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Stratigraphic and petrologic analysis of trends within the Spencer Formation sandstones : from Corvallis, Benton County, to Henry Hagg Lake, Yamhill and Washington counties, Oregon

Brent Joseph Cunderla
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AN ABSTRACT OF THE THESIS OF Brent Joseph Cunderla for the Master of Science in Geology presented July 22, 1986.

Title: Stratigraphic and Petrologic Analysis of Trends Within the Spencer Formation Sandstones; From Corvallis, Benton County, to Henry Hagg Lake, Yamhill and Washington Counties, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

Robert O. Van Atta, Chairman

Marvin H. Beeson

Richard E. Thoms

Within the thesis study area Spencer Formation arkosic/arkosic lithic sandstone lithofacies of Narizian age crop out in a sinuous north-northwesterly band from the Corvallis area into the Henry Hagg Lake vicinity ten kilometers southwest of Forest Grove, Oregon.

Twenty eight surface samples and eight sidewall cores from the DeShazer 13-22 natural gas exploration well, were analyzed petrographically for detrital framework mineral composition and their major oxide and rare earth element concentrations utilizing x-ray fluorescence spectrometry (XRF) and inductively coupled plasma emission spectrometry

(ICP) analysis, respectively. Twelve samples representing both lithofacies areally within the five separate Spencer Formation study areas, and stratigraphically within the DeShazer 13-22 well were selected for plagioclase composition, heavy mineral separates and scanning electron microscopy (SEM) - energy dispersive spectrometry (EDS) studies. These combined studies showed that two distinct lithofacies or informal members are present within the Spencer Formation in the thesis study area, they are; 1) a lower arkosic sandstone member, and 2) an upper arkosic to lithic arkosic sandstone member.

Petrographic analysis showed that the lower member contains more detrital grains of quartz and potassium feldspar, has two to three times more epidote, and contains more schist and quartzite rock fragments than the upper member lithofacies. In comparison the upper member sandstone lithofacies contains abundant plagioclase feldspar, three to four times more amphibole and pyroxene (commonly etched) detrital grains, and has abundant microlithic volcanic rock fragments.

Based on petrologic and accompanying geochemical evidence, provenance of the Spencer Formation sandstone lithofacies indicates both proximal volcanic and distal plutonic/metamorphic sources.

Scanning electron microscopy proved most valuable for complementing petrography and diagenetic studies. Elemental analysis and a variety of mineral-pore relationships were observed. Porosity within selected samples ranges from highly porous sandstones, to samples entirely cemented with sparry crystalline calcite containing abundant authigenic potassium feldspar and smectite, showing virtually no porosity.

Five individual clay species: chlorite, illite, smectite,

kaolinite, and mixed-layer illite/smectite were identified in selected samples utilizing x-ray diffraction (XRD).

Diagenetic evidence found within the Spencer Formation sandstones showed 1) compaction, 2) chemical etching of hornblende, augite and plagioclase feldspar, 3) dissolution of silicate grains (mainly plagioclase), 4) solution, and 5) formation of euhedral authigenic minerals (K-feldspar and zeolites), clays (crenulated smectite), and cement (crystalline sparry calcite).

Both major oxide and rare earth element geochemistry emphasized pre-determined petrologic trends. Major oxide findings showed that the upper member arkosic to lithic arkosic sandstone lithofacies are silica deficient and have elevated amounts of alumina, iron and magnesium in comparison to the lower member arkosic lithofacies. Concentrations of rare earth elements are two to three times higher in the upper member sandstone lithofacies, and have a europium fluctuation typical of the introduction of intermediate (andesite to dacite) volcanics.

STRATIGRAPHIC AND PETROLOGIC ANALYSIS OF TRENDS WITHIN
THE SPENCER FORMATION SANDSTONES; FROM CORVALLIS,
BENTON COUNTY, TO HENRY HAGG LAKE, YAMHILL
AND WASHINGTON COUNTIES, OREGON

by

BRENT JOSEPH CUNDERLA

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

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in
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1986

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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CHAPTER I

INTRODUCTION

Narizian-age Spencer Formation sandstone lithofacies are part of a thick and extensive late Eocene depositional sequence, consisting primarily of marine sandstone, mudrock and volcanic flowrock and breccia, in western Oregon and Washington. Deposition probably occurred within a volcanic fore-arc basin which occupied the present-day area of the Willamette-Puget Lowland, Olympic Mountains and Coast Ranges of Oregon and Washington (Snively and Wagner, 1963; Armentrout and Suek, 1985).

Sandstone lithofacies, like those found within the Spencer Formation, also occur in many other late Eocene sedimentary formations of western Oregon and Washington. Variances in sandstone composition reflect provenance and sediment distribution. Late Eocene arkosic sandstone lithofacies found within the Pacific Northwest differ from typical arkoses in that they contain dominantly plagioclase feldspar (Winters, 1984 and Byrnes, 1985). The predominance of proximal volcanic source material in certain geographic areas could vary sandstone composition to that more typical of lithic sandstones (Armentrout and Suek, 1985 and Van Atta, 1986).

Spencer Formation sandstone crops out discontinuously in the eastern foothills of Oregon's Coast Range geomorphic province in a narrow band, usually not more than a kilometer wide, forming a sinuous

outcrop belt with an average dip of fifteen degrees to the east (Schlicker, 1962 & Schlicker and Deacon, 1967). Outcrop patterns within the Spencer Formation are also greatly influenced by structure throughout the Coast Range.

From the type locality southwest of Eugene, Oregon, the north-northwesterly winding belt of arkosic and lithic arkosic Spencer Formation sandstone crops out prominently near Corvallis, Albany, and Dallas (Vokes and others, 1951), eventually ending north of Henry Hagg Lake vicinity, to the west of Forest Grove, Oregon.

Exploration for oil and natural gas in western Oregon over the last sixty years was intermittent with some sporadic noncommercial oil and natural gas shows, until the discovery of economic natural gas reservoir potential near Mist, Oregon, in May of 1979 (Bruer, 1980). Sandstone in the Spencer Formation has, during the past five years, been a prime target in exploration for natural gas in the Willamette Valley. The majority of natural gas production at Mist Gas Field, occurs in the "Clark and Wilson" arkosic sandstone lithofacies found within the lower portion of the Cowlitz Formation according to Bruer and others (1984) and Niem and others (1985). Clark and Wilson sands, according to Bruer and others (1984), may be coeval with Spencer Formation arkosic sandstone lithofacies, which occur stratigraphically within the lower part of the Spencer Formation. Bruer and others (1984) denoted these arkosic sandstones as the Spencer sand member (informal) within the Willamette Valley.

Purpose and Scope of Investigation

The purpose of this study was to determine petrologic and geochemical trends within the Spencer Formation in relation to stratigraphic characteristics of the arkosic and lithic sandstone facies denoted by Al-Azzaby (1980), Thoms and others (1983) and Van Atta (1986). Major oxide and rare earth element geochemical studies complemented petrographic trends established within the Spencer Formation. Diagenetic and alteration products found within the Spencer Formation sandstone lithofacies and their affects on sandstone porosity were also studied.

There are three specific goals this study investigated: 1) to define regional implications of the petrographic and geochemical relationships of lithic arkose and arkose sandstone lithofacies of the Spencer Formation, 2) use petrography, major oxide and rare earth element (REE) geochemistry to establish chemical, compositional, and mineralogical changes present both areally and stratigraphically within Spencer Formation sandstones, and 3) to utilize the scanning electron microscope (SEM) and accompanying energy dispersive spectrometer (EDS) to aid in mineral identification and study the affects of diagenetic and alteration products on porosity relationships within Spencer Formation sandstone lithofacies.

Location of Thesis Area

In order to deal with regional implications of the stratigraphic and petrographic relationships of lithic arkose and arkose sandstone lithofacies of the Spencer Formation a large study area was needed.

Five separate smaller study areas, including the type area, where the Spencer Formation sandstone crops out are established for this study (Figure 1). These five areas include: 1) Western Tualatin Valley, 2) Monmouth, 3) Albany, 4) Corvallis and 5) Spencer Formation type-section southwest of Eugene, Oregon. The western Tualatin Valley study area includes those Spencer Formation sandstone outcrops in the Henry Hagg Lake, Patton Valley and Williams Canyon vicinities studied by Al-Azzaby (1980), Thoms and others (1983) and Van Atta (1986). Some sample localities from the type area are those studied by Gandra (1977).

Methodology of Investigation

Using existing maps and field study, outcrops were studied and samples were collected from the Spencer Formation sandstone in the study area. Study, sampling and stratigraphic measurement of exposed sections of the sandstone lithofacies was done from late June until September of 1985. Location of the Spencer Formation outcrops are listed in Appendix A. Description of primary sedimentary structures and lithology were done at each sampling locality. Selected samples from Spencer Formation sandstones characteristic of the four northern areas, excluding the type area, were chosen for more detailed plagioclase composition, heavy mineral separates, clay mineral assemblage and SEM-EDS studies. Samples collected from the type locality along Spencer and Coyote Creeks southwest of Eugene were utilized for comparison with the samples collected within the four separate areas to the north within the thesis study area.

Eight sidewall core samples from the DeShazer 13-22 natural gas

Figure 1. Location map of the thesis area.

exploration well, located northeast of Salem, Oregon near the community of St. Louis, were also analyzed.

Samples labeled with "SP" are surface samples while those starting with the prefix "ONG" are sidewall core samples from the DeShazer 13-22 natural gas exploration well. The one or two digit number after "ONG" indicates the sidewall core sample number. Sample number "1" being the first and stratigraphically lowest sidewall core sample collected from within the Spencer Formation. The last four digits, ie. "2319", indicate depth in feet down hole at which the sidewall core sample was collected, measured from the kelly bushing on the drill stem.

Lithofacies differentiation within the informal upper and lower members are based on observations made in the field. Stratigraphic findings reflect those observations made by Gandera (1977) and Al-Azzaby (1980). No sedimentary texture analysis or paleontological work was completed. Both Gandera (1977) and Al-Azzaby (1980) discuss these topics.

During field reconnaissance of the thesis study area (Figure 1), limited exposure of outcrops, long covered intervals and lack of fault contacts cropping out at the surface, made it difficult to construct composite stratigraphic columns and attempt surface correlations. Thus, defining the stratigraphic and spatial relationships of the arkose and lithic arkose sandstone of the Spencer Formation utilizing only surficial data was very difficult. To overcome the stratigraphic problems encountered in the field, the locations of underlying and overlying formation contacts were obtained from previous workers and their accompanying geologic maps. Together with strike and dip

measurements taken at each outcrop, an approximated position of the outcrop being studied and where it occurred stratigraphically within the Spencer Formation was determined.

Conventional and impregnated thin sections allowed petrographic characteristics and some pore relationships to be determined. The Scanning Electron Microscope (SEM) and the accompanying Energy Dispersive Spectrometer (EDS) instrumentation were utilized to provide additional information on porosity and mineralogy of selected samples. SEM photomicrographs offer high resolution, magnification and excellent depth of focus. They were utilized to: (1) examine size, shape and distribution of pores as well as aperture characteristics, (2) examine textural and morphological aspects of mineral grains, and (3) differentiate between detrital and diagenetic clay minerals.

Both major oxide and rare earth element (REE) composition of selected samples were determined, utilizing x-ray fluorescence spectrometry (XRF) and inductively coupled plasma emission spectrometry (ICP). Dr. Peter Hooper of Washington State University-Pullman, did both the XRF and ICP geochemical analysis.

X-ray diffraction analysis provided determination of clay minerals present within selected samples.

Previous Work

Turner (1938) first proposed the name Spencer Formation for a sequence of marine sandstones and shales located approximately 16 kilometers west-southwest of Eugene in the vicinity of Spencer and Coyote Creeks. Fossil assemblages collected by Turner in the Spencer

Formation correlate with late Eocene Tejon strata in California, and with Coaledo and Cowlitz Formation fossils of Oregon. Turner proposed the name Comstock Formation for those sediments stratigraphically overlying the Spencer Formation and lying unconformably beneath the Fisher Formation along Spencer Creek. Based on the fauna collected from the Comstock Formation Turner believed it to be nonmarine. The Comstock fauna described by Diller (1900) and Sanborn (1937) found in the lower portion of the Fisher Formation near Comstock, Oregon should not be confused with fauna present in the Comstock Formation proposed by Turner (Beaulieu, 1971).

Mundorff (1939) described the geology of the Salem quadrangle. He encountered a similar fauna characterized by Turner within the Comstock Formation and termed them the "Helmick Beds". Allison (1953) also described a similar fauna in the Albany area.

Baldwin (1947, 1964) described the geology in the Dallas-Valsetz, Oregon area. There he found rocks with lithologies and marine fossil assemblages earlier noted by Turner in his study of the Spencer Formation type area, indicating that the Spencer Formation continued north from the type section to Corvallis, Albany and Dallas.

Vokes and others (1951, 1954) mapped the Spencer Formation in the southern and central portions of the Willamette Valley. They included the Lorane Shale at the base of the Spencer Formation and combined the Comstock Formation designated by Turner with part of the upper Spencer Formation.

Schlicker (1962) noted the occurrence of the Spencer Formation in the Yamhill quadrangle west of Gaston, Oregon, approximately 40

kilometers southwest of Portland. Hoover (1963) recognized and mapped the Spencer Formation from the type section to the southern limit in the Anlauf and Drain quadrangles west of Cottage Grove, Oregon. Hoover (1963, p. 30-32) separated the Spencer from the underlying Tyee Formation and overlying Fisher Formation based on lithology and characteristic marine fossil species distinct to the Narizian-Refugian Stages.

During the mid 1960's to early 1970's a series of U. S. Geological Survey Water-Supply papers were published, all of which included hydrologic and general geologic information about the Spencer Formation. Hart and Newcomb (1965) investigated the Spencer Formation in the Tualatin Valley area. Frank (1973, 1974 & 1976) did hydrologic studies which included the Spencer Formation in the Eugene-Springfield, Corvallis-Albany, and Harrisburg-Halsey areas. The most recent ground water study including the Spencer Formation was done by Gonthier (1983) in the Dallas-Monmouth area of Polk, Benton and Marion Counties. The above U. S. Geological Survey Water Supply Papers listed chemical analysis of water from wells which penetrate Spencer Formation sandstone within the Willamette Valley. Most of the water samples collected showed high concentrations of sodium, potassium, calcium and magnesium which may be typical either of poorly recharged aquifers or of conate water. According to Gonthier (1983), water sampled from some wells in the Dallas-Monmouth area, contained such a high percent of dissolved solids that it is unsuitable for irrigation or human consumption.

Enlows and Oles (1966) studied authigenic silicates within the Spencer Formation in the Corvallis, Oregon area.

Gandera (1977) worked in the Spencer Formation type-section designated by Turner (1938) southwest of Eugene. He revised work done by Vokes and others (1951), subdividing the Spencer into informal upper and lower members based on petrography, paleontology and lithology. He also reclassified some Tyee Formation sediments as belonging to the Spencer Formation. In the northern portion of the Spencer Formation outcrop area, Al-Azzaby (1980) revised field mapping done by Schlicker (1962) and Schlicker and Deacon (1967) near Henry Hagg Lake, Patton Valley, and Williams Canyon. Al-Azzaby (1980) also informally subdivided the Spencer Formation in his study area into an upper and a lower member, based on field observations and petrography. He also investigated the provenance, depositional environment, and diagenetic characteristics of some of the late Eocene and Oligocene Formations within the western Tualatin Valley, including the Spencer Formation.

A detailed description of the lithology including sedimentary structures and textural analysis, petrology and paleontology found within the Spencer Formation in the western Tualatin Valley area, are given by Thoms and others (1983). Thoms and others (1983) and Van Atta (1986), based on their findings, also subdivide the Spencer Formation into upper and lower members (informal).

None of these previous works illustrate the regional petrologic or geochemical trends within the Spencer Formation. Detailed petrographic work done in this study complimented by the findings of previous workers will better define the Spencer Formation lower and upper members (informal) previously established by Gandera (1977), Al-Azzaby (1980), Thoms and others (1983) and Van Atta (1986).

Linda Baker, a graduate student in geology at Oregon State University, is currently working on a master's thesis study of the Spencer Formation stratigraphy and depositional environment. Her area of study includes Spencer Formation sandstone outcrops west and south of Salem, Oregon, from Monmouth and Corvallis.

CHAPTER II

STRATIGRAPHY

Geologic Setting

The geologic history of western Oregon has been dominated by the interactions of the Juan de Fuca Plate, (a remnant of the Farallon Plate) the Pacific and the North America Plates. The Farallon Plate, an oceanic lithospheric plate, was separated in the early Eocene from the Pacific Plate by the East Pacific Rise (Drake, 1982). The Farallon Plate was separated from the North America Plate by a trench (Drake, 1982).

According to Armentrout and Suek (1985) arc-type volcanism with associated seamount chains developed during early Eocene (Figure 2a). Umpqua, Siletz River, and Tillamook Volcanics in western Oregon are representative of these seamount basalt sequences (Snively and Wagner, 1963). In the early to mid-Eocene, this area was a deep marginal oceanic basin with a base of oceanic rise basalt overlain by accreted seamounts and oceanic islands.

According to Armentrout and Suek (1985), blockage of the subduction zone occurred prior to mid-Eocene time. Subsequent blockage of the subduction zone caused it to jump westward and a forearc basin was formed (Simpson and Cox, 1977). Middle Eocene Tyee and Fluornoy Formation sediments were transported from uplifted Klamath sources into the forearc basin located behind the trench (Snively and MacLeod, 1977).

Molenaar (1985) interprets the Tyee Formation as marginal basin deposits. The Yamhill Formation sediments were originally thought to be the distal turbidite sequences associated with the Flournoy Formation (Baldwin, 1976), but paleocurrent evidence studied by Heller (1983) indicates that the source was from the east rather than the Klamaths in the south.

During late mid-Eocene the Klamath source was eroded to moderate relief, and the mid-Eocene basin was segmented into the shallow shelf basins by uplifts and active volcanism (Snively and Wagner, 1963). Snively and MacLeod (1977) interpret this period as a time with renewed subduction and rejuvenation of local eruptive volcanic centers. Uplift and widespread erosion as well, caused a regional unconformity below late Eocene sediments. On top of this unconformity late Eocene Cowlitz, Spencer, and Nestucca Formations were deposited by the invading sea (Baldwin, 1964). Armentrout and Suek (1985) illustrate their concept of the middle to late Eocene paleogeography of western Oregon and Washington in Figure 3.

According to Al-Azzaby (1980), Thoms and others (1983) and Van Atta (1986), the lower member (informal) of the Spencer Formation contains marine mollusca fossils characteristic of outer to mid-neritic water depths while upper member (informal) lithofacies contains coal and pebbly horizons which indicate a near shore to estuary depositional environment and in some places may be non-marine.

In the late Eocene to the mid-Miocene (Figure 2c), the subduction zone may have shifted westward, while uplift in the areas of the Klamath Mountains and present-day Vancouver Island, with subduction in between,

Figure 2a. Early Eocene tectonic and geologic framework showing seamount chains formed along a spreading ridge and volcanism above an eastward-dipping subducted plate.

Figure 2b. Middle Eocene tectonic and geologic framework showing westward jump in subduction zone between Farallon-Kula plates and more eastern North American plate

Figure 2c. Late Eocene tectonic and geologic framework showing coastal plain progradation into shelf margin fore-arc basin and local subsea fan development within the basin.

Figure 2. Reconstruction of the Eocene tectonic and geologic framework of northwestern Oregon and southwestern Washington. Diagrams from Armentrout and Suek (1985, their Figures 19, 20 & 21). The relative direction of plate movement or faulting is shown with arrows.

produced a trough, within which locally shallow basins formed (Snively and others, 1980). The shoreline paralleled the present-day Cascade Mountain foothills. During this time, sedimentation was continuous within the trough and there was active tectonism in the area.

By early Oligocene time, the ancestral Cascades as well as locally active volcanoes contributed volcaniclastic material to the trough. Regional uplift during early and mid-Oligocene time shifted the depositional environment northward (Snively and Wagner, 1963). Continental sediments of the Fisher Formation were deposited in the southern Willamette Valley, while shallow water marine sediments of the Eugene and Keasy Formations were deposited in the south-central and northern Willamette Valley. Marine deposition was even more restricted in late Oligocene time due to broad uplift associated with widespread emplacement of gabbroic sills (Snively and Wagner, 1963). There is no record of marine sedimentary deposition in the southern and central Willamette Valley after the Oligocene. By early Miocene time, the shoreline was located west of the present day Coast Range. In the mid-Miocene, flows of the Columbia River Basalt Group were erupted and flowed as far west as the Pacific Ocean (Beeson and others, 1979). The flows crop out from south of Salem to northwest of Portland. During Pliocene and Pleistocene time, local sands and silts were deposited in the northern Willamette Valley (Beaulieu, 1971) and marine deposition was very restricted.

Spencer Formation Stratigraphic Relationships

To the north of the Corvallis-Albany area, Spencer Formation

Figure 3. Paleogeography of western Oregon and Washington during middle to late Eocene. Diagram after Armentrout and Suck (1985, their Figure 11). Figure shows a wide coastal plain across which quartzite and feldspathic sands were transported from metamorphic-plutonic sources inland. Localized volcanic activity caused sandstone composition to become more lithic. An increase in volcanic activity during late Eocene could have contributed elevated concentrations of plagioclase, hornblende and augite within Spencer Formation upper member (informal) sandstones. Armentrout and Suck (1985) did not incorporate Coast Range rotation models such as those developed by Simpson and Cox (1977), Magill and Cox (1980) and Heller (1983) into their paleogeographic reconstruction model. B = Bellingham, S = Seattle, O = Olympia, P = Portland, E = Eugene, CB = Coos Bay.

sandstone crops out in a narrow band, usually not more than a kilometer wide, forming a sinuous outcrop. South of the Corvallis-Albany area outcrop patterns are generally less sinuous and Spencer sediments commonly crop out in larger areas within the eastern Coast Range foothills. Thickness of the Spencer varies greatly throughout the study area. Southwest of Eugene near the type section, along Spencer and Coyote Creeks, the Spencer is approximately 500 meters thick. In the Corvallis area the Spencer thickens to between 800-1,500 meters (Vokes and others, 1951). Spencer thickness again decreases north of Corvallis to about 800 meters near Dallas, and eventually thins to approximately 100 meters west of Forest Grove according to Baldwin (1976) and Beauleiu (1971). Bruer and others (1984) utilizing subsurface exploration well data and Van Atta (1986) using measured sections in the Henry Hagg Lake vicinity and Patton Valley, have estimated Spencer Formation thickness to be 500 meters within the western Tualatin Valley. Previous workers may have underestimated Spencer Formation sandstone thickness within the western Tualatin Valley.

For the purpose of this project five smaller geographic areas, including the type area, were utilized to determine Spencer Formation stratigraphic relationships (Figure 1). Spencer Formation contact relationships are shown in the Eocene stratigraphic correlation chart of the Willamette Valley and northwestern Oregon (Figure 4).

The Yamhill Formation unconformably underlies Spencer Formation sandstone lithofacies from the western Tualatin Valley southward into the Albany-Corvallis, Oregon area (Bruer and others, 1984). Within the type area Gandra (1977) believed the Spencer Formation was

unconformably underlain by the Lorane Shale and Heller (1983) interprets the underlying sediments to be upper Tyee which accompany the same stratigraphic position.

Al-Azzaby (1980), Thoms and others (1983) and Van Atta (1986) subdivided Spencer Formation lithofacies into informal upper and lower members based on sedimentary textures, structures and petrography within the western Tualatin Valley. Spencer Formation relationships with unconformably overlying sedimentary formations are varied in the western Tualatin Valley. Al-Azzaby (1980) denoted overlying sediments as Stimson Mill Beds, while Thoms and others (1983) consider the Spencer Formation to be overlain by rocks of Pittsburg Bluff age equivalent based on paleontological evidence. Armentrout and others (1983) and Bruer and others (1984) refer to them as upper Eocene to Oligocene marine sedimentary rocks.

According to Bruer and others (1984) subsurface correlation, the lower part of the Spencer Formation within the western Tualatin Valley appears to be coeval with the Clark and Wilson sandstone (informal) of the Cowlitz Formation and they may interfinger with each other. Bruer and others (1984) "Correlation Section 24" of northwestern Oregon informally names those arkose sandstones in the lower part of the Spencer Formation as the "Spencer sand member" (Figure 5).

Spencer Formation sandstone may be locally underlain by and interfinger with the Nestucca Formation within the southern part of the western Tualatin Valley area southward into the Monmouth, Oregon vicinity. Within the Monmouth and Albany-Corvallis areas Eugene Formation lithofacies unconformably overlies the Spencer Formation.

Figure 4. Correlation chart of the Willamette Valley and northwestern Oregon. After Armentrout and others (1983) with stratigraphic columns compiled by: (1) Baldwin and Brownfield, (2) Brownfield and Beeson, and (3) Armentrout and others.

South of the Corvallis, Oregon study area Fisher and Spencer Formation lithofacies may interfinger (Bruer and others, 1984).

Spencer Formation arkose to lithic arkose sandstone lithofacies are similar to many of the middle to late Eocene arkosic sandstones of western Oregon and Washington. The Coaledo Formation found in the Coos Bay, Oregon area, Nestucca Formation of the west-central Willamette Valley and Cowlitz Formation of northwestern Oregon and southwestern Washington correlate with the Spencer Formation. Spencer Formation arkosic sandstone correlates with the mid- to late-Eocene Skookumchuck, Spiketon, Renton, Naches, Roslyn and Chumstick Formations in western Washington (Armentrout and others, 1983). Figure 6 shows the areas where the above arkosic sandstone formations crop out and Figure 7 shows an accompanying correlation chart which illustrates stratigraphic relationships.

Lithofacies Descriptions

It is shown by this present study that trends within Spencer Formation arkose to lithic arkose sandstone lithofacies generally reflect the textural and petrographic variations within the informal upper and lower members, which agrees with Gandera (1977), Al-Azzaby (1980), Thoms and others (1983), and Van Atta (1986). Sandstone lithofacies characteristic of the lower and upper members are not present or could not be differentiated within every one of the five smaller study areas (Figure 1). Petrographic and geochemical data obtained from the findings in this report aided in the separation of the informal upper and lower members (Figure 8) in those areas where Spencer

Figure 5. Portion of Bruer and others (1984) Correlation Section 24, northwestern Oregon, depicting Spencer Formation lithofacies within the study area.

Formation sandstone was difficult to distinguish stratigraphically.

Lower Member (informal)

The lower lithofacies consists predominately of a gray to greenish gray (5 GY 6/1) highly micaceous, arkosic sandstone which weathers to orange brown (10 YR 6/4) . Sandstone beds are massive and generally lack cementing agents, causing them to be extremely friable. Despite the lack of cement, massive friable sandstone outcrops commonly form steep almost vertical exposures with little slumping. Outcrop exposure may be related to good permeability, causing sandstone to readily drain off water before slope rotation occurs. Sample locality SP-12 was collected from one of the most southerly exposures of the lower member lithofacies, which consists of 12 meters of vertical, friable sandstone. Limonite partings, which commonly cut at angles to the massive sandstone, give a sense of false bedding planes. Sedimentary structures are rare within the massive sandstones except for fine laminae (1 cm) with concentrations of biotite. No cross-bedding was observed. Although no granulometric analysis was completed, the lower member is obviously predominately coarser grained than the upper member. No fossils were noted within the massive sandstone but bioturbation was evident in several outcrops.

Upper Member (informal)

The upper member consists of very pale orange (10 YR 8/2) to gray to greenish gray (5 GY 6/1) medium to thin bedded (1 m) arkosic to lithic arkosic silty sandstone and mudstone. When weathered the sandstone is moderate yellowish brown (10 YR 5/4) to grayish orange (10

Figure 6. Generalized outcrop map of middle to late Eocene arkosic sandstone formations in northwestern Oregon and western Washington (modified after Winters, 1984, his Figure 19). SP = Spencer Formation, COW = Cowlitz Formation, SK = Skookumchuck Formation, S = Spiketon Formation, NA = Naches Formation, RO = Roslyn Formation, CH = Chumstick Formation, RN = Renton Formation. Cities as reference points: B = Bellingham, E = Eugene, O = Olympia, P = Portland, S = Seattle, Y = Yakima.

Figure 7. Chronostratigraphic correlation chart of middle to late Eocene arkosic sandstone formations in western Oregon and Washington (modified after Winters, 1984, his Figure 33). Stratigraphic relationships of the arkosic sandstones shown in the outcrop map (Figure 6) are discussed here. 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; and 10 = Wells.

YR 7/4). Sedimentary structures include trough cross-bedding and numerous micaceous laminations. In the Albany-Corvallis area abundant pelecypods and gastropods were collected but were not identified. Trace fossils in the form of burrows are commonly found. Overall, this lithofacies is better cemented with clays and calcite. Carbonaceous material (wood fragments) are also present. Schlicker (1962), Gandra (1977) and Al-Azzaby (1980) make references to coal occurrences within the upper part of the Spencer Formation. Thin (1-5 mm) hard bright coal partings were noted in the upper part of the Spencer out of the study area west of Eugene, Oregon. Concretions occur in the upper lithofacies within the Corvallis and Monmouth study areas and to the north in the vicinity of Henry Hagg Lake. The best exposure of concretions within the study area occur along the north side of Henry Hagg Lake northwest of the dam. Concretions at the Henry Hagg Lake locality commonly have a diameter greater than one meter. Figure 8 shows the stratigraphic relation between the upper and lower members (informal) of the Spencer Formation within the thesis area.

Figure 8. Generalized stratigraphic model of the relationships between the Spencer Formation informal lower and upper members from Corvallis to Henry Hagg Lake, Oregon.

CHAPTER III

SEDIMENTARY PETROLOGY

Methods and Sample Preparation

A total of 35 grain mounts and epoxy-impregnated thin sections were studied to analyze the petrologic nature of the Spencer Formation within the study area. Medium-grained sandstone samples were consistently utilized where possible to minimize the effects of grain-size variations on framework mineral composition and to aid in identifying lithic fragments.

Thin sections were impregnated with a blue epoxy to show pore space relationships and stained for both potassium and plagioclase feldspars, using the methods of Bailey and Stevens (1960). Thin sections were ground in oil to alleviate any problems encountered with swelling clays.

The grain mounts are actually thin sections of reconstructed rock. A split of disaggregated rock was incorporated into plastic epoxy resin, allowed to harden, a billet was cut, and ground down to 30 microns thickness. This process best shows the original consolidated friable rock composition. The thin sections of reconstructed rock are also stained for both plagioclase and potassium feldspars. A majority of the samples studied in thin section were reconstructed grain mounts due to the friable nature of most samples of sandstone.

Framework Mineral Grain Counting Techniques

Point counting techniques were utilized for the 12 thin sections while the remaining 23 grain mounts were line counted. Detrital framework mineral grain parameters outlined by Dickinson (1970) and Dickinson and Suezk (1979) were utilized in this study. Table I shows the general framework mineral grain categories utilized for both point and line counting techniques and their representative symbols. A minimum of five-hundred framework grains were counted for each sample. Typically a grid pattern of ten evenly spaced rows of fifty or more counts per row was used for each thin section and grain mount. This spacing allowed for a large enough grid pattern, so that individual framework grains were not counted more than once. Five very fine-grained sandstones were also examined in thin section. A minimum of one thousand framework grains were counted to allow for a grid spacing pattern suitable for covering the largest portion of the thin section. This spacing best illustrated sample composition.

Table II summarizes quartz, feldspar, and lithic framework components in each Spencer Formation sample studied in thin section. The number of counts and relative percentages for each framework grain category are listed. Muscovite, biotite, accessory and authigenic minerals, and unknowns are combined in the "other" category.

TABLE I

GENERAL FRAMEWORK GRAIN CATEGORIES

Category	Symbol
Monocrystalline quartz	Qm
Polycrystalline quartz	Qp
Plagioclase feldspar	P
Potassium feldspar	K
Volcanic and Metavolcanic rock fragments	Lv
Sedimentary and Metasedimentary rock fragments	Ls
Metamorphic Aphanitic rock fragments	Lm

Detrital Framework Mineral Grains

Quartz

Monocrystalline and polycrystalline quartz content within the Spencer Formation averaged 27% and 6% in the lower member arkosic lithofacies and 20% and 4% respectively in the upper member. Quartz grains studied in thin section within both lithofacies consisted of three types: 1) monocrystalline quartz, 2) equidimensional polycrystalline quartz, and 3) foliated polycrystalline quartz. Both monocrystalline and polycrystalline quartz are more abundant in the lower member.

Monocrystalline Quartz

In thin section, under plane polarized light, monocrystalline quartz was distinguished by clear colorless angular to sub-angular grains which are often fractured. Under cross polarized light, monocrystalline quartz exhibited low birefringence and undulose to

TABLE 11

TOTAL DETRITAL FRAMEWORK GRAIN POINT COUNT DATA

SAMPLE NAME	TOTAL COUNTS	Q ₁	n	Q ₂	n	Q ₃	n	Q ₄	n	P	n	K	n	F	n	L _v	n	L _m	n	L _s	n	L _t	n	OTHER	n
LOWER MEMBER (INFORMAL)																									
Western Tualatin Valley Area																									
SP-1	525	174	33	33	6	207	39	124	24	124	19	4	10	2	0	0	29	6	97	18					
SP-5	502	179	28	28	9	172	38	123	25	123	21	5	14	3	12	0	35	7	79	16					
SP-6	508	180	29	29	10	175	40	125	26	125	22	6	15	4	13	2	35	7	80	16					
SP-11	508	169	33	33	8	171	42	125	26	125	21	5	14	3	10	0	35	7	69	14					
SP-65	666	137	23	23	44	7	181	30	148	24	11	2	2	0	25	4	38	6	183	30					
SP-67	514	136	26	26	41	8	177	34	149	29	10	2	22	4	0	0	32	6	133	26					
SP-69	507	113	22	22	34	7	147	29	149	29	19	4	41	8	1	0	61	12	102	20					
Hornmouth Area																									
SP-12	502	158	31	31	4	178	35	147	29	147	4	1	8	2	0	0	12	2	91	18					
SP-41	500	149	30	30	7	168	36	126	28	126	10	2	43	9	7	1	60	12	89	18					
SP-67	501	111	22	22	18	129	26	80	16	80	17	3	11	2	6	1	34	7	203	41					
Albany Area																									
SP-60	1016	116	11	11	32	3	146	15	171	17	28	3	31	3	0	0	59	6	609	60					
SP-62	511	148	29	29	31	6	179	35	110	22	7	1	71	14	4	1	98	19	48	9					
SP-68	507	119	23	23	35	7	154	30	141	28	7	1	35	7	4	1	46	9	55	11					
Spencer Formation Type Area																									
SP-35	503	108	21	21	13	3	121	24	180	36	32	6	4	1	1	0	37	7	125	25					
LOWER AVERAGE																									
DeShazer 13-22 Well Sidewall Cores																									
QAC-1-2319	512	132	30	30	29	6	181	35	140	27	6	1	7	1	3	1	16	3	79	15					
QAC-2-2211	503	134	27	27	28	5	167	33	137	29	13	2	17	3	2	0	27	4	89	16					
QAC-5-2216	505	136	28	28	29	6	185	34	143	28	8	2	17	3	2	0	27	4	52	10					
QAC-10-2259	512	162	36	36	36	7	198	39	127	25	13	3	21	4	4	1	38	7	43	8					
UPPER MEMBER (INFORMAL)																									
Western Tualatin Valley Area																									
SP-6	523	107	20	20	12	2	119	23	72	14	6	1	3	1	1	0	10	2	289	55					
SP-11	503	93	19	19	20	4	113	23	141	28	21	4	50	10	1	0	72	14	131	26					
SP-74	501	86	17	17	21	5	102	21	125	25	20	4	22	4	3	1	48	10	149	30					
SP-75A	500	86	17	17	21	5	102	21	128	26	21	4	22	4	3	1	48	10	149	30					
Hornmouth Area																									
SP-14	503	99	20	20	21	4	120	24	130	26	66	13	0	0	0	0	66	13	110	22					
SP-79	511	77	15	15	7	1	84	16	190	37	62	12	30	6	2	0	94	18	112	22					
SP-83	523	132	25	25	19	4	151	29	146	28	19	4	33	6	1	0	53	10	131	25					
SP-86	503	134	27	27	23	5	157	31	124	25	6	1	19	4	2	0	27	5	163	32					
Albany Area																									
SP-59	1064	210	20	20	46	4	256	24	389	37	20	2	41	4	0	0	61	6	329	31					
Corvallis Area																									
SP-55	1001	160	16	16	16	2	176	18	363	36	9	1	3	0	0	0	12	1	357	36					
SP-57A	1008	198	20	20	46	5	244	24	330	33	16	2	55	5	1	0	72	7	259	26					
SP-58	1005	144	14	14	37	4	161	18	413	40	14	1	31	3	0	0	45	4	326	32					
SP-68	500	84	17	17	29	6	113	23	131	26	17	3	24	5	2	0	43	9	151	30					
Spencer Formation Type Area																									
SP-32	500	108	22	22	22	4	130	26	190	38	28	6	0	0	0	0	28	6	104	21					
UPPER AVERAGE																									
DeShazer 13-22 Well Sidewall Cores																									
QAC-12-2224	503	122	24	24	27	5	149	30	88	17	24	5	18	4	1	0	43	9	176	35					
QAC-14-2220	500	108	22	22	34	7	142	28	119	24	17	3	24	5	3	1	44	9	100	20					
QAC-17-2214	500	133	27	27	49	10	182	36	137	31	14	3	24	5	3	1	41	8	72	14					

n = number of counts in each category.
 Other Category Includes: microfossils, heavy and authigenic minerals, cementing agents, matrix, pore spaces, and unknowns.
 See TABLE 11 for explanation of grain category parameters.

non-undulose extinction. Monocrystalline quartz derived from schists, gneisses and granitic rocks commonly exhibits undulose extinction (Williams and others, 1982).

Polycrystalline Quartz

Two different types of polycrystalline quartz, equadimensional (30%) and foliated (70%), were predominant within the Spencer Formation. Equadimensional polycrystalline quartz consisted of a non-orientated aggregate of equant quartz crystals with both sutured and straight crystal boundaries. Occasionally crystal aggregate size varied and was non-uniform. Foliated polycrystalline quartz grains consisted of elongated and orientated crystal aggregate which exhibited both straight and sutured crystal boundaries. Chert grains were found in many of the samples. It is recognized in thin section by its microcrystalline or microgranular makeup of equant aggregate quartz crystals. Typically equadimensional polycrystalline quartz grains are characteristic of a igneous rock source while foliated polycrystalline quartz grains are commonly derived from rocks of metamorphic origin (Williams and others, 1982).

Feldspar

Total feldspar content is consistent throughout the Spencer Formation sampling area and commonly equals or exceeds total quartz content except in some samples collected from the lower member or more quartzose arkosic rich lithofacies. Approximately 40 percent of the framework grains in each sample consisted of plagioclase and potassium feldspars combined. Although total feldspar content was uniform

throughout the samples, potassium feldspar content within the lower member is commonly higher than in the upper member, where as in the lower member plagioclase feldspar framework grains are more abundant than potassium feldspar. Like quartz, feldspar detrital framework grains are angular to sub-angular.

Plagioclase Feldspar

Plagioclase feldspar was stained by the method outlined by Bailey and Stevens (1960) and is distinguishable in thin section by its reddish-pink color when viewed in plane polarized light. Plagioclase is commonly clear and unaltered, although, some framework grains show noticeable alteration or replacement with sericite and clay minerals around the periphery and less commonly along cleavage planes. Plagioclase chemical composition was calculated, by the method discussed in Shelley (1985, p. 258) and illustrated by Hammond (personal communication, 1985). One-hundred plagioclase feldspar detrital grains were counted for each selected sample to determine the plagioclase composition percentages in Table III. According to Williams and others (1982), determination of plagioclase chemical composition serves as one of the best indicators of provenance.

Plagioclase feldspar composition ranges from albite ($An=0-10\%$) to labradorite ($An=50-70\%$) with oligoclase being the most common analyzed in thin section. Albite and oligoclase are more common within the lower member lithofacies while andesine and labradorite are predominant within the upper member. Table III illustrates individual plagioclase compositional percentages for selected Spencer Formation samples.

TABLE III

PLAGIOCLASE COMPOSITION* OF SELECTED SPENCER
FORMATION SANDSTONE LITHOFACIES

Plagioclase, An(anorthite) Percent

Sample Number	0-10 Albite	10-30 Oligoclase	30-50 Andesine	50-70 Labradorite
<hr/>				
LOWER MEMBER (INFORMAL)				
SP-1	18	58	18	6
SP-60	7	53	33	7
SP-87	15	80	5	-
ONG-1-2319	25	62	13	-
ONG-3-2311	21	69	6	4
ONG-10-2259	13	40	31	16
LOWER AVERAGE	17	60	18	6
UPPER MEMBER (INFORMAL)				
SP-57A	12	52	28	8
SP-74	3	73	20	4
SP-81	7	53	40	-
ONG-12-2224	6	63	25	6
ONG-17-2214	8	43	37	12
UPPER AVERAGE	7	57	30	6
<hr/>				

*Number of plagioclase detrital grains is equal to percent
All averages are rounded to the nearest percent.

Potassium Feldspar

Potassium feldspar stained with sodium cobaltinitrite can be readily distinguished from plagioclase in thin section by its distinct yellow color when viewed under plane polarized light. The majority of potassium feldspar grains are altered like plagioclase and commonly have degraded irregular grain boundaries. Microcline was observed most

readily, being distinguished by its distinct cross-hatch twinning, while orthoclase generally shows simple or no twinning. Sanidine shows similar characteristics to orthoclase but can be determined by its small optic angle (Williams and others, 1982). Sanidine was not readily identified in thin section and is believed to be rare if not absent from the samples analyzed. The occurrence of orthoclase and microcline was only noted and their relative percentages were not determined.

Rock Fragments

Volcanic Rock Fragments

Three types of volcanic rock fragments were observed in thin section, they include; 1) microgranitic, 2) microlithic, and 3) felsic.

Microgranitic rock fragments were distinguished by the presence of granular quartz, potassium feldspar, and muscovite within the rock fragment. They were differentiated from foliated metamorphic rock fragments, which are often compositionally alike, by the lack of schistose fabric or foliation.

Microlithic volcanic rock fragments are the most prevalent lithic grains studied in thin section. They consisted of small lath-shaped phenocrysts of plagioclase, commonly with no apparent textural arrangement, incorporated within an aphanitic groundmass. According to Williams and others (1982) microlithic rock fragment composition varies from intermediate to mafic.

Felsic volcanic rock fragments are least common in thin section.

Metamorphic Rock Fragments

Quartzite and schistose rock fragments were the two types of metamorphic rock fragments found in thin section. Quartz grains consisting of larger irregular crystal aggregates showing stretched and sutured grain boundaries were categorized as quartzite. Schistose-type rock fragments consisted of foliated and elongated crystals of quartz and mica, predominately muscovite.

Sedimentary Rock Fragments

Sedimentary rock fragments were noted in trace amounts in most samples analyzed. Only aphanitic grains of siltstone or shale and chert were identified.

Mica

Both muscovite and biotite are present in all samples analyzed. Mica framework grains commonly account for five to ten percent of the sample composition. Biotite is generally two to three times more abundant than muscovite, but in some samples equal amounts were observed. Mica flakes noted in thin section are commonly bent and often pinched between more rigid mineral grains due to post depositional compaction.

Glaucanite

Glaucanite was found only in trace amounts within some of the Spencer Formation sandstone samples. Typically glaucanite occurred as small rounded greenish-brown pellets commonly squeezed between opposing

detrital grains. Al-Azzaby (1980, pp. 40-42) discussed glauconite and its implications within the Spencer and Yamhill Formations studied in Yamhill and Washington Counties, Oregon. He believes that the glauconite may have formed within the Spencer Formation from the degradation of igneous and metamorphic rock fragments. Because glauconite is readily deformed, it may be more abundant in Spencer Formation sandstone than determined by petrography. It is probable that glauconite could have been misinterpreted as detrital clay minerals, become incorporated into matrix material, or been destroyed during the process of sandstone disaggregation.

Clays

Because of the fine-grained nature of clays, they are very difficult to differentiate optically (Shelley, 1985, p. 237). In thin section clays were noted but no attempt was made to identify clay minerals present although the majority was probably characteristic of the smectite group. Detailed determination of clay mineral assemblages present in Spencer Formation sandstone lithofacies is discussed in Chapter's IV and V, Scanning electron microscopy (SEM) and X-ray diffraction of clay minerals, where both SEM-EDAX and X-ray diffraction (XRD) techniques were utilized.

Heavy Minerals

Heavy minerals were separated by the technique described by Van Atta (personal communication, 1985) utilizing the heavy liquid tetrabromo ethane (specific gravity 2.96 at 25° C). These mineral

separates are widely utilized for studying the provenance of sedimentary formations (Leupke, 1984). After determining weight percentages of heavies in a two gram sample, covered grain mounts were made. A minimum of two-hundred heavy mineral grains were counted for each sample (counts were normalized to equal 100 percent). Opaque heavy minerals, which predominately include magnetite and ilmenite, were eliminated from counting procedures because they occur in dominately equal amounts in all samples prepared and therefore would have little bearing on determining heavy mineral petrographic trends.

The Spencer Formation upper member sandstone lithofacies contains heavy mineral assemblages that constitute as much as 12 percent (weight percent) of selected samples. Common heavy minerals found within the Spencer Formation are epidote, hornblende, augite, zircon and apatite, with minor amounts of garnet, sphene, tourmaline, rutile and kyanite. Percentages of heavy minerals characteristic of selected Spencer Formation samples are listed in Table IV.

Epidote

Epidote is the most common heavy mineral found within the Spencer Formation sandstones except for hornblende in some samples within the upper member. Epidote occurs typically as yellow to greenish-yellow polycrystalline grains exhibiting a kaleidoscope appearance under cross-polars when the microscope stage is rotated. Epidote is commonly found as a heavy mineral in rocks of metamorphic origin characteristic of greenschist facies or metamorphosed carbonate rocks (Shelley, 1985, p. 177).

Hornblende

Hornblende is one of the most widely distributed rock-forming minerals, occurring in both igneous and metamorphic rocks (Klein and others, 1985). Within the Spencer Formation four different types of hornblende were determined; green etched, brown, blue-green and oxyhornblende or basaltic hornblende. Green hornblende and augite commonly exhibit very pronounced spike-like terminal protrusions characteristic of etching. Typically etched amphibole and pyroxene grains are too delicate to be transported any distance without degradation and are likely a product of epidogenesis and may have continued to form from post depositional percolating ground water (Ehlers and Blatt, 1980, p. 400). Scanning electron microscopy evaluation of selected upper member samples (Chapter IV) show etching effects on hornblende and augite grains. Brown hornblende exhibits similar optical properties as green hornblende but rarely exhibits etching. Blue-green hornblende is typically associated with a metamorphic source (Dana and Ford, 1949). Oxyhornblende (Basaltic hornblende) which is recognized by its intense brown red-brown color (Shelley, 1985, p. 216) only occurs in one sample, SP-60, collected in the lower member northwest of Albany, Oregon. Basaltic hornblende occurs in a variety of volcanic rocks ranging in composition from basalts to trachytes (Deer and others, 1967, p. 176).

One grain of glaucophane was found within the DeShazer sidewall core sample ONG-10-2259, which is characteristic of the middle part of the Spencer Formation sandstone lithofacies. Shelley (1985, p. 218) states that glaucophane is characteristic of regionally metamorphosed

rocks typical of greenschist to higher-pressure lawsonite-glaucophane facies.

Augite

Augite averages two percent in the lower lithofacies and seven percent in the upper member with two samples of the upper member, SP-74 and SP-81, having elevated percentages of green etched augite. Augite is commonly gray-green and is etched similar to green hornblende but can be distinguished by the lack of pleochroism and a large extinction angle. Typically augite comes from basalts and alkaline igneous rocks such as syenites, trachytes, and phonolites (Shelley, 1985).

Zircon

Euhedral to subhedral prismatic colorless, brown and rose colored zircon grains were most common. Minor angular to sub-angular and well rounded grains are also present. Extreme relief, commonly exhibiting a series of halos concentric to the grain boundary, and straight extinction were utilized for distinguishing zircon. Detrital zircon grains average twelve percent of the heavy minerals examined within Spencer Formation sandstone lithofacies studied. According to Shelley (1985, p.173) zircon is a common accessory mineral in volcanic rocks, plutonic igneous rocks, predominately granites and syenites, and may also occur as an accessory mineral in schists and gneisses.

Apatite

Apatite which averages nine percent, is the next most abundant heavy mineral found in the Spencer Formation sandstone lithofacies. Apatite in the samples is predominately colorless subhedral prisms and

TABLE IV

HEAVY MINERAL ASSEMBLAGES FOUND IN SELECTED SPENCER
FORMATION SANDSTONE OUTCROP SAMPLES

Heavy Mineral	Samples Numbers					
	SP-1	SP-57A	SP-60	SP-74	SP-81	SP-87
Epidote	47.5	23.0	26.5	19.5	19.0	26.0
Green Hornblende	8.5	31.0	10.5	28.0	24.5	4.0
Brown Hornblende	5.0	10.0	5.0	1.5	2.5	2.0
Blue-green Horn.	--	2.5	0.5	2.0	1.0	--
Oxyhornblende	--	--	1.5	--	--	--
Augite	1.5	10.0	4.0	12.5	23.5	2.0
Zircon	19.0	7.0	14.0	17.0	12.0	17.0
Apatite	6.0	9.5	12.5	7.5	5.0	12.0
Garnet	2.5	1.5	1.5	3.0	6.5	19.0
Sphene	3.5	2.0	11.5	4.0	3.0	11.0
Tourmaline	3.5	1.5	5.5	2.0	1.0	4.0
Rutile	2.0	1.0	5.5	2.0	1.5	3.0
Kyanite	1.0	1.0	1.5	1.0	0.5	--
Weight Percent*	3.7	12.4	11.5	8.4	5.5	3.6

*Weight percent of heavy minerals in Spencer Formation samples are calculated from a two gram sample. Heavy minerals constitute that portion from the 3.75 to 4.25 phi interval.

TABLE IV
(CONTINUED)

HEAVY MINERAL ASSEMBLAGES FOUND IN SELECTED SPENCER FORMATION
SIDEWALL CORES FROM THE DESHAZER 13-22 EXPLORATION WELL

Heavy Mineral	Samples Numbers					
	ONG-1 2319	ONG-3 2311	ONG-10 2259	ONG-12 2224	ONG-17 2214	ONG-23 2202
Epidote	36.0	42.5	32.5	21.0	13.0	17.0
Green Hornblende	12.0	12.0	5.5	33.0	41.5	7.0
Brown Hornblende	5.0	2.5	2.5	3.5	4.5	2.0
Blue-green Horn.	2.0	2.5	--	1.0	5.5	--
Oxyhornblende	--	--	--	--	--	--
Augite	6.0	7.0	5.0	4.0	5.0	--
Zircon	12.0	6.0	8.0	4.5	12.5	20.0
Apatite	11.0	13.5	11.0	10.0	6.5	13.0
Garnet	5.0	4.5	14.5	15.0	2.0	25.0
Sphene	4.0	4.0	12.0	4.0	5.5	7.0
Tourmaline	4.0	2.0	3.0	1.0	1.5	6.0
Rutile	2.0	2.0	4.5	2.5	1.5	3.0
Kyanite	1.0	1.0	0.5	0.5	1.0	--
Andalusite	--	0.5	--	--	--	--
Glaucophane	--	--	0.5	--	--	--
Weight Percent*	2.3	3.5	11.9	1.9	6.7	1.2

*Heavy minerals constitute that portion from the 3.75 to 4.25 phi interval. Some DeShazer 13-22 sidewall core samples weighted less than two grams so weight percentages were normalized based on initial weight.

sub-rounded to rounded grains. The abundance of rounded grains indicates that much of the apatite came from pre-existing recycled sedimentary rocks. Apatite is a common accessory mineral found in a variety of igneous and metamorphic rocks (Shelley, 1985, p. 303).

Garnet

Garnet occurs as small broken subhedral to anhedral grains (chips). Garnet grains average five percent of heavy minerals within the Spencer Formation sandstone lithofacies studied. The majority of garnet observed was reddish-pink or rose colored which is most characteristic of iron-rich almandine (Shelley, 1985, p. 158). This variety of garnet is typically associated with regionally metamorphosed rocks, commonly schists.

Sphene

Sphene occurs as sugary-brown sub-hedral chips and less commonly as cross hatched euhedral diamond-shaped grains. Sphene accounts for about three percent of the heavy minerals found within the selected Spencer Formation sandstone samples, except for SP-60, ONG-1-2319 and ONG-10-2259, which are all from the lower member in the Monmouth area, which all contain approximately 11 percent sphene. Sphene was recognized by its distinctive brown color and high dispersion. Shelley (1985, p. 171) states that sphene is a common accessory mineral found in intermediate and acid plutonic igneous rocks but can occur in a wide variety of metamorphic rocks.

Tourmaline

Tourmaline occurred as green and less commonly black and dark blue euhedral to subhedral prismatic shaped grains. Tourmaline characteristic of the Spencer Formation samples is presumed to be of the iron-rich schorl variety because of the color distinctions and strong pleochroism. The lower member sandstone lithofacies averages 3.5 percent tourmaline while the upper member averages 1.5 percent of the heavy minerals examined. Granites, pegmatites, schists and gneisses commonly contain schorl as an accessory mineral (Shelley, 1985, p. 186).

Rutile

Rutile occurs in trace amounts (4 to 6 grains) in the Spencer Formation sandstones analyzed and are typically brown to deep-red elongated prisms and broken subhedral grains. According to Deer and others (1967, p. 417) and Shelly (1985, p. 280) rutile is a widely distributed accessory mineral found in intermediate to acidic plutonic rocks as well as iron-rich schists and gneisses. In sample SP-87, from the lower member within the Monmouth area, contains one light brown hornblende grain with numerous very small rutile needles.

Kyanite and Andalusite

Kyanite only occurs in trace amounts (1-3 grains) in the heavy mineral fraction of the Spencer Formation analyzed. One grain of andalusite was identified within the lower member, in the DeShazer well sidewall core sample ONG-3-2311. Both kyanite and andalusite occur as angular grains. Kyanite and andalusite typically form in regionally metamorphosed pelitic rocks according to Shelley (1985, p. 161 & 162).

Sandstone Petrography

Spencer Formation sandstone framework mineral grains consist of varying amounts of quartz, feldspar, lithic rock fragments (volcanic, metamorphic and sedimentary), mica (predominately biotite with lesser muscovite), and heavy mineral assemblages (epidote, amphibole, and pyroxene with lesser amounts of zircon, apatite, garnet, sphene, tourmaline and rutile). Table II, lists detrital framework mineral grains. Additional information depicting plagioclase composition and heavy mineral separates of selected samples are listed in Table's III and IV. Descriptions of framework grains depicting both mineral and rock components are listed from page 29 to 36. The majority of samples collected lack cement and are friable, except for those samples collected from the Corvallis and Albany area. Calcite, clays, silica and iron oxides were the four types of cement noted in decending order.

Typically feldspar grains equal or outnumber quartz, lithic fragments, and accessory minerals, except in a few samples (SP-1, SP-3, SP-11, SP-67 and SP-81) collected from sandstones characteristic of the lower member. These samples contain more monocrystalline quartz. Plagioclase feldspar ranges from 14 to 41 percent and is more abundant than potassium feldspar which varies from 3 to 21 percent (Table II). All the samples analyzed contained varying amounts of fresh and altered feldspar grains which are angular to subangular. Potassium feldspar grains more commonly showed noticeable grain degradation due to weathering along grain boundaries and cleavage planes.

Plagioclase composition ranges from albite to labradorite. Variety in composition occurred in many of the samples, commonly having two or

three different types of plagioclase occurring within each sample. Oligoclase was the most abundant plagioclase composition observed. A summary of plagioclase composition found in selected Spencer Formation samples is given in Table III.

Potassium feldspar consisted predominantly of microcline with lesser amounts of orthoclase. Sanidine was not readily observed and is believed to be rare in these samples. Increased amounts of potassium feldspar are characteristic in the lower member. Those samples which have higher monocrystalline quartz content generally contain more potassium feldspar (Table II).

Monocrystalline quartz grains, predominately clear and some with small inclusions, occur as a major constituent of all the samples ranking only second to plagioclase grains. Monocrystalline quartz grains average 28 percent in the lower member sandstone lithofacies as well as the lower portion of the DeShazer 13-22 well and 20 percent in the upper member sandstone lithofacies. The ratio of monocrystalline to polycrystalline quartz is commonly 3 to 1 in many of the samples. Polycrystalline quartz averages seven and four percent for the lower and upper member sandstone lithofacies, respectively.

Lithic fragments make up as much as 18 percent of Spencer Formation sandstones. The most common rock fragments noted are of the microlithic volcanic variety containing abundant plagioclase laths. These lithic grains are most abundant in the upper member sandstone lithofacies. Several samples from the upper member within the the Monmouth, Oregon area, exhibit granophyric texture illustrating eutectic intergrowths of quartz and alkali feldspar.

The next most abundant lithic rock fragments were schistose metamorphics with foliated and elongated crystals of quartz and mica (predominately biotite). These rock fragments, which make up between one and nine percent of the sample, are more prevalent within the lower member and in those samples stratigraphically lower in the DeShazer 13-22 well.

Sedimentary rock fragments consisting of siltstones and claystones are rare. They make up less than one percent of the sandstone except for two samples (SP-5 & SP-65). Chert grains are found in trace amounts in many of the samples.

Heavy mineral assemblages noted in Spencer Formation sandstone lithofacies were epidote, amphibole (hornblende and glaucophane), pyroxene (augite), zircon, apatite, garnet, sphene, tourmaline, with trace amounts of rutile, kyanite and andalusite. The relative abundances of these heavy minerals in selected Spencer Formation samples are shown in Table 4.

Epidote and hornblende are the two most abundant heavy minerals. Epidote is most common within the lower member sandstone lithofacies averaging 36 percent. Hornblende, predominately of the green variety and commonly etched, is two to three times more abundant in the upper member, averaging 32 percent.

Augite is the only other heavy mineral which shows any affinity in Spencer Formation sandstone lithofacies. Augite averages two percent in the lower member and stratigraphically lower within the DeShazer well, nine percent in the upper member and five percent stratigraphically higher in Spencer Formation sandstone samples within the DeShazer 13-22 well.

Zircon, apatite, garnet, sphene, tourmaline, rutile, kyanite, andalusite and glaucophane occur in variable amounts with the Spencer Formation lithofacies studied (Table IV). Although these heavy minerals show little correlation with lithofacies variations they are of extreme importance in determining provenance.

Sandstone Classification

Sandstone classified as "arkosic" contains 25 or more percent feldspar, predominantly potassium feldspar according to Pettijohn and others (1972), Folk (1974), and Williams and others (1982).

The data obtained from point counts is normalized and plotted on ternary diagrams. Explanation of grain parameters utilized for classification of sandstones is shown in Table V. Recalculated normalized values utilized in ternary compositional diagrams are outlined in Table VI.

Folk's (1974) sandstone classification (QFL ternary diagram), modified with stability poles adapted from Hayes (1979) was utilized for classifying Spencer Formation sandstone samples (Figure 9a). This classification scheme was used because: 1) it best graphically depicts sandstone categories, 2) it emphasizes provenance, climate and tectonic factors, and overall mineralogic characteristics, 3) it serves as a basis for more recent work done by Dickinson and Suczek (1979) relating sandstone composition and plate tectonics, and 4) it allows for comparison between other studies previously done.

The majority of late Narizian arkosic sandstones found in the Pacific northwest, are typically enriched with plagioclase rather than

TABLE V

DEFINITION OF GRAIN POPULATIONS FOR
TERNARY COMPOSITIONAL DIAGRAMS

Ternary Diagram	Uppermost Pole	Lower Left Pole	Lower Right Pole
QFL	Q Quartzose grains (= $Q_m + Q_p$)	F Feldspar grains (= $P + K$)	L Unstable aphanitic lithic fragments (= $L_v + L_s$)
Q_mFLt	Q_m Monocrystalline quartz grains	F (same as above)	Lt Total aphanitic lithic fragments (= $L + Q_p$)
Q_mPK	Q_m (same as above)	P Plagioclase Feldspar grains	K Potassium Feldspar grains

potassium feldspar (Byrnes, 1985). Winters (1984, p. 63, fig. 21) and Byrnes (1985, p. 24, fig. 7) both illustrate ratios of polycrystalline quartz (Q_p) versus total quartz ($Q_p + Q_m$), plagioclase (P) versus total feldspar (F), and volcanic lithics (L_v) versus total unstable lithics ($L_v + L_s$) content for eight middle to late Eocene arkosic sandstone formations in western Oregon and Washington (Figure 10). Averages for the Spencer Formation upper and lower members area also shown in Figure 10. All eight formations noted by Winters (1984) and Byrnes (1985) showed plagioclase was more abundant. Gandra (1977), Al-Azzaby as well as this present study (Table VI) illustrate that plagioclase content

Figure 9. a) Folk's (1974) classification scheme for sandstone composition modified with stability poles (Hayes, 1979). The grain parameters for the QFL ternary diagram are: total quartz (Q), total feldspar (F), and total aphanitic lithic fragments (L). b) Spencer Formation samples plotted.

overall is more abundant than potassium feldspar within the Spencer Formation sandstones.

Utilizing Folk's classification (Figure 9), two groupings of samples, studied in this project, could be subdivided into informal upper and lower Spencer Formation members such as Gandra (1977) and Al-Azzaby (1980) did. Spencer Formation samples from both outcrop locations and the DeShazer 13-22 well sidewall cores are plotted in Figure 9b. A majority of the samples plot within the "arkose" category with the remainder classified as "lithic arkoses". Lower member samples average 45 percent quartz, 45 percent feldspar (potassium feldspar 11 percent, plagioclase 26 percent) and 10 percent lithic fragments. The upper member samples averaged 30 to 35 percent quartz, 55 percent feldspar (potassium feldspar 9 percent, plagioclase 30 percent) and 15 percent lithic fragments.

Bruer and others (1984) place the more arkosic lithofacies (Clark and Wilson equivalent) stratigraphically above a major unconformity separating the Spencer Formation from the Yamhill Formation. This study substantiated Bruer's criteria, finding that those sandstones collected from both outcrops and the DeShazer 13-22 well, within the lower part of the Spencer Formation closest to the Yamhill Formation contact, are more arkosic. Sandstones found stratigraphically higher are more lithic.

Interpreting these two different sandstone lithofacies with respect to their stratigraphic position is very difficult because only scattered outcrops occur and the complex nature of faulting patterns is obscured at the surface. Only with sophisticated reliable seismic methods and interpretation could fault locations and offsets be known, allowing

Figure 10. Ratio of polycrystalline quartz (Q_p) to total quartz (Q), plagioclase (P) to total feldspar (F), and volcanic lithic fragments to total lithic fragments (L_v/L) for Spencer Formation informal upper and lower members. The diagram also shows other middle to late Eocene arkosic sandstone units for comparison (modified after Byrnes, 1985, his Figure 7).

for the samples collected to be accurately positioned stratigraphically.

Distribution of quartz, feldspar and heavy minerals within the Spencer Formation sandstones provided the best indicators of provenance. Petrographic studies showed that the lower (member) lithofacies has characteristically more monocrystalline quartz and potassium feldspar which are diagnostic of a metamorphic plutonic source. Epidote is also more prevalent within the lower lithofacies reemphasizing a metamorphic origin.

An overabundance of plagioclase feldspars is characteristic of Pacific northwest Narizian sandstone formations (Byrnes, 1985). Predominance of plagioclase within these formations is attributed to plagioclase-enriched Pacific-circium batholiths (Dickinson, 1970). In this study elevated amounts of plagioclase occurred in the upper member of the Spencer Formation sandstone lithofacies. Plagioclase composition (oligoclase and andesine) from selected upper member sandstone samples indicated that the elevated plagioclase content was characteristic of a volcanic source.

Pittman (1970) believes that plagioclase feldspar composition is an essential indicator of provenance in sedimentary rocks. According to Dickinson (1970) "a majority of granitic rocks in the Circum-Pacific batholiths are plagioclase-rich varieties" and are commonly classified as granodiorites. Pettijohn and others (1972) also made reference to "plagioclase arkoses" citing the Paleocene Swauk Formation in Washington as an example, for which they believe the source was presumably a quartz diorite.

High percentages of amphibole (hornblende) and pyroxene (augite)

are also characteristic of the upper sandstone lithofacies.

Within the next section of this chapter entitled "Detrital Modes" Dickinson and Suczek, (1979) sandstone classification schemes (QFL, QmFLt, and QmPK ternary plots) emphasize provenance characteristics and were applied to Spencer Formation sandstone lithofacies.

Detrital modes

Detrital framework mineral grain parameter categories (Table VI) developed by Dickinson and Suczek (1979) are utilized in this study for constructing additional ternary compositional diagrams (Figures 11 to 14) which are used to define provenance. According to Dickinson and Suczek (1979) these ternary plots emphasize the following aspects of sedimentary rocks: Q-F-L, shows mineral grain stability (weathering, provenance and transport); Qm-F-Lt, shows mineral grain size of source rock; and Qm-P-K, shows the dominant monocrystalline grain types. Dickinson and Suczek (1979) believe that sandstone composition is directly related or influenced by provenance and modes of transportation which ultimately reflect on sandstone maturity. Based on samples collected worldwide from a variety of basinal environments, Dickinson and Suczek (1979) categorized three dominant provenance types: 1) Continental Block, 2) Recycled Orogen, and 3) Magmatic Arc (Figures 11a and 12a).

The QFL ternary diagram (Figure 11) emphasizes grain stability with relation to weathering, provenance relief, transportation mechanism and source rock (Dickinson and Suczek, 1979). Unlike Folk's (1974) classification, although the exact same framework grain components (only

TABLE VI

SPENCER FORMATION NORMALIZED POINT COUNT DATA UTILIZED FOR TERNARY DIAGRAMS

SAMPLE NAME	Q	F	L	Qm	F	Lt	Qm	Qp	L	Qm	P	K
LOWER MEMBER (INFORMAL)												
Western Tualatin Valley Area												
SP-1	48	45	7	44	49	7	74	14	12	48	34	19
SP-3	50	41	9	46	45	9	72	13	15	51	35	15
SP-5	45	47	8	38	53	9	65	20	15	42	39	19
SP-11	48	44	8	43	49	9	69	17	14	47	43	10
SP-65	43	48	9	36	54	10	63	20	17	40	43	16
SP-67	46	45	8	40	51	9	65	20	15	44	48	7
SP-69	36	49	15	30	53	16	54	16	29	36	48	15
Mormouth Area												
SP-12	43	54	3	40	57	3	83	11	6	42	39	20
SP-81	44	41	15	39	45	16	62	14	25	47	40	13
SP-87	43	45	11	40	48	12	68	11	21	45	33	22
Albany Area												
SP-60	36	49	14	31	53	16	56	15	29	37	54	9
SP-62	39	40	21	34	43	23	53	11	35	44	33	23
SP-90B	34	56	10	29	60	11	60	18	23	32	38	30
Spencer Formation Type Area												
SP-35	32	58	10	30	60	10	68	8	23	33	55	12
LOWER AVERAGE	42	47	11	37	51	12	65	15	20	42	42	17
DeShazer 13-22 Well Sidewall Cores												
ONG-1-2319	42	55	4	38	58	4	77	15	8	39	36	25
ONG-3-2311	42	53	5	38	57	5	76	13	11	40	40	20
ONG-5-2276	37	57	6	32	61	6	71	15	14	35	40	25
ONG-10-2259	42	50	8	37	54	9	69	15	16	41	32	27

TABLE VI
(CONTINUED)

SPENCER FORMATION NORMALIZED POINT COUNT DATA UTILIZED FOR TERNARY DIAGRAM

SAMPLE NAME	Q	F	L	Qm	F	Lt	Qm	Qp	L	Qm	P	K
UPPER MEMBER (INFORMAL)												
Western Tualatin Valley Area												
SP-8	51	45	4	48	47	5	83	9	8	50	34	16
SP-71	31	50	20	27	53	21	50	11	39	34	51	16
SP-74	40	42	18	36	45	20	57	11	31	45	41	14
SP-75A	30	56	14	26	59	15	55	14	31	30	45	24
Monmouth Area												
SP-14	31	53	17	27	56	18	53	11	35	32	42	25
SP-79	21	55	24	20	56	24	43	4	53	26	64	10
SP-83	39	48	14	35	50	14	65	9	26	41	46	13
SP-86	46	46	8	42	49	9	73	13	15	46	43	11
Albany Area												
SP-59	35	57	8	30	61	9	66	15	19	33	62	5
Corvallis Area												
SP-55	27	71	2	25	73	2	85	9	6	26	59	15
SP-57A	33	58	10	28	62	10	63	15	23	31	52	16
SP-58	27	67	7	22	71	7	64	16	20	24	69	7
SP-88	32	55	12	26	60	13	54	19	28	30	47	22
Spencer Formation Type Area												
SP-32	33	60	7	29	64	7	68	14	18	31	55	14
UPPER AVERAGE	34	54	12	30	57	12	63	12	25	34	51	15
DeShazer 13-22 Well Sidewall Cores												
ONG-12-2224	46	41	13	41	45	14	64	14	22	47	34	18
ONG-14-2220	36	54	11	30	58	12	58	18	24	34	37	30
ONG-17-2214	43	48	10	35	54	11	60	22	18	39	46	14

See TABLE V for explanation of grain category parameters.

NOTE: Computed values for some categories may have a 1 % error factor.

QFL diagram) were utilized, Dickinson and Suczek's, (1979)

classification is predominately used for recognition of provenance.

Nearly all the Spencer Formation samples plotted within the continental block provenance, with a few samples depicted between this and within the plutonic enriched portion of the magmatic arc provenance.

Notably, total feldspar content (F) is increased in those samples collected in the upper member.

The QmFLt ternary plot (Figure 12) emphasizes lithic content rather than stressing quartzose-type grains illustrated in the QFL ternary diagram (Figure 11). This ternary diagram (QmFLt) shows a shift of increased total feldspar (F) and lithic (Lt) content than noted in the QFL plot (Figure 11b). Oregon Natural Gas Development Company's DeShazer 13-22 well best illustrates this increased amount of lithic components (QmFLt plot) grading upwards into the Spencer Formation lithofacies typical of the upper member (Table VII).

Spencer Formation samples plotted in the QmFLt ternary diagram (Figure 12) plot within the same general area as in Figure 11 (QFL Plot) within the Continental Block provenance, in the plutonic rich portion of the Magmatic Arc provenance field.

The QmPK ternary diagram (Figure 12) emphasizes dominant monocrystalline framework mineral grain types; monocrystalline quartz (Qm), plagioclase (P), and potassium feldspar (K). Dickinson and Suczek (1979) utilize these grain parameters to illustrate increasing sandstone maturity or stability (Figure 13a). An emphasis on chemical and mechanical stability of sandstone samples (Hayes, 1979) was previously denoted in the QFL plot (Figure 10). Figure 13 also stresses the

Figure 11. a) Dickinson and Suzek's (1979) QFL ternary diagram utilized for sandstone classification emphasizing mineral grain stability, provenance and transport. b) Spencer Formation sandstone samples plotted.

Figure 12. a) Dickinson and Suzek's (1979) QmFLt ternary diagram utilized for sandstone classification emphasizing mineral grain stability. b) Spencer Formation sandstone samples plotted.

TABLE VII

LITHIC ROCK FRAGMENT CONTENT (QmFLt PLOT) DESHAZER
13-22 WELL SIDEWALL CORE SAMPLES

Sidewall Core Sample	Lithic Components (percent)
Lower Member	
ONG-1-2319	10
ONG-3-2311	11
ONG-5-2276	12
ONG-10-2259	16
Upper Member	
ONG-12-2224	21
ONG-14-2220	20
ONG-17-2214	21

importance between plutonic (continental block) and volcanic (magmatic arc) sources.

The QmPK plot (Figure 13b) denotes Spencer Formation samples predominately midway between the "Qm" and "P" poles. Those samples closest to the "P" pole are characteristic of the informal upper member which depict a decreasing ratio of plutonic/volcanic components. Spencer Formation samples plotting closest to the "Qm" pole are characteristic of increased maturity similar to "Clark and Wilson" type sands found within the lower portion of the Cowlitz Formation according to Bruer and others (1984) and Niem and others (1985).

The QmQpL ternary diagram (Figure 14) emphasizes those concepts noted in the QFL, QmFLt, and QmPK plots (Figures 10 to 13). The two most important concepts are: 1) DeShazer 13-22 side wall core samples show an increased amount of lithic rock fragments, predominately

Figure 13. a) Dickinson and Suzek's (1979) QmPK ternary diagram utilized for sandstone classification emphasizing the dominant monocrystalline grain types. b) Spencer Formation sandstone samples plotted.

volcanic, stratigraphically higher in the well, and 2) those samples characteristic of the lower member and lower in the DeShazer well are highest in monocrystalline quartz content and best correlate with "Clark and Wilson" type sands found within the lower Cowlitz Formation occurring stratigraphically above the Yamhill-Cowlitz unconformity outlined by Bruer and others (1984) correlation section.

Figure 14. Ternary QmQpL diagram of Spencer Formation samples emphasizing polycrystalline grains and lithic fragment content.

CHAPTER IV

SCANNING ELECTRON MICROSCOPY

Explanation of SEM Methods and Sample Preparation

The scanning electron microscope (SEM) and accompanying energy dispersive spectrometer (EDS) were utilized for five main objectives. Objectives were to: 1) utilize the SEM to complement petrography, 2) examine textural and morphological aspects of mineral grains, 3) determine elemental composition of selected mineral grains, 4) determine, if possible, detrital and diagenetic clay minerals, and 5) examine size, shape, and distribution of pore spaces.

Advantages the SEM has over conventional petrographic methods are; three-dimensional analysis of mineral grains and pores, higher magnification, ease of sample preparation, and greater depth of field and resolution (Welton, 1984). A detailed explanation of SEM and EDS systems and their functions are beyond the scope of this study. Wischnitzer (1981) outlines in detail the various parts of the SEM and their functions as well as the theory on how the SEM works. Welton (1984) summarizes how the SEM operates, how a photomicrograph is obtained and SEM analysis of elements. Whalley (1978) discusses how scanning electron microscopy is utilized in the study of sediments. Welton (1984) utilized the energy dispersive x-ray spectrometer (EDX), now referred to as the EDS. Samples were prepared by the method presented by Dash (personal communication, 1985). Sample

methodology mimics that outlined by Welton (1984).

Those twelve samples utilized for determination of plagioclase composition and heavy mineral assemblages were examined in the SEM. Samples were all sputter coated with a conductive gold-palladium mixture to obtain a clear image of the sandstone sample. Coating thickness is so thin, approximately 200 angstroms ($1\text{\AA} = 10^{-8}$ cm), that it does not impede or interfere with mineral identification. An accelerating voltage of 20,000 volts (20kv) with a ten millimeter working distance and a sample tilt of 45 degrees allowed for the best sample resolution and elemental-mineral identification.

Photomicrograph Interpretation

Sample magnification, located in the lower left-hand corner of the photomicrograph, is measured in thousands (ie., 0.33kx = magnified 330 times). Accelerating voltage (kv) and photo number are located in the lower right-hand portion of the photomicrograph. Magnification shown in the photomicrographs is discussed in microns ($1 \text{ micron} = 10^{-4}$ cm or 10^4 angstroms) per inch.

X-Ray Analysis of Minerals

Welton (1984, pp. 4-7) gives an excellent overview of SEM elemental analysis and identification of minerals utilizing x-ray analysis. Welton (1984) utilized the energy dispersive x-ray spectrometer (EDX) which is the same as the energy dispersive spectrometer (EDS) used in this study. Note that in the spectral analysis of minerals given in both the text and in Appendix B no major element with an atomic number

less than 11 (Na sodium) will yield a peak. An energy table depicting the elements and their characteristic x-ray transition states is illustrated by Welton (1984, p. 228-229).

Only minerals which were unique and showed good morphological form are utilized and discussed within this section. Additional elemental identification of mineral grains are covered within the section entitled "Mineral Morphology and Pore Relationships". The following four photomicrographs (Figures 15 to 18) exhibit excellent examples of authigenic and detrital minerals. A coordination system of letter (A-Q) and number (1-13) will be utilized for describing crystal and mineral grain locations within photomicrographs. The two most interesting minerals observed within these Spencer Formation sandstone lithofacies are authigenic euhedral crystals of heulandite (Figure 15) and potassium feldspar (Figure 16).

Euhedral crystals of authigenic heulandite (Figure 15, F7, K8 & M5) are rare. Sample ONG-12-2224 from the DeShazer 13-22 well sidewall cores was the only sample in which authigenic heulandite was noted. According to Welton (1984) "heulandite is similar in morphology to clinoptilolite, but typically contains less potassium." The spectrum of heulandite (Figure 15) does not show a potassium peak.

Euhedral authigenic crystals of potassium feldspar (Figure 16), often occurring as overgrowths, are common within the DeShazer 13-22 well sidewall core samples, but are less abundant in samples collected at the surface. The silicon to aluminum ratio of 3:1, pronounced potassium peak ($K\alpha_1 = 3.3$ keV) shown in the accompanying EDS spectral analysis, and crystal morphology are diagnostic of authigenic potassium feldspar (Welton, 1984, pp. 28-31).

a

A B C D E F G H I J K L M N O P Q

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13

b

X-RAY
Live: 100s
Real: 110s

100s Preset: 100s Remaining: 0s
9% Dead

< .000
FS= 2K
MEM1:

20.480 >
47 CTS

Figure 15. a) Photomicrograph showing euhedral authigenic crystals of heulandite (zeolite) in sample ONG-12-2224 (1 inch = 31 microns). b) Energy dispersive spectral analysis of heulandite.

a

A B C D E F G H I J K L M N O P Q

1 2 3 4 6 6 7 8 9 10 11 12 13

b

X-RAY
Live: 123s
Real: 19% Dead

100s Preset: 100s Remaining: 0s

Figure 16. a) Photomicrograph showing euhedral authigenic potassium feldspar (I8), pyrite framboid (N5) and wispy smectite in sample ONG-17-2214 (1 inch = 22 microns). b) Energy dispersive spectral analysis of authigenic potassium feldspar.

Within the same photomicrograph (Figure 16), depicting sample ONG-17-2214, a solitary round framboid of pyrite (N5) occurs as an aggregate of crystals. According to Welton (1984, p. 192) framboids of pyrite can occur as an isolated crystal or in lenses and are easily identified by their well-defined morphology in the SEM. Recognition of the pyrite framboid was done solely by morphology.

Figure's 17 and 18 show examples of amphibole (hornblende) and pyroxene (augite) after etching has occurred. It was difficult to distinguish between augite and hornblende by EDS spectral analysis because their chemical make up is very similar. Sodium and magnesium were deficient within the detrital grain (Figure 17) but a slight potassium peak ($K\alpha_1 = 3.3$ keV) is ascertainable, thus this etched grain is probably hornblende. The excellent spinose morphology is similar to that studied by Edelman and Doeglas (1932, p. 482-491).

In Figure 18 the EDS spectral analysis is more indicative of augite because of the absence of the $K\alpha_1$ (3.3 keV) potassium peak and a more pronounced ($K\alpha_1$ 3.7 keV) calcium peak. A good magnesium peak ($K\alpha = 1.3$ keV) is also present. Etching in this sample SP-57A occurs as slight degradation along grain boundaries and cleavage planes. Samples SP-57A (Corvallis area) and SP-74 (Western Tualatin Valley area) both from the upper member contain some of the highest percentages of etched amphibole and pyroxene of those samples petrographically analyzed for heavy mineral assemblages within the Spencer Formation sandstone lithofacies. Etching of amphibole and pyroxene was rare within the DeShazer 13-22 sidewall core samples.

a

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b

X-RAY
Live: 126s
Real: 100s Preset: 100s Remaining: 0s
21% Dead

Figure 17. a) Photomicrograph showing a detrital grain of hornblende which has been extensively etched in sample SP-74 (1 inch = 40 microns). b) Energy dispersive spectral analysis of etched hornblende grain.

a

A B C D E F G H I J K L M N O P Q

1 2 3 4 6 6 7 8 9 10 11 12 13

b

Figure 18. a) Photomicrograph showing a detrital grain of augite with some sign of etching in sample SP-57 (1 inch = 80 microns). b) Energy dispersive spectral analysis of etched augite grain.

Clay Mineral Relationships

The smectites are commonly referred to as the montmorillonite group of minerals, which includes montmorillonite, biedellite, nontronite, saponite and mixed-layer smectite-illite (Almon and Davies, 1981, p. 90). Smectite was the only clay-mineral observed with SEM-EDS analysis. According to Welton (1984, p.72) individual crystals of smectite can not be distinguished within the SEM. Smectite which has been expanded is usually crenulated or flaky (Welton, 1984, pp. 76-77). Figure 19 shows smectite clay from sample ONG-12-2224 coating a detrital grain exhibiting this flaky nature. Major elements characteristic of smectite, outlined by Welton (1984, pp. 72-83) are Si, Al, K, Ca, Mg and Fe. Elemental analysis of the sample in Figure 19 had peaks characteristic of all these elements except magnesium.

Smectite clays observed in the SEM and analytically x-rayed with the EDS characteristically form a flaky coating on grains and line pore cavities. The origin of the smectites depicted in this suite of Spencer Formation sandstone lithofacies is difficult to determine, but is believed to be predominately detrital.

In this study it was difficult to identify specific clay mineral species utilizing SEM-EDS techniques because 1) clays are often interlayered (mixed-layer) such as montmorillonite is commonly interlayered with illite or chlorite, and 2) clays commonly form very thin coatings and the x-ray beam often will pass through the clay mineral giving a bias or contaminated elemental analysis of underlying materials. Separating clays of the 2 micron fraction from these samples and utilizing x-ray diffraction techniques gave better results

a

A B C D E F G H I J K L M N O P Q

1 2 3 4 6 6 7 8 9 10 11 12 13

b

Figure 19. a) Photomicrograph showing authigenic smectite exhibiting a crenulated form in sample ONG-12-2224 (1 inch = 5 microns). b) Energy dispersive spectral analysis of smectite grain.

to determine clay-type.

Chlorite is likely to be present within these samples because of the elevated abundance of biotite within Spencer Formation sandstone lithofacies. As biotite alters to chlorite, potassium ions (K^+) are most easily removed from the crystal lattice, they become mobile and are lost (Carroll, 1981, p. 19). If chlorite is present in these samples analyzed with the SEM-EDS its identification is masked by the pronounced potassium peak ($K\alpha_1 = 3.3\text{keV}$) characteristic of biotite.

Mineral Morphology and Pore Relationships

Within the Spencer Formation sandstone lithofacies analyzed a variety of mineral-pore relationships were observed. Factors likely to influence pore space availability in the selected samples studied are 1) minerals present - authigenic versus detrital, especially clays, 2) extent of weathering, 3) compaction of sands and pore water composition during lithification, 4) cementing and matrix materials, and 5) textural makeup of the sandstone.

Four samples; SP-1 (lower member-western Tualatin Valley area), SP-57A, (upper member-Corvallis area), SP-81 (upper member-Monmouth area), and SP-87 (lower member-Monmouth area) from surface outcrops of Spencer Formation sandstone lithofacies represent different types of pore-mineral relationships. A series of four pairs of photomicrographs (Figures 15 to 18) magnified both 65 and 650 times were used to illustrate these parameters.

Sample SP-1 (Figure 20) is very friable in hand sample. The lack of clay minerals, cement and matrix material coating mineral grains or in

Figure 20. a) Sample SP-1 showing detrital mineral grains, quartz (C8), plagioclase (F3), quartz (J3) and potassium feldspar (M10). Note the lack of cement and authigenic minerals (1 inch = 400 microns). b) Magnification (1 inch = 39 microns) of SP-1 showing euhedral K-feldspar (F10), smectite (I10), stacking of K-feldspar rhombs (J3) and detrital potassium feldspar (B7).

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a

A B C D E F G H I J K L M N O P Q

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b

Figure 21. a) Sample SP-81 showing detrital mineral grains of glauconite (P8) and hornblende (H12). Note the abundance of sparry calcite cement reducing pore spaces (1 inch = 400 microns). b) Magnification (1 inch = 40 microns) of sample shows abundant smectite clay. Minerals identified are hallosite (I2) and biotite (F8 & J8).

pore spaces and the large spaces present between mineral grains seen in the photomicrographs (Figures 20a & 20b) account for the sample being friable. Magnification of the sample 650 times showed abundant potassium feldspar (predominately overgrowths) with some smectite coating mineral grains.

Detrital mineral grains are relatively easy to identify in sample SP-81 (Figure 21) but inter-grain pore spaces are dominately filled with a mixture of calcite cement and smectite. Between the grains and cementing agents some pore space is still recognizable (Figure 21a). Magnification (650x) of sample SP-81 (Figure 21b) shows the existence of abundant crenulated or flaky smectite. The needle or rod shaped crystals (Figure 21b, H2) exhibit the morphology of halloysite (Welton, 1984, p. 70).

Sample SP-57A (Figure 22) is a very fine-grained Spencer Formation sandstone typical of the upper member sandstone lithofacies. A combination of the fine-grained matrix material and calcite cement have significantly reduced pore space availability and made detection of mineral grains difficult (Figure 22a). Magnification of sample SP-57A (Figure 22b) 650 times shows abundant clay minerals present, dominantly smectite but illite (H9) and chlorite (N7) are also present. Abundant clay minerals found within this fine-grained sandstone sample have significantly reduced pore spaces.

No detrital mineral grains are readily visible in sample SP-87 (Figure 23) which is extensively cemented with crystalline calcite. In outcrop this sandstone is very resistant to weathering. Virtually no pore space is recognizable in the photomicrograph (Figure 23a) of sample

Figure 22. a) Sample SP-57A showing abundant clay mineral grains and some sparry calcite cement filling pore spaces (1 inch = 400 microns). Biotite (N6) and biotite altering to chlorite with abundant calcite cement (K7-K11 to P7-P11). b) Magnification (1 inch = 40 microns) of SP-57A showing illite (H9), iron oxides (L4), chlorite (N7) and smectite (C11).

Figure 23. a) Sample SP-87 showing abundant crystalline sparry calcite cement (1 inch = 400 microns). Sphene? (M3), sparry calcite cement (C6), degraded plagioclase (P9) and crystalline calcite (I4). b) Magnification (1 inch = 40 microns) of SP-87 showing bent biotite (G10), crystalline calcite (I7), plagioclase detrital grain (A1-A13 to D1-D13) and small anhedral crystals of calcite (A1).

SP-87. Crystalline calcite cement commonly exhibits concoidal fracturing (Figure 23a, D6). Magnification (650x) of the sample (SP-87) showed biotite (G10 & L4) being bent around a plagioclase detrital grain (A1-12 to D 1-12) with crystalline calcite cement (I7) protruding between biotite (001) cleavage planes. Some limited pore space is available between biotite cleavage planes but is likely filled with calcite cement away from the surface of the sample. Note that very little clay minerals, especially smectite, are present in this samples (SP-87, Figure 23b).

CHAPTER V

X-RAY DIFFRACTION ANALYSIS OF CLAY MINERALS

The twelve samples utilized previously for plagioclase composition, heavy mineral separates and SEM-EDS mineralogic studies are also utilized for determining clay mineral assemblages by x-ray diffraction. The clay size fraction was separated into the two micron and less size fractions and were mounted on ceramic tiles utilizing the methods described by Van Atta (personal communication, 1985).

Diffraction patterns of well orientated kaolinite show a strong $7\text{\AA}$ peak at $12.5^\circ 2\theta$. According to Carroll (1970, p. 8), samples containing unorientated or poorly crystalized kaolinite may show a series of peaks from 3.37 to 2.55 angstroms. Heating kaolinite to 550°C (meta kaolinite) should totally collapse the $7\text{\AA}$ peak (Carroll, 1970). It is possible that the furnace utilized to heat the samples may not have reached 550°C allowing for only partial collapse of the kaolinite. Carroll (1970) shows diffractograms of well crystallized and poorly crystallized kaolinite. Kaolinite from sample ONG-1-2319 shows the best crystalline form, when compared to the other two sample containing kaolinite, ONG-3-2311 and ONG-17-2214. The $7\text{\AA}$ peaks are less intense and broad in the later two samples. Kaolinite, with good $7\text{\AA}$ diffractogram peaks (001) is only present within subsurface DeShazer 13-22 sidewall core samples. According to Hower and others (1976) the $7\text{\AA}$ peak could be a combination of kaolinite and chlorite which commonly

form an intense $7\text{\AA}$ peak at approximately $12^\circ 2\theta$. Kaolinite was believed to be present because heating of the sample to 550°C showed a partial reduction in $7\text{\AA}$ peak height and intensity.

The X-ray diffraction patterns of illite, muscovite, and biotite are all very similar, making it difficult to distinguish these three minerals in diffractograms. According to Carroll (1970) muscovite and illite diffractogram patterns are extremely difficult to differentiate, except for muscovite which may show a more intense $10\text{\AA}$ peak than illite. The illite peak is commonly broad, covering an area from 6 to $9.5^\circ 2\theta$ with the $10\text{\AA}$ peak occurring at $8.5^\circ 2\theta$. Illite interlayered with smectite can be distinguished because peak position will shift as a result of the smectite swelling the clay inter-layer d-spacings after glycolation. Carroll (1970, p. 22) states that although biotite and muscovite have similar diffractogram patterns ($1.50\text{\AA}$ for muscovite versus $1.52\text{\AA}$ for biotite), the intensity of biotite peaks is reduced with an increase in iron content.

Illite commonly occurs within those samples having mixed-layer illite/smectite clays. Detection of illite was difficult because the representative $10\text{\AA}$ peak of illite was often combined with and obscured by second and third order illite/smectite peaks.

Chlorite is distinguished by a $14+\text{\AA}$ peak, which upon glycolation does not expand and after heating to 600°C for one hour the chlorite structure is destroyed and the peak disappears (Carroll, 1970, p. 33). Determination of chlorite in the diffractograms was hindered by the large, broad illite/smectite $14\text{\AA}$ peak. Chlorite ($14\text{\AA}$ peak) was most abundant in Spencer Formation lower member sandstone lithofacies

samples. Chlorite plus kaolinite was observed within the three lower samples (lower member) of the DeShazer 13-22 well. Reduction in $7\text{\AA}$ ($12^\circ 2\theta$) peak size and intensity after heating to 550°C allowed for the chlorite-kaolinite determination. Some mixed-layer illite/smectite clay was present within the two lower member samples (ONG-1-2319 and ONG-3-2311) of the DeShazer 13-22 well.

Carroll (1970, p. 27, Fig. 7) describes three observations which are characteristic of smectite clay diffractograms: 1) untreated or air dried smectite should have a first order (001) peak at approximately $15\text{\AA}$, 2) glycolating or applying DMSO to the sample should shift the dominant (001) $15\text{\AA}$ peak to $17\text{\AA}$ and show a smaller (002) second order peak at $8\text{\AA}$, and 3) upon heating, the large $17\text{\AA}$ peak is reduced significantly to a $9\text{\AA}$ peak. Diffractograms representative of ONG-23-2202 untreated, DMSO treated and heated (550°C) samples mimic those observations given by Carroll.

Weaver (1956) showed that illite/smectite clay minerals are "from the standpoint of diagenesis the most important mixed-layer clay minerals". According to Hower (1981) the best determination of mixed-layer illite/smectite clay diffractograms can be determined from ethylene glycol treated samples. Samples from this study were treated with dimethyl sulfoxide (DMSO), an organic solvent much like ethylene glycol. Dimethyl sulfoxide works faster and often provides better results than ethylene glycol. Srodon (1980) found that glycol-smectite treatment was often variable.

According to Hower (1981) "it is possible to recognize illite/smectite clay mineral interlayering schemes and estimate the

composition" by study and interpreting illite/smectite gylcolated diffractograms.

Mixed-layer illite/smectite clays are most abundant and are observed more often within surface samples collected from the upper member. Untreated and dimethol sulfoxide (DMSO) treated samples SP-60, ONG-12-2224, ONG-17-2214, and ONG-23-2202 from the Spencer Formation upper member sandstone lithofacies show excellent illite/smectite peaks. Samples ONG-17-2214 and ONG-23-2202 (upper member) probably contain less than 20 percent illite, because the diffractogram patterns show peaks which are more characteristic of smectite.

Clay minerals are most prevalent within the upper member of the Spencer Formation sandstone. These sandstone are commonly finer-grained than lower member sandstones and contain higer concentrations of chemically unstable minerals (plagioclase, hornblende and augite) and rock fragments (microlithic volcanics) which degrade into clay minerals assemblages. Smectite, mixed-layer illite/smectite and chlorite are most common within the upper member. Illite, biotite, and muscovite concentrations are difficult to compile because diffractogram patterns for these three minerals are virtually identical. The majority is probably mica. Complications with the temperature guage on the kiln utilized to heat samples may have caused only partial collaspe of kaolinite, allowing for the $7\text{\AA}$ peak to persist.

CHAPTER VI

DIAGENESIS

Diagenesis includes those physical and chemical processes which have influenced the mineralogical and textural aspects of Spencer Formation arkosic and lithic arkose sandstone lithofacies. Without the complementary scanning electron microscopy study, petrography would have only shown minimal diagenetic evidence. The SEM techniques proved extremely viable for denoting authigenic minerals and their relationships with pore spaces and detrital framework mineral grains.

The following diagenic observation were found through petrographic analysis within this present study. Etching of hornblende and augite was common within the upper member sandstone lithofacies. The only cementing agent commonly detected in thin section was sparry calcite. Mineral grains were commonly pushed apart by the growth of calcite cement in pore spaces. Feldspar grains showed noticable alteration or replacement with sericite and clay minerals around the periphery and less commonly along cleavage planes. The presence of clay minerals was only noted in thin section.

Clay minerals observed in the SEM are of two types 1) replacement and 2) authigenic. Authigenic clay (smectite) by far is more abundant and found coating both mineral grains and pore spaces.

Authigenic potassium feldspar is very abundant especially in DeShazer 13-22 sidewall core samples. Single euhedral crystals, rhombs

and stacking of rhombs are characteristic forms of authigenic potassium feldspar.

Authigenic heulandite was observed within the ONG-12-2224 sample. Heulandite occurs as euhedral crystals lining pore spaces.

Calcite was the most abundant cement in Spencer Formation upper member sandstone lithofacies. Scanning electron microscopy showed that calcite occurs as coarse sparry crystals filling pore spaces.

According to Hayes (1979) four factors which influence the degree of sandstone diagenesis are 1) preburial, 2) prediagenic tectonic setting, 3) provenance, and 4) deposition environment. Within this present study three important factors which most influenced diagenetic processes within the Spencer Formation sandstone lithofacies are 1) compaction, 2) pore and interstratified formational water composition, and 3) temperature. Decomposition of detrital mineral grains and rock fragments and formation of euhedral authigenic minerals and cementing agents rely on these criteria for development.

Hayes (1979) subdivides porosity reducing processes into three categories; 1) mechanical, 2) chemical, and 3) the combination of 1 & 2. Mechanical destruction involves compacting of the sandstone to reduce original porosity. Compaction was evident in thin section by the presence of muscovite and biotite flakes which have been bent or wrapped around adjacent detrital mineral grains. Chemical reduction of available pore space involves cementation, replacement and recrystallization of minerals. Petrologic studies showed evidence of four distinct diagenetic chemical processes within Spencer Formation sandstone lithofacies; 1) chemical etching of amphibole and pyroxene, 2)

cementation by calcite, 3) degradation or replacement of plagioclase and potassium feldspar, and 4) recrystallization of authigenic zeolites, potassium feldspar and clay minerals. Authigenic mineral identification would have been limited if not absent from this study without SEM-EDS analysis.

Scanning electron microscope studies of selected samples showed two very important diagenetic processes; 1) dissolution of silicate grains and 2) solution or formation of authigenic minerals. Stability of detrital minerals present will ultimately affect decomposition processes and formation of authigenic minerals

The best example of combination (mechanical-chemical) reduction of porosity within Spencer Formation sandstones is the degradation of biotite. Hayes (1979) indicates that biotite is very unstable chemically and may form hydrous clay minerals early in the sandstone diagenesis. The clays (chlorite) may expand slightly or become structurally weak allowing for further compaction and reduction of pore space.

According to Walker and Waugh (1973) minerals which have low stability, such as hornblende, augite and plagioclase in the Spencer Formation, will show degradation and advanced alteration, while more stable minerals, such as potassium feldspar or quartz, will exhibit little alteration. The presence of chemically etched hornblende and augite grains shows the effects of minerals which have low stability caused by weathering and water percolation.

Porosity can also be enhanced "secondary porosity" during sandstone diagenesis according to Schmidt and McDonald (1979) and Hayes (1979).

The dissolution of detrital grains and rock fragments as well as authigenic minerals and cementing agents could introduce the availability of secondary pore spaces. Table VIII is a modification after Hayes (1979, Table 2, p. 130), showing detrital grains and authigenic minerals within the Spencer Formation sandstones which may be dissolved by aqueous solutions to produce solution pores.

TABLE VIII

CONSTITUENTS DISSOLVED TO PRODUCE SOLUTION PORES
WITHIN SPENCER FORMATION SANDSTONES*

Detrital	Authigenic
Feldspar (mainly plagioclase)	Void-filling cement
Biotite	Calcite
Amphibole (mainly hornblende)	Smectite
Pyroxene (mainly augite)	Chlorite
Other heavy minerals	Zeolites
Chert (small percentage)	Replacement minerals
Fine-grained volcanic	Calcite
rock fragments	Mixed-layer clays
	Chlorites
	Zeolites

*After Hayes, 1979.

Of the three criteria previously mentioned, percolating and interformational water composition, is probably the most important diagenetic parameter which influences degradation of detrital mineral grains and rock fragments and precipitation of authigenic minerals. According to Hayes (1979) the majority of available water during diagenesis is from the dewatering of shales and mudstones. Frank (1973, 1974, and 1976) and Gonthier (1983) discuss Spencer Formation water composition. Analysis from some water wells which have penetrated

Spencer Formation sandstones show high concentrations of Ca, Mg, N, K, HCO_3 , CO_3 , SO_4 , Cl and F (Frank, 1976 and Gonthier 1983). The presence of high concentrations of dissolved solids within the Spencer Formation indicate that active replacement and recrystallization of authigenic minerals may be occurring presently.

The paragenetic sequence of authigenic mineralization may vary greatly geographically and stratigraphically. The original sandstone composition and diagenetic processes within the Spencer Formation aided most in the formation of authigenic mineralization.

Clay mineral development probably occurred during compaction and within the early stages of diagenesis. Formation of chlorite is probably associated with the breakdown of biotite. Smectite, illite and mixed-layer illite/smectite may have formed from the degradation of volcanic rock fragments and recrystallization of detrital clay minerals.

Chemical breakdown of feldspars (mainly plagioclase), amphibole (hornblende), pyroxene (augite), and other heavy minerals occurred next. Dissolution of these mineral grains allowed free cations (mainly Ca^{++} , K^+ , Na^+ , and Fe^{++}) to become incorporated with pore space aqueous solutions. Dissolved solids accumulated to the point of saturation, when authigenic potassium feldspar, zeolites and additional clay minerals were precipitated. The presence of iron oxides and iron hydroxides allowed for the formation of pyrite framboids. Emplacement of calcite cement may have occurred during the latter stages of diagenesis. Very few authigenic minerals have recrystallized on calcite showing evidence that it was probably one of the last minerals to crystallize.

Paragenetic diagenetic and mineralization sequences listed above are much more noticeable within the upper member. Obviously these sandstones contain more plagioclase feldspar, hornblende, augite and other heavy mineral detrital grain constituents which are more susceptible to chemical breakdown.

CHAPTER VII

GEOCHEMISTRY

Thirty-seven fine- to medium-grained Spencer Formation sandstone samples, including nine sidewall core samples from the Oregon Natural Gas Development Company's DeShazer 13-22 well, were analyzed for both major oxide elements and rare earth elements. Peter H. Hooper of Washington State University did the analysis utilizing two separate methods. X-ray fluorescence spectrometry (XRF) was utilized for determining major oxide element concentrations. Inductively coupled plasma emission spectrometry (ICP) was utilized for the analysis of Yttrium and a full suite of the lanthanide series elements, commonly referred to as rare earth element (REE) series. Yttrium is commonly included within the REE group because of geochemical similarities.

No previous geochemical data concerning major oxide and rare earth element concentrations exists for the Spencer Formation. Characterization of the Spencer Formation geochemistry is, therefore, initially important. Secondly, geochemical trend data was complimented with petrography work to help illustrate possible changes in provenance area of the arkosic and lithic sandstone lithofacies within the Spencer Formation. Kadri and others (1983) utilized instrumental neutron activation analysis (INAA) techniques to analyze samples from the Cowlitz, Keasey, Pittsburg Bluff and Astoria Formations as well as samples from the Columbia River Basalt Group in northwestern Oregon to

characterize minor element composition and to identify their provenances.

Major oxide and rare earth elements analyzed for this study are listed in Table IX.

TABLE IX
ELEMENTS ANALYZED FOR IN SPENCER FORMATION SAMPLES

<u>Major Oxide Elements</u>		<u>Rare Earth Elements (REE)</u>	
Silicon(Si)	Calcium(Ca)	Yttrium(Y)*	Gadolinium(Gd)
Aluminum(Al)	Magnesium(M)	Lanthanum(La)	Dysprosium(Dy)
Titanium(Ti)	Potassium(K)	Cerium(Ce)	Holmium(Ho)
Iron(Fe)	Sodium(Na)	Praseodymium(Pr)	Erbium(Er)
Manganese(Mn)	Phosphorus(P)	Neodymium(Nd)	Ytterbium(Yb)
		Samarium(Sm)	Lutetium(Lu)
		Europium(Eu)	

*Yttrium is not a REE, but has similar geochemical properties.

X-ray Fluorescence (XRF) Analysis

Major Oxide Geochemistry

Major oxides represent the overall bulk chemical composition of the Spencer Formation sandstones. Table X shows major oxide element concentrations for the Spencer Formation samples analyzed. Samples starting with "SP" are surface samples while those labeled with prefix "ONG" are sidewall core samples from the DeShazer 13-22 well.

Provenance and relief of the source area, physical sorting, type and extent of weathering, transportation, and diagenesis are some of the factors effecting chemical composition of sandstones (Pettijohn, 1963; Bhatia, 1978). Grain size also influences sandstone mineral composition. According to Pettijohn (1963), silica content generally

TABLE X

MAJOR OXIDE CHEMICAL ANALYSIS OF SPENCER FORMATION SAMPLES

SAMPLE NAME	SiO2	Al2O3	TiO2	Fe2O3	FeO	MnO	CaO	MgO	K2O	Na2O	P2O5
LOWER MEMBER (INFORMAL)											
Western Tualatin Valley Area											
SP-1	79.51	12.12	0.31	0.83	0.95	0.02	1.51	0.26	2.45	1.97	0.091
SP-3	78.56	12.94	0.30	0.87	0.99	0.01	1.17	0.21	2.82	2.08	0.052
SP-5	78.48	14.92	0.29	0.68	0.78	0.00	0.60	0.00	2.90	1.33	0.026
SP-11	78.47	13.12	0.49	0.95	1.09	0.02	1.43	0.20	2.35	1.84	0.042
SP-65	70.29	16.89	0.87	2.04	2.33	0.04	1.18	1.14	3.43	1.75	0.038
SP-67	71.68	15.37	0.61	2.32	2.66	0.04	1.14	1.06	3.24	1.79	0.078
SP-69	76.81	13.76	0.39	1.06	1.21	0.03	1.27	0.45	2.98	1.99	0.043
Monmouth Area											
SP-12	76.95	15.15	0.61	0.58	0.66	0.00	1.21	0.10	2.72	1.99	0.032
SP-81	76.67	14.76	0.63	1.36	1.56	0.02	0.82	0.31	2.40	1.41	0.059
SP-87	59.65	11.06	0.36	1.04	1.19	0.24	18.59	2.59	2.06	3.06	0.151
Albany Area											
SP-60	58.94	16.00	1.57	5.28	6.04	0.12	5.98	2.98	1.12	1.75	0.219
SP-62	79.40	14.99	0.45	0.51	0.59	0.00	0.63	0.00	2.30	1.11	0.037
SP-90B	79.06	12.97	0.30	0.62	0.71	0.01	1.38	0.08	2.64	2.17	0.042
Spencer Formation Type Area											
SP-35	69.65	15.28	0.48	1.96	2.24	0.06	3.14	1.93	2.43	2.76	0.090
LOWER AVERAGE	73.87	14.24	0.55	1.44	1.64	0.04	2.86	0.81	2.56	1.93	0.071
DeShazer 13-22 Well Sidewall Cores											
ONG-1-2319	73.25	14.27	0.53	1.85	2.12	0.04	1.59	0.97	3.26	2.05	0.082
ONG-3-2311	72.84	14.29	0.57	2.13	2.44	0.03	1.52	0.95	3.13	2.02	0.080
ONG-5-2276	73.66	14.52	0.53	1.76	2.01	0.03	1.58	0.74	2.98	2.11	0.077
ONG-8-2266	68.73	18.74	1.07	2.88	3.30	0.06	1.42	0.60	1.81	1.30	0.096
ONG-10-2259	77.75	13.01	0.28	0.72	0.82	0.01	1.33	0.32	3.42	2.27	0.062
UPPER MEMBER (INFORMAL)											
Western Tualatin Valley Area											
SP-8	67.38	17.94	0.94	3.31	3.80	0.09	0.96	1.57	2.66	1.26	0.086
SP-71	71.31	17.27	0.99	2.49	2.85	0.02	0.89	0.56	2.46	1.09	0.077
SP-74	71.40	14.89	0.78	3.17	3.63	0.02	1.21	0.55	2.64	1.62	0.120
SP-75A	70.27	15.02	0.70	4.37	5.00	0.03	0.76	0.54	2.01	1.17	0.122
Monmouth Area											
SP-14	70.94	21.20	2.16	1.85	2.12	0.04	0.11	0.00	1.50	0.07	0.019
SP-79	69.52	20.27	1.02	2.11	2.42	0.03	0.34	0.82	2.94	0.47	0.060
SP-83	76.60	13.89	0.61	1.60	1.84	0.04	0.64	0.46	2.84	1.40	0.072
SP-86	65.18	16.15	1.07	4.95	5.67	0.02	2.12	1.22	1.80	1.65	0.177
Albany Area											
SP-59	65.82	14.74	1.10	3.87	4.43	0.09	4.22	2.23	1.48	1.86	0.150
Corvallis Area											
SP-55	69.65	15.90	0.76	2.42	2.77	0.05	2.61	1.12	2.62	2.25	0.163
SP-57A	63.54	14.31	1.25	4.79	5.48	0.10	3.86	2.88	1.82	1.80	0.166
SP-58	69.28	14.72	0.74	2.43	2.78	0.05	3.83	1.79	2.35	1.89	0.135
SP-88	69.79	15.63	0.68	2.53	2.90	0.06	2.39	1.37	2.30	2.14	0.213
Spencer Formation Type Area											
SP-32	74.92	14.47	0.54	2.04	2.34	0.02	1.00	0.46	2.63	1.49	0.083
UPPER AVERAGE	69.69	16.17	0.95	3.00	3.43	0.05	1.78	1.11	2.29	1.44	0.117
DeShazer 13-22 Well Sidewall Cores											
ONG-12-2224	72.28	14.50	0.56	1.92	2.20	0.03	2.24	0.84	3.25	2.11	0.085
ONG-14-2220	72.23	14.37	0.53	1.86	2.13	0.02	2.58	0.94	3.04	2.19	0.108
ONG-17-2214	71.49	14.47	0.61	2.24	2.57	0.03	2.34	1.20	2.83	2.13	0.084
ONG-23-2202	69.94	15.38	0.74	3.13	3.59	0.05	2.75	1.90	0.54	1.88	0.106

All values are in percent.

decreases as grain size diminishes, while alumina and K_2O content usually increases. Samples SP-8 and SP-79 are very fine-grained sandstones, and noticeably have lower SiO_2 content and higher concentrations of Al_2O_3 and K_2O . Amount and type of cementing agents will also alter sandstone bulk chemical composition. For example, SP-87 contains abundant calcite cement, CaO content exceeds 18 percent thus affecting the overall silica content, even though the sandstone is medium-grained and has a high quartz content. Middleton (1960) contends that since the principal cementing agents are usually silica (SiO_2) and carbonates (Ca and Mg) geochemical analysis values may be erroneous and valueless. A majority of the samples selected for geochemical analysis contain little if any cement. Therefore, erroneous chemical compositional effects caused by interstitial cementing agents should be minimal. It is very important when studying major oxide composition of sandstone that the data is complemented with detailed petrographic analysis.

Gandera (1977), Al-Azzaby (1980), as well as this study have documented that Spencer Formation sandstone lithofacies are predominately arkose and lithic arkose (Folk's classification, 1974). Lithic fragments and plagioclase content become more prevalent to the south and within the informally named Spencer Formation upper member (Gandera; 1977, and this study). Generally Spencer Formation arkoses contain 35 percent or more feldspars, of which plagioclase is dominant. Geochemical analysis of the major oxide elements SiO_2 , Al_2O_3 and K_2O in arkosic sandstones have average values of 70-85%, 7-14% and 3-6% respectively (Pettijohn, 1963). The average values for silica (72%)

alumina (15%) and K_2O (2.5%) for this study (Table X) vary slightly from Pettijohn's criteria. Total iron content ($FeO + Fe_2O_3$) is commonly lower for feldspar-rich sandstones. Sandstone samples analyzed in this study average five percent total iron (both ferric and ferrous). Escalated total iron content in the sandstone samples could be related to the high biotite to muscovite ratio, approximately 3:1, and the influx of mafic lithic rock fragments located stratigraphically in the upper Spencer Formation sandstone lithofacies. Generally arkoses contain little if any calcium and magnesium except for those sandstones cemented with carbonates (SP-35, SP-55, SP-57A, SP-58, SP-59, SP-60, SP-86 & SP-87). Calcium content averages about one percent except for those samples cemented with calcite. Potassium (K_2O) usually exceeds sodium (Na_2O) in arkoses (Pettijohn, 1963). Because of the dominance of plagioclase feldspar (albite) over potassium feldspar (predominately microcline and lesser amounts of orthoclase) in the Spencer Formation sandstones analyzed, K_2O/Na_2O ratios are close to 1/1. Titanium (TiO_2) content usually increases as grain size decreases and is commonly found in conjunction with alumina (Al_2O_3), Pettijohn (1963). Samples analyzed in this study which had elevated TiO_2 content have higher percentages of Al_2O_3 . Average TiO_2 content in Spencer Formation sandstones was 0.7 percent. Manganese (MnO) and phosphorus (P_2O_5) are generally minor constituents of sandstones. Average values of 0.04 and 0.09 percent, respectively were obtained for the Spencer Formation sandstones analyzed.

Two plots (Figures 24 & 25) of silica SiO_2 versus aluminum (Al_2O_3) and K_2O versus Na_2O , were constructed to visually illustrate sample variances. Samples are noted with a "+" symbol lower member and "x" for

upper member surface outcrop samples or with "*" for DeShazer 13-22 well sidewall core samples.

Figure 24 shows two groupings, 1) those samples with higher concentrations of silica (70+ percent) and aluminum deficient (less than 15 percent) and 2) samples deficient in silica (less than 70 percent) and elevated amounts of aluminum (greater than 15 percent). The sample grouping with higher concentrations of silica are characteristic of lower member (informal) lithofacies and those sidewall cores from lower in the DeShazer 13-22 well. Higher concentrations of alumina are associated with very fine-grained sandstones including those with elevated plagioclase and volcanic lithic content, which are characteristic of the upper member (informal) and southern lithofacies.

Figure 25 illustrates K_2O versus Na_2O content. A majority of the samples plot within two groupings. Samples plotting in the upper right-hand quadrant of Figure 25 have elevated concentrations of both K and Na. These samples are typically enriched with potassium feldspar and are characteristic of the Spencer Formation lower member (informal) lithofacies.

Attempts have been made to correlate the composition of sandstone to provenance and related plate tectonic topics (Middleton, 1963; Dickinson, 1970; Pettijohn, 1963; Schwab, 1975; Van de Kamp, 1976; Dickinson and Suczek, 1979 and Bhatia, 1981). Recent work by Van de Kamp (1976) and Bhatia (1981) emphasize sandstone composition utilizing major oxide element geochemistry to determine plate tectonic settings.

SPENCER FORMATION SANDSTONE

Figure 24. Major oxide cross plot diagram of silica (SiO_2) versus alumina (Al_2O_3) content in the Spencer Formation sandstones analyzed. Informal upper and lower member grouping area shown.

SPENCER FORMATION SANDSTONE

Figure 25. Major oxide cross plot diagram of K₂O (potassium) versus Na₂O (sodium) content in the Spencer Formation sandstones analyzed. Informal upper and lower member grouping area shown.

Inductively Coupled Plasma (ICP) Analysis

Rare Earth Element Geochemistry

Rare earth element concentrations in Spencer Formation sandstone lithofacies analyzed are listed in Table XI. All REE values are in parts per million (ppm).

According to Balashov and others (1964) and Fleet (1984), most REE's in sandstones are concentrated in the clay fraction and to a lesser extent, heavy mineral assemblages. The fact that shales usually have higher concentrations of REE's signifies that the clay size fraction favors an enrichment of lanthanide type elements. Overall RE concentrations in sediments and sedimentary rocks (shales and sandstone) generally have similar REE patterns. Major contributions to the study of rare earth elements in sediments and sedimentary rocks are credited to: Haskin & Gehl, 1962; Balashov and others, 1964; Wilderman & Haskin, 1965; Haskin and others, 1966; and Ronov and others, 1967. Rare earth element sources and concentrations in seawater and marine sediments is discussed by Piper (1974). Fleet (1984) emphasizes weathering, contents in sediments and sedimentary rocks, and diagenetic effects on REE's. Table XII shows average concentrations (ppm) of REE's in sediments, principally sandstones, according to Balashov and others (1964), Haskin and others (1966), Ronov and others (1967) and Kay (1972). Table XII also includes REE concentrations found by Kadri (1982) within the Cowlitz Formation and the average concentration of REE's within the Spencer Formation sandstones analyzed in this present study.

TABLE XI

RARE EARTH ELEMENT CONCENTRATIONS OF ANALYZED SPENCER FORMATION SANDSTONE SAMPLES

SAMPLE NAME	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu	Y
LOWER MEMBER (INFORMAL)													
Western Tualatin Valley Area													
SP-1	13.12	26.71	3.28	13.28	2.66	0.72	2.24	1.99	0.42	1.32	1.22	0.20	10.20
SP-3	13.64	26.98	3.33	13.38	2.74	0.79	2.35	2.09	0.45	1.39	1.37	0.22	10.80
SP-5	9.14	17.41	2.20	8.77	1.77	0.52	1.49	1.40	0.32	0.99	0.99	0.17	7.60
SP-11	18.92	31.34	4.45	17.96	3.60	0.98	3.15	2.72	0.58	1.74	1.65	0.26	14.30
SP-65	30.37	60.41	7.63	31.01	6.37	1.58	5.39	4.43	0.86	2.52	2.26	0.34	19.40
SP-67	20.35	38.05	4.29	16.63	3.18	0.80	2.65	2.34	0.49	1.54	1.48	0.24	12.40
SP-69	16.84	32.65	3.94	15.08	2.86	0.77	2.39	2.02	0.46	1.39	1.31	0.21	10.90
Monmouth Area													
SP-12	26.89	43.64	6.09	24.44	4.68	1.07	3.94	3.27	0.67	2.17	1.94	0.31	17.30
SP-81	32.60	58.97	8.06	34.40	6.22	1.55	5.47	4.65	0.89	2.85	2.40	0.36	24.10
SP-87	13.18	24.74	2.91	11.77	2.24	0.59	1.89	1.76	0.37	1.24	1.11	0.18	10.30
Albany Area													
SP-60	15.72	33.86	4.44	19.19	4.80	1.53	5.03	4.57	0.93	2.76	2.51	0.39	26.30
SP-62	21.07	30.12	5.92	24.77	5.28	1.33	4.31	3.53	0.68	2.05	1.84	0.29	15.90
SP-90B	14.30	23.02	3.23	12.16	2.11	0.66	1.71	1.62	0.40	1.17	1.13	0.18	8.30
Spencer Formation Type Area													
SP-35	16.09	31.49	3.76	14.93	3.03	0.88	2.64	2.24	0.48	1.48	1.39	0.22	12.00
LOWER AVERAGE	18.73	34.24	4.54	18.41	3.68	0.98	3.19	2.76	0.57	1.76	1.61	0.26	14.3
DeShazer 13-22 Well Sidewall Cores													
ONG-1-2319	16.57	32.70	4.03	16.50	3.12	0.86	2.67	2.39	0.49	1.58	1.49	0.23	12.00
ONG-3-2311	17.93	35.38	4.32	17.68	3.45	0.92	3.00	2.67	0.54	1.81	1.61	0.24	13.70
ONG-5-2276	16.61	33.64	4.13	16.57	3.18	0.89	2.86	2.66	0.57	1.80	1.74	0.27	13.90
ONG-8-2266	16.32	32.31	4.14	16.04	3.01	0.84	2.65	2.34	0.50	1.75	1.51	0.23	11.80
ONG-10-2259	10.74	20.66	2.65	10.99	2.06	0.65	1.74	1.54	0.33	1.07	0.99	0.17	7.80
UPPER MEMBER (INFORMAL)													
Western Tualatin Valley Area													
SP-8	40.10	63.95	9.62	40.65	8.56	2.08	7.96	6.90	1.37	4.07	3.72	0.55	36.10
SP-71	34.80	67.16	7.51	30.14	5.59	1.14	4.56	3.62	0.72	2.42	2.22	0.35	19.50
SP-74	40.34	81.45	8.78	34.71	6.40	1.03	5.03	3.87	0.78	2.56	2.39	0.38	20.30
SP-75A	25.57	52.50	5.70	22.83	4.37	0.87	3.74	3.23	0.66	2.22	2.16	0.36	18.00
Monmouth Area													
SP-14	22.90	50.43	5.78	24.81	5.71	1.64	5.51	5.17	1.02	3.20	3.18	0.50	27.00
SP-79	39.75	74.23	9.11	38.16	6.64	1.46	5.49	4.62	0.94	3.08	2.79	0.42	26.30
SP-83	29.75	63.57	7.20	29.35	5.36	1.13	4.41	3.86	0.78	2.49	2.26	0.35	19.60
SP-86	32.66	82.68	7.87	32.61	6.62	1.65	6.42	5.90	1.17	3.60	3.10	0.46	35.20
Albany Area													
SP-59	30.54	56.70	7.06	29.62	6.25	1.58	5.96	5.11	1.03	3.14	2.87	0.45	28.80
Corvallis Area													
SP-55	34.39	63.92	7.50	30.37	6.05	1.37	5.42	4.78	0.96	3.02	2.80	0.44	26.80
SP-57A	42.38	86.86	9.42	38.78	8.01	1.72	7.00	5.84	1.13	3.56	3.40	0.52	29.80
SP-58	29.14	53.99	6.37	25.28	5.03	1.15	4.46	3.94	0.82	2.58	2.49	0.38	22.90
SP-88	34.02	70.87	7.95	31.90	5.80	1.49	4.78	3.87	0.78	2.41	2.05	0.32	18.80
Spencer Formation Type Area													
SP-32	43.82	68.76	9.71	40.64	7.20	1.49	5.34	3.90	0.76	2.51	2.09	0.32	20.20
UPPER AVERAGE	34.30	66.95	7.83	32.13	6.26	1.41	5.43	4.62	0.92	2.92	2.68	0.41	24.95
DeShazer 13-22 Well Sidewall Cores													
ONG-12-2224	14.70	28.65	3.74	14.81	2.93	0.92	2.58	2.27	0.49	1.51	1.36	0.21	11.00
ONG-14-2220	13.72	26.67	3.58	13.97	2.79	0.89	2.52	2.34	0.53	1.56	1.48	0.24	12.40
ONG-17-2214	15.55	30.81	4.20	16.24	3.19	0.95	2.84	2.45	0.53	1.91	1.52	0.23	11.90
ONG-23-2202	20.69	46.42	5.81	25.24	6.02	1.19	6.24	6.44	1.31	4.09	4.15	0.62	35.90
KC11*	23.84	50.59	6.23	26.84	5.35	1.53	5.06	4.73	0.92	2.84	2.43	0.36	23.5

All values are in ppm
 *KC11 is the standard

To determine if any of the Spencer Formation samples collected have any patterns of enrichment or depletion in rare-earth element values, graphs of chondrite-normalized values (Spencer Formation/chondrite) versus element (atomic number) were plotted (Figures 26 to 28). Recalculated chondrite-normalized values for the REE's are listed in Table XIII. Chondrite normalized ratios are plotted on three cycle logarithmic scale versus increasing atomic number. The atomic numbers increase intermittently from 51 for La through 76 for Lu. The reason chondrite normalized REE concentrations are utilized is to standardize the values to see if, 1) REE concentrations indicate whether or not the samples analyzed have typical sedimentary REE contents and, 2) to identify enrichments and/or depletions in a single REE or groups of REE's (Fleet, 1984).

By analyzing the Spencer Formation/chondrite versus element graphs (Figures 26 to 28) and finding fluctuations in the slope of the line, between individual REE's and groups of REE's, offers the best evidence for fluctuations in sample composition trends and groupings. The principal purpose in looking for slope fluctuations is to isolate rare-earth elements which may be utilized in cross-plots to show relationships or variencies between individual Spencer Formation samples. The greatest variety of slope occurred between europium (Eu) and gadolinium (Gd). Two rare earth element patterns are observed in the Spencer Formation/Chondrite graphs; those samples enriched in Eu, while the others depleted in Eu. Samples depleted (negative slope) in europium are commonly enriched in the other REE's.

TABLE XII

AVERAGE CONCENTRATIONS (PPM) OF REE'S IN SEDIMENTS AND SANDSTONE

AUTHOR'S NAME	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu	Y
Balashov, et al., 1964 (A)	36.00	69.00	9.70	34.00	7.50	-	7.10	5.20	-	4.00	3.70	-	45.00
Haskin, et al., 1966 (B)	2.50	-	0.56	2.30	-	0.09	0.43	-	0.05	0.20	0.28	0.03	1.80
Haskin, et al., 1966 (C)	9.50	14.50	3.30	17.00	2.00	0.72	2.50	-	0.62	2.00	1.10	-	13.00
Haskin, et al., 1966 (D)	22.00	33.00	6.20	-	4.80	-	4.60	-	0.89	-	-	-	20.00
Haskin, et al., 1966 (E)	26.00	35.00	6.20	24.00	4.70	1.00	4.70	-	0.54	1.30	1.63	0.24	13.00
Haskin, et al., 1966 (F)	10.50	-	2.40	10.60	1.60	0.55	1.50	-	0.25	0.77	0.64	-	9.60
Haskin, et al., 1966 (G)	74.00	206.00	25.00	71.00	17.00	3.50	10.20	-	2.20	4.70	-	-	41.00
Ronov, et al., 1967 (H)	17.00	33.00	4.00	16.50	3.70	0.70	3.10	2.60	-	1.60	1.20	-	15.00
Kay, 1972 (I)	39.00	75.00	10.00	37.00	7.00	2.00	6.10	6.00	1.40	4.00	3.40	0.60	-
Kadri, 1982 (J)	42.80	-	-	-	8.75	-	-	-	-	-	1.23	0.00	-
This Study (K)	23.92	46.05	5.67	23.13	4.56	1.13	4.00	3.47	0.71	2.23	2.05	0.32	18.36

(A) Russian platform sand samples (40 samples).

(B) St. Peter Sandstone, Belleville, Wisconsin (Ordovician).

(C) Portlandian, Kimball Creek, Oregon (Jurassic).

(D) Cape Blanco Sandstone, Cape Blanco, Oregon (Jurassic or Cretaceous).

(E) Sebastian Sandstone, Cape Sebastian, Oregon (Cretaceous).

(F) Kettleman Hills, California (Tertiary).

(G) Glauconite-bearing sandstone (origin unknown).

(H) Russian platform sandstone samples (6,051 samples).

(I) Average ppm in Sediments, includes shales, sandstones & carbonates.

(J) Cowlitz Formation Sandstone, NW Oregon (Eocene) (5 samples).

(K) Spencer Formation Sandstone, Willamette Valley, Oregon (Eocene) (37 samples).

TABLE XIII

CHONDRITE NORMALIZED RARE EARTH ELEMENT CONCENTRATIONS OF ANALYZED SPENCER FORMATION SAMPLES

SAMPLE NAME	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Er	Yb	Lu	Y
LOWER MEMBER (INFORMAL)													
Western Tualatin Valley Area													
SP-1	39.7	30.9	26.9	21.1	13.1	9.4	8.2	5.8	5.6	5.9	5.5	5.8	-
SP-3	41.3	31.2	27.3	21.2	13.5	10.2	8.6	6.1	5.9	6.2	6.2	6.6	-
SP-5	27.7	20.1	18.0	13.9	8.7	6.7	5.4	4.1	4.2	4.4	4.5	4.9	-
SP-11	57.3	36.2	36.5	28.5	17.7	12.7	11.5	8.0	7.6	7.7	7.5	7.7	-
SP-65	92.0	69.8	62.6	49.2	31.4	20.6	19.6	13.0	11.3	11.2	10.3	10.1	-
SP-67	61.7	44.0	35.1	26.4	15.7	10.3	9.6	6.8	6.5	6.9	6.7	7.1	-
SP-69	51.0	37.7	32.3	23.9	14.1	10.0	8.7	5.9	6.1	6.2	6.0	6.2	-
Monmouth Area													
SP-12	81.5	50.5	49.9	38.8	23.0	13.9	14.3	9.6	8.9	9.6	8.8	9.1	-
SP-81	98.8	68.2	66.0	54.6	30.6	20.1	19.9	13.6	11.8	12.7	10.9	10.6	-
SP-87	39.9	28.6	23.8	18.7	11.0	7.7	6.9	5.2	4.8	5.5	5.1	5.3	-
Albany Area													
SP-60	47.6	39.1	36.4	30.5	23.7	19.8	18.3	13.4	12.3	12.3	11.4	11.5	-
SP-62	63.8	34.8	48.5	39.3	26.0	17.3	15.7	10.3	8.9	9.1	8.4	8.4	-
SP-90B	43.3	26.6	26.5	19.3	10.4	8.6	6.2	4.7	5.2	5.2	5.1	5.4	-
Spencer Formation Type Area													
SP-35	48.7	36.4	30.8	23.7	14.9	11.5	9.6	6.6	6.3	6.6	6.3	6.5	-
LOWER AVERAGE	56.7	39.6	37.2	29.2	18.1	12.8	11.6	8.1	7.5	7.8	7.3	7.5	-
DeShazer 13-22 Well Sidewall Cores													
ONG-1-2319	50.2	37.8	33.0	26.2	15.4	11.1	9.7	7.0	6.4	7.0	6.8	6.9	-
ONG-3-2311	54.3	40.9	35.4	28.1	17.0	11.9	10.9	7.8	7.1	8.0	7.3	7.1	-
ONG-5-2276	50.3	38.9	33.9	26.3	15.7	11.5	10.4	7.8	7.5	8.0	7.9	8.0	-
ONG-8-2266	49.4	37.4	33.9	25.5	14.8	10.9	9.7	6.8	6.6	7.8	6.9	6.8	-
ONG-10-2259	32.5	23.9	21.7	17.4	10.1	8.5	6.3	4.5	4.3	4.3	4.5	4.9	-
UPPER MEMBER (INFORMAL)													
Western Tualatin Valley Area													
SP-8	121.5	73.9	78.9	64.5	42.2	27.0	28.9	20.2	18.1	18.1	16.9	16.1	-
SP-71	105.5	77.6	61.5	47.8	27.6	14.8	16.6	10.6	9.5	10.7	10.1	10.4	-
SP-74	122.2	94.2	71.9	55.1	31.5	13.4	18.3	11.3	10.3	11.4	10.8	11.2	-
SP-75A	77.5	60.7	46.7	36.2	21.5	11.3	13.6	9.5	8.7	9.9	9.8	10.5	-
Monmouth Area													
SP-14	69.4	58.3	47.4	39.4	28.1	21.3	20.0	15.1	13.4	14.2	14.5	14.6	-
SP-79	120.5	85.8	74.6	60.6	32.7	18.9	20.0	13.5	12.3	13.7	12.7	12.4	-
SP-83	90.2	73.5	59.0	46.6	26.4	14.7	16.0	11.3	10.2	11.1	10.3	10.3	-
SP-86	99.0	95.8	64.5	51.8	32.6	21.4	23.3	17.2	15.4	16.0	14.1	13.5	-
Albany Area													
SP-59	92.6	65.6	57.9	47.0	30.8	20.5	21.7	14.9	13.5	14.0	13.1	13.2	-
Corvallis Area													
SP-55	104.2	73.9	61.5	48.2	29.8	17.7	19.7	14.0	12.6	13.4	12.7	12.9	-
SP-57A	128.4	100.4	77.2	61.5	39.5	22.4	25.5	17.1	14.9	15.8	15.5	15.2	-
SP-58	88.3	62.4	52.2	40.1	24.8	15.0	16.2	11.5	10.7	11.5	11.3	11.2	-
SP-88	103.1	81.9	65.2	50.6	28.6	19.4	17.4	11.3	10.3	10.7	9.3	9.3	-
Spencer Formation Type Area													
SP-32	132.8	79.5	79.6	64.5	35.5	19.4	19.4	11.4	10.0	11.1	9.5	9.4	-
UPPER AVERAGE	103.9	77.4	64.2	51.0	30.8	18.4	19.8	13.5	12.1	13.0	12.2	12.2	-
DeShazer 13-22 Well Sidewall Cores													
ONG-12-2224	44.5	33.1	30.7	23.5	14.4	12.0	9.4	6.6	6.5	6.7	6.2	6.2	-
ONG-14-2220	41.6	30.8	29.3	22.2	13.7	11.5	9.2	6.8	6.9	6.9	6.7	6.9	-
ONG-17-2214	47.1	35.6	34.5	25.8	15.7	12.3	10.3	7.2	6.9	8.5	6.9	6.8	-
ONG-23-2202	62.7	53.7	47.6	40.1	29.7	15.5	22.7	18.8	17.3	18.2	18.9	18.2	-
KCl1*	72.3	58.5	51.1	42.6	26.4	19.8	18.4	13.8	12.1	12.6	11.0	10.5	-

All values are Chondrite Normalized

*KCl1 is the standard

Figure 26 illustrates those samples which have little fluctuation in slope between europium and gadolinium. Typically these samples have lower concentrations of rare earth elements, approximately one-third the REE content as samples with pronounced europium deficiencies are plotted in Figure 26. Despite the obvious depletion in Eu, all other REE's in the upper member samples are predominately enriched (Figure 27).

Oregon Natural Gas and Development Company's DeShazer 13-22 well side wall core samples are plotted in Figure 28. Samples ONG-23-2202, which is stratigraphically the highest sample analyzed in the DeShazer 13-22 well, was the only side wall core sample depicting an europium depletion. The standard utilized by Dr. Hooper, KC-11, is also plotted with these samples in Figure 28.

Kadri (1982) and Kadri and others (1983) utilized cross-plots to best characterize and group Tertiary Formations in northwestern Oregon. Kadri (1982) found that principally five elements; potassium (K), sodium (Na), scandium (Sc), lanthanum (La) and samarium (Sm) best illustrated the Tertiary Formations and the Columbia River basalts. Because this present study involved comparison of the REE geochemistry within one formation, only subtle variations can be ascertained. Groupings of samples, like that done by Kadri (1982), understandably are more difficult to derive in this study.

Plots of Eu and Gd (Figure 29) or the ratio Eu/Gd or vice versa against higher concentration elements which have a wide range of values, such as La, best illustrated groupings within the Spencer Formation samples. Europium/ gadolinium was plotted against lanthium (Figure 30). This plot differen- tiates two sample groups; 1) those samples

Figure 26. Plot of rare earth elements versus chondrite/sample for lower member (informal) sandstones. Abbreviations of REE's utilized are given in Table IX.

Figure 26. Continued

Figure 27. Plot of rare earth elements versus chondrite/sample for upper member (informal) sandstones. Abbreviations of REE's utilized are given in Table IX.

Figure 27. Continued

Figure 28. Plot of rare earth elements versus chondrite/sample for sidewall core samples taken from the DeShazer 13-22 natural gas exploration well. Abbreviations of REE's utilized are given in Table IX.

Figure 28. Continued

lower in both La and Eu, and 2) those samples higher in Eu and La. Generally, samples analyzed from the lower member are depleted in rare earth elements but have relatively higher europium contents.

The two most abundant REE's characteristic of Spencer Formation arkosic and lithic arkose sandstone lithofacies are lanthanum (La) and samarium (Sm). Concentrations of these two REE's are plotted in Figure 31. The lower lithofacies samples, which contain approximately one-third to one-half the REE content of the southern and upper lithofacies, are depicted in the lower left-hand portion of Figure 31. The lower lithofacies samples, which contain approximately one-third to one-half of the REE content of the informal upper member lithofacies are depicted in the lower left-hand portion of Figure 20. Upper member sandstones La and Sm concentrations plot in the center and upper right hand portion of Figure 31.

Amount of fines in the sandstone may show some variance in major oxide and RE element abundances. This evidence is most noticeable for major oxide concentrations, but showed little effect on REE abundances. Increases in Al_2O_3 , K_2O , MgO , and Na_2O may reflect clays present.

SPENCER FORMATION SANDSTONE

Gadolinium Versus Europium Content

Figure 29. Rare earth element cross plot diagram of gadolinium (Gd) versus europium (Eu) content in the Spencer Formation sandstones analyzed. Informal upper and lower member grouping area shown.

SPENCER FORMATION SANDSTONE

Figure 30. Rare earth element cross plot diagram of europium/gadolinium (Eu/Gd) versus lanthanum (La) content in the Spencer Formation sandstones analyzed. Informal upper and lower member grouping area shown.

SPENCER FORMATION SANDSTONE

Figure 31. Rare earth element cross plot diagram of lanthanum (La) versus samarium (Sm) content in the Spencer Formation sandstones analyzed. Informal upper and lower member grouping area shown.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Summary

Stratigraphic variances or trends studied within the Spencer Formation upper and lower member sandstone lithofacies reflect depositional environments such as sediment dispersal systems, paleocurrent directions and water depth. Spencer Formation sandstone can be subdivided stratigraphically into lithofacies based on sedimentary structures and textures. The lower member consists of massive, friable, unfossiliferous, fine- to medium-grained arkosic sandstones void of sedimentary structures except for micaceous laminae (1-2 cm). The upper member consists of small to medium beds (1m) of interbedded mudstone and arkosic to lithic arkosic sandstones which are poorly- to well-cemented with calcite and smectite, occasionally exhibiting trough cross-bedding and numerous micaceous (biotite) laminae. Some horizons contain abundant invertebrate fossils (pelecypods and gastropods), while others are carbonaceous to coaly or concretionary.

The stratigraphic observations though, can only be regarded as generalizations, because fluctuations in stratigraphy do occur within the informal upper and lower Spencer Formation sandstones. There are also geographic trends within the Spencer Formation sandstones. Below is a list illustrating changes in Spencer Formation sandstone

lithofacies generally from north to south.

- overall finer-grained except the extreme southern portion of the study area where the upper member comes in contact with the Fisher Formation, where conglomerates consisting of large clasts (lcm - 1m) occur
- becomes more tuffaceous to pumiceous
- commonly more resistant and overall well cemented
- contains more invertebrate fossils

Sedimentary petrology of selected Spencer Formation sandstone samples shows that there are obvious differences in detrital framework mineral grains, and lithic fragments between the lower and upper member sandstone lithofacies. Distribution of quartz, feldspar and heavy minerals within the Spencer Formation sandstones provided the best indicators of stratigraphic and geographic trends.

Lower member arkosic lithofacies have higher concentrations of monocrystalline quartz and potassium feldspar (predominately microcline). Metamorphic rock fragments consisting of schist and quartzite are most common. Study of heavy mineral separates shows that epidote is commonly two to three times more abundant in the lower member. The abundance of monocrystalline quartz, quartzite, potassium feldspar, muscovite, epidote and schistose rock fragments suggest derivation from a continental plutonic source such as the Idaho batholith.

Upper member arkosic to lithic arkosic lithofacies contains an abundance of plagioclase feldspar (oligoclase and andesine). Microlithic volcanic rock fragments with lath-shaped phenocrysts of plagioclase are most abundant. Hornblende and augite, commonly etched, are three to four times more abundant than in the lower member sandstone

lithofacies. The abundance of amphibole, pyroxene and plagioclase indicates an influx of a volcanic source. Influx of volcanic rock fragments from pre-ancestral Cascade-type volcanics, originating in late Eocene within the area of the present day southern Cascade Mountains could be a possible source for plagioclase contents within the upper member.

Scanning electron microscopy proved most viable for complimenting petrographic findings, elemental analysis of mineral grains and authigenic minerals, and pore space-mineral grain relationships. Clay mineral assemblages, although detected, are compositionally difficult to differentiate with the SEM. A variety of mineral-pore relationships were observed, ranging from friable, highly porous samples to samples entirely cemented with calcite and smectite showing virtually no porosity.

Kaolinite, chlorite, illite, smectite, and mixed-layer illite/smectite are the clay minerals identified by X-ray diffraction.

Diagenesis within the Spencer Formation upper and lower member sandstones is evident by bent and crushed detrital grains (mostly mica), development of authigenic clay (smectite), potassium feldspar, and zeolites (heulandite) minerals as well as the emplacement of calcite cement. In thin section petrographic evidence of diagenetic processes within Spencer Formation sandstones was limited to 1) compaction, 2) chemical etching of amphibole and pyroxene, 3) calcite cement, 4) degradation of plagioclase and 5) presence of clays. Scanning electron microscopy studies complemented petrographic studies showing two additional important diagenetic processes; 1) degradation of silicate

grains and 2) solution or formation of authigenic minerals (potassium feldspar, smectite, zeolite and calcite). Development of authigenic minerals is probably aided by the over abundance of K^+ , Na^+ , Ca^{+2} , and Mg^{+2} cations which are characteristic of either poorly recharged aquifers or connate water.

Weathering effects within the Spencer Formation sandstones are compounded by elevated amounts of rainfall and temperate climate conditions in western Oregon as well as the effect of percolating ground water. Chemical etching of pyroxene and amphibole detrital grains within the upper member, degradation of both potassium and plagioclase feldspars, and the break-down of volcanic rock fragments into clay minerals may be accelerated by weathering within the Spencer Formation sandstones. Etching of amphibole and pyroxene is rare in the DeShazer 13-22 well sidewall core samples.

There is a definite correlation between sandstone petrography and the major oxide and rare earth element geochemistry. Arkose and lithic arkose sandstones of the upper member contain abundant plagioclase, hornblende, augite and other heavy minerals. Hornblende especially, has the ability to retain rare earth elements within its crystal lattice structure. Higher concentrations of REE's may occur within the upper member because it is commonly finer-grained than the lower member allowing for concentration of REE's within the clay mineral fraction.

Both major oxide and rare earth element geochemistry proved viable for categorizing Spencer Formation sandstone lithofacies. Major oxide geochemical findings showed that the upper member is silica deficient and has elevated amounts of alumina, iron and magnesium when compared to

the sandstone lithofacies of the lower member. Rare earth element abundances were two to three times higher in upper member sandstone lithofacies than found within the lower member.

Petrologic and geochemical evidence found in this study indicate that there are two main sources from which Spencer Formation arkosic and lithic arkose sandstone lithofacies have originated. Both distal metamorphic and plutonic rocks and proximal volcanics are combined within the Spencer Formation. Gandera (1977), Al-Azzaby (1980), Thoms and others (1983) and Van Atta (1986) have also come to this conclusion with regard to the provenance of the Spencer Formation. Petrographic and accompanying geochemical findings of this study indicate four possible source areas for these metamorphic/plutonic minerals and lithic fragments. The areas are: 1) north-central Washington, 2) granitic rocks once exposed but are now overlain by massive outpourings of Columbia River basalts in central and N.E. Washington, 3) Idaho Batholith and, 4) Blue Mountains complex. Figure 32 shows this author's representation of possible source areas where detrital minerals and rock fragments originated. Volcanic rock fragments were consolidated into predominately "arkosic" sands being derived from plutonic sources to the east (Dott, 1966; Dott and Bird, 1979).

Influx of volcanics with increased amounts of heavy minerals (ie. amphibole and pyroxene) and clay mineral assemblages, would account for the elemental anomalies observed, reemphasizing the switch in provenance to an influx of intermediate volcanics within upper and southern sandstone lithofacies. These samples also have a distinctive europium anomalies typical of intermediate (andesite to dacite) volcanics.

Figure 32. Authors interpretation of provenance or source area for Spencer Formation sands during late Eocene. Large arrows show regional direction for arkosic sand sources. Medium-sized arrows show localized flow of arkosic sands around volcanic highs and the introduction of volcanic (andesite to dacite) material from ancestral Cascade development. Proximal shedding of volcanic lithic material is shown by small arrows. A = Albany, C = Corvallis, E = Eugene, G = Gaston, M = Mist, P = Perrydale, Pt = Portland.

Conclusions

Spencer Formation stratigraphy is probably better understood in the northern portion of the study area (western Tualatin Valley area), with the exception of the Corvallis area. Defining the stratigraphic position of the Spencer Formation in the Corvallis area is complicated not only by the Corvallis fault zone, a structurally complex series of SW-NE trending dip-slip faults, but also by the numerous intrusive volcanics (believed to be late Eocene to early Oligocene) which have structurally disturbed and locally warped the Spencer Formation sandstones. Additionally, in the Corvallis area, the upper part of the Yamhill Formation is very similar to the lower part of the lower member of the Spencer Formation elsewhere with respect to lithology, paleontology and petrography. Bruer and others (1984) referred to this upper part of the Yamhill Formation as the Miller sand member (informal). Therefore, based on the stratigraphic relationships observed in the field as well as the petrographic and geochemical results obtained within this present study, only preliminary subdivision of the Spencer Formation into upper and lower members can only be inferred within the Corvallis area.

Locally, only subtle differences in sandstone petrology and geochemistry within the Spencer Formation are apparent. Within the northern four separate study areas definite differences in the petrography and geochemistry occur. The upper member contains more plagioclase, hornblende, augite, volcanic rock fragments (microlithic) in comparison to the lower member. In contrast, the lower member contains more potassium feldspar, monocrystalline quartz, epidote,

and metamorphic rock fragments (schist and quartzite). Overall the lower member is deficient in major oxide concentrations (SiO_2 being the exception) and in the suite of REE's studied when compared to the upper member.

To further define the petrologic and geochemical trends developed in this present study the following areas should have more detailed work: 1) better stratigraphic control, 2) accompanying micropaleontological studies, 3) delineate structural complications, and 4) study of additional samples to further define petrology, major oxide and trace and REE geochemistry. Measurement of detailed composite stratigraphic sections with accompanying microfossil (dominately foraminifera) assemblage controls would certainly better define stratigraphic positioning of the informal members, especially in the Corvallis area. Also, utilization of ditch samples and additional sidewall cores from other gas exploration wells within the Willamette Valley would be important in further determining variations in petrology and geochemistry both areally and stratigraphically within the informal upper and lower members of the Spencer Formation.

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APPENDIX A

SPENCER FORMATION SAMPLE LOCATIONS

- SP-1 Latitude 45° 26' 15"; Longitude 123° 11' 45"
Gaston Quad., Washington Co., Ore.,
T1S, R4W, NE1/4, SE1/4, Sec. 32, road cut along
Patton Valley Road, east of Gaston, Oregon.
- SP-3 Latitude 45° 24' 12"; Longitude 123° 10' 53"
Gaston Quad., Yamhill Co., Ore.,
T2S, R4W, NW1/2, NE1/4, Sec. 16, road cut along
Canyon View Road, east of Gaston, Oregon.
- SP-5 Latitude 45° 24' 11"; Longitude 123° 10' 28"
Gaston Quad., Yamhill Co., Ore.,
T2S, R4W, NW1/4, NW1/4, Sec. 15, road cut along
Russell Creek Road, east of Gaston, Oregon.
- SP-8 Latitude 45° 20' 37"; Longitude 123° 07' 10"
Dundee Quad., Yamhill Co., Ore.,
T3S, R4W, SW1/4, NE1/4, Sec. 1, road cut along
Woodland Loop Road.
- SP-11 Latitude 45° 19' 45"; Longitude 123° 06' 45"
Dundee Quad., Yamhill Co., Ore.,
T3S, R4W, NW 1/4, NW 1/4, Sec. 7, road cut along
State Highway 240 east of Yamhill, Oregon.
- SP-12 Latitude 44° 46' 02"; Longitude 123° 13' 32"
Monmouth Quad., Polk Co., Ore.,
T9S, R4W, SE1/4, SW1/4, Sec. 30, in old clay pit
off old State Highway 99W south of Monmouth,
Oregon.
- SP-14 Latitude 44° 48' 15"; Longitude 123° 14' 03"
Monmouth Quad., Polk Co., Ore.,
T9S, R5W, SE1/4, NE1/4, Sec. 12, road cut along
Brateny Road.
- SP-32 Latitude 44° 00' 10"; Longitude 123° 17' 20"
Elmira Quad., Lane Co., Ore.,
T18S, R5W, SE1/4, NE1/4, Sec. 16, outcrop along
Petzold Road southeast of Veneta, Oregon.

- SP-35 Latitude 43° 59' 45"; Longitude 123° 14' 25"
Fox Hollow Quad., Lane Co., Ore.,
T18S, R5W, NE1/4, NW1/4, Sec. 24, outcrop along
Pine Grove Road.
- SP-55 Latitude 44° 31' 05"; Longitude 123° 23' 20"
Wren Quad., Benton Co., Ore.,
T12S, R6W, NW1/4, NW1/4, Sec. 23, outcrop along
Evergreen Road south of Philomath, Oregon.
- SP-57A Latitude 44° 32' 15"; Longitude 123° 17' 35"
Corvallis Quad., Benton Co., Ore.,
T12S, R5W, SE1/4, SE1/4, Sec. 9 outcrop along
Brooklane Nash Avenue south of Corvallis.
- SP-58 Latitude 44° 35' 55"; Longitude 123° 12' 50"
Corvallis Quad., Benton Co., Ore.,
T11S, R5W, NW1/4, SE1/4, Sec. 23 outcrop along
Highland Way Road north of Corvallis.
- SP-59 Latitude 44° 38' 25"; Longitude 123° 12' 50"
Lewisburg Quad., Benton Co., Ore.,
T11S, R4W, NE1/4, SE1/4, Sec. 6 outcrop along
Pettibore Road northeast of Lewisburg.
- SP-60 Latitude 44° 38' 40"; Longitude 123° 08' 25"
Lewisburg Quad., Benton Co., Ore.,
T11S, R4W, SE1/4, NW1/4, Sec. 2 outcrop along
Scenic Drive west of North Albany.
- SP-62 Latitude 44° 40' 05"; Longitude 123° 08' 00"
Lewisburg Quad., Benton Co., Ore.,
T10S, R4W, SE1/4, SW1/4, Sec. 26 outcrop along
Scenic Drive west of North Albany.
- SP-65 Latitude 45° 29' 25"; Longitude 123° 12' 25"
Gaston Quad., Washington Co., Ore.,
T1S, R4W, NE1/4, NW1/4, Sec. 17 along
Henry Hagg Lake Road.
- SP-67 Latitude 45° 28' 15"; Longitude 123° 12' 10"
Gaston Quad., Washington Co., Ore.,
T1S, R4W, SW1/4, NE1/4, Sec. 20 on the south
side of Henry Hagg Lake Dam.
- SP-69 Latitude 45° 25' 05"; Longitude 123° 11' 35"
Gaston Quad., Yamhill Co., Ore.,
T2S, R4W, NW1/4, NW1/4, Sec. 9

- SP-71 Latitude 45° 21' 20"; Longitude 123° 07' 55"
Carlton Quad., Yamhill Co., Ore.,
T2S, R4W, SW1/4, NW1/4, Sec. 36
- SP-74 Latitude 45° 18' 10"; Longitude 123° 07' 05"
Carlton Quad., Yamhill Co., Ore.,
T3S, R4W, NE1/4, NW1/4, Sec. 24. along Yamhill
Road.
- SP-75A Latitude 45° 16' 50"; Longitude 123° 06' 30"
Dundee Quad., Yamhill Co., Ore.,
T3S, R3W, SE1/4, NW1/4, Sec. 30 outcrop
along Oak Springs Farm Road.
- SP-79 Latitude 44° 54' 10"; Longitude 123° 18' 40"
T8S, R4W, NE1/4, SW1/4, Sec. 4 road cut along
Mistletoe Road south of Dallas.
- SP-81 Latitude 44° 52' 50"; Longitude 123° 17' 20"
Airlie North Quad., Polk Co., Ore.,
T8S, R5W, SE1/4, SW1/4, Sec. 15 west of Monmouth,
Oregon.
- SP-83 Latitude 44° 50' 40"; Longitude 123° 18' 15"
Airlie North Quad., Polk Co., Ore.,
T8S, R5W, NW1/4, SE1/4, Sec. 28 northwest of
Monmouth, Oregon.
- SP-86 Latitude 44° 47' 05"; Longitude 123° 14' 05"
Monmouth Quad., Polk Co., Ore.,
T9S, R4W, SW1/4, SW1/4, Sec. 18 road cut
along Helmick Road (old 99W) south of Monmouth.
- SP-87 Latitude 44° 47' 10"; Longitude 123° 13' 25"
Monmouth Quad., Polk Co., Ore.,
T9S, R4W, NE1/4, SW1/4, Sec. 18 road cut
along Helmick Road (old 99W) south of Monmouth.
- SP-88 Latitude 44° 34' 50"; Longitude 123° 17' 35"
Corvallis Quad., Benton Co., Ore.,
T11S, R5W, SE1/4, SE1/4, Sec. 28 outcrop at
corner of Sylvan Street and Witham Hill Drive,
Corvallis.
- SP-90B Latitude 44° 38' 45"; Longitude 123° 11' 20"
Lewisburg Quad., Benton Co., Ore.,
T11S, R4W, SW1/4, NW1/4, Sec. 5 outcrop along
Pettibore Road northeast of Lewisburg.
- DeShazer Well Latitude 45° 07' 12"; Longitude 122° 55' 35"
Gervais Quad., Marion Co., Ore., T5S, R2W, NE1/4,
SW1/4, Sec 22 2.5 kilometers northeast of Gervais,
Oregon.

APPENDIX B

ADDITIONAL X-RAY SPECTRUMS UTILIZED FOR IDENTIFICATION OF MINERALS WITH THE SCANNING ELECTRON MICROSCOPE

Quartz

X-RAY
Live:
Real:

100s Preset: 100s Remaining: 0s
122s 18% Dead

Potassium Feldspar

X-RAY
Live:
Real:

100s Preset: 100s Remaining: 0s
125s 20% Dead

Plagioclase Feldspar

X-RAY
Live: 100 s Preset: 100 s Remaining: 0 s
Real: 120 s 17% Dead

Biotite

X-RAY
Live: 100 s Preset: 100 s Remaining: 0 s
Real: 121 s 17% Dead

Calcite

X-RAY
Live: 120s
Real: 120s

100s Preset: 100s Remaining:
17% Dead

0s

Sphene

X-RAY
Live: 128s
Real: 128s

100s Preset: 100s Remaining:
22% Dead

0s

Glauconite

X-RAY
Live: 128s
Real: 100s Preset: 100s Remaining: 0s
22% Dead

Smectite

X-RAY
Live: 122s
Real: 100s Preset: 100s Remaining: 0s
18% Dead