.00	47.90	1.80	12.30	0.30	170.00	30.00
N15	640.00	120.00	50.90	2.00	19.90	0.40	160.00	20.00
S4	450.00	80.00	49.30	1.70	5.00	0.19	71.00	11.00
S10	470.00	90.00	92.00	3.00	8.10	0.20	74.00	12.00
S11	480.00	90.00	73.00	2.00	7.60	0.20	70.00	11.00
BQM4	720.00	110.00	91.00	3.00	10.70	0.30	23.00	4.00
GSP1	460.00	70.00	251.00	6.00	2.22	0.11	6.80	1.60
BCR1	670.00	130.00	53.90	1.90	38.00	0.40	18.00	4.00

MEB THESIS 2ND CT

SAMPLE	CS		EU		FE		HF	
CH8	4.40	± 0.80	1.26	± 0.07	4.63	± 0.04	6.10	± 0.02
CH16	4.30	0.80	1.21	0.07	4.93	0.05	5.10	0.20
CH29	7.90	1.40	1.20	0.07	4.45	0.05	6.10	0.20
SN17T	3.50	0.70	1.04	0.06	5.23	0.05	4.26	0.18
SN19	3.10	0.60	1.10	0.06	4.23	0.04	4.63	0.19
SN32	2.60	0.50	0.88	0.06	5.70	0.05	4.11	0.18
SN47	3.10	0.60	0.88	0.06	5.37	0.05	4.25	0.20
N3	2.50	0.50	1.08	0.09	6.13	0.06	3.90	0.20
N7	3.80	0.70	1.06	0.07	7.13	0.06	3.43	0.17
N10	2.60	0.60	1.13	0.08	7.62	0.07	3.20	0.20
N12	2.10	0.40	1.08	0.07	5.03	0.05	4.80	0.20
N15	3.50	0.60	1.02	0.07	5.86	0.06	3.74	0.19
S4	2.40	0.50	0.88	0.06	5.74	0.05	2.90	0.15
S10	3.10	0.60	0.91	0.06	3.47	0.04	5.80	0.20
S11	2.60	0.50	0.81	0.06	3.55	0.04	3.84	0.17
BQM4	8.20	1.50	1.01	0.06	4.46	0.05	4.90	0.20
GSP1	0.69	0.15	0.83	0.04	1.56	0.02	6.00	0.20
BCR1	1.00	0.20	2.06	0.07	13.40	0.06	4.70	0.19

MEB THESIS 2ND CT SAMPLE	RB	±	SC	±	TA	±	TH	±
CH8	140.00	30.00	10.59	0.06	1.52	0.11	8.50	0.30
CH16	90.00	20.00	13.25	0.07	1.25	0.10	6.40	0.20
CH29	190.00	40.00	12.53	0.07	1.77	0.12	10.10	0.30
SN17T	110.00	20.00	10.03	0.05	1.40	0.10	7.60	0.30
SN19	110.00	20.00	10.30	0.06	1.22	0.09	7.40	0.20
SN32	90.00	20.00	10.22	0.05	1.19	0.09	6.60	0.20
SN47	79.00	20.00	12.27	0.07	0.91	0.08	4.45	0.19
N3	69.00	19.00	16.84	0.08	0.79	0.08	3.80	0.20
N7	51.00	16.00	13.84	0.06	0.85	0.08	2.97	0.16
N10	70.00	20.00	22.04	0.10	0.71	0.08	2.50	0.20
N12	43.00	14.00	15.81	0.07	0.81	0.07	4.17	0.20
N15	69.00	18.00	16.16	0.07	0.91	0.08	3.62	0.19
S4	100.00	20.00	8.46	0.04	1.26	0.09	5.07	0.19
S10	120.00	30.00	9.34	0.05	1.54	0.11	9.40	0.30
S11	90.00	20.00	8.03	0.05	1.25	0.09	8.10	0.30
BQM4	180.00	40.00	10.60	0.06	1.16	0.09	20.90	0.60
GSP1	130.00	30.00	2.25	0.02	0.52	0.05	43.20	1.10
BCR1	47.00	13.00	33.00	0.09	0.91	0.07	6.00	0.20

APPENDIX B

SAMPLE LOCATION SITES

FORMATION	SAMPLE	LOCATION	QUADRANGLE	ELEV.(FT)
CARBONADO	SN3	SW1/4,SE1/4,SW1/4, SEC.12,T13N,R4E	MORTON 15'	1320
	SN19	SE1/4,NW1/4,SW1/4 SEC.11,T13N,R4E	MORTON 15'	1520
	SN22	SW1/4,NE1/4,SW1/4 SEC.11,T13N,R4E	MORTON 15'	1560
	SN38	NE1/4,SE1/4,SE1/4 SEC.10,T13N,R4E	MORTON 15'	1780
	SN58	NW1/4,NE1/4,SW1/4 SEC.10,T13N,R4E	MORTON 15'	2320
SUMMIT CREEK SANDSTONE	S4	SE1/4,NE1/4,NE1/4 SEC.13,T14N,R10E	WHITE PASS 15'	3160
	S5	NE1/4,SE1/4,SW1/4 SEC.13,T14N,R10E	WHITE PASS 15'	3140
	S6	NE1/4,SE1/4,SW1/4 SEC.13,T14N,R10E	WHITE PASS 15'	3120
	S10	NE1/4,SW1/4,SW1/4 SEC.13,T14N,R10E	WHITE PASS 15'	3100
	S12	NW1/4,SE1/4,SE1/4 SEC.13,T14N,R10E	WHITE PASS 15'	3080
	S12TK	NW1/4,SE1/4,NW1/4 SEC.13,T14N,R10E	WHITE PASS 15'	3070
NACHES	N3	NE1/4,NW1/4,SE1/4 SEC.21,T18N,R14E	EASTON 15'	3840

	N7	NE1/4,SE1/4,NE1/4 SEC.21,T18N,R14E	EASTON 15'	3760
	N12	SW1/4,NW1/4,NE1/4 SEC.22,T18N,R14E	EASTON 15'	3720
	N14	SW1/4,NE1/4,SW1/4 SEC.22,T18N,R14E	EASTON 15'	3800
	N15	SW1/4,NE1/4,SE1/4 SEC.22,T18N,R14E	EASTON 15'	3840
	N22	SW1/4,SE1/4,SW1/4 SEC.22,T18N,R14E	EASTON 15'	3720
	N23	SW1/4,SW1/4,SE1/4 SEC.22,T18N,R14E	EASTON 15'	3640
CHUMSTICK	CH1	SW1/4,SE1/4,NW1/4 SEC.33,T24N,R19E	CHIWAUKUM 4SE, 7.5'	820
	CH8	SE1/4,SW1/4,NE1/4 SEC.32,T24N,R19E	CHIWAUKUM 4SE, 7.5'	1240
	CH16	SE1/4,SE1/4,SE1/4 SEC.26,T24N,R18E	CHIWAUKUM 4SE, 7.5'	990
	CH18	NW1/4,SW1/4,NE1/4 SEC.9,T24N,R18E	CHIWAUKUM 4SE, 7.5'	1580
	CH26	SE1/4,NE1/4,SE1/4 SEC.24,T25N,R17E	CHIWAUKUM 4NW, 7.5'	1440
	CH29	NW1/4,NE1/4,SW1/4 SEC.18,T25N,R18E	CHIWAUKUM 4NW, 7.5'	1620