AN ABSTRACT OF THE THESIS OF

Linda J. Baker for the degree of Master of Science in Geology presented on March 3, 1988.

Title: The Stratigraphy and Depositional Setting of the Spencer Formation, West-central Willamette Valley, Oregon; a Surface-subsurface Analysis

Abstract approved: Redacted for Privacy
Dr. Kieth F. Oles

The late Eocene Spencer Formation crops out in the low hills on the western edge of the central Willamette Valley, Oregon. Surface exposures in eastern Benton and southeastern Polk Counties and oil/gas well records and cuttings in Polk, Marion and Linn Counties were studied to determine Spencer stratigraphy, regional lithologic variations, and depositional environment. Methods used include: study of outcrops, petrography, texture, and well cuttings, as well as the correlation of well logs and microfossil data of McKeel (1984, 1985). The distribution of the underlying early-late Eocene Yamhill Formation is also briefly considered.

The Yamhill Formation consists of the Miller sandstone member enclosed between mudstones. The lower and middle Yamhill record shoaling from bathyal to marginal marine depths, and they are overlain by bathyal upper Yamhill mudstones. The Miller sandstone is lens-shaped, trends parallel to the Corvallis fault, and reaches a maximum thickness of approximately 2,000 feet on the east side of the fault. The Miller sandstone grades westward into bathyal mudstones, and eastward into

volcanic tuffs and flows. Thinning of the Miller sandstone and upper Yamhill mudstone along the Corvallis fault suggests movement during early late Eocene. The absence of Yamhill strata along the outcrop belt to the southwest may be related to this tectonic activity. Alternatively, Yamhill strata may have been misidentified as Tyee Formation or Spencer Formation.

The Spencer Formation was deposited in a tectonically active forearc basin during a transgression which was interrupted by several short-term regressional/progradational events. The Spencer is stratigraphically divided (informally) into a lower sandstone-rich member and an upper mudstone member; it is also divided geographically (informally) into northwestern, east-central, and southern provinces. The lower member is 700 feet thick in the northwestern and southern areas, and thickens to 1400 feet in the east-central area. As compared to the north and south areas, sandstones in the east-central area are coarser (fine to medium versus very fine to fine), the sandstone to siltstone ratio is higher, and volcanic interbeds are more common. Deposition is thought to have been at inner shelf and shoreface depths, grading eastward into nonmarine. In the northwestern area, abundant hummocky cross-bedding of arkosic to arkosic-lithic lower Spencer sandstones suggests deposition on a storm wave-dominated shelf. Periods of shoaling to shoreface depths are indicated. In the south, sandstones are markedly more volcanic-rich (dominantly arkosic litharenites), contain more fossils, and are more highly bioturbated. Shelf-storm deposits in the south are normally graded with a basal lag of coarse volcanic grains and fossils. Besides a more proximal volcanic source, a shoal/barrier within the southern part of the basin may have caused the different sediment character. Deposition was probably at middle to inner shelf depths at the outcrop belt. It may have deepened slightly eastward before shoaling to nonmarine in the easternmost part of the study area. Volcanism was active nearby on the eastern and southeastern margins of the basin. Small volcanic centers within the basin may have created highs and acted as localized volcanic sources.

As transgression continued, upper Spencer mudstones were deposited at middle to upper bathyal depths. Volcanic activity increased on the eastern edge of the basin. Mudstones grade eastward and upward into tuffs and flows of the eastern Willamette volcanic facies.

The Stratigraphy and Depositional Setting of the Spencer Formation, West-central Willamette Valley, Oregon; a Surface-subsurface Analysis

by

Linda J. Baker

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INTRODUCTION

The Spencer Formation consists of sandstones, siltstones, and mudstones deposited in a forearc basin in western Oregon during late Eocene time. These strata crop out in a north-south belt along the western edge of the Willamette Valley from Yamhill south to the Drain Quadrangle (Fig. 1). The Spencer extends eastward in the subsurface, where it is buried beneath younger deposits of the Willamette Valley. Compositionally, Spencer sandstones range from micaceous arkoses to volcanic litharenites in composition, and many are tuffaceous. Mudstones are a minor part of the section. Other late Eocene units which have been correlated with the Spencer include the Cowlitz, Coaledo, and Nestucca Formations (Beaulieu, 1971).

Despite stratigraphic and lithologic similarities between the Spencer Formation and the gas-producing Cowlitz Formation, the Spencer has never been studied in detail in the central Willamette Valley. The Spencer Formation stratigraphy, sandstone distribution, lithologic variability, provenance, and details of the depositional environment are poorly defined in this area. Problems also exist with the late Eocene stratigraphy as defined in the subsurface and the surface of the study area, and with an anomalously thick section of Spencer in the Corvallis area. In an effort to solve these problems and fill the information gap, this study examines characteristics of the Spencer in outcrops and well logs from eastern Benton and southeastern Polk

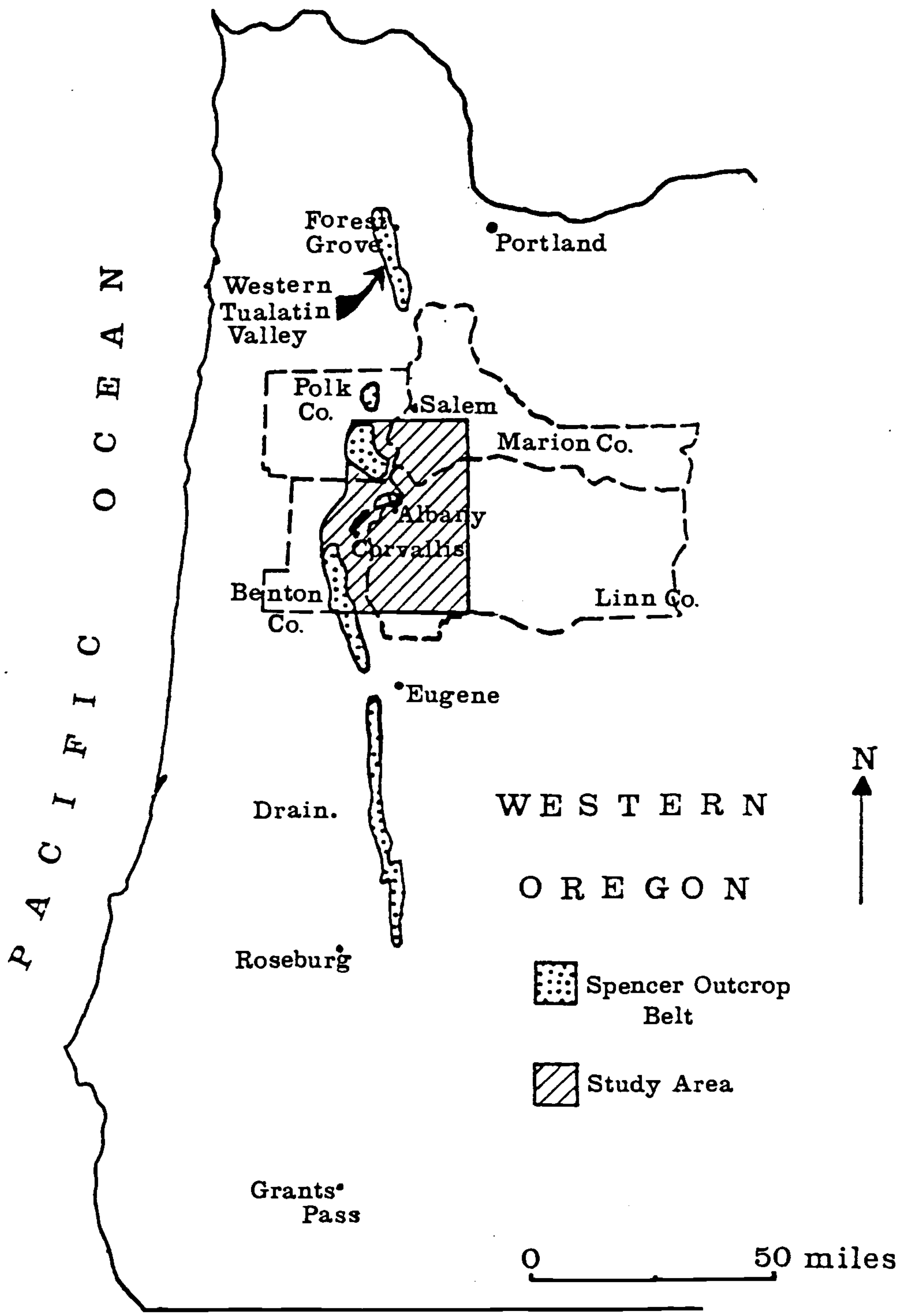


Figure 1: Location of the study area in the central Willamette Valley, and extent of the Spencer outcrop.

Counties, along with well logs from western Linn and Marion Counties. The primary objectives of this work are: (1) to describe the lithology of the Spencer at the surface; (2) to examine Spencer stratigraphy at the surface and in the subsurface by the correlation of well logs and outcrops; (3) to determine vertical as well as lateral changes in Spencer lithology; and (4) to outline possible depositional environments and provenance of Spencer strata. A regional approach to studying the Spencer was necessary because of limited exposure, extreme weathering, and the reconnaissance nature of previous work.

LOCATION AND ACCESSIBILTY

Spencer Formation outcrops lie in a roughly north-south band across eastern Benton and Polk Counties. Field work was conducted within the Monroe, Corvallis, Albany, Dallas, and southern Salem 15-minute Quadrangles (Fig. 1). A good network of main and local highways provides easy access to the study area. However, private ownership of much of the land occasionally restricts work. Outcrops are limited because of the humid climate, dense vegetation, and deep weathering. Road cuts and quarries are invaluable for providing exposures. Stream beds generally do not provide sufficient exposure because Spencer outcrops are in the gently sloping foothills of the eastern Coast Range.

Subsurface information from 36 wells in western Linn and Marion Counties is on file with the Oregon Department of Geology and Mineral Industry (King and others, 1982) However, electric logs are available for only 17 of these wells. Copies of well logs were obtained from Northwest Oil Report Co. of Portland, Oregon.

PREVIOUS WORK

The Spencer Formation was originally named by Turner (1938) for outcrops along Spencer and Coyote Creeks just south of Eugene, Oregon. Based on macrofossils, Turner correlated the Spencer with late Eocene Tejon strata in California, and with the Coaledo and Cowlitz Formations of western Oregon. The geology of the southwestern and west central sections of the Willamette Valley was mapped by Vokes and others (1951, 1954). They also referred to the late Eocene sedimentary rocks as the Spencer Formation. Vokes and others (1951) located Spencer-age marine fossils within outcrops previously considered by Turner (1938) to be the nonmarine Comstock Formation. These rocks have since been included in the Spencer Formation.

Many papers which discuss the stratigraphy north and south of the study area include descriptions of the Spencer Formation. To the south, in the Anlauf and Drain Quadrangles, Hoover (1963) found a much thinner Spencer section, with less basaltic detritus and a few thin seams of impure coal. Gandera (1977) examined stratigraphy of middle to late Eocene formations in Lane County in the southwestern Willamette Valley.

Schlicker (1962) originally identified Spencer sandstones to the north of the study area, in the Yamhill quadrangle. More detailed studies of the petrology and stratigraphy of the Spencer Formation in the northern Willamette and western Tualatin Valleys (Washington and Yamhill Counties) were conducted by Al-Azzaby (1980), Thoms and others (1983), and Cunderla (1986). The sandstones, siltstones, and mudstones referred to as the Stimson Mill Bed by Al-Azzaby should be included in the Spencer Formation (Thoms and others, 1983).

Within the study area, late Eocene rocks were first noted in the literature by Mundorff (1939), who referred to them as the Helmick Beds. Vokes and others (1954) relabeled them as Spencer Formation and mapped their distribution. The Spencer also is described in Allison's (1953) study of geology in the Albany Quadrangle. The geology of Dallas and Valsetz Quadrangles, in the northern part of the study area, was mapped and described by Baldwin in 1947, and revised in 1964. He found a relatively thick section of Spencer, which is locally interbedded with volcanic flows. The flows are thought to be similar to volcanic units interbedded with the Cowlitz and Nestucca Formations. Authigenic silicates in the Spencer were studied by Enlows and Oles (1966). Bela's report on the Geologic Hazards of Eastern Benton County (1979) includes a brief description of the Spencer Formation, along with geologic maps of the area. Bela (1981) also made a geologic map of the Salem 15-minute quadrangle. Diagenesis and soil formation of Spencer sandstones in the northern study area were discussed by Glassman (1978). A recent thesis by Cunderla (1986) studied the petrography and chemistry of the Spencer to the north and within the northern portion of the study area. Macrofossils within the study area are currently being studied by Tim Fleming, a geology student at Montana State University.

Several studies of a more regional nature contain descriptions of the Spencer Formation. McWilliams (1968) examined the lithostratigraphy and biostratigraphy of central-western Oregon. His work included stratigraphic sections from the Toledo, Monroe, Buena Vista, Sheridan, and Yamhill-Gales Creek areas. Brief descriptions of the Spencer are also included in Beaulieu's (1971) summary of geologic formations of western Oregon, and Baldwin's (1974, 1975) reports on the Eocene stratigraphy of southwest Oregon. A regional view of late Eocene stratigraphy, along with interpreted paleogeography, is discussed in Snavely and Wagner's (1963) paper on the Tertiary geologic history of western Oregon and Washington.

A few subsurface studies have been made using well information from the study area. Bruer and others (1984) constructed a cross-section which extends south into the study area. McKeel (1984, 1985) identified microfossils and studied the biostratigraphy of several of the wells.

METHODS

Field Methods

Field work was accomplished during 1985 and 1986. Fall and early spring are the best times for viewing outcrops because of reduced vegetative cover and decreased potency of poison oak. A base map for the area was compiled from geologic maps made by Vokes and others (1954), Bela (1981), Baldwin and others (1955), and Baldwin (1964). Information concerning lithology, sedimentary structures, bedding, fossil content, grain size, texture, and attitudes were gathered where exposure permitted such identifications. Measured sections were described and drawn where exposure was sufficient. Rock colors are based on the Rock-color Chart of the Geologic Society of America.

Petrology

The pervasive alteration and poor induration of Spencer Formation sediments causes problems in making thin sections. Thirty thin sections were prepared and analyzed for composition and texture. Many of the samples required impregnation with epoxy before sawing. Thin sections were stained for potassium feldspar using sodium cobaltinitrite. Eleven thin sections were in sufficiently good condition to be point-counted using over 500 points per thin section.

Grain Size Analysis

A settling tube was used to measure the distribution of grain sizes larger than 4.75 phi for 15 samples. The settling tube was chosen for these analyses because relatively accurate results can be obtained more rapidly than with sieves. Furthermore, grain sizes based on settling velocity are thought to be a more significant indicator of depositional environment than geometrically defined sizes (Blatt and others, 1980).

Samples from outcrops throughout the study area were disaggregated mechanically, and ultrasonically. Where necessary samples were placed in dilute acetic acid to dissolve carbonate cement, or oxalic acid to dissolve iron cement. Disaggregated samples were washed through a 400-mesh screen, and the portion smaller than 0.038 mm was discarded. This fine-grained material was not measured because the formation of clays during weathering, diagenesis, and the procedure of mechanical disaggregation would distort the original depositional population.

The sediments were analyzed using the settling tube at Portland State University. Thiede and others (1976) discussed the equipment and sample processing in detail. Briefly, the tube is 230 cm high and 20 cm in diameter. The 0.50 to 0.75 grams of prepared sample is spread in a single layer over the introduction plate which had been coated with a thin layer of photoflo. The plate is inverted and mounted on the introduction mechanism at the top of the tube. When the sample is dropped all the grains are released nearly simultaneously at the same time as a microswitch activates the digitizing equipment. The grains settle onto a plate at the bottom of the tube which is attached to a strain gauge. The amount of sediment accumulating is measured at prescribed intervals and processed through a microprocessor and a Hewlett-Packard 41C programmable calculator. The calculator produces a list of relative quantities of each grain size and a histogram, both at 0.25 phi intervals.

Conversions from measured settling velocity are calculated for spheres with density 2.65g/cm using the equation of Gibbs and others (1971):

$$r = \frac{0.055804v^2\rho_f + \sqrt{0.003144v^4\rho_f^2 + [g(\rho_s-\rho_f)][4.5\eta v + 0.008705v^2\rho_f]}}{[g(\rho_s-\rho_f)]}$$

where:

r = sphere radius (cm)
v = velocity (cm/s)
η = dynamic viscosity of fluid (poise)
g = acceleration of gravity (cm/s^2)
ρ_f = density of fluid (g/cm2)
ρ_s = density of sphere (g/cm2)

The radius is then converted to phi size using:

$$\phi = -\log_2 \frac{2r(\text{mm})}{1\ \text{mm}}$$ (Krumbein, 1938).

Many of the errors associated with settling tube measurement are reduced with the Portland State University equipment. The larger size of the tube reduces wall effects. Introducing sediment one layer thick minimizes any erroneous readings caused by non-instantaneous release of the sample, or by smaller grains being entrained behind larger grains. Smaller samples also reduce these entrainment effects. However, with smaller quantities of sample, the chance for getting a slightly unrepresentative split is increased. Drawbacks with the system include distortion of results from tube vibration, and loss of information on the finer sizes resulting from premature system shut down caused by a quirk in the microprocessor. Several samples were run twice or three times in an effort to reduce error.

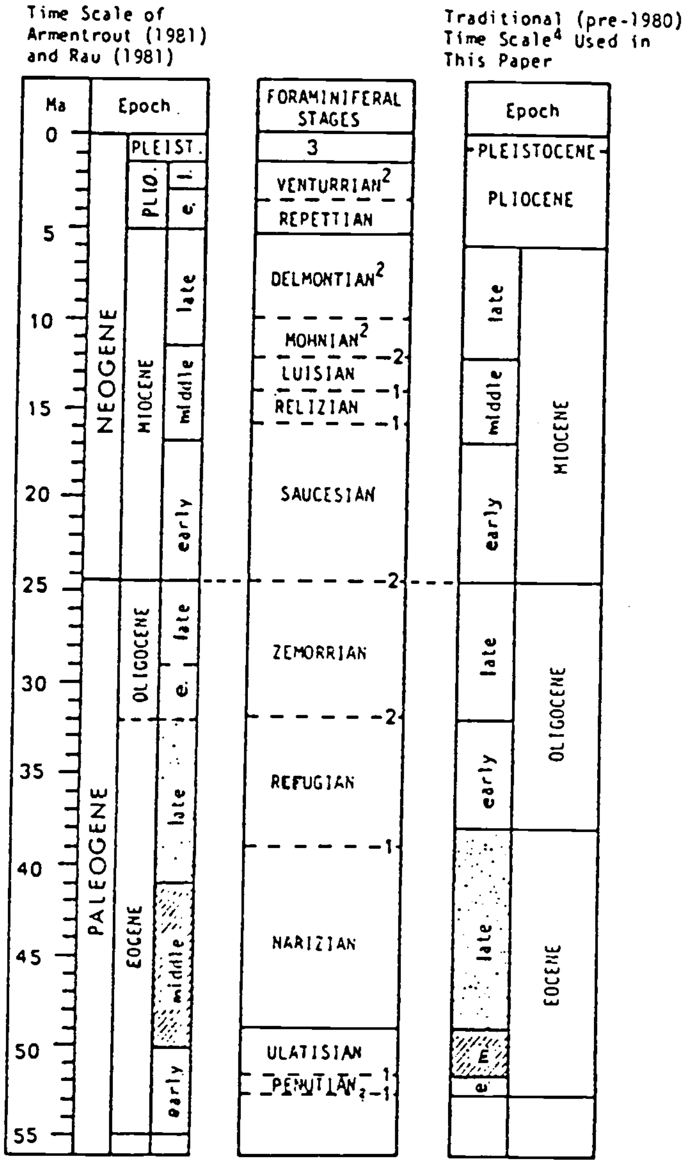
The results from the settling tube were then processed with the computer program (SEDANAL). This program, also described in Thiede and others (1976), calculates median and mean grain size, skewness, and kurtosis using Inman, and Folk and Ward statistics. The equations used in the calculations are listed in Appendix 1.

Subsurface Data

The subsurface correlations are based on analyses of electric logs, mud logs, and cuttings. Spontaneous potential and resistivity logs are available for about half the wells in the central Willamette Valley and are the major tools used in correlation. Sonic, gamma ray and neutron density logs also were used, when available. Mud logs were important for interpreting correlations in wells with poor electric log definition. Well cuttings from ten wells, on file with the Oregon Department of Geology and Mineral Industries, were examined with a binocular microscope. Lithologic logs were made; cuttings were most helpful for gross correlations and determining the accuracy of mud logs.

TIME SCALE DEFINITION

In 1981, Armentrout proposed changing the correlation of Oregon and Washington biostratigraphic units to world-wide chronostratigraphic units. The provincial usage of the European series-epoch and stage-age



1 after Armentrout (1981)

2 after Rau (1981)

3 Foram stages of the Pleistocene include the Hallian and underlying Wheelerian

4 after Snavely and others (1969) and Rau (1970)

Figure 2: Comparison of the traditional (pre-1980) time scale and the time scale proposed by Armentrout (1981) for the Tertiary rocks of western Oregon and Washington (from Niem and Niem, 1984).

units would be altered for the Eocene and Oligocene as illustrated in Figure 2. More recent publications have included slightly different interpretations of global-provincial correlations (Armentrout and others, 1983; Prothero and Armentrout, 1985; also see Hardenbol and Berggren, 1978). These changes indicate that the global correlation of provincial units is currently undergoing a process of refinement. For this reason, and because the provincial usage is deeply entrenched in the literature, the traditional (pre-1980) correlations (Figure 2) as suggested by Niem and Niem (1984), will be used in this thesis. Provincial foraminiferal stages also will be included to further clarify ages.

REGIONAL GEOLOGY

CENOZOIC HISTORY

The Coast Range and Willamette-Puget Lowlands of western Oregon and Washington, and the Olympic Mountains of Washington, have been a tectonically active marginal basin through much of Cenozoic time (Niem and Niem, 1984). The present tectonic setting and generalized geology is illustrated in Figure 3. The basement of the marginal basin is a thick sequence of basalt which, in western Oregon, ranges in age from early Eocene in the south to middle Eocene in the north (Snavely and Wagner, 1963; Duncan, 1982). Geophysical, geochemical, and stratigraphic evidence, along with age relations and inferred plate motions, indicate these basalts were part of an anomalous seamount province, probably associated with some type of rifting/extension combined with hot spot activity (Snavely and MacLeod, 1977; Simpson and Cox, 1977; Duncan, 1982; Wells and others, 1984). During early to middle Eocene time these seamounts are thought to have clogged an east-dipping subduction zone located in the area of the present Cascade Range. The subduction zone then jumped westward to the present-day inner continental shelf (Snavely and others, 1980; Wells and others, 1984).

A deep forearc basin formed on top of the newly accreted crust. Sediments were probably derived from the uplifted Klamath Mountains to the south, and from rivers flowing through the Klamaths, draining Jurassic-Cretaceous arc complexes in Idaho, northern Nevada and adjacent areas (Heller and Ryberg, 1983). A thick sequence of sedimentary strata was deposited in deltaic, shelf, and submarine fan settings during early to middle Eocene (Fig. 4a). The basin received

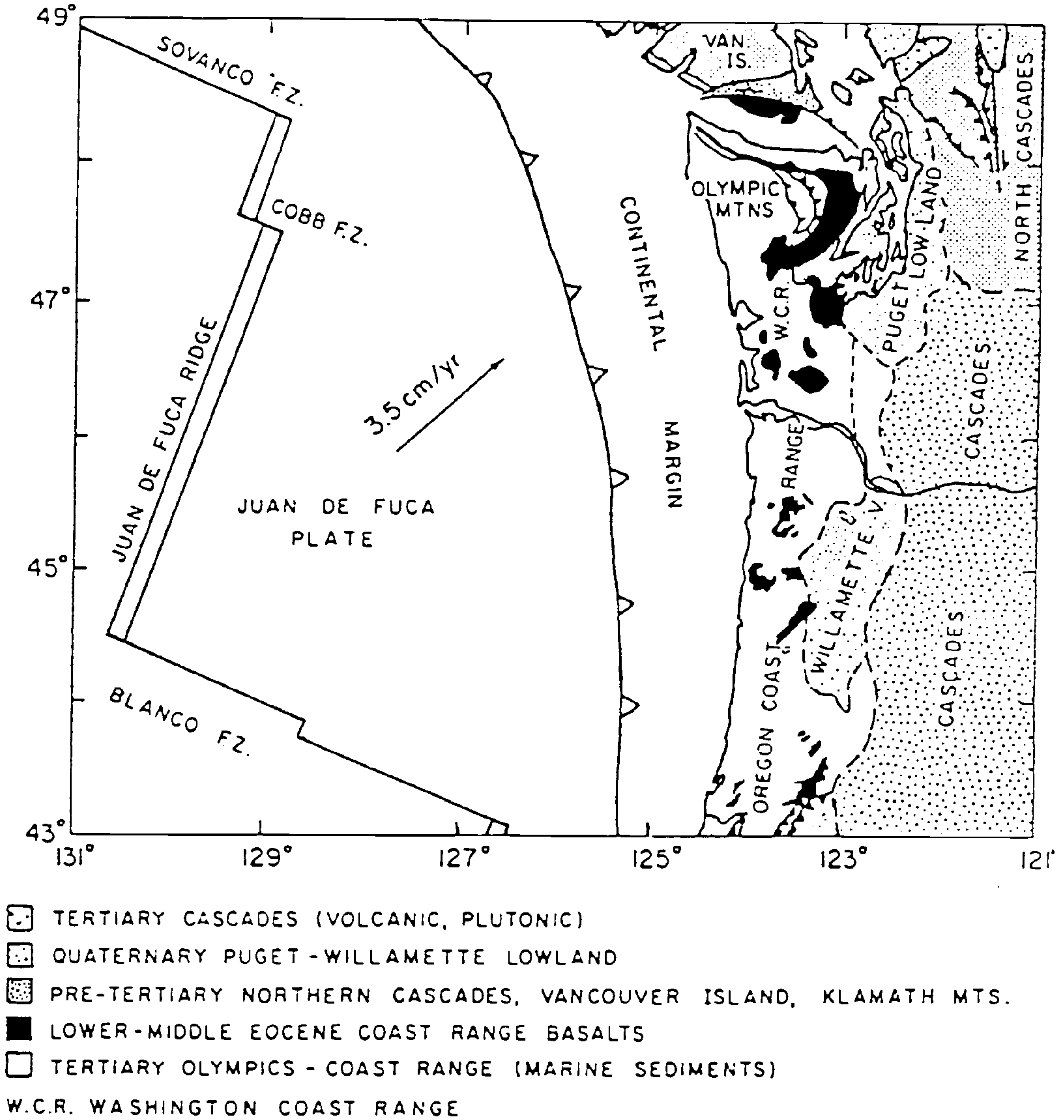


Figure 3: Generalized tectonic and geologic map of western Oregon and Washington (from Niem and Niem, 1984).

marine sediments throughout the Eocene, except around local volcanic centers which formed islands and shoals within the basin (Snavely and Wagner, 1963). Localized uplift and volcanism during late Eocene segmented the basin and reduced the area of marine deposition (Fig. -4b). Pre-late Eocene unconformities are present along the basin margins and volcanic build-ups, whereas conformable sequences are postulated for the deeper parts of the basin. Nearshore and shelf sandstones and siltstones were deposited in the eastern parts of the basin, with siltstones and mudstones being deposited to the west. Cascade arc volcanism was active along the southeastern edge of the basin, and migrated northward throughout the late Eocene and Oligocene time. Intermittent volcanism continued within the northern and western parts of the forearc basin (Snavely and Wagner, 1963). The resulting subaerial to submarine mafic to intermediate lavas, breccias, lapilli tuffs and associated intrusives interfinger with sedimentary rocks of the basin (Niem and Niem, 1984).

During Oligocene time, the southern part of the basin experienced mild regional uplift and the emplacement of gabbroic sills. Marine deposition was restricted to the west flank of the uplift, and to the northern Willamette Valley area (Fig. 4c). In the southern part of the basin, volcanic-rich continental deposits were accumulating (Snavely and Wagner, 1963).

Oblique subduction and associated underthrusting are thought to have occurred during much of the Cenozoic. Evidence from the continental margin suggests transverse movement during late middle to early late Eocene. Renewed underthrusting in middle late Eocene caused uplift and basin segmentation. A period of basin extension is believed

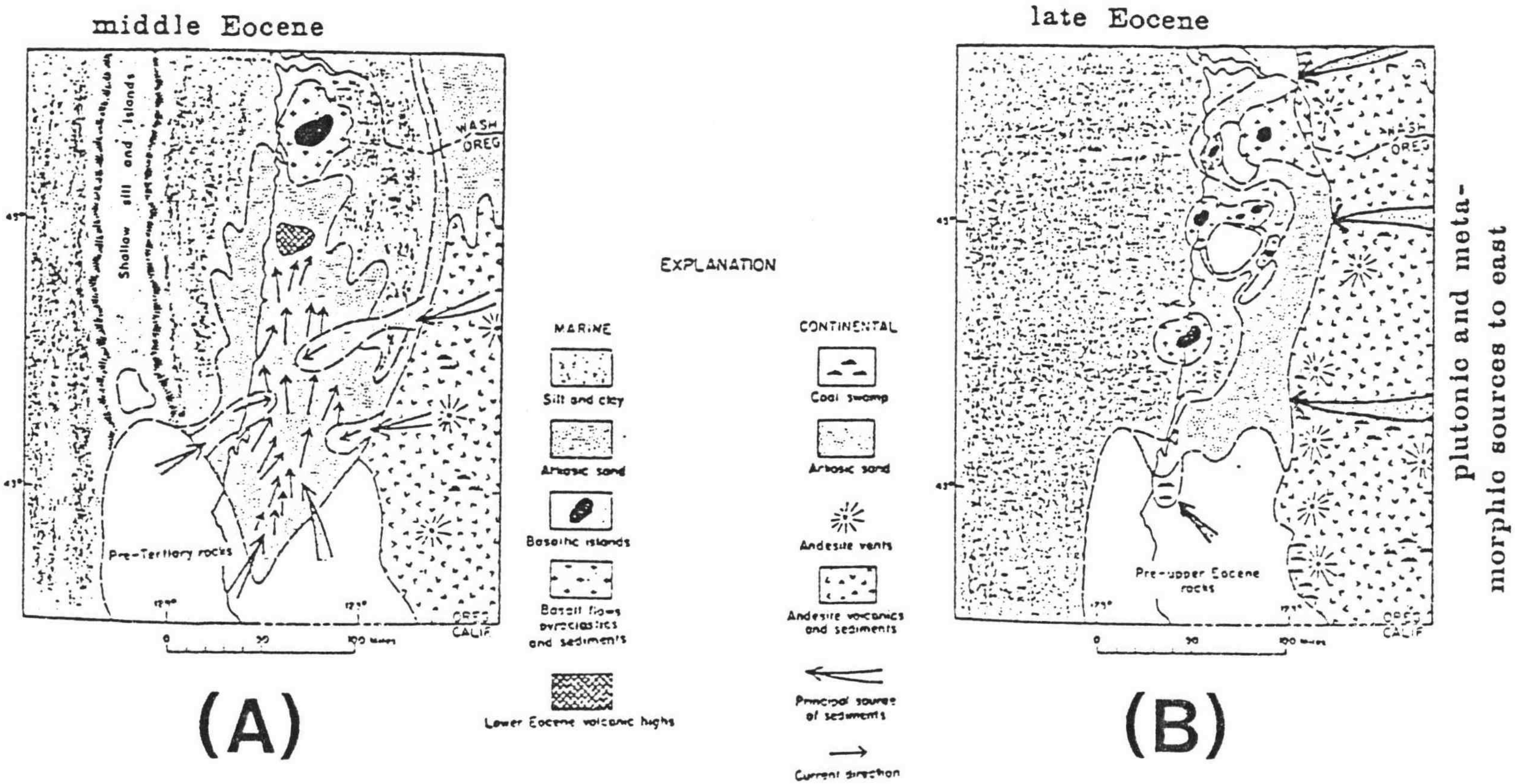


Figure 4: Cenozoic geologic history of western Oregon: (A) middle Eocene; (B) late Eocene; (C) Oligocene; and (D) Miocene (modified from Snavely and Wagner, 1963)

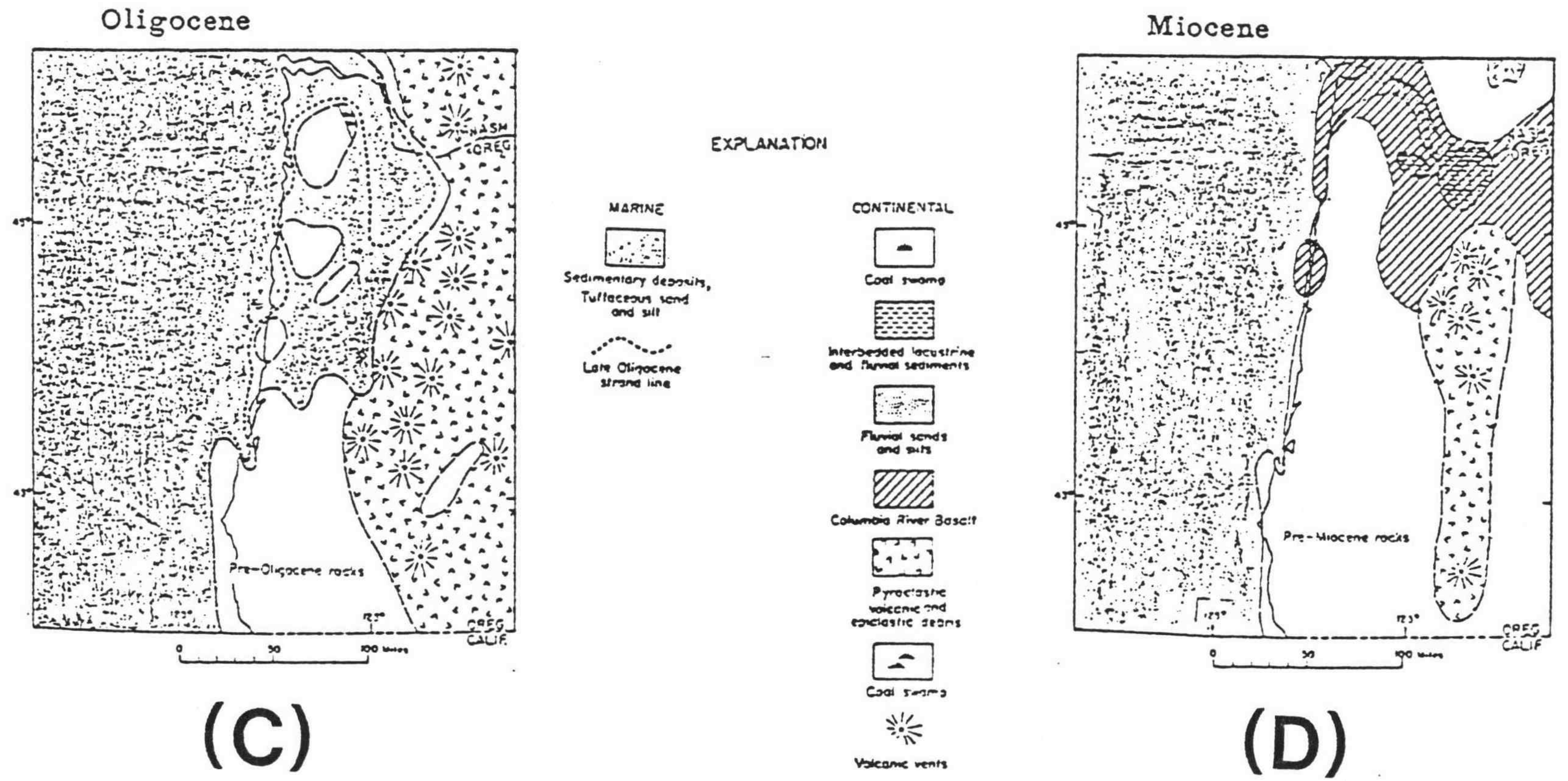


Figure 4 (cont.)

to have occurred from late Eocene to middle Miocene based on extensive intrusions and continuous deposition (Snavely and others, 1980). Wells and others (1984) indicate a reduction of plate convergence rates by one third during this same period.

Renewed underthrusting in middle Miocene is thought to have caused extensive folding and faulting along northeast and northwest structural trends. The resulting uplift shifted marine deposition westward to the present day coastline and continental shelf area (Fig. 4d; Niem and Niem, 1984). Uplift of the Coast Range, combined with downwarping of the Willamete Valley, is thought to have continued well into Pliocene time (Snavely and others, 1977).

During the middle Miocene, the Columbia River Basalts were erupted from vents in western Idaho and eastern Washington and Oregon. These flood basalts flowed over much of eastern Oregon and Washington, and down an ancestral Columbia, into the northern Willamette Valley (Snavely and Wagner, 1963). Basalts also may have flowed through topographic lows in the subdued Miocene Coast Range and been deposited along the coast as far south as Waldport (Fig. 4d; Beeson and others, 1979).

Paleomagnetic data from volcanic and sedimentary rocks of the marginal basin indicate western Oregon has been rotated more than 50° clockwise since middle Eocene (Simpson and Cox, 1977; Beck and Plumley, 1980; Magill and others, 1981) All but 29° was apparently accomplished before intrusion of the Marys Peak sill 30 mya (Oligocene) (Clark, 1969). Rotation may have been the result of: (1) subduction and plate reorganization during accretion of the seamount terrane; (2) basin and range extension; and/or (3) shearing caused by oblique subduction (Simpson and Cox, 1977; Magill and others, 1981).

EOCENE STRATIGRAPHY

The Eocene stratigraphy of the south and central parts of the western Oregon Cenozoic marginal basin is somewhat controversial. It is discussed in some detail in order to outline basin history prior to deposition of the Spencer Formation, and to clarify the nomenclature used in this study. In northwestern Oregon, the stratigraphic nomenclature is currently being redefined based on detailed surface and subsurface studies initiated after the discovery of the Mist gas field in 1979 (Newton, 1979). Readers are referred to Van Atta (1971), Niem and Van Atta (1973), Niem and others (1985), Armentrout and Suek (1985) and Rarey (1985) for more detailed discussions of the stratigraphic section of northwestern Oregon.

The Siletz River Volcanic Series

The Siletz River Volcanic Series presumably forms the basement throughout the central Oregon Coast Range. The thickness of the series is estimated to be 10,000 feet, with areas near former volcanic centers up to 20,000 feet thick (Snavely and others, 1968). The upper contact of the Siletz River Volcanics is an unconformity and the basal contact is nowhere exposed.

Within the study area, this thick sequence of basalts is exposed in a fault block west of Corvallis and an uplift west of Dallas (Plate I). The Siletz River Volcanics consist of submarine pillow lavas, amygdaloidal basalt flows, flow breccias and minor interbedded tuffaceous siltstones. The basalts are principally dark greenish gray, aphanitic to finely crystalline, and tholeiitic to olivine tholeiitic in composition (Snavely and others, 1968). Chlorite, zeolite, and calcite formed by secondary alteration are abundant (Vokes and others, 1954).

An upper thin-bedded tuffaceous member, named the Kings Valley Siltstone, conformably overlies and possibly interfingers with the volcanics. Exposures of these tuffaceous siltstones and water-laid tuffs are found in Kings Valley, northwest of Corvallis. The member thickness has been estimated to be 3,000 feet (Vokes and others, 1954; Penoyer and Niem, 1975).

The Siletz River Volcanics are thought to have originated primarily as submarine eruptions from oceanic volcanic centers. The Kings Valley Siltstone represents a late pyroclastic phase of Siletz River volcanism (Vokes and others, 1954). This tuffaceous unit may have been deposited at the same time as the upper Siletz River alkalic basalts (pillows, flows, and breccias, with minor tuffaceous interbeds), which crop out near Ball Mountain west of Valsetz (Snavely and others, 1968).

The Siletz River Volcanic Series is largely early Eocene in age, with lower flows as old as latest Paleocene (Snavely and Vokes, 1949). Flows near Ball Mountain and immediately beneath the Yamhill in the Mill Creek area may be middle Eocene (Ulatisian) in age (Snavely and others, 1968; McWilliams, 1973; Duncan, 1982). Microfossils indicate a middle Eocene (Ulatisian) age for the Kings Valley Siltstone (Rau _in_ Snavely and others, 1968).

Other basaltic units presumed to form the basement of the Oregon and Washington Coast Ranges include the Roseburg Volcanics to the south, the lower Tillamook Volcanics in northwestern Oregon, and the

Crescent Volcanics in southwest Washington (Fig. 5) (Snavely and Wagner, 1963; Snavely and others, 1968, 1970; Beaulieu, 1971; Baldwin, 1975; Wells and others, 1984; Molenaar, 1985). Although these units are generally considered correlative to the Siletz River Volcanics, Duncan (1982) found that crystallization ages decrease from approximately 62 My in the Roseburg area to 49 My for the Crescent Volcanics near the Grays River in southwestern Washington.

Early and Middle Eocene Stratigraphic Problems

The basement volcanics are overlain by a thick section of forearc sedimentary rocks. Several conflicts exist in the stratigraphic nomenclature of these lower and middle Eocene strata in the southern part of the basin (Roseburg, Drain, Elkton area). Diller (1898) originally divided this structurally complex sequence of strata into the Umpqua and overlying Tyee Formations. The Umpqua is present south of Reedsport, and the Tyee has been mapped as far north as Salem (Fig. 6; Snavely and Vokes, 1949; Vokes and others, 1951, 1954; Baldwin, 1955; Wells and Peck, 1961).

In 1965, Baldwin subdivided the Umpqua into the Roseburg, Lookingglass and Flournoy Formations (Fig. 7; also see Baldwin 1974, 1975). Baldwin (1975) also stated that Tyee strata only extend north to the Siuslaw River. Middle Eocene sedimentary rocks to the north were included in the older Flournoy rather than the overlying Tyee Formation (Fig. 6).

Molenaar (1985) favored retaining the name Umpqua Formation for sedimentary rocks below the Tyee, and using four of five members from Baldwin's Roseburg, Lookingglass and Flournoy Formations to subdivide the Umpqua (Camas Valley, White Tail Ridge, Tenmile and Bushnell Rock

Figure 5: Correlation of Tertiary strata in western Oregon. Data from Armentrout and others (1983), Vokes and others (1954), and Rarey (1985).

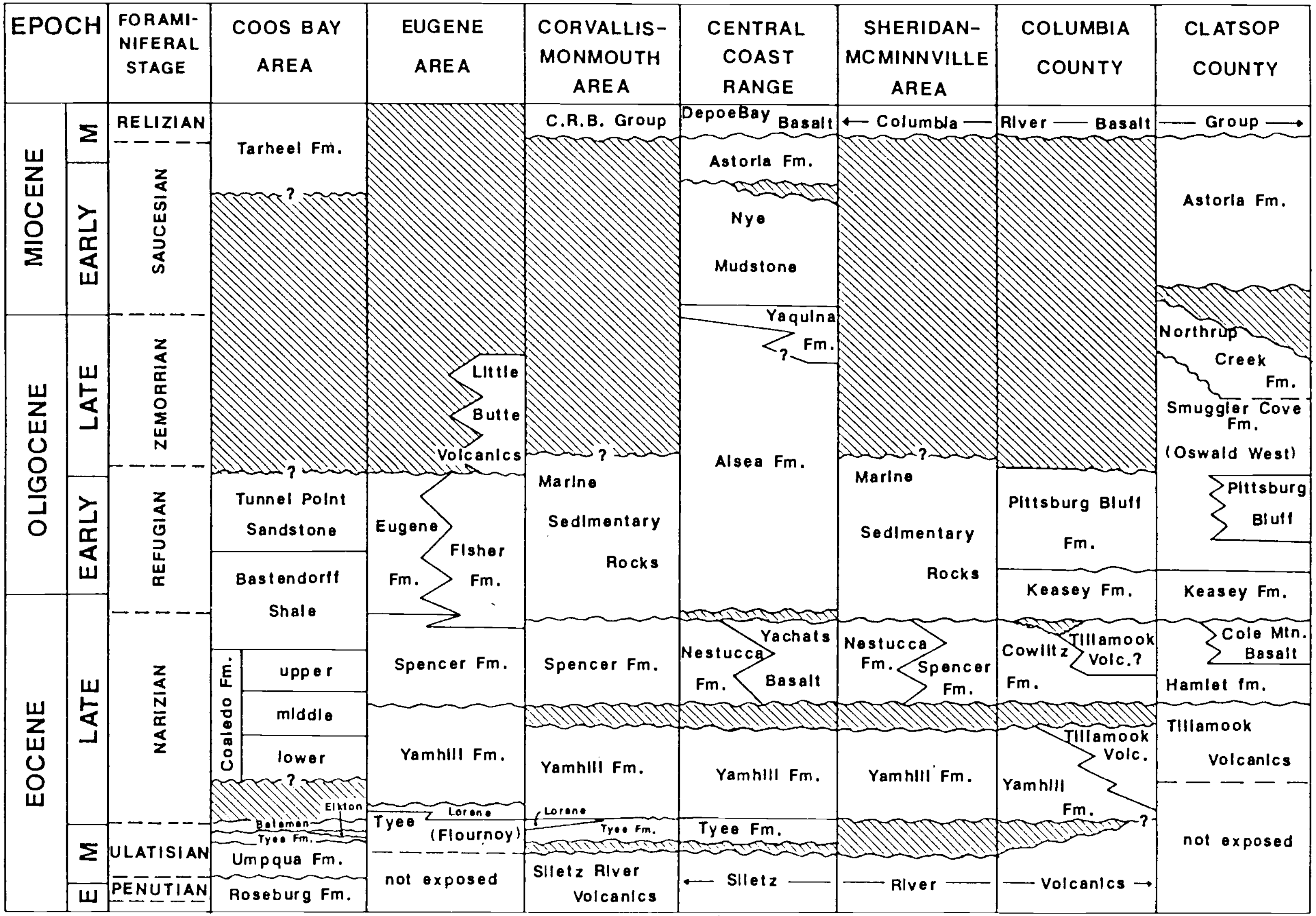

EPOCH
FORAMINIFERAL STAGE
COOS BAY AREA
EUGENE AREA
CORVALLIS-MONMOUTH AREA
CENTRAL COAST RANGE
SHERIDAN-MCMINNVILLE AREA
COLUMBIA COUNTY
CLATSOP COUNTY
MIOCENE
M
EARLY
OLIGOCENE
LATE
EARLY
EOCENE
LATE
M
E
RELIZIAN
SAUCESIAN
ZEMORRIAN
REFUGIAN
NARIZIAN
ULATISIAN
PENUTIAN
Tarheel Fm.
?
?
Tunnel Point Sandstone
Bastendorff Shale
Coaledo Fm.
upper
middle
lower
?
Elkton
Bateman
Tyee Fm.
Umpqua Fm.
Roseburg Fm.
Little Butte Volcanics
Eugene Fm.
Fisher Fm.
Spencer Fm.
Yamhill Fm.
Tyee
Lorane
(Flournoy)
not exposed
C.R.B. Group
?
Marine Sedimentary Rocks
Spencer Fm.
Yamhill Fm.
Lorane
Tyee Fm.
Siletz River Volcanics
DepoeBay Basalt
Astoria Fm.
Nye Mudstone
Yaquina Fm.
?
Alsea Fm.
Yachats Basalt
Nestucca Fm.
Yamhill Fm.
Tyee Fm.
← Siletz
← Columbia
?
Marine Sedimentary Rocks
Nestucca Fm.
Spencer Fm.
Yamhill Fm.
River
River — Basalt
Pittsburg Bluff Fm.
Keasey Fm.
Cowlitz Fm.
Tillamook Volc.?
Tillamook Volc.
Yamhill Fm.
?
Volcanics →
— Group →
Astoria Fm.
Northrup Creek Fm.
Smuggler Cove Fm.
(Oswald West)
Pittsburg Bluff
Keasey Fm.
Cole Mtn. Basalt
Hamlet fm.
Tillamook Volcanics
not exposed

Figure 5

22

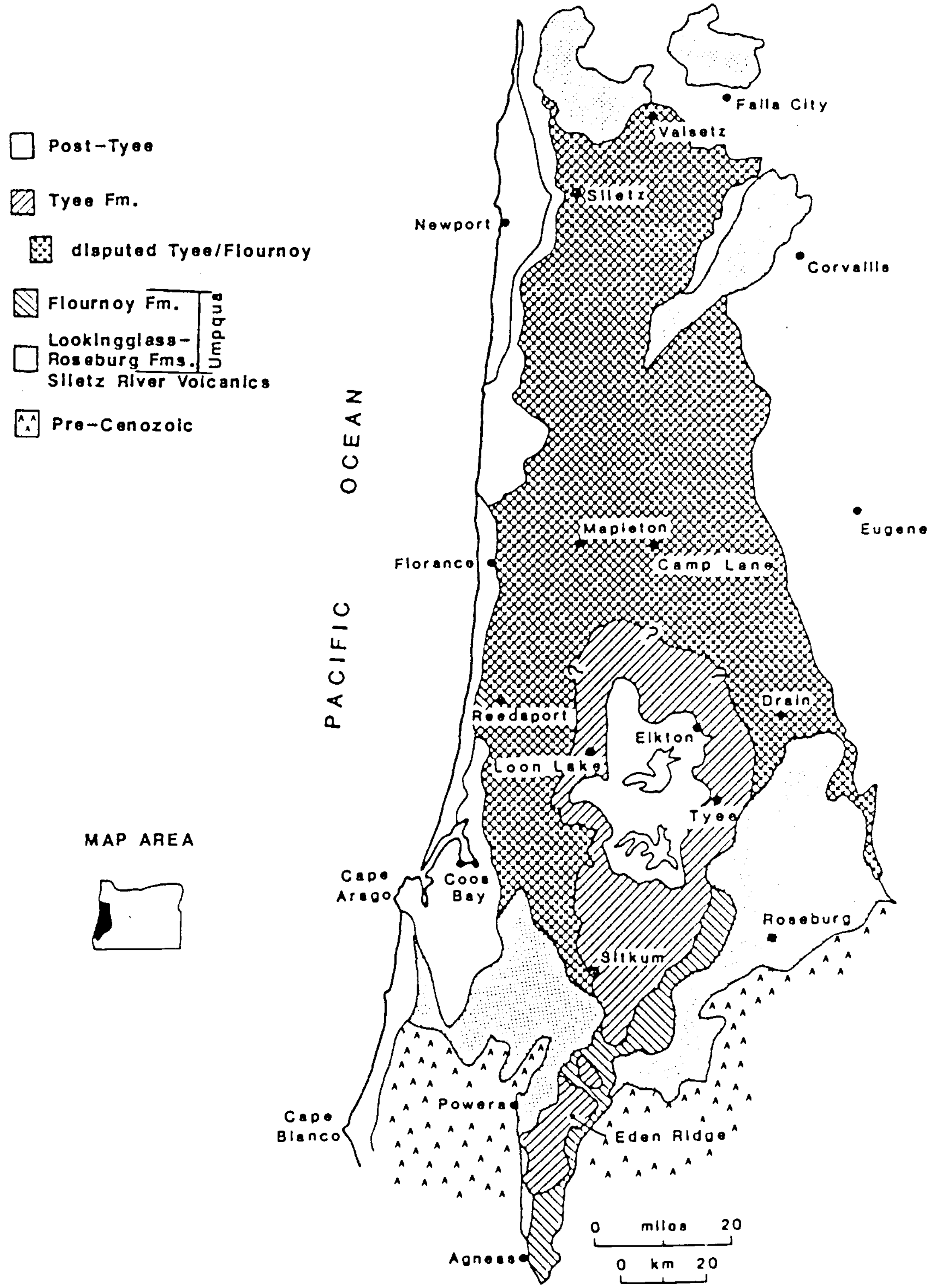


Figure 6: Simplified geologic map of early and middle Eocene strata in the Oregon Coast Range (after Chan and Dott, 1983).

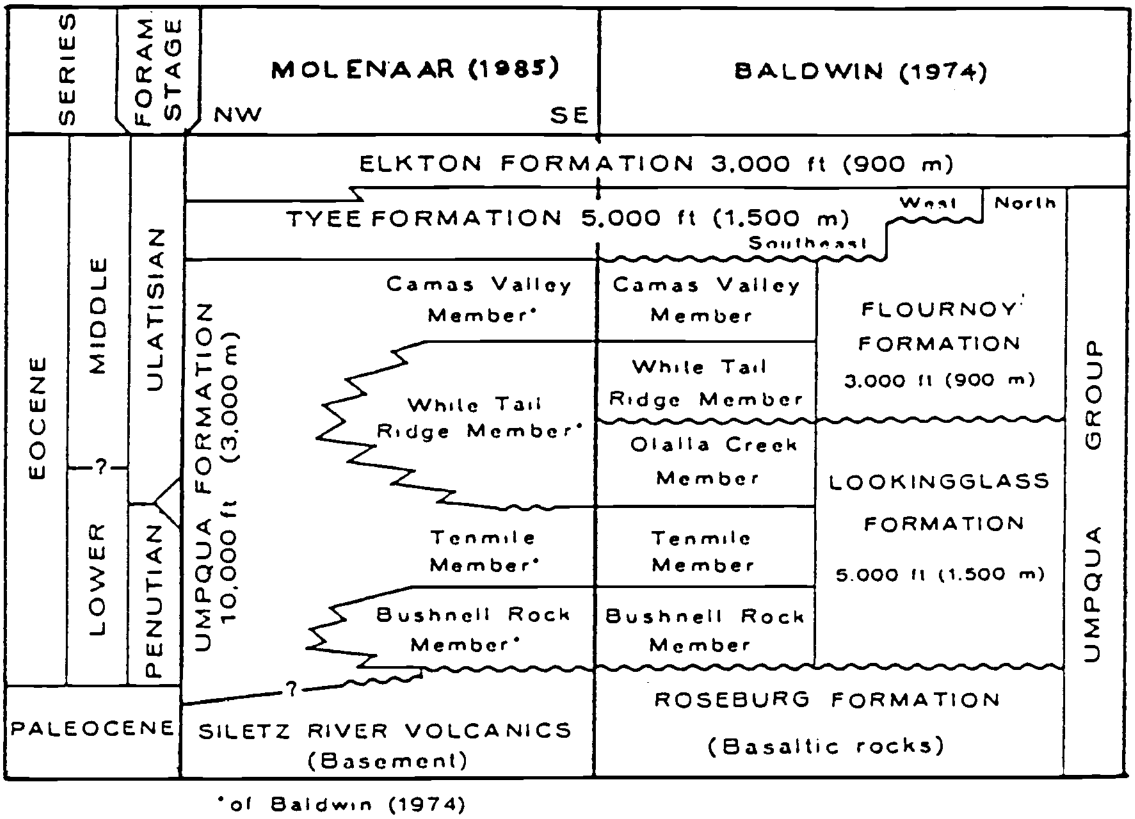


Figure 7: Comparison of terminology and contact relations of lower and middle Eocene stratigraphic units of Baldwin (1974) and Molenaar (1985) (from Molenaar, 1985).

members; Fig. 7). Furthermore, Molenaar believed that middle Eocene rocks to the north correlate with the younger Tyee as originally mapped, and not the Flournoy Formation.

Structural complexities, thick vegetation, similar lithologies and close age relations prohibit a clear-cut resolution to these terminology problems at this time. In this study the term Tyee Formation will be used to describe the middle Eocene sediments in the study area. However, the reader should keep in mind Baldwin's contention that these rocks are actually slightly older and correlate with the Flournoy Formation.

The Umpqua Formation/Group

The lower to middle Eocene Umpqua sedimentary rocks consist of approximately 10,000 feet of mudstones, siltstones, sandstones, and lesser amounts of conglomerates (Baldwin, 1974). The Umpqua does not extend north into the study area (assuming strata mapped as Tyee are not Flournoy as Baldwin (1975) proposed). Deposition of the Umpqua in the south is thought to have been contemporaneous with the eruption of the uppermost Siletz River Volcanics and deposition of the Kings Valley Silstone in the central part of the basin (Corvallis, Dallas area; Vokes and others, 1954).

The Tyee and Elkton Formations

The Tyee Formation overlies Umpqua strata in the south and the Siletz River Volcanics in the central part of the basin (Fig. 5). The basal contact is considered to be an angular unconformity at the basin margins (Baldwin, 1974, 1975), but conformable in deeper parts of the basin (Molenaar, 1985). In the central part of the basin, where the Tyee rests on Siletz River Volcanics, the unconformity is thought to be localized, occurring where Tyee beds lap onto topographic highs (Snavely and others, 1964). The Tyee Formation (originally mapped as the Burpee in the Newport area by Schenk, 1927, and Vokes and others, 1949) consists of as much as 6,000 feet of middle Eocene (Ulatisian) sediments (Baldwin, 1961; Vokes and others, 1951, 1954; Snavely and others, 1964).

The southernmost Tyee strata (Eden Ridge and Sitkum area) are primarily marine and nonmarine micaceous sandstones and conglomerates, with local coal beds and peaty mudstones. Farther to the north, rhythmically bedded fine- to coarse-grained micaceous arkosic and lithic sandstones, siltstones, and mudstones are the dominant rocks. Beds thin and silt content generally increases northward (Baldwin 1974, 1975; Lovell, 1969; Chan and Dott, 1983; and Molenaar, 1985). The Tyee Formation is inferred to have been deposited in a sand-rich delta to submarine fan (Chan and Dott, 1983, 1986) or submarine ramp (Heller, 1983). Paleocurrent measurements indicate transport from south to north (Snavely and others, 1964).

The study area is located near the northern part of the Tyee submarine fan system (Molenaar, 1985). Rhythmically bedded units range in thickness from 0.5 foot to 12 feet, thinning northward. The base of each bed is typically medium- to coarse-grained, highly micaceous and arkosic. Sandstones grade upward through fine-grained sandstone to siltstone and, at some places, mudstone. Plant fragments are abundant in the siltstones and mudstones. In the Albany-Corvallis area, the Tyee has been described as consisting predominantly of siltstone with interbedded sandstone. Rare beds containing subangular basalt clasts at the base, and fining upwards to dark greenish grey tuffaceous silty sandstone have also been mapped as Tyee in this area (Vokes and others, 1954).

In the study area, the Tyee Formation crops out as far north as the southern part of the Dallas and south-central part of the Valsetz Quadrangles (Plate I). The overall section thickness, estimated to be 4,000 feet in the southern part of the study area, is thought to decrease northward to 2,000 feet (Vokes et al, 1954; Baldwin, 1964). Tyee beds are thought to grade upward (Baldwin, 1964) and northward (Snavely and others, 1964) into the Yamhill Formation (fig. 5).

The Elkton Siltstone lies conformably and gradationally above rhythmically bedded Tyee strata (Baldwin, 1961). Near Elkton, the thickness is estimated to be 3,000 feet. The dominant lithologies are mudstone and siltstone with some sandstone lenses (Baldwin, 1974). The Elkton has been correlated with the Lorane Siltstone (considered an upper member of the Tyee), and with the lower part of the Yamhill Formation (Vokes and others, 1954; Bird, 1967; Snavely and others, 1969; Baldwin, 1974). In the Eugene area, the Lorane Siltstone is much thinner than the Elkton (600-700 feet; Gandera, 1977). A section of the Lorane may also be present in the southern part of the study area (Vokes and others, 1954). The Lorane is similar to the Elkton, consisting dominantly of siltstone and mudstone, with local fine-grained sandstone lenses. Plant debris, and alternating dark and light laminations are common within the section. Foraminifera indicate a middle to early late Eocene age (Ulatisian and possibly lower Narizian) for the Elkton-Lorane beds (Rau in Baldwin, 1961; Stewart in Vokes and others, 1951, Stewart, 1957).

Alternatively, Baldwin (1975) suggested that the Lorane is older than the Elkton Siltstone, a conclusion based on his correlation of the middle Eocene beds north of the Siuslaw River with the Flournoy Formation rather than the Tyee. Microfossil similarities between these units are thought to be controlled mainly by facies changes and not age differentials.

The Yamhill Formation

The Yamhill Formation consists primarily of faintly bedded medium to dark gray mudstones and siltstones with thin interbeds of arkosic, glauconitic and basaltic sandstone (Baldwin and others, 1955; Baldwin, 1964; Al-Azzaby, 1980; Wells and others, 1983). In the Dallas-Falls City area, an angular unconformity separates the Yamhill and either the Siletz River Volcanics or the Tyee Formation. The unconformable contacts are apparently the result of onlapping a volcanic high, while farther out in the basin the Tyee grades up into the Yamhill (Baldwin and others, 1955; Baldwin, 1964). Farther north in the Tualatin Valley, the Yamhill concordantly overlies Tillamook volcanics (Siletz River Volcanics of Wells and others, 1983, Rarey, 1985) (Schlicker and Deacon, 1967).

The Yamhill crops out only in the northern part of the study area (Plate I). Immediately north of the thesis area, along Mill Creek, the Yamhill type section includes sandstones near the base. The basal 500 feet consists of thin bedded, fine-grained sandstone and siltstone. Beds of basalt conglomerate and breccia, sandy limestone, and lime--cemented sandstone containing abundant abraded shells are present locally, where the Yamhill lapped onto the volcanic high. These strata are overlain by 500 feet of massive to thick-bedded basaltic sandstone.

The sandstones grade upward into a 4,000 foot thick section of faintly bedded siltstone and mudstone typical of the Yamhill Formation (Baldwin and others, 1955).

The lower 1,000 feet of siltstone and sandstone has been dated as late middle to early late Eocene, and may be correlative to the Elkton and Lorane Siltstones (Fig. 5; Stewart in Baldwin and others, 1955; Baldwin, 1964). The upper Yamhill has been dated as early late Eocene (latest Ulatisian to early Narizian) (Rau in Baldwin, 1964). Based on microfossils, Gaston (1974) estimated a bathyal depth for the lower part of the Mill Creek section, shallowing to neritic for the middle and upper parts.

In the eastern part of study area, a thick section of Yamhill has been delineated in the subsurface by Bruer and others (1984). Well correlations indicate that the Tyee thins to roughly 200 foot and is overlain by about 3,400 feet of Yamhill. A 1,900 feet thick sandstone, the Miller sandstone member, is included within the Yamhill.

In northwestern Oregon, the definition and extent of the Yamhill Formation is not clear. The Yamhill section described by Al-Azzaby (1980) in Washington County includes thick layers of mudstone, shale, and siltstone, with relatively minor amounts of fine-grained sandstones commonly containing glauconite. However, these Yamhill strata overlie the Tillamook Volcanics, which is in conflict with the proposed restriction of the Yamhill to the mudstones which overlie Siletz River Volcanics and interfinger with Tillamook Volcanics (Wells and others, 1983). In the subsurface, Bruer and others (1984) also included the mudstone unit between the Tillamook Volcanics and the Cowlitz Formation in the Yamhill. Rarey (1985) and Mumford (in prep.) show that microfauna in this section are different from those at the type Yamhill section along Mill Creek, and are more analogous to those in the Nestucca Formation. They believe these mudstones overlying the Tillamook Volcanics should be included in their informally defined late Eocene Hamlet formation (Niem and Niem, 1985).

The thickness of the Yamhill Formation is variable. Thickness estimates include 5,000 feet in the Mill Creek area, and 4,000 feet in the southern Yamhill Valley. Southward near Dallas beds thin substantially, then thicken in the structural basin occupied by the Little Lukiamute River (Baldwin, 1964). To the north, Schlicker and Deacon (1967) estimated a 2,000 foot thick section in the Yamhill quadrangle, and Al-Azzaby (1980) measured a 4,800 feet thick section farther north in southern Washington County. The thickness northeast of Newport is thought to be greater than 2,000 feet (previously mapped as lower Toledo by Vokes and others, 1949; Snavely and others, 1969).

The Coaledo, Spencer, and Cowlitz Formations

During the latest Eocene the marginal basin was segmented into three major depocenters. The Coaledo Formation was deposited to the south near Coos Bay, Spencer deposition extended in a north-south band in the east-central part of the basin, and the Cowlitz Formation was deposited to the north (Fig. 5).

The Coaledo Formation was deposited rapidly as a delta and coastal swamp complex in warm shallow seas (Dott, 1966; Baldwin, 1974; Baldwin and Beaulieu, 1973; Dott and Bird, 1979). The Coaledo Formation has been divided into three members. The upper and lower shallow water, coal-bearing sandstone members are separated by a middle, deeper water mudstone member. The sandstones are fine- to coarse-grained, tuffaceous, feldspathic and lithic arenites. Thin beds of siltstone and mudstone, commonly containing carbonaceous material and coal, are interbedded with the sandstones.

The Coaledo has been dated as latest Eocene (upper Narizian) and is approximately 6,000 feet thick (Baldwin and Beaulieu, 1973). The Coaledo Formation is conformably overlain by the 2,900 foot thick Bastendorff Shale. The Bastendorff Shale has been dated as mostly late Eocene with the upper part early Oligocene (Refugian) (Stewart, 1957), and as entirely late Eocene by (McKeel, 1972).

As will be discussed in more detail later, the Spencer Formation has been subdivided into a lower, primarily sandstone member, and an upper siltstone and mudstone member (Thoms and others, 1983). The lower sand-rich unit is thought to have been deposited in a strandline to middle shelf environment (Al-Azzaby, 1980; Thoms and others, 1983). The upper siltstone unit may have been deposited in a somewhat deeper shelf setting at upper bathyal depths (Schlicker, 1962; Thoms and others, 1983).

The estimated thickness of the Spencer Formation varies greatly along its outcrop. From the Comstock area to Eugene, and on to Corvallis, the Spencer has been reported to thicken from about 250 feet to 2,500 feet, to 4,500 feet. The Spencer is thought to thin northward from Corvallis to about 2,500 feet near Dallas, and to 1,600 feet in Yamhill and Washington Counties (Vokes and others, 1954; Hoover, 1963; Baldwin, 1964; Thoms and others, 1983).

Thick late Eocene pyroclastic andesitic ash flows and breccias present to the south are included in the lower Fisher (Hoover, 1963), and the Colestin Formations (Wells, 1956; this also includes the

Calapooya Formation of Wells and Waters, 1934). These units record early Western Cascades volcanism on the southeast margin of the forearc basin, which contributed pyroclastic debris to the Coaledo and Spencer Formations (Baldwin, 1974; Niem and Niem, 1984). The lower Fisher overlies the Spencer to the south and may be partially correlative to the upper Spencer siltstone to the north (Beaulieu, 1971).

The Cowlitz Formation crops out in northwestern Oregon and southwestern Washington. In the Upper Nehalem River area, Warren and Norbisrath (1946) divided the Cowlitz into four members; (1) a basal basalt conglomerate; (2) a lower shale/siltstone member; (3) a sandstone member; and (4) an upper shale/mudstone. Van Atta (1971) found a similar stratigraphy; however, he pointed out that the basal conglomerate was discontinuous and local. Recent work by Rarey (1985), Niem and others, (1985), and Mumford (in prep.) has separated the two lower members from the Cowlitz Formation, and included them in the informally defined Hamlet formation. This restriction of the Cowlitz Formation to the sandstone and upper mudstone makes the Cowlitz section in northwestern Oregon similar to the Cowlitz of Washington as originally defined by Weaver (1937), Henricksen (1950), and later by Wells (1981). The restricted Cowlitz unconformably overlies the Hamlet formation (Rarey, 1985; Niem and others, 1985). The lower sandstone (named the Clark and Wilson) is the gas reservoir at the Mist gas field (Newton, 1979). It consists primarily of fine-grained arkosic sandstone with silty sandstone near the base (Niem and others, 1985). Cowlitz sandstones are interpretted to be largely storm-dominated, shallow marine shelf to nearshore deposits (Van Atta, 1971; Timmons, 1981; Jackson, 1983; Shaw, 1986). The sequence of sandstones may represent a prograding coastal plain with delta influence (Alger, 1985). An alternative hypothesis is that deposition occurred in a narrow seaway between basaltic highlands at depths extending to upper bathyal. The upper siltstone member is thought to have been deposited at bathyal depths (Niem and others, 1985).

Late Eocene basic volcanic flows and breccias associated with the Cowlitz Formation in northwestern Oregon were originally thought to be interbeds of Goble Volcanics (Wilkinson and others, 1946; Van Atta, 1971). However, recent mapping and chemical analyses suggest they are in fault contact with the Cowlitz, and correlate with the Tillamook Volcanics (Jackson, 1983).

The Nestucca and Toledo Formations

Deeper water sediments were deposited to the west of the Spencer and Cowlitz Formations. The Nestucca Formation unconformably overlies Siletz River Volcanics, Tyee, or Yamhill strata. It consists primarily of thin-bedded tuffaceous siltstones with interbeds of massive mudstone, and arkosic, basaltic, and glauconitic sandstones (Snavely and others, 1969). Basalt flows, breccias, and pyroclastic rocks, which closely resemble the Tillamook Volcanics, are locally abundant (e.g., Yachats Basalt; Armentrout and others, 1983). Basaltic sandstones and basaltic boulder conglomerates are interbedded with basalt flows near volcanic centers. The Nestucca thickness ranges from 800 to 8,000 feet near the coast (Snavely and Vokes, 1949; Snavely and others, 1969), and is about 2,000 feet in the Sheridan-McMinville area (Baldwin and others, 1955). Foraminifera indicate the Nestucca is latest Eocene to early Oligocene (upper Narizian to lower Refugian), with bathyal depths of deposition (Snavely and others, 1969). However, macrofossils from sandstones adjacent to volcanic centers indicate shallow water deposition (Snavely and Vokes, 1949).

The Toledo Formation was originally mapped along the coast from Yaquina to Heceta Head by Vokes and others (1949). The nomenclature has since been changed. The lowermost Toledo is now included in the Yamhill Formation, and the middle part is included in the Nestucca Formation (Snavely and others, 1969).

OLIGOCENE STRATIGRAPHY

Marine deposition was shifted to the north and west by mild regional uplift in the south during early Oligocene (Refugian). Nonmarine andesitic to dacitic pyroclastic units and basaltic lavas of the Little Butte Volcanics and Fisher Formation were deposited in the foothills of the western Cascades. These deposits interfinger with shallow marine tuffaceous sandstones and siltstones of the Eugene Formation in the central Willamette Valley (Beaulieu and others, 1974; Niem and Niem, 1984). Within the northeastern part of the thesis area correlative units are poorly exposed and have been mapped as undifferentiated Eocene and Oligocene sediments. This unit contains interbedded tuffaceous sandstones and siltstones (Vokes and others, 1954; Baldwin, 1964).

Farther north and west, deeper water tuffaceous siltstones and mudstones of the Keasy, Oswald West (Smuggler Cove of Rarey, 1985 and Niem and others, 1985), and Alsea (upper Toledo of Vokes and others, 1949) Formations were deposited (Niem and Niem, 1984). The Pittsburg Bluff Formation was deposited over the Keasey in delta to outer shelf depositional settings in the northern part of the basin (Van Atta, 1971; Newton and Van Atta, 1976). During latest Oligocene (Zemorrian) the strandline shifted to the west and northwest flanks of the present--day Coast Range. This deposition is recorded by the Yaquina Formation (Niem and Niem, 1984).

INTRUSIVE ROCKS

Dikes, sills, and sill-like intrusive bodies of gabbro and basalt are present throughout the Oregon Coast Range. Within the study area intrusives are particularly abundant in the Monroe quadrangle and in the Falls City area, commonly occurring along formational contacts (Vokes and others, 1954; Baldwin, 1964). The intrusives are fine- to medium-crystalline with porphyritic diabasic textures (Vokes and others, 1954). Baldwin (1964) reports some intrusions of dioritic composition. The intrusion of sills is thought to have occurred by parting along bedding planes and uplift of the sedimentary cover with only local and minor deformation. The intruded sedimentary country rock shows minor baking. The lack of pervasive banding or preferred orientation of crystals indicate little movement during cooling (Baldwin, 1964).

The intrusions cut Siletz River Volcanics, Tyee, and Spencer strata, indicating a post-Eocene emplacement. In the Eugene area intrusives cut middle Oligocene sediments and are surrounded by younger basalts of Miocene(?) age, implying a late Oligocene age (Vokes and others, 1951).

STRUCTURE OF THE STUDY AREA

The thesis area lies on the east flank of the Coast Range anticlinorium, an extensive uplift forming the central part of the Oregon Coast Range. Within the study area a broad anticlinal fold plunges northeastward across the Monroe and Corvallis Quadrangles.

Immediately northwest, a northeast-plunging syncline is present in the Dallas-Valsetz area. Sedimentary beds generally dip eastward at 5° to 15°. However, dips are locally variable as a result of faulting, intrusions, and landsliding (Vokes and others, 1954; Baldwin, 1964). The dip directions differ slightly between Spencer and Tyee beds, as a result of uplift and folding prior to Spencer deposition (Baldwin, 1964).

Because of poor exposure faults cannot be directly traced at the surface, but must be distinguished by lineaments on areial photographs, juxtaposition of strata, steeply dipping beds adjacent to the fault zone, and opposing dips within fault blocks (Bela, 1979). The Corvallis fault is the major fault in the area and has been traced for about 35 miles, trending N50°E from within the Coast Range to north of Corvallis. The Corvallis fault is actually a zone of steep shears up to 500 feet wide which includes blocks of sandstone and basalt (Lawrence and others, 1980). The amount offset, sense of offset, and timing of movement are poorly defined. Vokes and others (1954) believed the fault had several thousand feet of reverse(?) offset during early to middle Eocene as evidenced by an angular unconformity between the Tyee and Spencer beds adjacent to the fault zone. Lawrence and others (1980) believed the fault to be an east-dipping normal fault, possibly with a component of strike-slip motion. The vertical displacement was estimated to be at least 5,000 feet, with movement occurring during late Eocene and during reactivation after the Oligocene intrusive episode. No evidence has been found of Quaternary deposits cut by the Corvallis fault, idicating that the fault is not currently active (Bela, 1979).

The Corvallis fault, as drawn by Vokes and others (1954) contains problems in the bend near the Philomath area. Lawrence and others (1980) estimated 5,000±2,000 feet of displacement near Mary's Peak and in Lewisburg. However, as mapped by Vokes and others (1954), only several hundred feet of offset was present south of Philomath. Major lineations in LANDSAT, SLAR, and U-2 high flight photography indicate the fault may be offset by younger structures in this area as indicated in Figure 8 (Lawrence *in* Bela, 1979; Lawrence and others, 1980).

The Kings Valley fault which also trends northeast, is thought to be a steeply west-dipping normal fault with 700±100 feet of vertical offset (Lawrence and others, 1980). Based on magnetic anomalies, Bromley and Snavely (1964) believed the offset may have been as much as 2,000 feet. Displacement on the fault dies out to the southwest. The motion postdates emplacement of the Mary's Peak sill at 30 mya (Lawrence and others, 1980). The Kings Valley fault is offset by several smaller northwest-trending faults (Vokes and others, 1954). The Glenbrook fault is the continuation of a northeast-trending normal fault mapped in the Elmira quadrangle to the south; displacement is thought to be less than that of the Corvallis fault (Vokes and others, 1954). Steep-limbed drag folds are present on the downthrown sides of both the Corvallis and Glenbrook faults (Vokes and others, 1954; Gandera, 1977). Many other minor faults present within the study area are associated with intrusions or larger faults (Bela 1979).

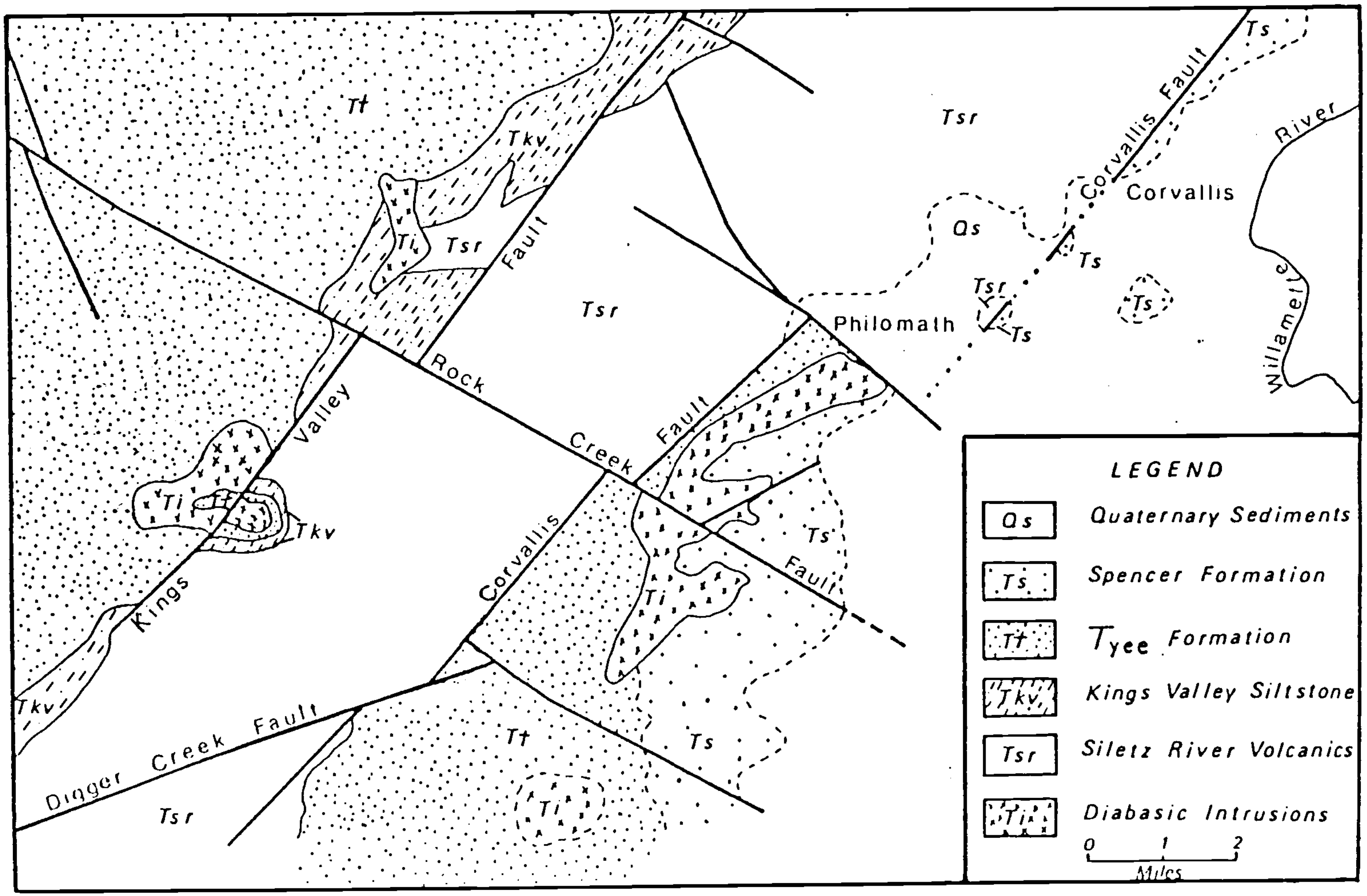


Figure 8: Lawrence and others (1980) interpretation of geology and structure in the Philomath area showing the Corvallis fault displaced by younger structures.

RESULTS OF SUBSURFACE ANALYSIS

Analysis of well logs was essential for developing a stratigraphic framework of the Spencer, as well as for understanding the pattern of lithologic changes throughout the study area. Stratigraphic interpretation based on field exposure alone was very difficult because of the limited and isolated outcrops, and because of structural complications caused by intrusions and faulting. The subsurface work is discussed first so that surface data can be presented in terms of a stratigraphic framework. The distribution of the underlying mudstones and the sandstones of the Yamhill Formation will also be discussed briefly.

Information of varying quality is available from 37 wells within the study area (Fig. 9). Many wells do not have electric logs or sufficiently detailed information to clearly delineate formations. Several of the wells do not penetrate the total thickness of the formations studied. Two stratigraphic cross-sections (Plates II, III) were constructed using spontaneous potential and resistivity logs. Mud logs, well cuttings, and biostratigraphic work by McKeel (1984, 1985) were used in addition to electric logs in making lithostratigraphic correlations. Many of the correlations are modified from the cross-section of Bruer and others (1984). Depths have been estimated to the nearest five feet.

The lithologic descriptions are generalized because they are either based on mud logs or on a limited examination of well cuttings. The exact composition of volcanic units is unknown. They are commonly referred to as basalts in mud logs and in this report, but some could have a more silicic composition. Depositional depths cited from McKeel's (1984, 1985) biostratigraphic work are based on Ingle's (1980)

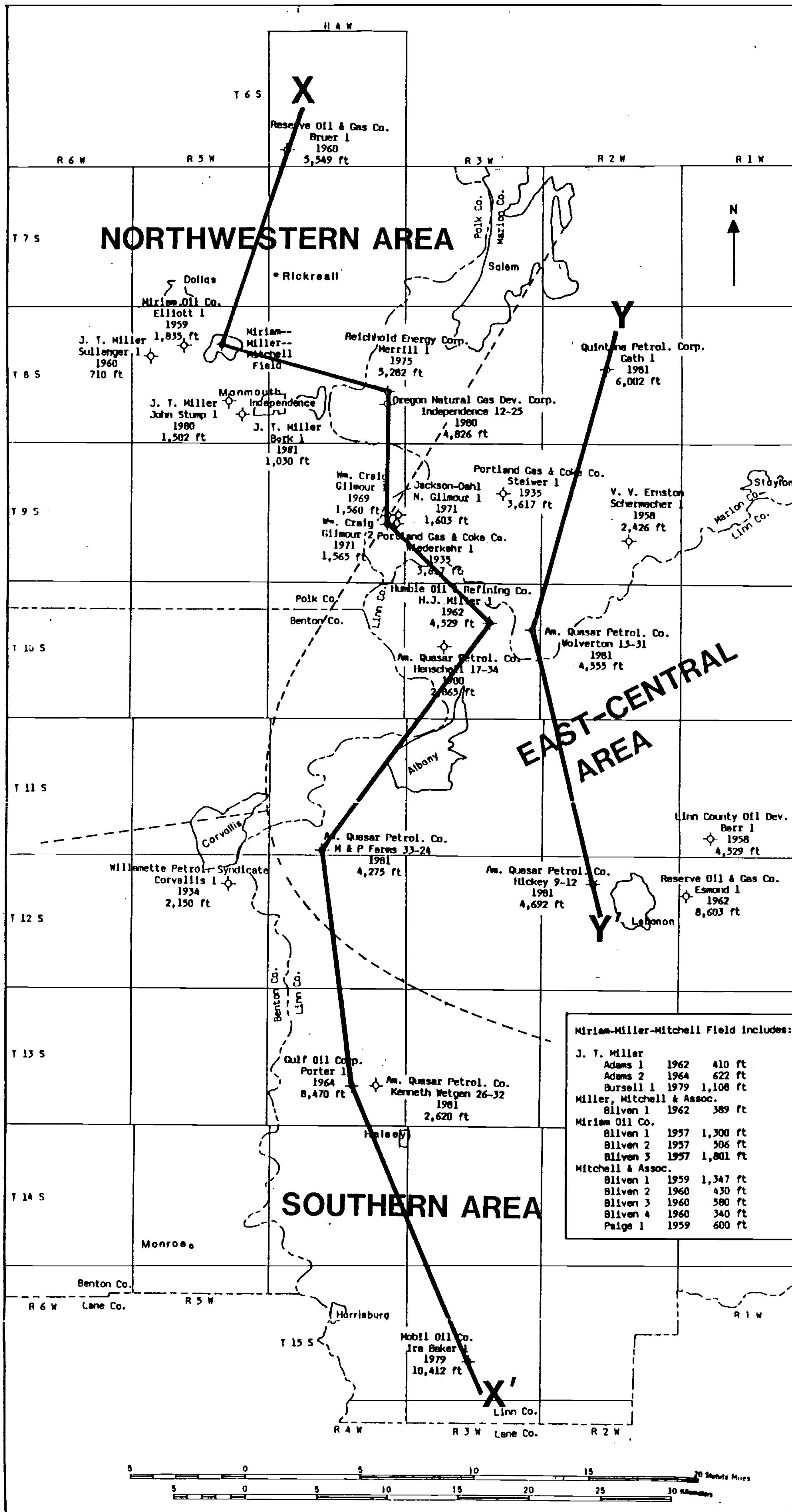


Figure 9: Reference map showing locations of wells and stratigraphic cross-sections. Bold print indicates wells having electric logs. Cross-section X-X' and Y-Y' are illustrated on plates II and III respectively. Also shown is the generalized subdivision of the study area into domaines based on stratigraphic characteristics of the Spencer Formation as observed in wells. Dashed lines indicate approximate boundaries of domaines.

research in southern California. The maximum water depths of biofacies are 150 feet for inner neritic, 470 feet for outer neritic, 1,560 feet for upper bathyal, 4,700 feet for upper middle bathyal, and 6,250 feet for lower middle bathyal.

The cross-sections illustrate the variable Spencer stratigraphy in the north-south and east-west directions (Plates II, III). Parts of the Yamhill Formation, Eugene Formation, and Narizian volcanic units also are illustrated. The datum is the base of the Spencer, an unconformity, and the one horizon which could be identified with reasonable certainty in all the logs. The correlations are considered to be most reliable in the north and central parts of the study area. To the south, the correlations are more speculative because wells have wider spacing, biostratigraphic information is minimal, and volcanic input is abundant and variable.

YAMHILL STRATIGRAPHY

Only the upper parts of the Yamhill Formation are illustrated on the correlation sections (Plates II, III). Within the subsurface of the study area the Yamhill Formation includes a lower volcanic-rich mudstone, a thick sequence of interbedded sandstones and siltstones (the Miller sandstone), and an upper mudstone unit. Foraminifera indicate an early Narizian age for the Yamhill Formation (McKeel, 1984, 1985).

The lower Yamhill mudstone (not illustrated in the cross-section), consists of volcanic-rich mudstones, siltstones, and minor sandstones. In the south and central areas basalt flows(?) and tuff beds are present in the section. The lower Yamhill grades southeastward into the Yamhill volcanics. Formainifera indicate outer neritic to middle bathyal depositional depths (McKeel, 1985).

The Miller sandstone member of the Yamhill Formation consists of very fine- to medium-grained sandstones with interbedded siltstones and mudstones. The sandstones are poorly to well sorted, have subangular to subrounded grains, and are variably tuffaceous, arkosic, and micaceous with local concentrations of lignite (coal beds?). Glauconite is locally present, and may indeed be a characteristic of one of the uppermost sandstones (McKeel, 1985). The volcanic proportion, including tuff beds and volcanic rock fragments, increases southeastwards. Well cuttings of many of the Miller and Spencer sandstone beds are similar. McKeel (1984, 1985) indicates deposition at outer neritic to upper bathyal depths for the lower Miller sandstone, shallowing upsection to inner neritic and nonmarine (Plates II, III).

The Miller sandstone member is lens shaped (Fig. 10), attaining its greatest thickness in the center of the study area. The sandstone body is oriented northeast-southwest, paralleling the Corvallis fault. To the north, the Miller sandstone pinches out into Yamhill siltstones and mudstones. Only a few, very thin sandstones are present in the Bruer well (Plate II). The Miller sandstone also thins to the south where it undergoes a facies change to a volcanic-rich sequence of tuffs, welded tuffs, basalts, dacites(?), and tuffaceous sandstones. This unit was labeled the Cascade volcanic facies by Bruer and others (1984), and will be called the Yamhill volcanic facies in this study. The Yamhill volcanic facies is up to 7,000 feet thick in the Baker well, and interfingers with the Miller sandstone in the Porter well (Bruer and others, 1984).

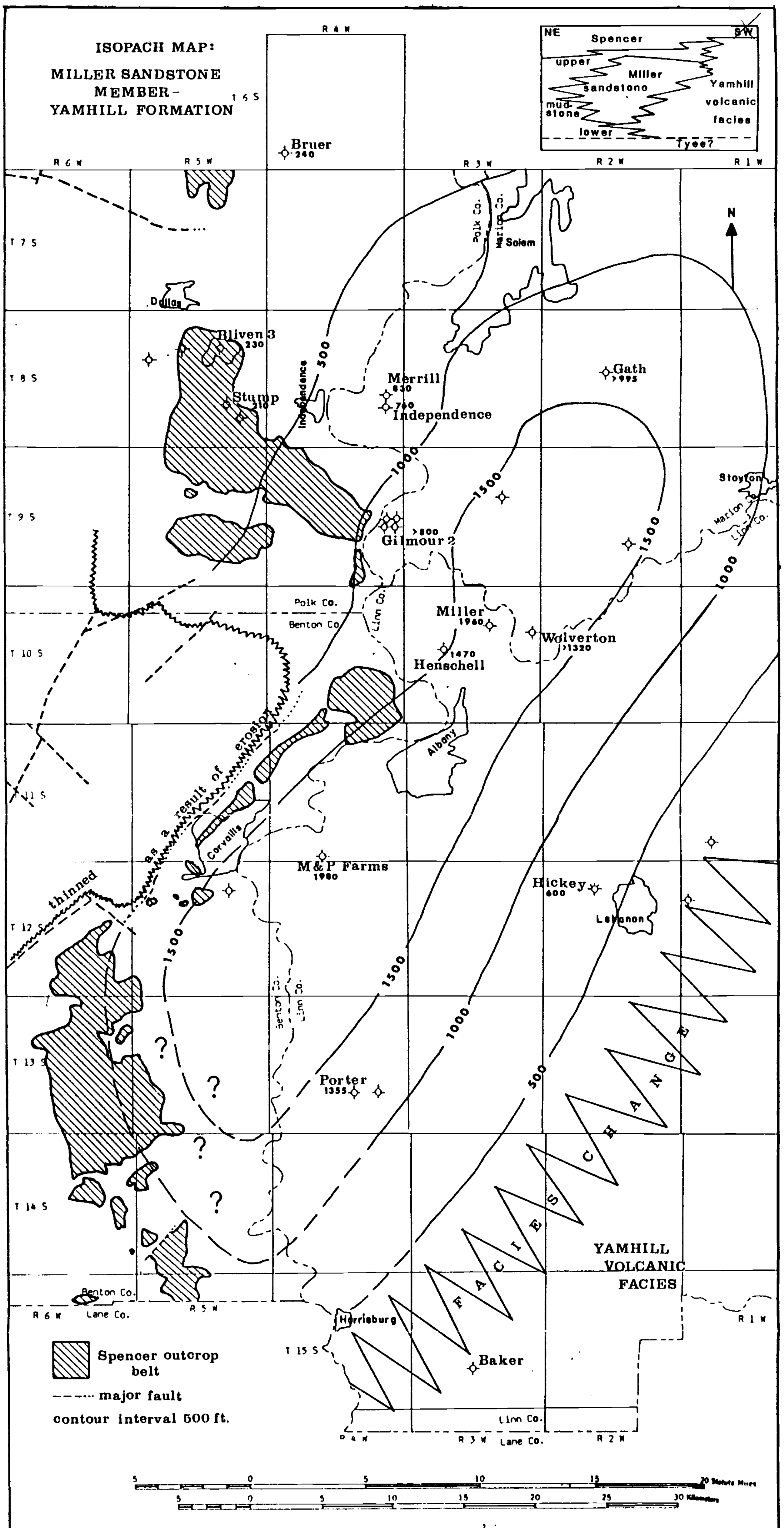


Figure 10: Isopach map of the Miller sandstone member of the Yamhill Formation. Inset in upper right corner shows interpreted relationship of the Miller sandstone, Yamhill mudstones and Yamhill volcanic facies.

The upper Yamhill mudstone is present in the northern and east-central parts of the study area (Plates II, III). It consists of siltstones, mudstones, and minor sandstones. Well cuttings of upper Yamhill mudstones and siltstones can sometimes be distinguished from those of the Spencer because they are harder, and generally brown instead of blue grey. Foraminifera indicate that the upper Yamhill was deposited at upper to middle bathyal depths (McKeel, 1984, 1985). Variable amounts (0-300 feet) of upper Yamhill mudstone are present between the Miller sandstone and the unconformity separating the Yamhill from the Spencer (Fig. 11). In the M & P Farms well (Plate II), the Spencer lies directly on top of the Miller sandstone. The contact between the Spencer and Miller sandstones is marked by a mixed neritic to bathyal foraminifera assemblage, suggesting erosion and incorporation of upper Yamhill mudstone clasts into the lower member of the Spencer during transgression. The upper Yamhill is also absent farther south where Spencer sandstones lay directly on the Yamhill volcanics.

SPENCER STRATIGRAPHY

Based on the stratigraphic sequences interpreted from well logs, the Spencer basin within the study area will be subdivided into three depositional domains: (1) northwestern; (2) east-central; and (3) southern (Fig. 9). Spencer stratigraphy in the study area is similar to that described in the western Tualatin Valley, where a lower highly micaceous sandstone member is overlain by an upper siltstone and mudstone member (Stimson Mill Beds of Al-Azzaby, 1980) (Thoms and others, 1983). In the following discussions, the lower member of the Spencer Formation is subdivided into upper and lower parts. This

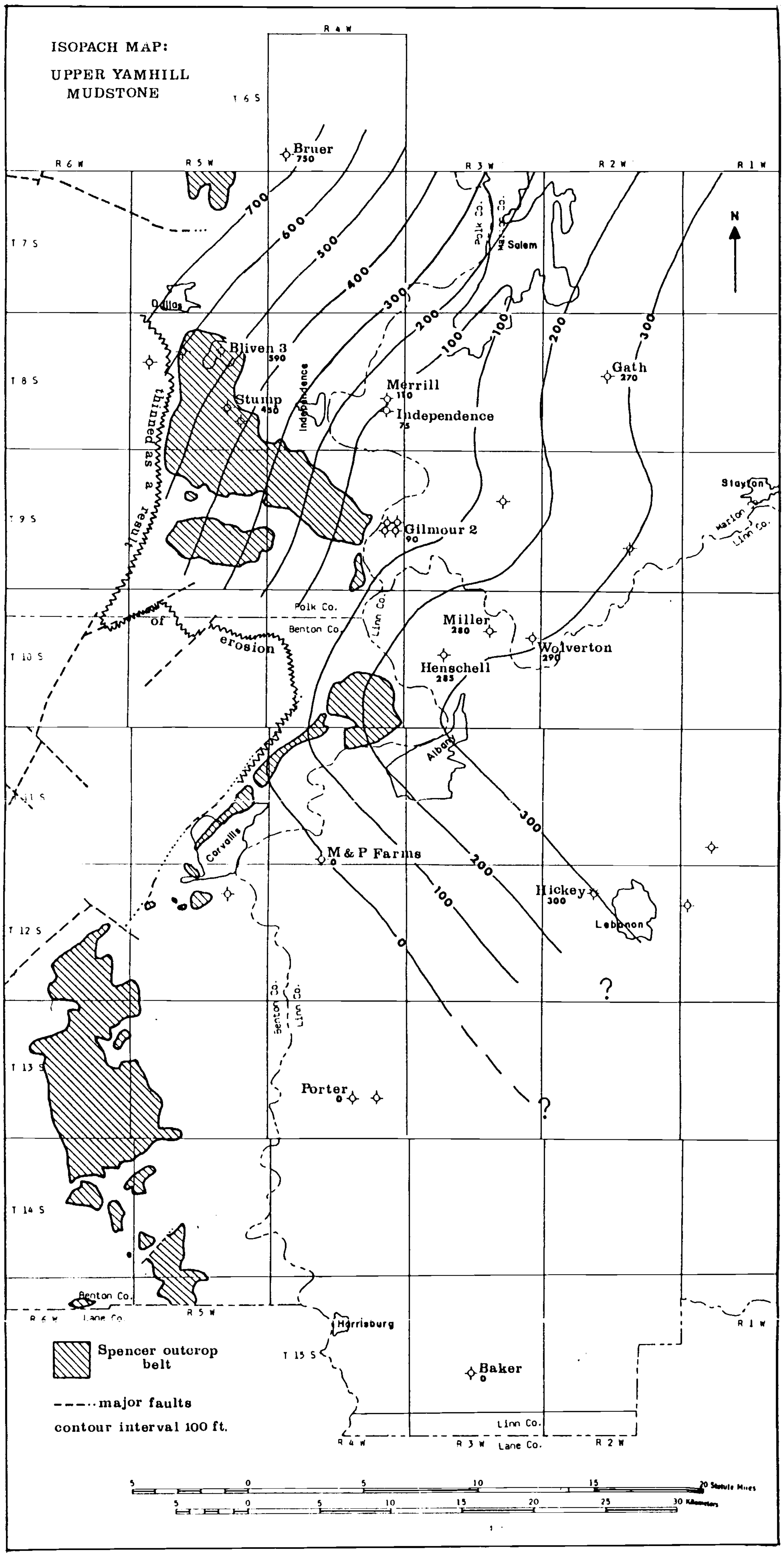


Figure 11: Isopach map of the upper Yamhill mudstone.

subdivision is very generalized, and is used primarily to discuss changes in the lithofacies during deposition of the lower member.

In the northwestern domain (Bruer, Bliven, and Merrill wells; Fig. 9), the lower member of the Spencer Formation consists of interbedded sandstones and siltstones and minor mudstones (Plate II). The sandstones are generally very fine- to fine-grained, have subangular to subrounded grains, and are arkosic, micaceous, and tuffaceous. Some units are medium-grained, well sorted and less tuffaceous; others contain carbonaceous debris; and some are glauconitic. The siltstones are tuffaceous and locally glauconitic. The relative amounts of siltstone and sandstone vary widely in the lower member. On Plates II and III, the lithologies of the lower member of the Spencer are grouped into two general categories: sandstones with siltstone interbeds, and siltstones with sandstone interbeds. Microfossils are scarce in the lower Spencer, but McKeel (1984) suggested inner to middle neritic depths for parts of the section. Siltstone is more abundant in wells farther northwest, perhaps indicating increasing depth in this direction.

The upper member of the Spencer Formation is dominantly mudstone, silty mudstone and tuffaceous siltstone. Foraminifera indicate deposition at middle bathyal depths, with a deepening upsection from upper to lower middle bathyal, followed by shallowing again to upper middle bathyal (McKeel, 1984). In the Merrill well (Plate II), the upper member of the Spencer is overlain by a late Narizian volcanic unit, deposited at neritic to upper bathyal depths (McKeel, 1984), which consists of tuffs, and interbeds of tuffaceous sandstones. This volcanic unit will be called the eastern Willamette volcanics.

In the east-central domain (Gath, Miller, Wolverton, and Hickey wells; Fig. 9), the lower member of the Spencer Formation is sandier, up to 400 feet thicker, and contains more volcanic interbeds than in the northwestern and southern domains (Fig. 12, Plates II, III). The sandstones range from very fine- to medium-grained, and have subangular to subrounded grains. Compositionally, the sandstones are similar to those of the northwest domain, except for a higher percentage of volcanic detritus, particularly in the upper beds. Lignite is locally abundant in well cuttings from many sandstone and siltstone units. To the east in the Hickey well, the lower sandstones of the lower member are more commonly medium-grained and notably well sorted. As usual, microfossils are rare in the lower member, but McKeel (1984, 1985) interpreted neritic deposition for parts of the central wells (Miller, Wolverton), and neritic, marginal marine, and possibly nonmarine for parts of the Hickey well (Plates II, III).

Both sandstones and volcanic rocks in the upper part of the Miller well were mapped as the Eugene Formation by Bruer and others (1984). In this report, however, these strata are included in the lower member of the Spencer Formation based on correlation with a late Narizian section in the nearby Wolverton well. The basalt beds in these wells are assumed to have an extrusive rather than intrusive origin because they are associated with basaltic sandstones and tuff beds.

To the east, the upper member of the Spencer Formation is absent, and the lower member grades upward into, and interfingers with, the eastern Willamette volcanics (Plate III). Lava flows(?), tuff beds, and subordinate sedimentary rocks are present in the eastern Willamette volcanics. Sedimentary rocks, which are more abundant in the lower

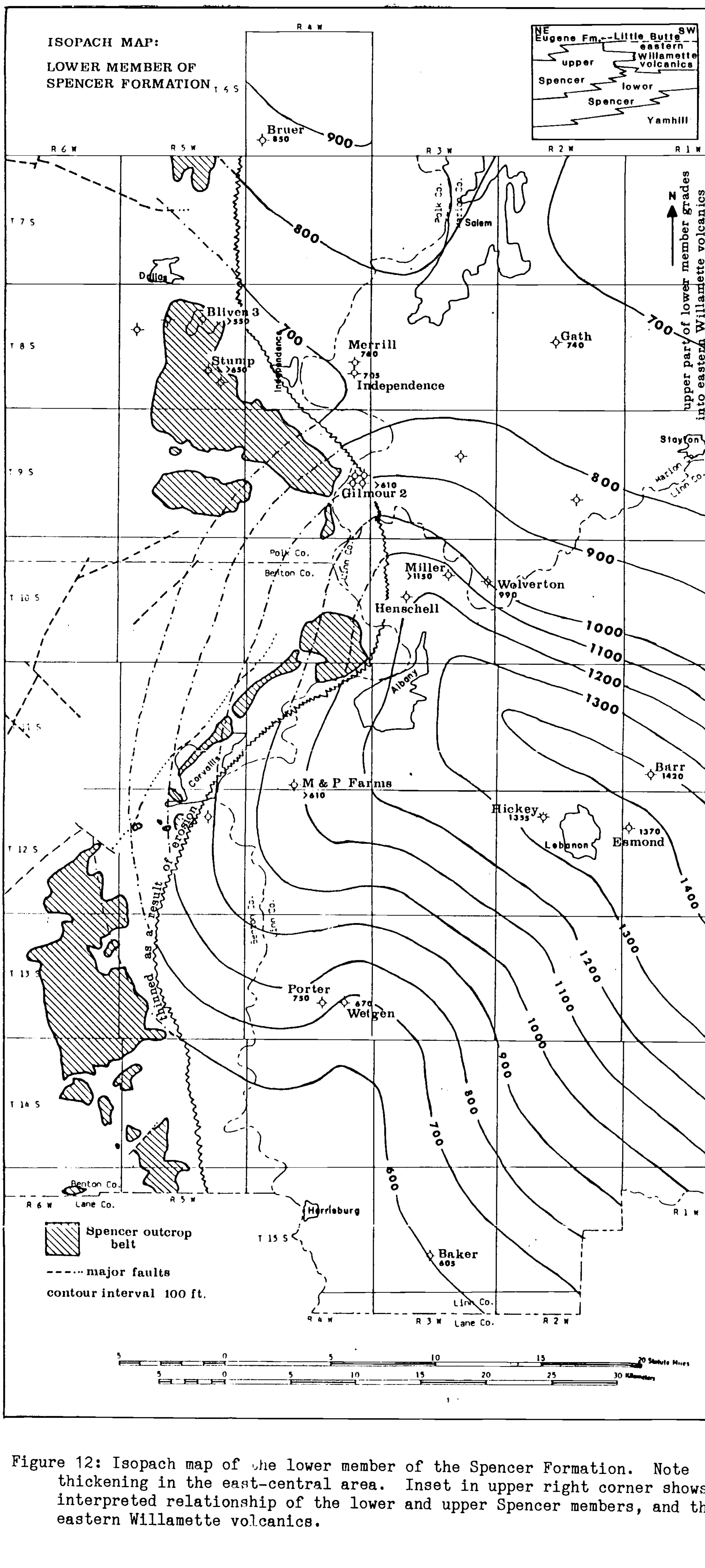


Figure 12: Isopach map of the lower member of the Spencer Formation. Note thickening in the east-central area. Inset in upper right corner shows interpreted relationship of the lower and upper Spencer members, and the eastern Willamette volcanics.

parts of the eastern Willamette volcanics, include conglomerates, fine- to medium-grained basaltic sandstones, and tuffaceous siltstones. Microfossils from sedimentary beds within the eastern Willamette volcanics in the Gath well are late Narizian in age (McKeel, 1984). Other units are considered correlative based on comparison with the Gath and Wolverton wells.

A section of the upper member of the Spencer Formation overlies a tongue of the eastern Willamette volcanics in the centrally located Wolveron well (Plate III). These upper member strata consist of tuffaceous siltstones, deposited at upper to middle bathyal depths (McKeel, 1984), along with minor tuffs and basalts. In the Gath well to the northeast, correlative sedimentary beds within the eastern Willamette volcanics were deposited at slightly shallower, upper bathyal to outer neritic depths (McKeel, 1984).

The eastern Willamette volcanics are similar to the lower Fisher Formation mapped at the surface in the Eugene area (Vokes and others, 1951). However, the lower part of the Fisher Formation is thought to be Oligocene in age (Vokes and others, 1951), while the eastern Willamette volcanics are largely late Eocene (late Narizian). The upper parts of the eastern Willamette volcanics could extend into the Refugian (Oligocene), and be equivalent to the Fisher, Little Butte Volcanic series, or Colestin Volcanics.

Only the lower part of the lower member of the Spencer section was logged in the Gilmour-2 and M & P Farms wells. Strata of the lower member are very sand-rich in both wells. The sandstones are tuffaceous, arkosic, and micaceous, and generally very fine- to fine-grained. Some zones are coarse-grained. In the M & P Farms well, several beds contain medium-grained sandstones with volcanic rock fragments. Lignite is common in well cuttings from these beds. McKeel (1985) suggested neritic to marginal marine deposition for much of the lower member of the Spencer in the M & P Farms well, deepening upsection to upper to upper middle bathyal (Plate II). The M & P Farms mud log indicates that this deeper section, located above the top of the electric log, consists of 300 feet of tuffaceous siltstone, and then at least 100 feet of sandstone. Well cuttings from volcanic units in the lowermost Spencer are coarsely-crystalline, suggesting an intrusive origin. The Gilmour and M & P Farms wells are interpretted to be transitional between the central and both the northwestern and the southern domains (Fig. 9).

In the southern domain (Porter and Baker wells; Fig. 9), a volcanic influence is significant throughout the Spencer section. In the Porter well, siltstones and tuff beds are dominant in the lower member of the Spencer Formation (Plate II). The sandstone interbeds are very fine- to fine-grained and commonly contain coarse volcanic clasts (pumice?). To the southeast, in the Baker well, the lower member of the Spencer consists of tuffs, basalts, conglomerates, and very fine- to fine-grained tuffaceous sandstones. The conglomerate is composed of siltstone, sandstone, and tuff clasts in a clayey matrix.

Foraminifera were not useful for determining the depositional depths of the lower part of the lower member of the Spencer to the south in the Porter well. However, the strata are sandier than the upper to middle bathyal upper half of the lower member and were probably deposited at slightly shallower depths. Depositional depths in the Baker well are uncertain, but the lower volcanic-rich sandstones and conglomerates of the lower member of the Spencer may have been deposited under relatively shallow marine to nonmarine conditions. The uppermost 100 feet of the lower member were deposited at outer neritic or upper bathyal depths (McKeel, 1985). A deepening upwards sequence is indicated for the lower member of the Spencer in the southern domain.

The upper member of the Spencer Formation is present in the Porter well, and consists of tuffaceous siltstone and tuff. It is thicker than the upper member in wells to the northwest (Plate II). The upper member of the Spencer grades eastward into the eastern Willamette volcanics (e.g., Baker well; Plate II). McKeel (1985) interpreted nearshore to nonmarine depositional settings for some sedimentary beds in this volcanic unit.

Distribution of the Spencer Formation in the subsurface of the central Willamette Valley is summarized in a fence diagram (Fig. 13). The lower member of the Spencer Formation consists of interbedded siltstones and very fine- to fine-grained sandstones with minor medium-grained sandstones and mudstones. The sandstones are variably tuffaceous, arkosic, micaceous, or basaltic. The basaltic sandstones are more common in the upper parts of the eastern and central sections. At the base of the Spencer, siltstones with sandstone interbeds are dominant (Plates II and III). The relative proportions of sandstone and siltstone vary from place to place. Two or three intervals dominated by sandstone are present in most wells. The thickness of the lower member of the Spencer (Fig. 12), the amount of interbedded volcanics, and the ratio of sandstone to siltstone are all greater in the east-central area.

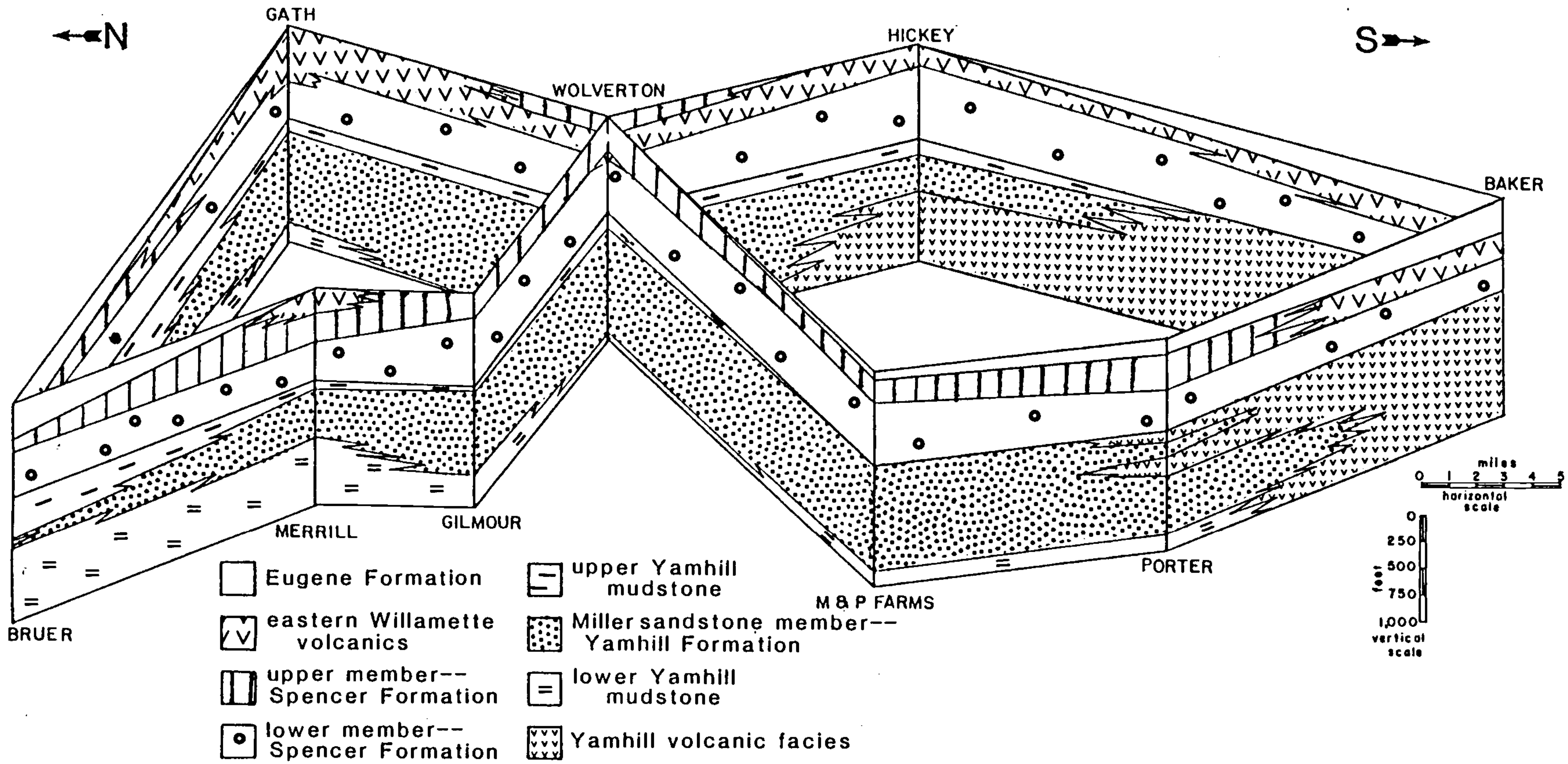


Figure 13: Fence diagram illustrating the distribution of the Spencer Formation, Yamhill Formation and the eastern Willamette volcanics. Where total stratigraphic sequences are not logged, thicknesses are interpreted from adjacent wells.

Most of the lower member of the Spencer Formation was deposited in neritic to marginal marine settings, possibly ranging to nonmarine in the east (Plates II, III; McKeel, 1984, 1985). However, foraminifera suggest upper to middle bathyal depths for the upper part of the lower member of the Spencer in the southeast part of the study area (Porter and Baker). The lower member of the Spencer Formation thickness averages 725 feet, except in the east-central area where it averages 1,000 feet (Fig. 12).

The thickness of the upper member of the Spencer Formation varies between 200 and 600 feet. Siltstones, tuffs and mudstones are the dominant lithologies. The upper member grades eastward into the eastern Willamette volcanics (Fig. 13; Plates II, III). Foraminifera indicate that the upper memberer was deposited at upper to middle bathyal depths, while the eastern Willamette volcanics were deposited at depths ranging from upper middle bathyal to neritic in the north, and neritic to marginal marine in the south (McKeel, 1984, 1985).

Well logs indicate that the total thickness of the Spencer Formation is approximately 1,500 feet east of Corvallis, 1,400 feet east of Monroe, and about 1,200 east of Dallas.

VOLCANIC UNITS

The characteristics of the Yamhill volcanic facies and the eastern Willamette volcanics are unknown. The eastern Willamette volcanics include units interpreted to be flows of basaltic composition, and abundant tuff beds. Tuff colors include white, grey, green, purple, and red; a few are reportedly welded. Tuffs are also common in the Yamhill volcanic facies, although well logs indicate flows may be more abundant. These flows are identified as basaltic or dacitic on mud logs. Interbedded and enclosing sedimentary units indicate that the Yamhill volcanics and eastern Willamette volcanics are primarily early and late Narizian in age, respectively.

The Yamhill volcanic facies and especially the eastern Willamette volcanics may be associated with early western Cascade volcanism. They are similar to the western Cascade volcanics, consisting chiefly of ash flow tuffs, with lava flows and epiclastic mudstone and sandstone interbeds. The oldest western Cascades are dated at 40 mybp (Priest and others, 1983). Depending on the time-scale used, the upper Narizian eastern Willamette volcanics were probably erupted between 45 and 36 mybp. Therefore the eastern Willamette volcanics are thought to be related to earliest western Cascade volcanism.

The Yamhill volcanic facies are older than 40 mybp, and could be a late stage of Siletz River volcanism. However, some units in the Yamhill volcanics are dacitic rather than basaltic suggesting that they may represent a very early episode of western Cascade volcanism. Cores and cuttings from these Narizian volcanics should be analyzed to determine their affinity, age, and to further define the Eocene geologic history of western Oregon.

SUBSURFACE CONSTRAINTS ON STRUCTURAL MOVEMENTS

The Yamhill and Spencer stratigraphies in wells within the study area do not precisely define the timing of movement on the Corvallis fault. The structure contour map on the base of the Spencer (Fig. 14) shows a fault with up to 1,700 feet of post-middle Narizian offset northeast of Albany, between the Miller and Wolverton wells (labeled Albany fault). A less prominent fault, with less than 700 feet of offset, has been drawn between the Porter and Wetgen wells to the

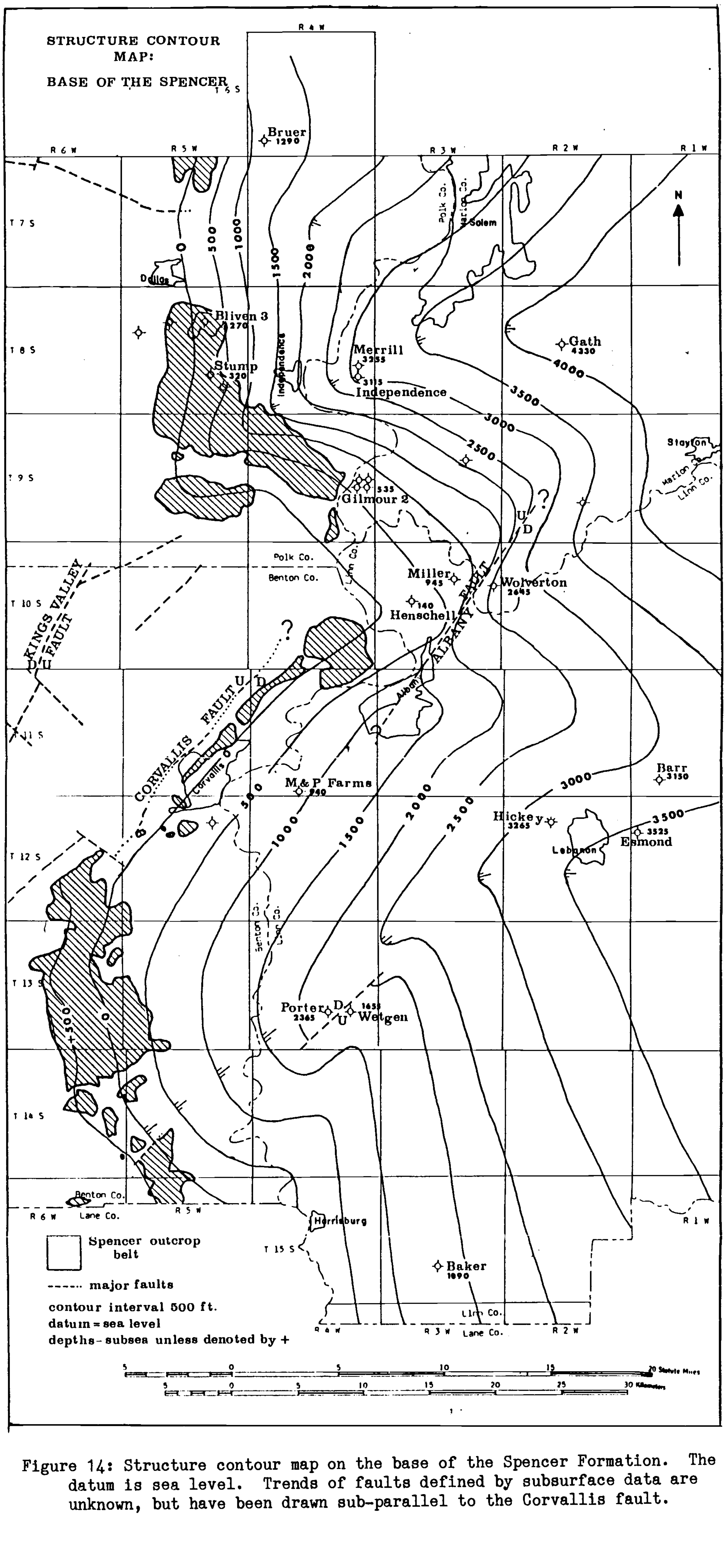


Figure 14: Structure contour map on the base of the Spencer Formation. The datum is sea level. Trends of faults defined by subsurface data are unknown, but have been drawn sub-parallel to the Corvallis fault.

south. Additional faults are probably present within the study area (e.g., between the Henschell and Miller wells); however, well control is insufficient to delineate these structures.

The trend of the Albany fault is poorly known; it has been drawn subparallel to the Corvallis fault (Fig. 14). The relatively uniform thicknesses of the Miller sandstone, upper Yamhill mudstone, and the lower part of the lower member of the Spencer Formation in the Miller and Wolverton wells (Plates II, III) argues against any major offset on the Albany fault during early to early late Narizian. The upper part of the lower member of the Spencer can not be definitely correlated because of poor log quality and variable volcanic content. The distribution of the Miller sandstone and upper Yamhill mudstone as indicated on isopach maps suggests movement on the Corvallis fault during Yamhill time. The Miller sandstone thickens parallel to, and on the downthrown side of the fault (Fig. 10). The upper Yamhill mudstone thins along the trend of the fault (Fig. 11). Timing of activity on the Corvallis fault and its relationship to the Albany fault will be considered in more detail in the discussion of late Eocene tectonic activity.

Estimates of offset on the Corvallis fault have been based on a stratigraphic succession of Siletz River-Tyee-Spencer. In light of the differing stratigraphy observed in wells to the east of the fault, estimates of fault offset are re-examined. Several assumptions are made: (1) the strata exposed along the eastern edge of the fault in the Corvallis-Albany area is the basal arkosic Spencer sandstone (Spencer? on Plate I) rather than Tyee as originally mapped (Vokes and others, 1954); (2) the Miller sandstone is approximately 1,000 feet thick along the fault and the upper Yamhill mudstone is absent (Fig. 10, 11); (3) the thicknesses of the lower Yamhill mudstone and possible Tyee strata are similar to those in the Miller well to the east, approximately 1,000 feet; (4) basalts on the upthrown side of the fault are the upper parts of the Siletz River Volcanics, and lie about 1,000 feet above younger sedimentary rocks on the downthrown side of the fault; and (5) the Kings Valley Siltstone thins to the east, and was between 0 and 500 feet thick at the fault. Based on these assumptions, offset in the Corvallis-Albany area would be between 3,000 and 3,500 feet. This estimate is similar to that of Vokes and others (1954), and to the lower estimates of Lawrence and others (1980). However, if faulting occurred during deposition of the Yamhill, as is suggested in this study, this estimate of fault offset may be high.

PETROLOGY AND STRATIGRAPHY OF SURFACE EXPOSURES

The Spencer Formation crops out in the low hills along the western border of the central Willamette Valley (Plate I). Parts of the area were originally mapped by Mundorff (1939), Baldwin (1947, revised 1964), Allison (1953), Vokes and others (1954), Beaulieu and others (1974), and Bela (1981). The geologic map included in this study (Plate I) is modified slightly from these earlier maps, and is based on the work of Bela (1978), Lawrence and others (1980), and on field work conducted during this study. Outcrops were examined to determine stratigraphic relations and possible depositional settings of the Spencer Formation.

Within the study area, outcrops are generally small, isolated, and commonly deeply weathered. Varying degrees of weathering and alteration are encountered depending on the proximity of outcrops to intrusions and major faults, and on the duration of outcrop exposure to the humid western Oregon climate. Intrusions are believed to be the cores of most of the low hills in the west-central Willamette Valley. This conclusion is based on outcrop exposures, the rocks encountered in water wells, and the baked nature of many of the exposed sedimentary rocks. Baked zones range from one to 10 feet wide. The baked sedimentary rocks are generally very resistant. However, intrusions often caused fracturing and minor faulting in the country rock beyond the baked zone. This fracturing, which also occurs close to major faults, locally increases the rate of weathering. Stratigraphic correlations are tentative because of uncertainties about the degree of warping associated with intrusions, the age of faulting, the termination of fault zones, and poor exposures.

LITHOLOGY/STRATIGRAPHY

The Spencer is lithologically and stratigraphically different north and south of Corvallis. Therefore, the Monmouth-Buena Vista area (north) and the Dawson-Belfountain-Monroe area (south) are discussed separately. Outcrops in the central Albany-Corvallis area are transitional, and more complex because of proximity to the Corvallis fault zone. The division of the Spencer Formation into a lower sandstone and siltstone member and an upper siltstone and mudstone member used in the subsurface analysis, also applies to the surface discussion. However, surface exposures of the upper member are rare. The terms upper, middle, and lower parts of the lower member of the Spencer are used in a very general way to refer to relative stratigraphic positions of outcrops within the lower member.

Monmouth-Buena Vista Area

In the northern part of the study area, the Spencer Formation is underlain by the Yamhill Formation. Because of poor exposure and lack of contrasting lithologies, the contact is approximately located up Copper Hollow Valley (Plate I; Baldwin, 1964). The type of contact is not clear, but it is assumed to be unconformable based on the change from eastward dips in the Tyee and Yamhill Formations to northward dips in the Spencer strata, and because there is regional unconformity beneath correlative late Eocene formations in western Oregon (Baldwin, 1964).

Micaceous arkosic sandstones are thought to represent the lower part of the lower member of the Spencer Formation in the northern part of the study area. They are exposed at the "clay" pit along old highway 99 (Fig. 15, #13), and about 1.5 miles north at Helmick Hill

Figure 15: Locations of Spencer outcrops in eastern Benton and southeastern Polk Counties. Outcrop numbers are refered to in the text.

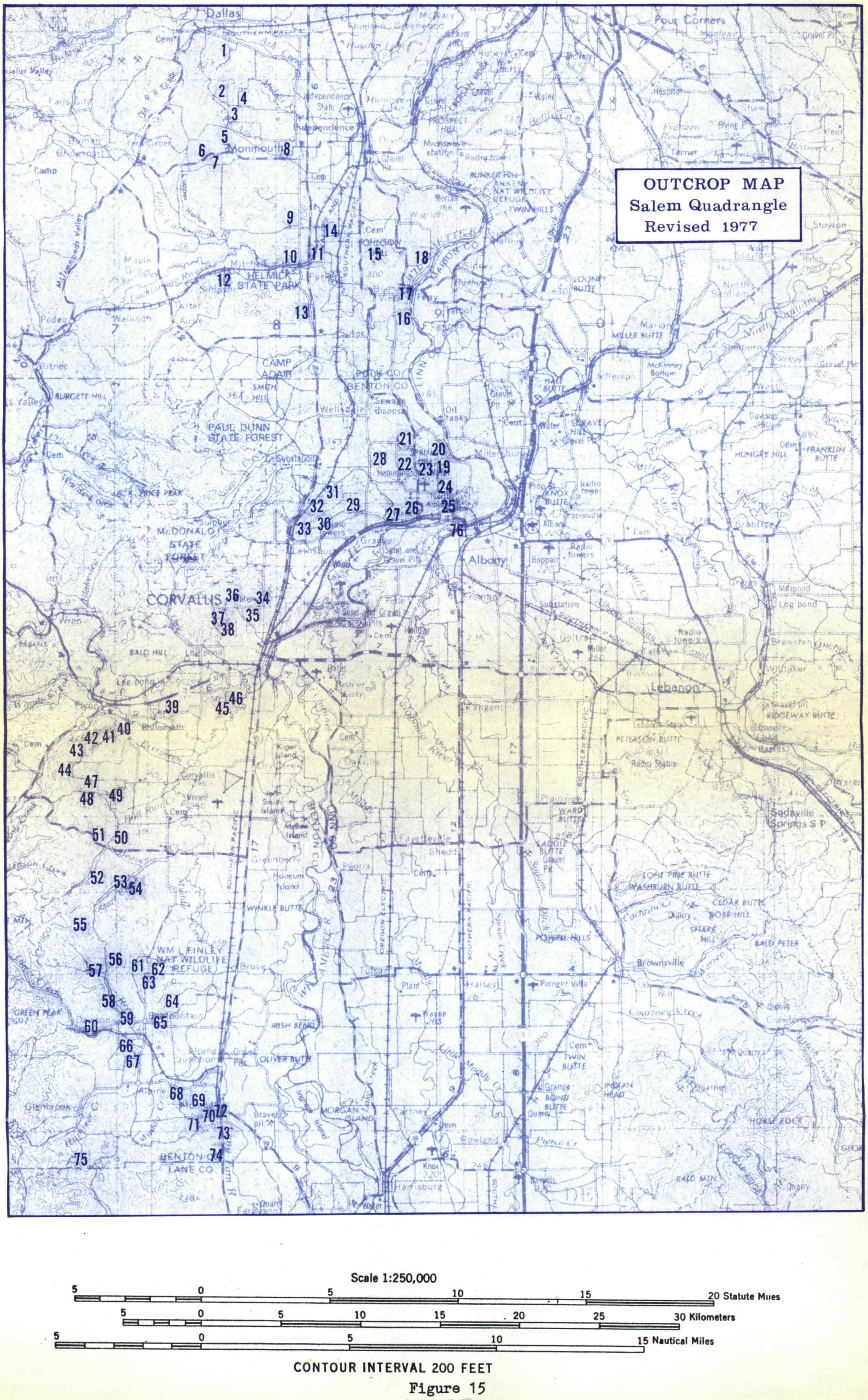
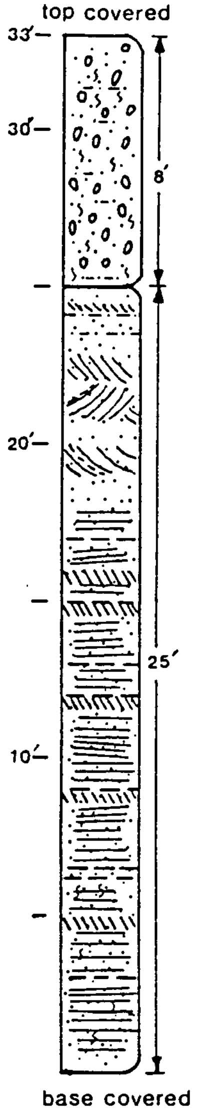

OUTCROP MAP
Salem Quadrangle
Revised 1977
Dallas
Monmouth
Independence
CAMP ADAIR
PAUL DUNN STATE FOREST
McDONALD STATE FOREST
CORVALLIS
Albany
Lebanon
Philomath
Harrisburg
Brownsville
Jefferson
WM L FINLEY NAT WILDLIFE REFUGE
HELMICK STATE PARK
BENTON LANE CO
POLK CO BENTON CO
Scale 1:250,000
5 0 5 10 15 20 Statute Miles
5 0 5 10 15 20 25 30 Kilometers
5 0 5 10 15 Nautical Miles
CONTOUR INTERVAL 200 FEET

Figure 15

(Fig. 15, #10,11). Characteristics of the outcrops are outlined in detail in Figures 16 and 18. The "clay" pit consists of a thick sequence of well sorted, fine-grained sandstone (Figs. 16, 17a). The lower part of the section is characterized by parallel laminations. Some sets of parallel laminations are slightly discordant, and are probably hummocky cross-stratification; irregular outcrop faces prevent a positive identification. Rare ripple cross-lamination sets, occasionally draped by thin mudstones, also are present. Upsection, low-angle cross-laminations and tangential trough cross-lamination sets are the dominant sedimentary structures. Partially eroded mud drapes are found along many foresets (Fig. 17b). The strata containing trough cross-laminae grade upward into an approximately eight foot thick section of highly bioturbated, clayey, fine-grained sandstone. The dominant burrow type resembles Thalassinoides; burrows are branching, approximately one inch in diameter, and have light gray, clayey sand halos up to 0.25 inches thick.

At Helmick Hill, the lower part of the section consists of interbedded siltstone and fine-grained sandstone (Fig. 18). Bioturbation has destroyed most of the sedimentary structures, and caused mixing of the interbedded lithologies. Relict parallel and low-angle cross-laminations (hummocky bedding) are delineated by concentrations of carbonaceous debris and mica (Fig. 19a). Fine- to medium-grained arkosic sandstones, present in the middle of the Helmick section, are generally well sorted and massive. However, large-scale trough cross-beds with mud rip-ups near the base of foresets, are locally found. The overlying bioturbated fine-grained sandstone is similar to the upper bioturbated unit at the "clay" pit,

OLD HIGHWAY 99 "CLAY" PIT



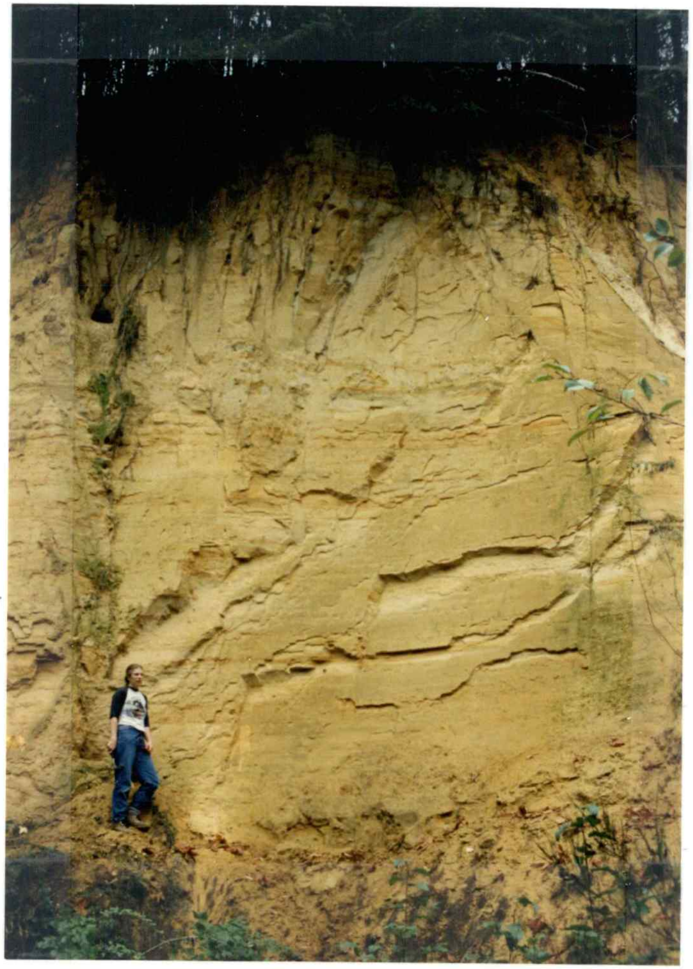
Grayish orange (10YR7/4) to light brown (5YR6/4), highly bioturbated, clayey fine-grained sandstone; probable Thalassinoides burrows averaging 1 inch in diameter with light gray (N7) clayey sand halos.

Very pale orange (10YR8.2) to light brown (5YR6/4), friable , well sorted, fine-grained arkosic sandstone. Lower 15 to 20 feet are massive to parallel laminated, with some sets showing low angle discourdances. Minor small-scale cross lamination and discontinuous to continuous 0.5 to 1 inch thick gray mudstone beds. Upper 5 to 10 feet are dominantly trough cross-bedded; mud drapes are present over many of the foresets; sets up to 3 feet thick. Minor small-scale cross-lamination. Bioturbation is minor, and includes Chondrites, Ophiomorpha, and Skolithos burrows.

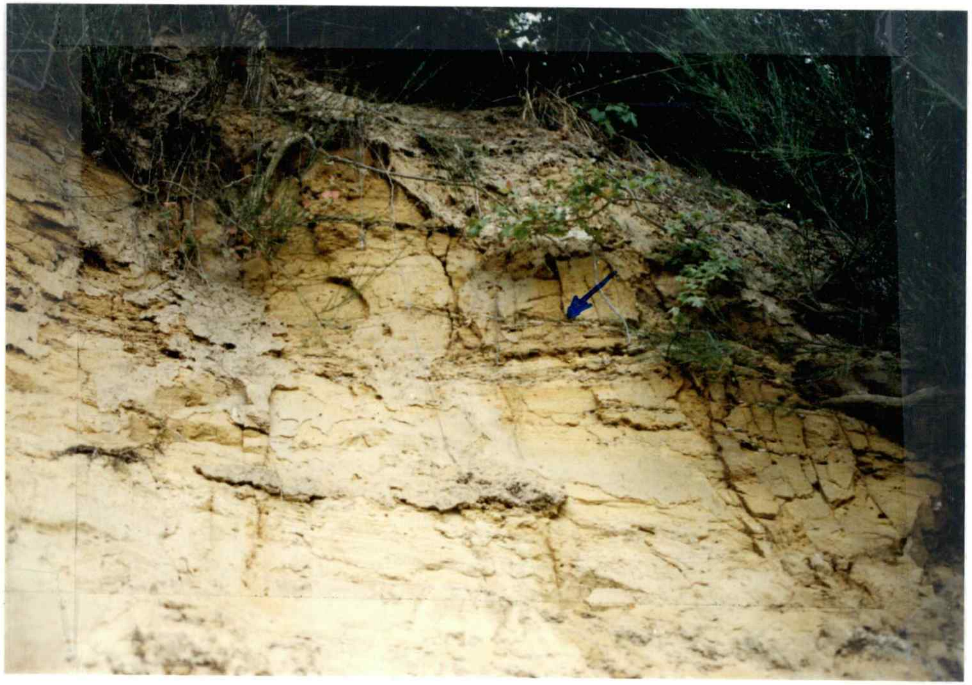
KEY

- sandstone
- siltstone
- mudstone
- large-scale cross-lamination
- small-scale cross-lamination
- parallel lamination
- hummocky cross-lamination
- convolute bedding
- bioturbation
- fossils
- articulate pelecypods
- mudstone clasts
- light gray clayey sand halo burrows

Figure 16: Stratigraphic section of lower part of lower member of Spencer Formation at old highway 99 "clay" pit.



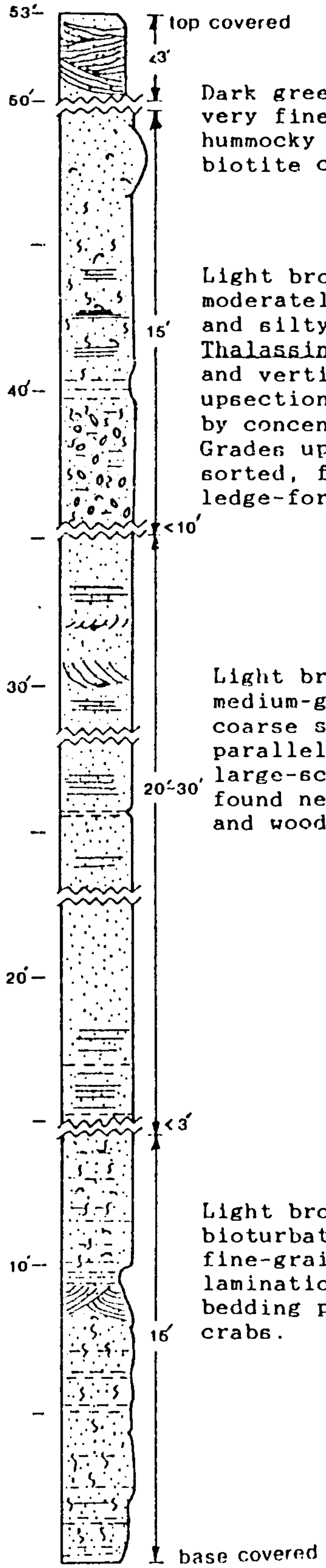
A



B

Figure 17: (A) Thick, well sorted, fine-grained sandstone exposed at the "clay" pit. (B) Mud drapes along foresets at the "clay" pit.

HELMICK HILL



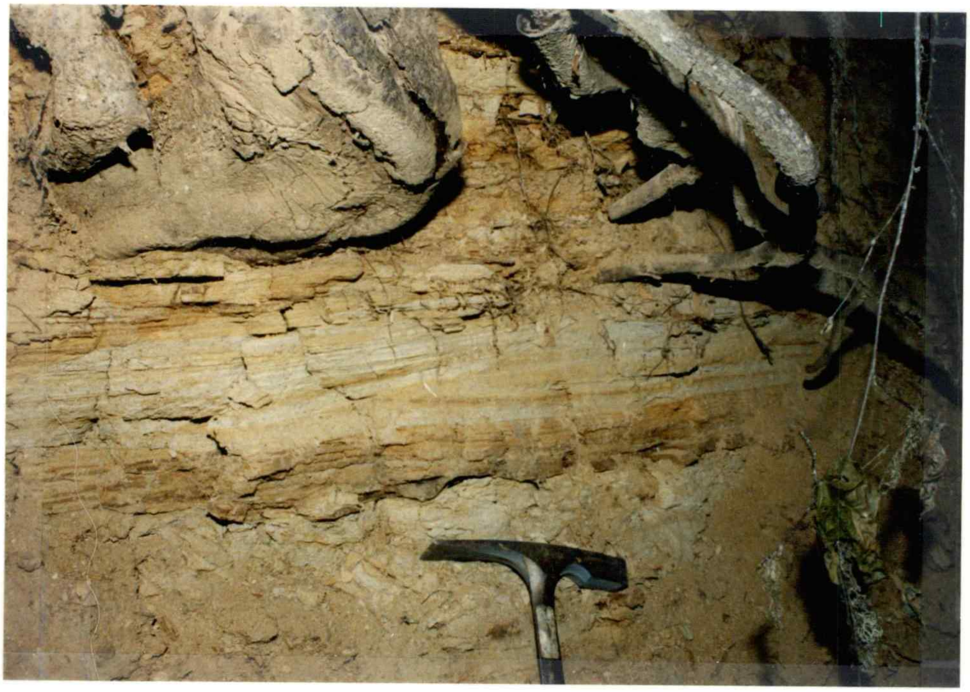
Dark greenish gray (5GY4/1), well sorted fine- to very fine-grained arkosic sandstone. Trough to hummocky cross-laminated with plant debris and biotite concentrated on bedding planes.

Light brown (5YR6/4) to light gray (N7), bioturbated, moderately sorted, fine- to medium-grained sandstone, and silty sandstone. Burrow types include Thalassinoides (?) with light gray clayey sand halos and vertical skolithos tubes. Bioturbation decreases upsection and relict parallel laminations are defined by concentrations of mica and plant fragments. Grades upward into a very light gray (N9), well sorted, fine-to medium-grained arkosic sandstone; a ledge-former containing calcite concretions.

Light brown (5YR5/6), friable, well sorted, fine- to medium-grained, arkosic to lithic sandstone. Rare coarse sandstone and thin claystone beds. Massive to parallel laminated with small-scale ripple and large-scale trough cross-lamination. Mud rip-ups found near the base of foresets. Some plant material and wood pieces found along bedding planes.

Light brown (5YR6/4) to light gray (N7), interbedded bioturbated siltstone, silty sandstone, and fine-grained sandstone. Relict parallel and hummocky lamination. Mica and plant fragments concentrated on bedding planes. Small pelecypods, gastropods and crabs.

Figure 18: Stratigraphic section of lower part of lower member of Spencer at Helmick Hill (symbols same as Figure 16).



A

B

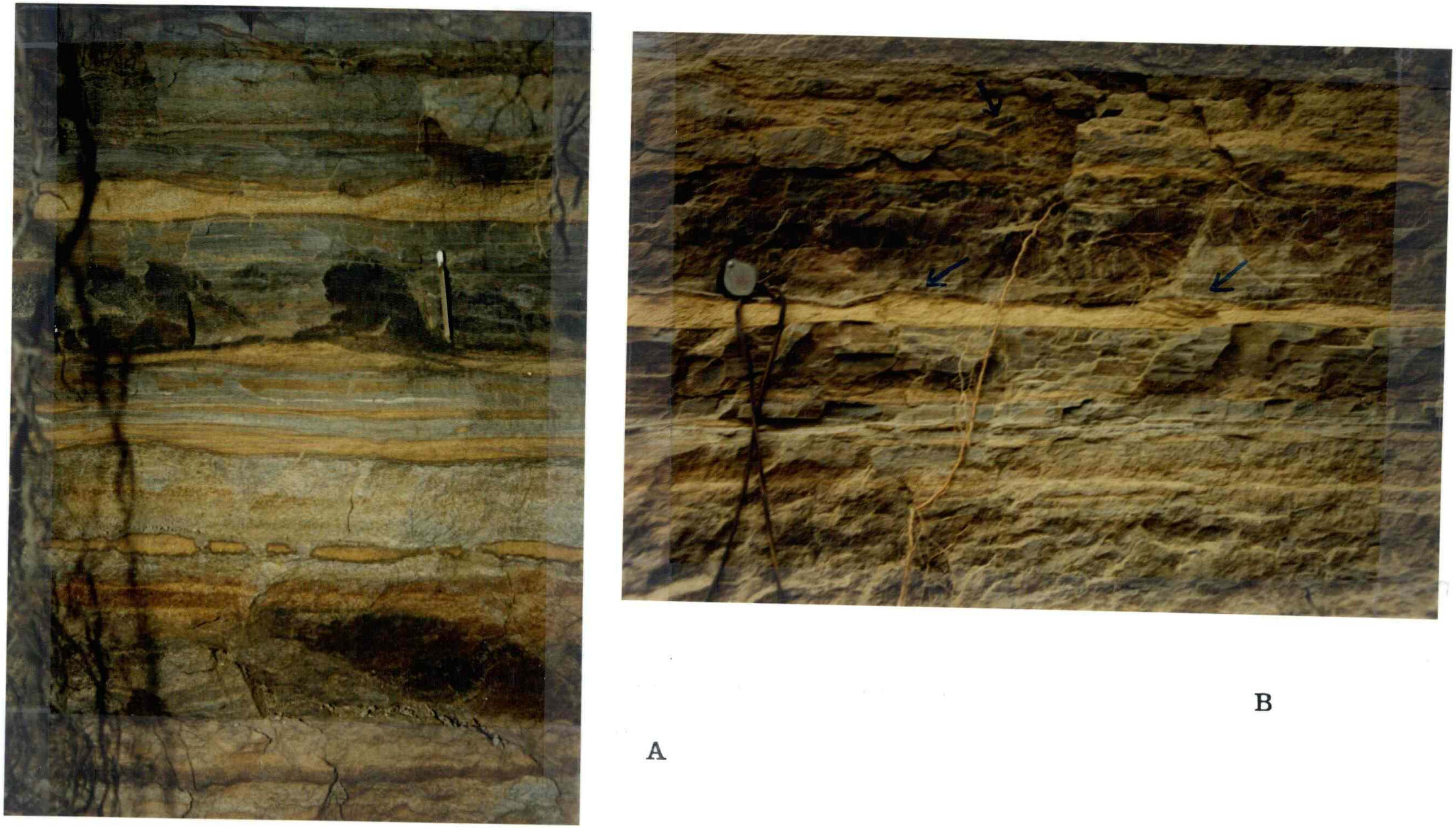
Figure 19: (A) Hummocky cross-stratification at Helmick Hill. (B) Bioturbated silty sandstone at Helmick Hill. Burrows surrounded by light gray, clayey sand halos are thought to be Thalassinoides.

containing abundant light gray halo burrows (Thalassinoides?; Fig. 19b). The degree of bioturbation decreases upsection; sorting improves, and the unit grades into a three to five foot thick calcite-cemented concretionary bed of well sorted, fine- to medium-grained sandstone. The uppermost bed exposed at Helmick Hill is a well sorted, very fine-grained sandstone showing hummocky cross-lamination. The sandstones at the "clay" pit and Helmick Hill are thought to correlate with lower sandstones in the Bruer, Bliven and Merrill wells (Plate II).

The middle part of the lower member of the Spencer Formation is not well exposed in the northern study area. Exposures west of Monmouth (Fig. 15, #2-5) indicate that the middle part of the lower Spencer is composed of siltstone, silty sandstone, and two compositionally different types of fine- to medium-grained sandstone. Thicker bedded sandstones are volcanic-rich and contain clasts up to granule size. Well sorted, fine-grained arkosic sandstones commonly are interbedded with siltstones containing wood fragments and plant debris. The volcaniclastic lithologies in the Monmouth area may be localized and related to active volcanism during deposition. Boulders of basalt, thought to be late Eocene in age, are exposed as float over a broad area on Mt. Pisgah (Fig. 15, #1). These dark gray (N3) porphyritic basalts with phenocrysts as basic as bytownite are similar to other late Eocene basalts interbedded with the Nestucca and the Cowlitz Formations to the north (Baldwin, 1964). The presence of a local volcanic high would explain the basaltic, tuffaceous, and coarse-grained nature of several exposures in the area, as well as pebbly and gravelly layers noted in water wells. The volcanic-rich beds are thought to interfinger with the arkosic beds.

Sandstones, from the upper part of the lower member of the Spencer Formation, are exposed at the summit of Monmouth Road (Fig. 15, #6,7), and in the bluffs along the Willamette River near Buena Vista (Fig. 15, #16-18). West of Monmouth, silty sandstone is overlain by interbedded organic-rich siltstone and well sorted, fine-grained sandstone Fig. 20a). The interbedded sandstones and siltstones show wavy to lenticular bedding. Sedimentary structures within the sandstones include parallel laminations, small-scale hummocky structures, and small-scale cross-lamination sets. Thicker sandstone beds have erosional bases and locally contain rip-up clasts of black siltstone (Fig. 20b). Ripple forms commonly are preserved on the top of sandstones.

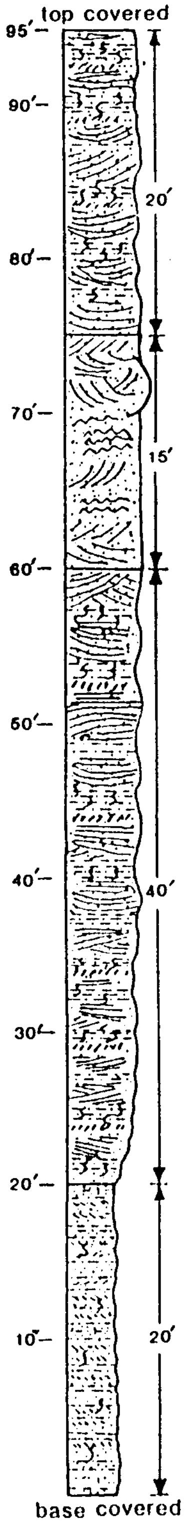
An interbedded lithology similar to the Monmouth beds is found at the base of the bluff at Buena Vista (Figs. 21, 22a). Bed thicknesses are variable and structures include parallel, hummocky, and small-scale cross-laminations. Bedding thickens upward and well developed hummocky sequences (see Dott and Bourgeois, 1982; Appendix IV) are exposed. Fine-grained sandstones have sharp lower contacts. The basal bedding is hummocky and commonly flattens upward into parallel laminations. At the top of many sandstone beds small-scale ripple cross-laminae are developed in very fine-grained sand. Bioturbated to laminated siltstones and mudstones overlie most sandstone sequences (Fig. 22b). Burrows, which are tentatively identified by the author as Rosselia are abundant, and commonly penetrate the underlying sandstone. Mica and organic material are concentrated on the walls of these back-filled,



A

B

Figure 20: (A) Interbedded dark gray, organic-rich siltstone and light brown, well sorted, fine-grained sandstone at the summit of Monmouth Road. Note the hummocky contacts and laminations. (B) Monmouth Road summit lithology showing mudstone rip-ups, preserved ripple forms, and cross-laminae.



BUENA VISTA BLUFFS

Interbedded sandstones, siltstones and mudstones similar to the 40 foot section below the amalgamated sandstone. Sandstone beds thin and mudstones thicken upsection.

Dark greenish gray (5GY41), well sorted, fine-grained arkosic sandstone. Amalgamated hummocky bedding which grades into trough bedding, sets up to 3 feet thick pass laterally into convolute bedding. Plant fragments concentrated on many bedding planes. Structures well preserved in large concretions.

Interbedded sandstone, siltstone, and mudstone. Sandstones are friable, well sorted, and light olive gray (5Y6/1) to grayish orange (10YR7/4) fine-grained or gray (N7) and very fine-grained. Siltstones and mudstones are dark gray (N4), contain plant debris, and are bioturbated. Bed thickness ranges from less than an inch to several feet. Mudstones thin and sandstones thicken upsection. Sandstones are laminated to bioturbated showing typical hummocky sequences. Roselia (?) and Arenicolites (?) are the dominant burrow types.

Interbedded fine-grained sandstone, siltstone, and mudstone. Sandstones are blue gray (5B6/1), well sorted, micaceous, carbonaceous, and arkosic. Siltstones and mudstones are dark gray (N4), rich in plant debris, and well indurated. Bed thickness is 0.1 to 12 inches. Hummocky to parallel laminations and small-acale ripple bedding are common. Minor vertical sand-filled burrows. Bedding thickness increases upsection.

Figure 21: Stratigraphic section exposed at the Buena Vista bluffs (symbols same as Figure 16).

Figure 22: (A) Spencer sandstone exposure at Buena Vista bluffs. The lower darker beds are thinly interbedded, very fine-grained sandstone and organic-rich siltstone. Overlying lighter colored beds contain hummocky sequences. (B) Hummocky cross-laminations at the Buena Vista bluffs. Basal bioturbated siltstone is the top of a lower hummocky sequence. Hummocky cross-bedding is the base of the next hummocky sequence. Bedding flattens upward and grades into a bioturbated siltstone (not shown). (C) Bioturbated siltstone near the top of a hummocky sequence. Back-filled, sand-cored burrows are *Rosselia*? and broad U-shaped burrows are *Arenicolites*?. Pelecypods found along bedding planes attest to marine deposition. (D) Amalgamated sandstone beds at Buena Vista. Low angle hummocky bedding grades into trough cross-bedding. Convolute bedding is barely visible under the bush to the left of the large trough.

A

B

Figure 22

C

D

Figure 22 continued

sand-cored, subvertical burrows. Broad U-shaped burrows are thought as Arenicolites (Fig. 22c).

Sandstone beds thicken upsection and the intervening siltstone beds thin. The unit passes upwards into a well sorted, fine-grained, arkosic sandstone with large concretions up to six feet in diameter. Hummocky cross-stratification grades into large scale trough cross-lamination (Fig. 22d). Convolute bedding also is common in this concretionary layer. This amalgamated sandstone unit is overlain by hummocky sequences consisting of interbedded sandstones and siltstones, similar to those below. Farther north along the Willamette River, bedding is similar to that at the base of the Buena Vista bluff, consisting of interlaminated to interbedded very fine-grained sandstone and organic-rich siltstone. An approximately eight foot thick mudstone bed also is present. Sandstones from the Buena Vista area are thought to correlate to upper sandstones in the Gilmour and Merrill wells (Plate II).

Very thin beds of resistant, very fine-grained silty sandstone in an altered mudstone are exposed in a small ditch near the summit of Oak Hill, west of Buena Vista. This may be the only exposure of the upper Spencer in the northern area. The sandstones show parallel laminations and possible ripple laminations. Mudstones of the upper Spencer do not generally crop out. The upper contact with the strata mapped as undifferentiated Eocene and Oligocene sediments is covered by river alluvium.

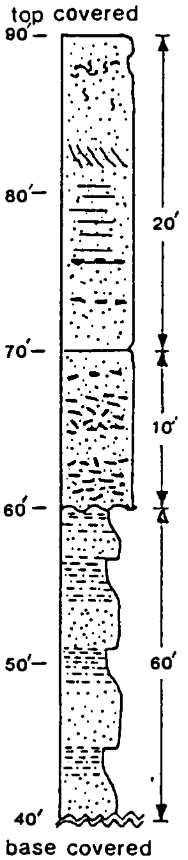
Starr Creek-Belfountain-Monroe Area

In the southern part of the study area the strata underlying the Spencer Formation have been mapped as the Tyee Formation (Vokes and others, 1954). However, in the subsurface to the east, up to 2,000 feet of the Yamhill Formation, including the Miller sandstone member, are present between Spencer and Tyee strata (Bruer and others, 1984; Plates II, III). Possible explanations for the absence of Yamhill (Miller) strata in the outcrop belt include: (1) the Yamhill strata may not have been deposited or may have been eroded prior to Spencer deposition; (2) lithologic and faunal similarities between Miller and Spencer sandstones may have caused previous workers to include Miller sandstones at the base of the Spencer Formation; or (3) the Miller sandstone member may have undergone a facies change to slope sandstones resembling the Tyee. Better exposures and more detailed fossil work are needed to determine the presence and define the extent of Miller sandstone and Yamhill mudstones at the southern outcrop belt.

The Miller sandstone may crop out adjacent to the Tyee/Spencer contact. Efforts to obtain microfossils from these questionable outcrops have, as yet, been unsuccessful. However, east of Dawson, preliminary identification of macrofossils found within a massive sandstone overlying typical Tyee strata imply a post-Tyee, pre-Spencer age. Specimens of Venericardia aragonia, which are commonly associated with the Umpqua Group of middle Eocene age (Weaver, 1942), were found in a bed containing fossils more typical of the Spencer Formation; a late middle to early late Eocene age is suggested (Tim Fleming, per. comm.). Further analysis of these specimens may help solve the Miller sandstone problem.

At the Dawson outcrop (Fig. 15, #60), approximately 50 feet of typical rhythmically-bedded Tyee strata are exposed (Fig. 23). The typical Tyee strata are disconformably overlain by a mudstone

DAWSON ROAD OUTCROP



SPENCER (MILLER?): Medium gray (N5), well indurated, well sorted, medium- to coarse-grained sandstone. Parallel laminated to massive with one 3 foot thick set of tangential trough cross-lamination. Ranges from lithic arkose to arkosic litharenite; contains scattered basalt pebbles. One fine- to medium-grained fossiliferous sandstone containing possible Venericardia aragonia pelecypods. Also thin mudstone rip-up beds.

Medium gray (N5) mudstone conglomerate: clasts up to 1.5 feet long; parallel laminated, with abundant carbonaceous debris. Clasts are rounded to angular and enclosed in a moderately sorted arkosic to lithic sandstone matrix. Sandstone matrix is medium- to coarse-grained and contains basalt pebbles.

TYEE: Rhythmically bedded medium gray (N5) to grayish orange (5YR5/2) sandstone, siltstone, and mudstone. Medium- to coarse-grained sandstone at base, fines upward to very carbonaceous mudstone at top. Beds 6 inches to 10 feet thick, parallel laminated to massive, sharp lower contact.

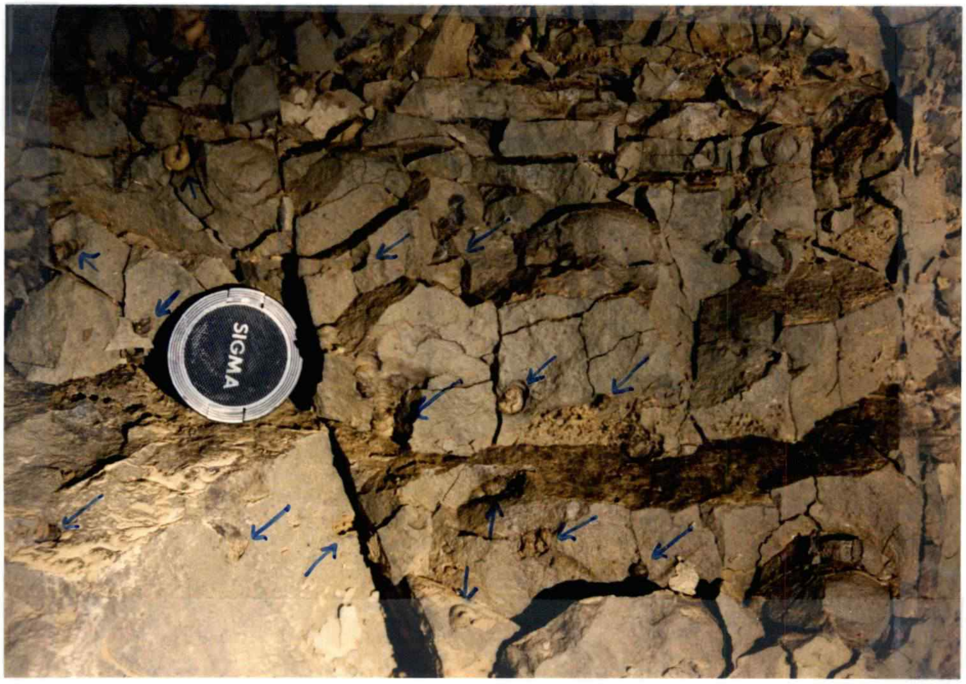
Figure 23: Stratigraphic section of Tyee and Spencer (and Miller sandstone?) exposed east of Dawson (symbols same as figure 16).

conglomerate (Fig. 24a). Mudstone clasts are similar to mudstone beds of the underlying Tyee; the clasts are light gray (N7), parallel laminated and contain abundant carbonaceous material. The coarse sand matrix surrounding the rounded to angular mudstone clasts is lithologically similar to Tyee sandstones. This very thick conglomerate bed is has an cut-and-fill lower contact. It is not clear whether the conglomerate bed is a slope or channel deposit within the Tyee Formation, or is the basal unit of the overlying, more massive strata (Spencer or Miller sandstone?). Two thin beds of mudstone rip-ups are found stratigraphically higher within the massive sandstones. Therefore, inclusion of the conglomerate within at the base of the Spencer is favored.

The mudstone conglomerate is overlain by well sorted, fine- to coarse-grained sandstones. Coarser beds contain rounded volcanic granules and thick beds of mudstone rip-ups. Sandstones are massive to parallel laminated. One set of large-scale trough cross-beds were visible. Fossils possibly indicating a post-Tyee/pre-Spencer age, were found in a fine- to medium-grained sandstone approximately 15 feet above the mudstone conglomerate. Minor breakage of the robust fossils, combined with the large-scale trough cross-beds, suggest deposition in shallow water, and not transportation by turbidity currents or slumping.

Until further fossil identification is completed, the sandstones overlying typical Tyee strata at the Dawson exposure will be included as the base of the Spencer. These sandstones contain more sedimentary rock fragments, quartz, and potassium feldspar and less volcanic rock fragments than the overlying Spencer sandstones. Similar fine- to

A



B

Figure 24: (A) Mudstone conglomerate at Dawson outcrop. May be basal Spencer conglomerate or slope deposit of the Tyee. (B) Bioturbated and highly fractured very fine-grained sandstone containing abundant Turritella.

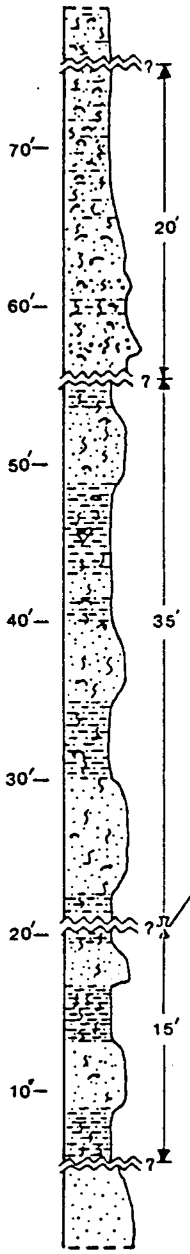
coarse-grained micaceous feldspathic litharenites also are present at the base of the Spencer near Baily Junction (Fig. 15, #68) and in poor exposes along Larson Road (Fig. 15, #67).

The remainder of the Spencer exposures in the southern area consist of interbedded fine-grained sandstone, silty fine-grained sandstone, and siltstone. Thin beds of pebbly to coarse-grained sandstone, composed dominantly of volcanic clasts and commonly containing abundant pelecypods and gastropods, are found throughout the section. The Spencer strata are markedly more tuffaceous than in the northern part of the study area; the sandstones classify as feldspathic litharenites, and rarely as lithic arkoses. The color of the Spencer is variable, depending primarily on the proximity to intrusives, and degree of weathering. Fresh exposures are tan, baked exposures are light gray (N7) or blue gray (5B6/1), and weathered exposures are light brown, dark yellowish orange, grayish orange and moderate yellowish brown (5YR6/4, 5YR5/6, 10YR6/6, 10YR7/4, and 10YR5/4, respectively).

Spencer strata assumed to overlie the basal fine- to coarse-grained arkosic litharenites are exposed in the low hill immediately east of Belfountain (Fig. 15, #65), and along the road west of Reese Creek Road (Fig. 15, #57). These outcrops consist of interbedded micaceous sandstones and silty mudstones (Fig. 25). The sandstones are thinly to thickly bedded, fine- to medium-grained, moderately sorted, and massive to laminated. Thin siltstone and silty mudstone interbeds and are highly bioturbated.

Similar, thicker bedded outcrops are present south and west of Monroe on Territorial and Coon Roads (Fig. 15, #71-74). Sandstones and siltstones are often fossiliferous (pelecypods and gastropods) and

IDEALIZED SECTION: LOWER PART OF LOWER MEMBER, SPENCER FORMATION--SOUTHERN AREA



Belfountain Road lithology: see Figure 26.

Medium gray (N6) to blue gray (5B6/1), highly bioturbated, fine-grained sandstone to siltstone. Sandstones are micaceous, arkosic litharenites containing large wood fragments, plant debris, pelecypods (articulate and disarticulate), gastropods, sharks teeth and disseminated pumice. Includes normally graded pebbly coarse sandstone to siltstone beds. Coarse grains are subangular to subround and dominantly volcanic.

Grayish orange (10YR7.4) to pale brown (5YR5/2) thickly bedded sandstone and siltstone. Sandstones are fine-grained, micaceous arkosic litharenites, and contain volcanic clasts up to pebble size, wood and plant fragments, and fossils. Siltstones and silty mudstones are bioturbated, massive to parallel laminated and fossiliferous.

Thinly to thickly bedded sandstone and siltstone. Sandstones are micacous, feldspathic litharenites which range from poor to well sorted, fine- to medium-grained, and massive to laminated. They contain fossils, plant fragments, disseminated pumice and rare wood fragments. Siltstones and silty mudstones are highly bioturbated with rare relict laminations, and some small fossils. Some siltstones coarsen upwards and contain thin sandstone interbeds. Other siltstones are abruptly overlain by sandstone and contain 0.5 to 1 inch sand filled burrows at the upper contact.

Dawson Road lithology: see Figure 23.

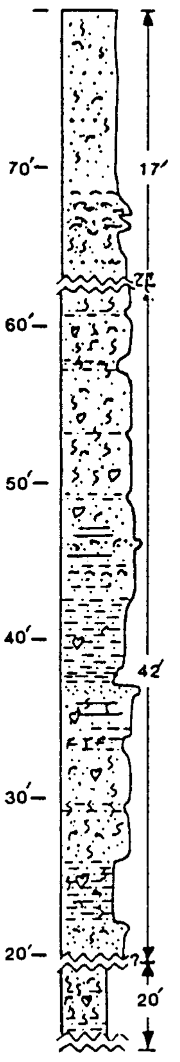
Figure 25: Idealized composite stratigraphic section of the lower Spencer in the southern area based on scattered outcrops (symbols same as Figure 16).

completely bioturbated. These interbedded sandstones and siltstones may correlate to the lower sand-rich beds in the Porter well (2,300 to 2,400 foot well depth; Plate II).

Strata thought to be typical of the middle part of the lower Spencer are exposed along Reese Creek Road, and Starr Creek Road (Fig. 15, #53,54,56,58). These exposures consist of thick sections of bioturbated, fine-grained volcanic-rich sandstone and siltstone. Articulated and disarticulated pelecypods are common, and gastropods (especially Turritella) are abundant (Fig. 24b). Disseminated plant debris, large wood fragments, and streaks of black organic-rich (fecal?) clay are common. These poorly sorted sandstones are micaceous and contain volcanic clasts up to pebble size. A thin normally graded bed, ranging from a pebbly conglomerate to fine sandstone, is poorly exposed at Reese Creek. Despite intense bioturbation, additional relict normally graded sequences are visible.

The extensive exposure along Belfountain Road (Fig. 15, #61) is thought to represent the upper part of the lower Spencer. Although baked and highly faulted, the lowermost part of the Belfountain outcrop resembles the Reese Creek lithology. The middle part of the Belfountain Road outcrop consists of interbedded fine-grained massive to laminated sandstones and siltstones (Fig. 26). The sandstones show some degree of bioturbation (Thalassinoides?). Articulate and inarticulate pelecypods, gastropods and wood fragments are present. Coarse-grained altered pumice clasts are disseminated throughout the section. Discontinuous dark yellowish orange (10YR6/6) clay beds are present in a few of the sandstones and siltstones. Thin volcanic-rich

BELFOUNTAIN ROAD



Gray (N5) to light brown (5YR6/4), moderately to well sorted, fine-grained, micaceous arkosic lithic sandstones with disseminated pumice clasts up to coarse size. Bioturbated to laminated with scattered pelecypods and gastropods. Contains very thin coarse beds of volcanic sandstone with minor shells and small-scale cross-beds. Also contains thin normally graded beds of fossil-rich, pebbly coarse- to very fine-grained sandstone. Volcanic clasts, fossils, and fossil fragments are concentrated at the base of the normally graded beds. Rarely fossils show current alignment.

Interbedded blue gray (5B6/1) to light brown (5YR6.4) sandstones and siltstone. Sandstones range from well sorted fine- to very fine-grained sandstone to moderately sorted silty sandstone. Sandstones are massive, with rare parallel laminations, and contain articulate and disarticulate pelecypods, gastropods, dentallium, wood fragments, burrows (Thalassinoides?), and disseminated pumice. Coarse volcanic sandstones which are overlain by yellow sticky mudstones are found at the top of some sandstones. Other normally graded fossiliferous coarse to pebbly volcanic beds are found within sandstones. Siltstones are massive to laminated, fossiliferous, partially bioturbated and contain yellow mudstone lenses. Siltstone abundance and bed thickness decreases upsection.

Highly faulted and baked gray (N5) siltstone to fine-grained sandstone. Bioturbated and containing abundant articulated pelecypods and large gastropods. Includes concretionary horizons with pyrite. Similar to upper lithology in idealized lower Spencer stratigraphic section: Figure 25.

Figure 26: Stratigraphic section of the outcrop along Belfountain Road (symbols same as Figure 16).

coarse-grained beds are present at the top of several sandstones. Similar lithologies are exposed along Beaver Creek Road (Fig. 15, #52).

Old Ma's fossil beds (Fig. 15, #55), exposed on the ridge between Reese and Starr Creeks, are tentatively correlated with the middle part of the Belfountain Road outcrop. Exposures are limited, but consist of laminated to bioturbated, interbedded well sorted, fine-grained sandstone and siltstone. Small pelecypods and volcanic grains are in places concentrated along bedding planes. Highly fossiliferous beds also are present, including one bed with many large (three inch) articulated specimens of Venericardia hornii clarki in life position (Fig. 27; Tim Fleming, per. comm.).

The stratigraphically highest part of the Belfountain outcrop (Fig. 26), and an outcrop about a half mile southeast along Bruce Road (Fig. 15, #62), are thought to represent the uppermost part of the lower Spencer. These well sorted fine- to medium-grained micaceous sandstones contain disseminated coarse pumice grains and relict parallel laminations. Normally graded fossil-rich pebbly beds occur at the bases of, or within the sandstones (Fig. 27). Entire fossils and fossil fragments are abundant in the coarse beds and some show current allignment. The grains are dominantly volcanic.

The highly bioturbated sandstones and siltstones of the middle-lower Spencer may correlate to the 1,980 to 2,300 foot well interval in the Porter well, and the better sorted overlying sandstones to the upper part of the lower Spencer in the Porter well (1,890-1,980 foot well depths; Plate II). The mudstones and siltstones of the upper member, including the upper contact with Oligocene strata, are not exposed in the southern area.

A

B

Figure 27: (A) Large pelecypods (Venericardia hornii clarki) in life position at Old Ma's fossil beds. (B) Concentrations of shells, shell fragments and volcanic clasts near the base of normally graded sandstones from the Bruce Road outcrop.

Albany-Corvallis Area

The stratigraphy of the Spencer Formation in the transitional Albany-Corvallis area does not clearly fit with the stratigraphy to the north or south. The close proximity of this narrow and poorly exposed outcrop belt to the Corvallis fault, combined with uncertainties about the precise fault trace and timing of offset, make construction of a stratigraphic section difficult. Furthermore, there are problems with the mapping of the underlying unit. Vokes and others (1954) and Bela (1978) mapped a small belt of Tyee (Flournoy) below the Spencer and adjacent to the fault; Lawrence and others (1980) mapped much of the same strata as Spencer. Allison (1953) did not mention any normally graded beds and thought the arkosic strata in the hills along the Corvallis fault resembled the Spencer.

Vokes and others (1954) described an anomalous section of Tyee immediately adjacent to the fault containing conglomeratic basaltic beds which grade upward into a olive gray (5Y4/2), tuffaceous, silty sandstones (Fig. 15, #37). These beds resemble sedimentary beds within the Siletz River Volcanics at Coffin Butte (Dr. A. Niem, per. comm.). The volcanic-rich beds were thought to be overlain by more typical Tyee strata, although containing more siltstone than the Tyee farther south. On the northwest side of Logsdens Ridge a few normally graded Tyee-like beds were found. However, other strata previously mapped as Tyee contain a few normally graded beds and abundant sandstone. Exposures consist of yellow gray (5Y8/1) to light gray (N7) arkosic to lithic sandstones with large mica flakes (primarily biotite). Some sandstones are well sorted, but others are poorly sorted and contain abundant carbonaceous debris. The interbedded siltstones commonly contain abundant plant debris, including some nearly whole leaves. The bedding is at places irregular with sharp contacts and lenses of siltstone within sandstones. Small gastropods (Turritella) and a pelecypod were found within one siltstone bed. These strata are micaceous and carbonaceous similar to the Tyee (Vokes and others, 1954), and parts of the Spencer. Well cuttings indicate that the Miller sandstone also is micaceous and carbonaceous. These questionable strata, exposed on Walnut Hill, Witham Hill, the west side of Spring Hill, and at the Philomath water tower (Fig. 15, #35,36; 75; 28; 39, respectively) may be the basal unit of the Spencer, the Miller sand member of the Yamhill, or an anomalous unit within the Tyee. Because an arkosic sandstone is present at the base of the Spencer in the Albany area and in the southern part of the study area, the strata adjacent to the Corvallis fault have been mapped as Spencer(?) (Plate I).

Immediately southwest of Philomath along Evergreen Road (Fig. 15, 41-44), the stratigraphic section is similar to that in the southern area. A medium-grained sandstone lies at the base of the Spencer. The remaining outcrops consist of fine-grained sandstones and siltstones with a few coarse-grained beds. Outcrops range from parallel laminated to massive. Minor bioturbation, gastropods, pelecypods, and plant fragments are present in some beds.

Fine-grained sandstone is the dominant Spencer lithology exposed on Country Club, Witham, and Walnut hills (Fig. 15, #45; 38; 34). The sandstones range from well sorted and parallel laminated to moderately sorted, massive and bioturbated. Thin beds of normally graded very coarse-grained sandstone to siltstone are present in all three hills.

Shells and shell debris are abundant near the base of these coarse layers. On Country Club Hill the coarse grained bed has a gradational lower contact. Over an interval of six inches the lower fine-grained sandstone passes upward into a pebbly coarse-grained layer that is moderately sorted and contains large robust pelecypods and fossil fragments showing current allignment. The grain size decreases upward to fine-grained sandstone. Burrows in the underlying fine-grained sandstone are filled with the coarser material.

Exposures northeast of Corvallis along Logsdens Ridge, and Spring Hill (Fig. 15, #29,30,32; 20-27) contain friable fine- to medium--grained arkosic sandstones which are overlain by beds composed of basaltic siltstone, fine-grained sandstone, basalt pebble conglomerate, and lenses of tuffaceous mudstone. Cross-bedding, hummocky and parallel laminations are visible in some arkosic sandstones. Micas and carbonaceous debris are concentrated along many laminae. Small (0.3 inch) clay-lined burrows are locally abundant. The easternmost exposure of this arkosic sandstone has thin interbeds of coarse sand to cobble-sized volcanic rock fragments including probable scoria clasts.

The contact with the overlying basaltic unit is thought to be gradational, with some interfingering of lithologies. Allison (1953) and Bela (1979) suggested an andesitic composition for these volcanics, while Vokes and others (1954) believed them to be basaltic. Rock fragments in thin section suggest a basaltic composition (Dr. E. Taylor, per. comm.). The best exposure of the volcanic lithology is along Scenic Drive (Fig. 15, #54). Spheroidally weathered basaltic sandstones, siltstones, and tuffaceous mudstones are interbedded near the base of the section (Fig. 28). The overlying basalt pebble conglomerates (Fig. 29a) are moderately to well sorted with rounded to subrounded clasts in grain contact and a clayey matrix. Conglomerate beds range from two to 13 feet thick, have sharp lower contacts, and appear to thin and pinch out to the west. Robust pelecypods were found locally concentrated near the base of the unit. The pebble conglomerates fine upward into basaltic sandstones.

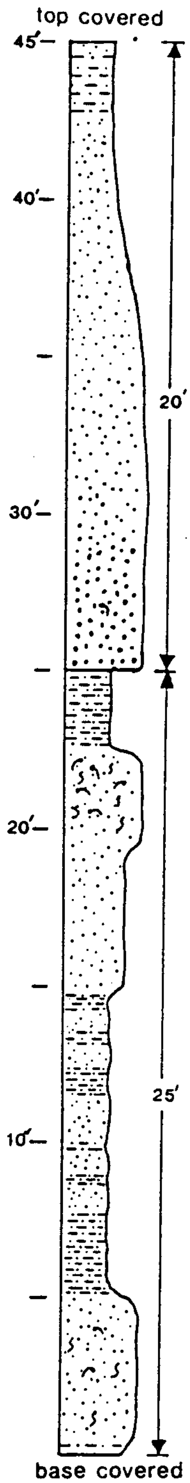
Arkosic sandstones in the west Albany area probably correlate to arkosic sandstones between 700 and 900 foot well depths in the Miller well, while overlying strata correlate to volcanics and volcaniclastic beds above the 600 foot well depth (Plate II).

Dark greenish gray (5GY4/1), very thinly bedded to massive volcanic-rich mudstones, which may be the upper member of the Spencer Formation, are exposed in the banks of the Calapooya River in Albany (Fig. 15, #76; Fig. 29b). The mudstones contain thin, normally graded, medium- to fine-grained sandstone beds.

PETROGRAPHY

The petrography and mineralogy of the Spencer Formation from the western Tualatin Valley, Monmouth, Albany, Corvallis, and the type-section southwest of Eugene, Oregon, were studied in detail by Cunderla (1986). Gandera (1977) summarized the petrography of the Spencer Formation in Lane County. In an effort to increase the data set and provide information from southern Benton County, thirty thin sections from the study area were examined. Eleven of the thin sections were point counted using the method of Dickinson (1970). Monocrystalline quartz (Qm), polycrystalline quartz (Qp), plagioclase (P), potassium feldspar (K), volcanic rock fragments (Lv), the combination of fine-grained sedimentary and metamorphic rock fragments

SCENIC DRIVE/SPRING HILL



Dark yellowish brown (10YR4/2) to brownish gray (5YR4/1), basalt pebble conglomerate. Moderately to well sorted, subrounded to rounded clasts in a clayey matrix. Conglomerate fines upward from pebble size to fine-grained sandstone and siltstone. Spheroidally weathered, sharp undulatory lower contact. Contains robust pelecypods, and a dentallium.

Interbedded grayish orange (10YR7/4), dark yellowish brown (10YR4.2) and brownish gray (5YR4/1) sandstone, siltstone, and mudstone. Sandstones are fine- to very fine-grained, basaltic, massive, and contain fossils, plant fragments and _Toredo_ bored wood pieces. Fossils are locally abundant. Siltstones are tuffaceous, and laminated to massive. Highly fractured and spheriodally weathered.

Figure 28: Stratigraphic section of volcanic-lithic beds exposed along Scenic Drive at Spring Hill (symbols same as Figure 16).

A

B

Figure 29: (A) Spheroidally weathered basalt pebble conglomerate in sharp contact with the underlying basaltic sandstone at Scenic Drive. (B) Upper Spencer basaltic mudstone with thin normally graded sandstone beds unconformably overlain by recent river deposits, west Albany.

(Ls+m), and micas plus heavy minerals (M+HM) were counted. Cements, matrix, and grains rendered unidentifiable by alteration were not counted. Because of the altered nature of the Spencer strata, many volcanic rock fragments containing microphenocrystic feldspars within an aphanitic lithic fragment were counted as volcanic rock fragments. In a fresher form they may have been counted as plagioclase according to Dickinson (1970).

The Spencer sandstones are primarily subangular to subrounded, with volcanic and sedimentary lithic fragments generally subrounded to rounded. The sorting is commonly poorer south of Corvallis, with the sandstones being texturally submature to immature. North of Albany, the sandstones are moderately to well sorted, and texturally submature to mature. The Spencer sandstones are classified as lithic arkoses and feldspathic litharenites using the Q-F-L ternary diagram of Folk (1974; Fig. 30a). When the point count results are used to classify sandstones, samples are grouped as arkoses and lithic arkoses because many unaltered volcanic rock fragments are counted as plagioclase (Fig. 30b). Except for the basal beds, coarser beds in the southern area classify as volcanic arenites.

The percentages of sandstone components, based on visual estimation and point counting, are listed in Tables 1 and 2 respectively. Very fine- to medium-grained sandstones are composed of 70 to 95% detrital grains. Cements, matrix, and pore space make up the remaining 5 to 30%. Cementing agents include calcite, silica, iron oxide, and rarely zeolite (see Enlows and Oles, 1966; Cunderla, 1986). Brown birefringent clays, which form the cementing matrix in many samples, are thought to be illite, mixed-layer illite/smectite, and chlorite (see Cunderla,

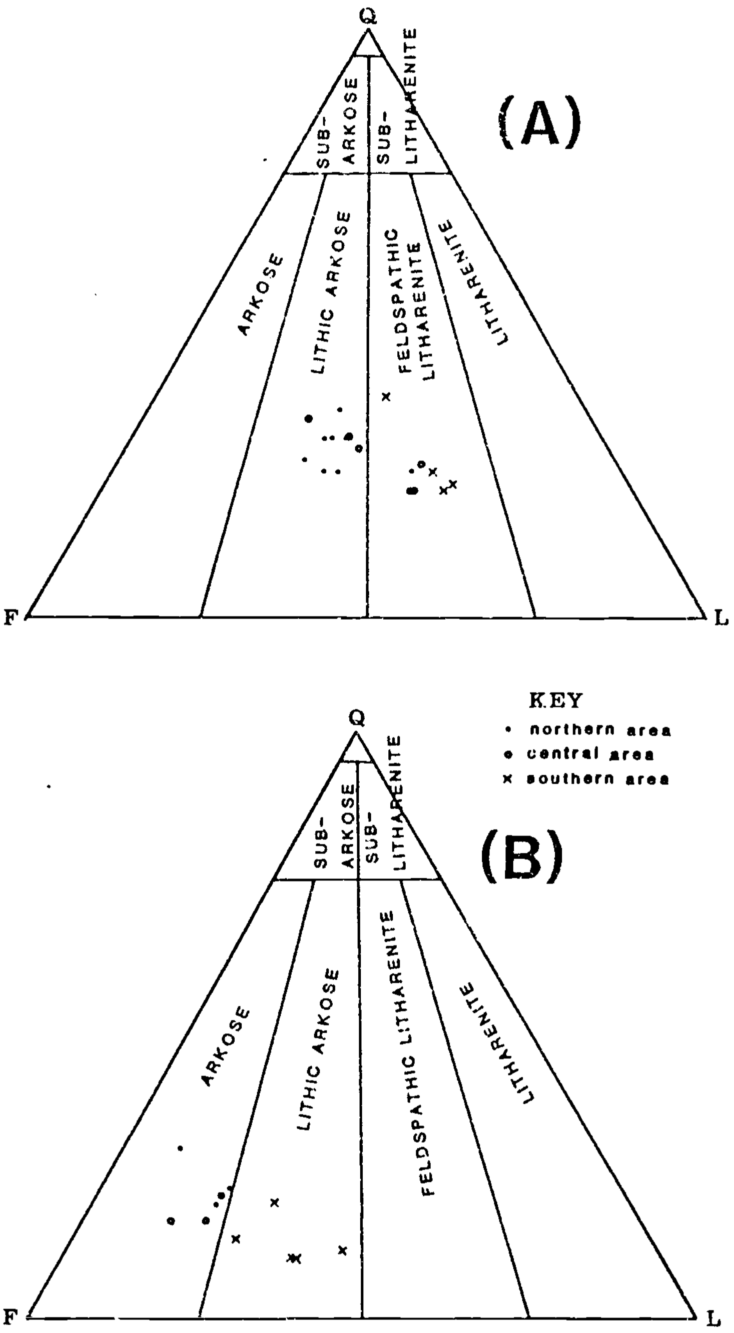


Figure 30: Mineralogic classification of Spencer sandstones using the system of Folk (1974), where Q=all quartz, F=all feldspar, and L=fine-grained rock fragments. (A) Results based on visual estimation. In general northern sandstones plot as lithic arkoses while southern sandstone are feldspathic litharenites. (B) Results based on point counting according to the method of Dickinson (1970). Sandstones plot as arkoses (northern) and lithic arkoses (southern). Point counts show a more arkosic composition because many volcanic grains were counted as plagioclase.

IDENTIFIABLE FRAMEWORK GRAINS-- VISUAL ESTIMATION RESULTS

LOCATION sample#/figure 101#	Quartz	Plagio-clase	Potassium Feldspar	Volcanic Rock Fragments	Other Rock Fragments	Micas	Heavy Minerals	Pore Space / Cement / Matrix	Other	NORMALIZED VALUES Quartz	Feldspar	Lithics
Helmick Hill 105/#10	20	14	13	13	5	2	1	40	-	31	41	28
Helmick Hill 107b/#10	20	15	10	30	5	2	1	17	-	25	31	44
Helmick Hill 106/#10	25	20	10	20	5	10	1	9	-	31	38	31
Helmick Hill 86/#10	20	15	10	15	5	5	2	20	8	31	38	31
Helmick Hill 86a/#10	25	20	12	20	3	1	1	18	-	31	40	29
Helmick Hill 87b/#10	15	15	10	15	0	1	1	2	1	27	46	27
"Clay" Pit 107d/#13	25	10	15	18	2	2	1	30	-	36	36	28
"Clay" Pit 94/#13	15	20	5	18	2	9	1	15	-	25	42	33
Monmouth 96c/#7	20	30	5	17	3	10	1	9	-	25	44	31
Baily Jct. 69/#68	35	15	10	22	8	3	1	5	-	38	28	34
Territorial Rd. 64/#73	15	15	10	18	2	2	2	2	-	31	38	31
Reese Creek Rd. 60#56	22	15	10	43	5	3	1	2	-	23	26	51
Belfountain Rd. 35b/#61	20	20	5	38	2	2	1	12	-	22	28	50
Belfountain Rd. 21m/#61	15	15	7	28	2	2	1	30	-	22	33	45
Bruce Rd. 77/#62	20	15	7	34	3	3	2	16	-	25	28	47
Witham Hill 94c/#38	25	20	12	25	5	4	1	7	-	29	37	34
Logsdens Ridge 79a/#30	20	25	5	40	0	4	3	3	-	22	33	45
Logsdens Ridge 79x/#29	25	18	15	16	2	2	1	22	-	34	42	24
Spring Hill 54d/#26	20	15	7	30	5	5	3	14	-	26	29	45

Table 1: Spencer sandstone composition based on visual estimation.

IDENTIFIABLE FRAMEWORK GRAINS -- POINT COUNT RESULTS

LOCATION sample#/figure 101#	Total Points	Qm	Qp	P	K	Lv	Ls+Lm	Micas + H.M.s	Normalized Q-F-L values
Coon Rd. 66b/#71	517	53/10%	7/1%	167/32%	55/11%	179/35%	13/3%	43/8%	12-47-41
Baily Jct. 69/#68	603	78/13%	22/4%	206/34%	75/12%	104/17%	37/6%	82/14%	20-53-27
Dawson 202b/#60	581	68/12%	13/2%	236/40%	117/20%	97/17%	33/6%	17/3%	14-62-24
Reese Creek Rd. 59a/#58	614	49/8%	9/2%	250/41%	75/12%	187/30%	17/3%	27/4%	11-55-34
Belfountain Rd. 32/#61	520	45/9%	5/1%	191/36%	82/16%	166/31%	6/1%	33/6%	11-55-34
Witham Hill 94c/#38	525	89/17%	14/3%	213/41%	65/12%	73/14%	12/2%	59/11%	22-60-18
Walnut Hill 95t/#35(Spencer?)	650	85/13%	14/2%	282/43%	125/19%	45/7%	34/5%	70/11%	17-70-13
Pettibone Rd. 79x/#29	590	73/15%	5/1%	217/43%	83/17%	71/14%	16/3%	34/7%	17-65-18
"Clay" Pit 107d/#13	514	75/15%	10/2%	166/32%	108/21%	65/13%	11/2%	79/15%	20-62-18
Helmick Hill 86a/#10	620	101/16%	34/5%	193/31%	141/23%	79/13%	32/5%	40/7%	23-58-19
Buena Vista 110h/#16	613	153/25%	8/1%	205/34%	131/21%	49/8%	0/0%	68/11%	29-62-9

Table 2: Spencer sandstone composition based on point counting according to the method of Dickinson (1970).

1986). The pore space reaches a maximum of 15% in some friable sandstones.

Quartz, feldspars, and rock fragments comprise 65 to 90% of the Spencer sandstones. The quartz content ranges between 15 and 35%, with the quartz being dominantly monocrystalline and clear. Inclusions are present in a few of the grains. Polycrystalline quartz is rare, and is generally made up of uniform grain sizes or elongate sutured grains. Feldspar is slightly more abundant than quartz, comprising up to 35% of samples.

Late Narizian arkosic sandstones from the Pacific Northwest are typically enriched in plagioclase relative to potassium feldspar (Byrnes, 1985; Winters, 1984; Cunderla, 1986). The Spencer Formation is no exception with contents of 15 to 30% plagioclase and 5 to 15% potassium feldspar. The plagioclase grains are generally subangular and show good cleavage faces. Although a few are unaltered, most plagioclase grains show some degree of sericitization, vacuolization, kaolinitization, and/or calcite replacement. Zoned crystals have been found in a few coarser grained samples (Fig. 31). The potassium feldspars show similar types of alteration, but to a lesser degree. Orthoclase is the dominant variety of potassium feldspar, and there are minor amounts of microcline.

Volcanic rock fragments (often counted as plagioclase in the point counts using to the method of Dickinson, 1970) are the dominant detrital component, occurring in quantities up to 40% in fine- to medium-grained sandstones, and 80% in coarser layers. Volcanic rock fragments are commonly made up of small plagioclase laths in an aphanitic groundmass. Rarely, grains show a pilotaxitic texture with

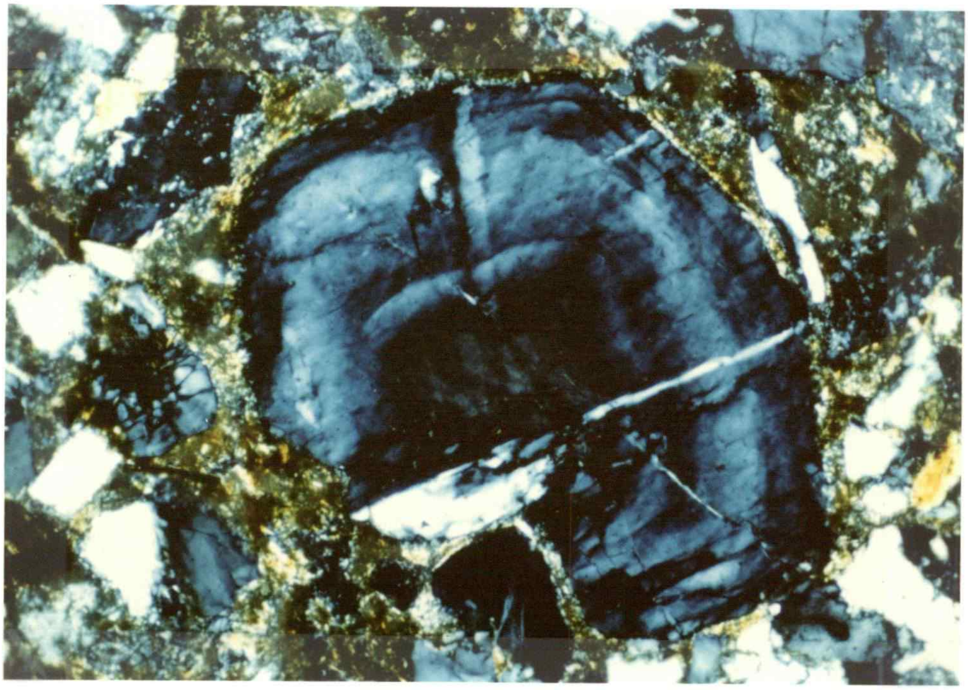


Figure 31: Photomicrograph of coarse subhedral zoned plagioclase from Baily Junction (Fig. 15 #68). Also note fine-grained, monocrystalline, clear quartz, and fresh and altered feldspars. Clayey matrix formed in part by crushing and alteration of volcanic rock fragments. Picture is 1.6 mm across.

alignment of laths. The volcanic rock fragments show varying degrees of alteration; most commonly grains are altered to brown clays (smectite/illite?) or chlorite. Replacement by calcite or microcrystalline silica also occurred. Crushed and altered volcanic grains form a pseudomatrix in several samples. Rarely, glass shard outlines can be seen, with the glass altered to clay. Some rock fragments which are completely altered to clays may have been pumice. Siltstone, mudstone, metamorphic and igneous rock fragments make up from 1 to 6% of the samples. The mica content ranges from 1 to 10%; biotite and bleached biotite are more abundant than muscovite.

Heavy minerals (1 to 2%) have been studied in detail by Cunderla (1986). He found epidote, hornblende (green, brown, blue-green, and oxyhornblende), augite, zircon, apatite, and minor amounts of garnet, sphene, tourmaline, rutile, and kyanite. Both Cunderla (1986), and Al-Azzaby (1980) found epidote to be very dominant in the lower part of the lower member. Hornblende (green and brown), epidote, augite, apatite, and zircon were noted in thin sections from this study. Brown to gray fibrous material, present up to 8% in one sample from Helmick Hill and in trace amounts in other samples, is thought to be plant debris. Organic matter (fecal?) also is present in trace amounts in several other samples.

Cunderla subdivided the Spencer Formation based on petrography and geochemistry. His work deals only with the sandstone lithofacies of the Spencer, which according to the nomenclature used in this study and in Thoms and others (1983), is the lower member of the Spencer Formation (Fig. 32). The lower part of the lower member of the Spencer in this study is approximately correlative to the lower member of Cunderla

Al-Azzaby (1980) western Tualatin Valley	Thoms and others (1983) western Tualatin Valley	Cunderla (1986) western Tualatin & central Willamette Valleys	This Study central Willamette Valley
Stimson Mill beds	upper member	not studied	upper member
upper member	upper part lower member	upper member	upper part lower member
			(middle part)
lower member	lower part lower member	lower member	lower part lower member
S P E N	C E R F	O R M A	T I O N

Figure 32: Comparison of terminology used to stratigraphically subdivide the Spencer Formation.

(1986), and the upper part of the lower member is equivalent to the upper member of Cunderla. The results of this study generally support Cunderla's petrographic subdivision, showing polycrystalline and total quartz, and potassium feldspar to be more abundant in the lower part of the lower member. Plagioclase and volcanic rock fragment contents are higher in the upper part of the lower Spencer and in the southern part of the study area.

TEXTURAL ANALYSIS

The grain size distribution of the sand-sized fraction (-1 to 4 phi; 2.0-0.0625 mm) of 15 samples was determined using a settling tube. Thirteen samples are from the lower member of the Spencer Formation, (10 from the northern more arkosic area, and three from the southern more volcanic-rich area). One samples is from the Miller sandstone member of the Yamhill Formation in the Henschell well, and another is from the strata mapped as Spencer? (Plate I) adjacent to the Corvallis fault. The textural analysis was completed in order to quantitatively characterize Spencer sandstone units, to show textural similarities and differences between the units, and to provide another line of evidence for interpreting depositional environment. The grain size data and frequency curves for each sample are shown in appendices II and III respectively. Values of mean, standard deviation, skewness, and kurtosis are presented in appendix II, and the averages in Table 3. These parameters were calculated according to the statistical formulas of Folk and Ward (1957) using the SEDANAL computer program (see methods; appendix I).

Grain sizes finer than 4 phi (0.0625 mm) were not measured because secondary processes including diagenesis, weathering, and crushing

GRAIN SIZE RESULTS

	MEAN (PHI)		STANDARD DEV. (PHI)		SKEWNESS		COARSEST 1% (PHI)		NUMBER OF SAMPLES
	Average	Range	Average	Range	Average	Range	Average	Range	
CENTRAL WILLAMETTE VALLEY (THIS STUDY) sand fraction (4 phi)	(Folk and Ward parameters)								
LOWER SPENCER									
SOUTHERN AREA	2.49	2.32-2.65	0.45	0.39-0.49	0.49	0.43-0.59	1.85	1.75-1.96	3
NORTHERN AREA	2.82	2.03-3.48	0.32	0.22-0.46	0.06	-0.21-0.44	2.20	1.04-2.77	10
WESTERN TUALATIN VALLEY (Van Atta, in press) sand fraction (4 phi)	(moment measures)								
LOWER SPENCER									
UPPER PART	2.97	1.94-3.60	0.58	0.35-0.84	0.45	-0.17-0.72	1.59		16
LOWER PART	2.80	2.63-3.33	0.39	0.11-0.59	0.38	-0.62-1.97	2.43	0.98-2.97	28
NORTHERN WILLAMETTE VALLEY (Al-Azzaby, 1980; VanAtta, in press) total sample	(Folk and Ward parameters)								
LOWER SPENCER									
UPPER PART	3.72	2.71-4.95	1.91	1.29-2.59	0.72	0.62-0.88			9
LOWER PART	4.09	3.36-4.51	1.84	1.28-2.42	0.72	0.57-0.82			6
UPPER SPENCER (Stimson Mill Beds)	4.16	3.45-5.46	2.30	1.81-2.74	0.69	0.65-0.74			4

Table 3: Average values for grain size parameters for the Spencer Formation from this study, Van Atta and Thoms (in prep) and Al-Azzaby (1980).

during disaggregation increase the volume of fines in the sample. Therefore, the amount of fine-grained material would not truly indicate conditions during deposition. As compared to whole sample analysis, the omission of fines increases the mean grain size. The standard deviation generally will decrease, indicating an apparent better sorting, and the samples tend to be more coarsely skewed. The magnitude of these changes can not be determined, but the trends should be noted when comparing these results with whole sample analysis of ancient rocks from other studies.

Grain size measurements indicate that the sand-sized fractions of Spencer sandstones in the central Willamette Valley are, on the average, fine-grained, well sorted, finely skewed, and mesokurtic (Table 3). Sandstones from the lower member of the Spencer Formation in the northern area are generally fine-grained, very well sorted, nearly symmetrical, and mesokurtic. Those from the southern area are slightly coarser (still fine-grained), well sorted, strongly fine skewed, and slightly leptokurtic. Although data is limited, lower Spencer sandstones from the northern and southern areas are clustered in distinct, slightly overlapping fields on a binary plot of mean grain size versus skewness, the northern area being finer grained and more coarsely skewed (Fig. 33a).

The sand-sized fraction of Spencer sandstones in the western Tualatin Valley has similar to slightly coarser grain sizes, poorer sorting (moderate to well sorted), and similar skewness averages (variable, averaging strongly fine skewed) (Table 3; Van Atta and Thoms, in prep). In the western Tualatin Valley, samples from the upper and lower parts of the lower member of the Spencer Formation are

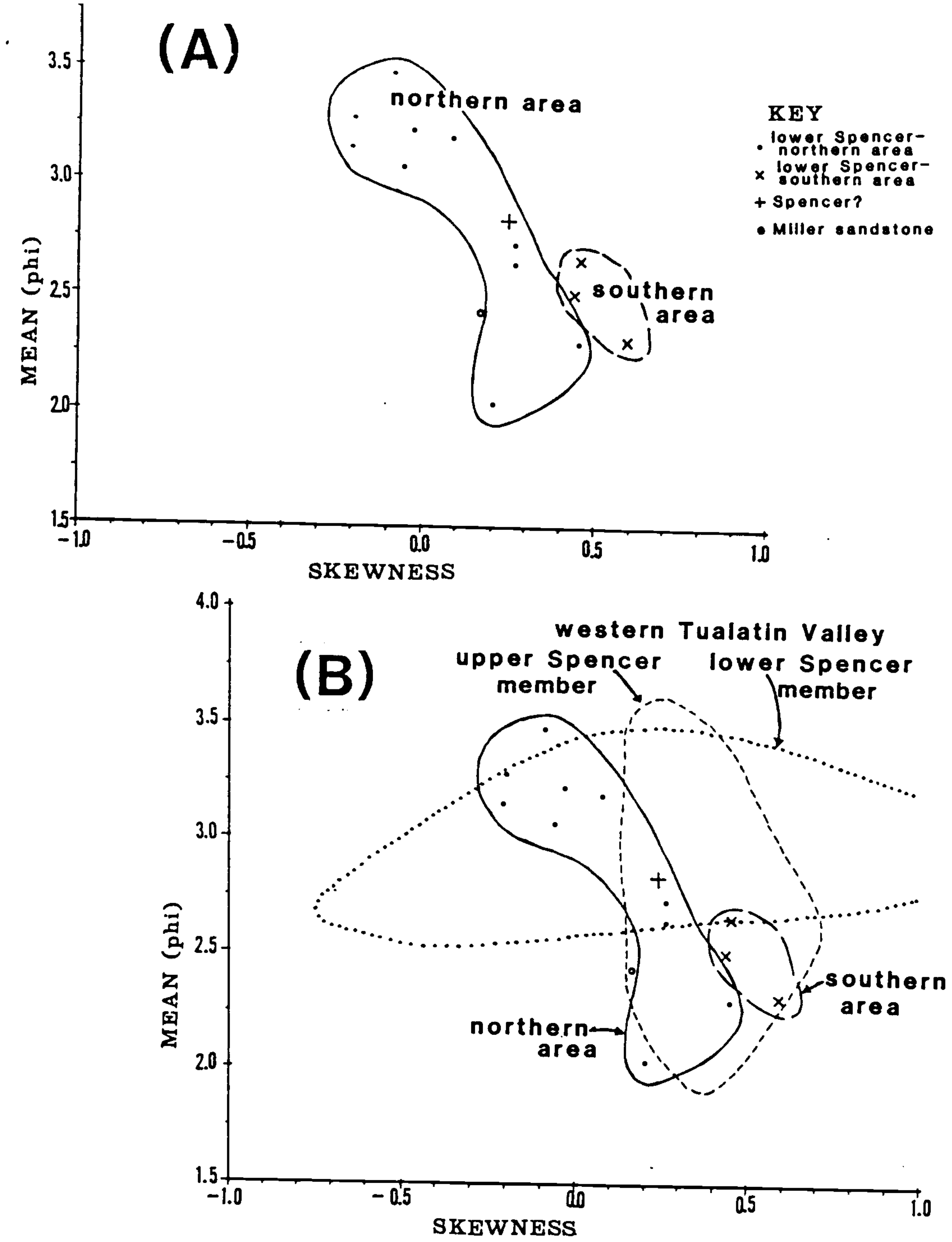


Figure 33: Binary plots of mean grain size versus skewness: (A) results from this study showing clustering of samples from the lower Spencer. (B) Binary plot as above showing field boundaries for the upper and lower parts of the lower member of the Spencer Formation as defined by Van Atta and Thoms (in prep) in the western Tualatin Valley.

grouped on a binary plot of mean size versus skewness (Fig. 33b). Samples from the upper and lower parts of the lower Spencer in the central Willamette Valley do not group into two distinct fields. However, samples from the northern part of the study area fall primarily within the field defined by the lower part of the lower Spencer in the western Tualatin Valley. Samples from the southern area fall within the field of the upper part of the lower Spencer. Depositional processes in the northern and southern aparts of the study area were probably similar to those in the lower and upper parts of the lower Spencer in the western Tualatin Valley, respectively. Al-Azzaby also studied the texture of Spencer sandstones in the northern Willamette Valley using sieve and pipette methods. His results, presented in Table 3, show the finer grain size, poorer sorting, and stronger fine skewness resulting from the inclusions of finer grain sizes in the analysis.

Binary plots of grain size parameters often are used as an aid in discriminating between depositional environments (e.g., Mason and Folk, 1958; Friedman, 1961, 1967; Shepard and Young, 1961; Moiola and Weiser, 1968). The environmental divisions generally are based on statistical analyses of grain sizes from modern sedimentary environments. The usefulness of these plots for this study is limited because most do not include analysis of shelf deposits, where fossil data indicates much of the lower member of the Spencer was deposited (Turner, 1938; Vokes, 1954; McKeel, 1984, 1985; Fleming, in review). The lack of data on recent shelf deposits, combined with the omission of fines in this study, hinders the use of these binary plots for discriminating between

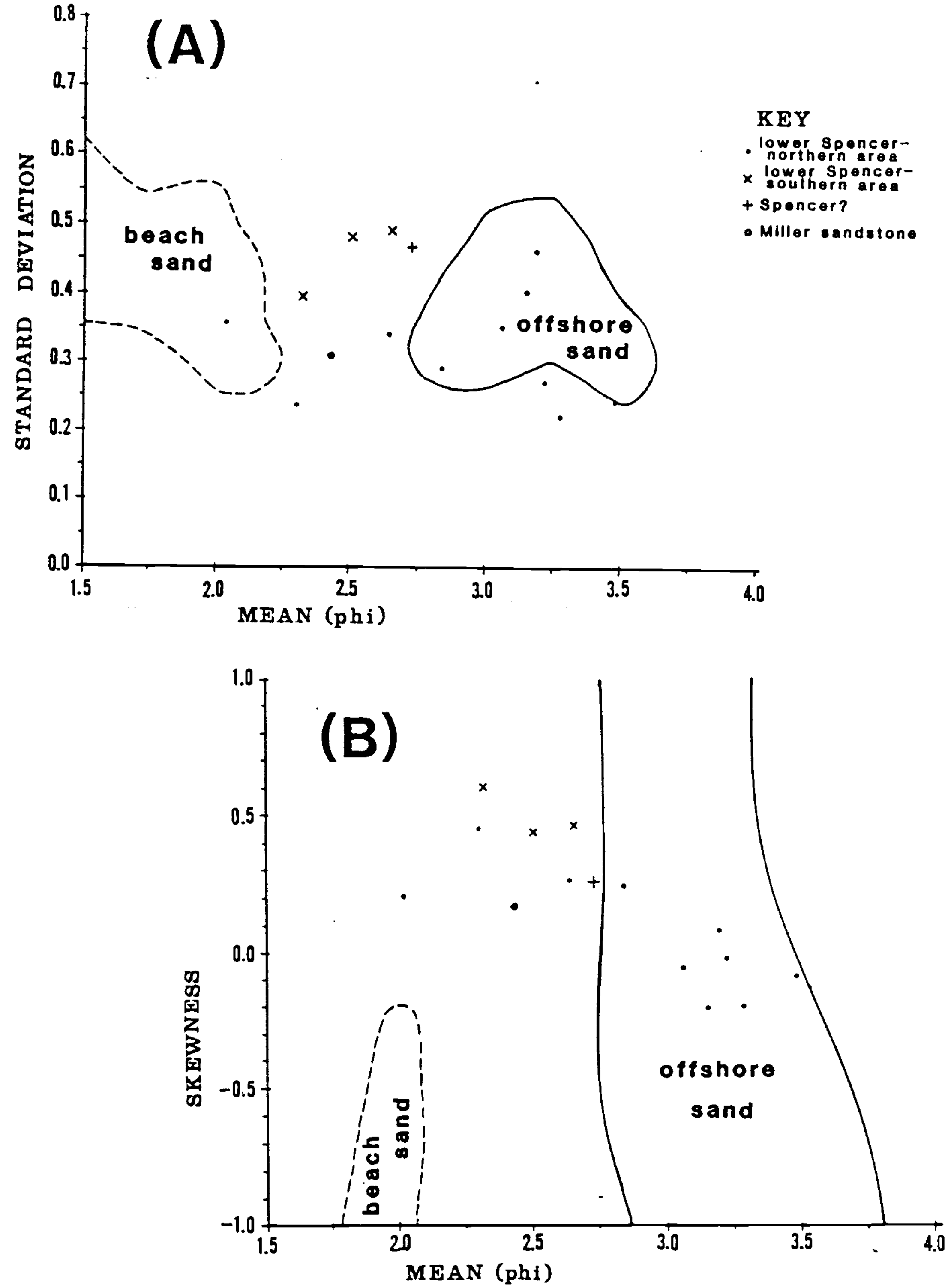


Figure 34: Binary plots of lower member of the Spencer Formation grain size data from this study. Beach and offshore field boundaries are after Kulm and others (1975). (A) Standard deviation versus mean grain size. (B) Skewness versus mean grain size.

depositional environments of the Spencer Formation in the central Willamette Valley.

Kulm and others (1975) presented two binary plots showing the distribution of grain size parameters of the sand-sized fraction (coarser than 4 phi) of beach and offshore samples from the Oregon coast. Generalized limits derived from the binary plots of Kulm and others (1975) are plotted along with data from this study in Figure 34. Lower Spencer sandstones from the northern area correlate relatively well with Kulm and others (1975) distribution of offshore sands. The two exceptions which plot closer to, and within the beach fields (samples 107 and 104b), are from the middle part of the Helmick Hill section. Sedimentary structures, combined with the differing textures, suggest shoaling to shoreface depths during deposition of these sandstones. Samples from the southern area do not clearly fit into either the beach or the offshore zones. The southern sandstones may be transitional between the beach and offshore zones, and/or have been deposited under slightly different sedimentary processes, resulting in a different textural signature than sediments on the modern Oregon beach and offshore zones.

The binary plot proposed by Passega (1957, 1964) is used for interpreting transport processes during deposition. The coarsest one percent, which is indicative of the competence of the transporting agent is plotted as a function of the median diameter, which is related to the complete range of particle sizes undergoing transport (Royse, 1970). The lower Spencer sandstones from the northern and southern parts of the study area plot within zones II and VIa (Fig. 35). These zones are thought to represent deposits formed by turbidity currents,

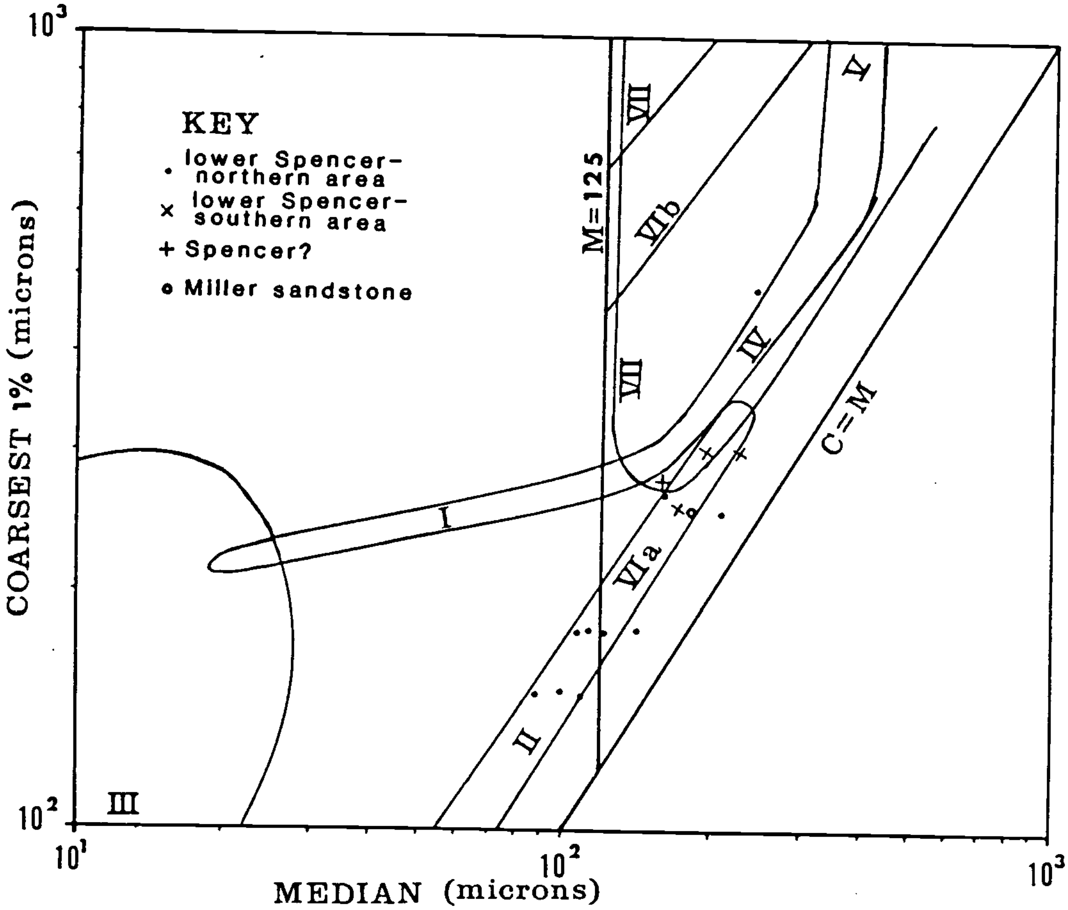


Figure 35: Binary plot of coarsest one percentile versus median grain size as discussed by Passega (1957).

or by tractive currents which lose speed gradually and uniformly, allowing the sediment in suspension near the bottom to remain graded and adjusted to velocity (Passega, 1957). Samples from the southern part of the study area have a coarser first percentile and plot closer to VIa. Since other sedimentologic characteristics of turbididy currents are missing, the tractive current interpretation is favored. One of the samples from Helmick Hill (107) plots within the beach zone (VII), supporting the interpreted shallow shoreface depositional environment. Samples from the lower part of the lower Spencer in the western Tualatin Valley also fall within the turbidty/tractive current field, while samples from the upper part are more widely scattered. Several plot in the field that is typical of beach processes (Van Atta and Thoms, in prep).

Based on the work of Passega (1957) and Kulm and others (1975), grain size data points to the lower Spencer in the northern part of the study area being deposited primarily on the shelf, under relatively uniform conditions associated with tractive currents. At least one episode of shallowing to shoreface depths is suggested. The lower Spencer to the south was probably deposited under more variable conditions and in a more transitional, possibly inner shelf setting.

Many of the samples show bimodality of polymodality (i.e., 77a, 95t, 28, 48, 107d, 96b, see appendix III). Several modes within one sample may indicate a mixing of sand from different sources. For example some of the sand in the bimodal samples could have been derived by longshore transport, while other grains were derived from nearby rivers carrying volcanic-rich loads. Bimodality in some of the samples may also have been caused by biogenic mixing of laminated deposits

(Friedman, 1967; Folk, 1974).

DISCUSSION

The combined study of surface and subsurface geology in the central Willamette Valley has permitted a better understanding of stratigraphy, late Eocene tectonic activity within the study area, and depositional environments of the Spencer Formation.

LATE EOCENE TECTONIC ACTIVITY

The late Eocene is thought to have been a tectonically active period on the western North America continental margin. Snavely and others (1980) proposed transverse movement during late middle to early late Eocene, followed by underthrusting in middle late Eocene, and extension from late Eocene to middle Miocene.

Movement on the Corvallis fault during and after Yamhill deposition (latest middle to early late Eocene) is suggested by thickness trends delineated on isopach maps. The Miller sandstone member is thickest in a belt parallel to, and on the downthrown side of the Corvallis fault (Fig. 10). In addition, the upper Yamhill mudstone thins across the northward extension of the upthrown fault block (Fig. 11). Thinning along the fault trend is probably related to nondeposition and/or erosion on a fault-generated high within the basin (Fig. 36). Basin subsidence on the downthrown side of the fault may have allowed the thick Miller sandstone lens to accumulate. The fault throw probably died out to the north; the magnitude of thinning of the Yamhill mudstone and thickening of the Miller sandstone decreases in this direction (Figs. 10, 11). Vokes and others (1954) and Lawrence and others (1980) believed movement on the Corvallis fault primarily occurred prior to Spencer deposition, based on a sharp angular

LATE IN MILLER SANDSTONE DEPOSITION

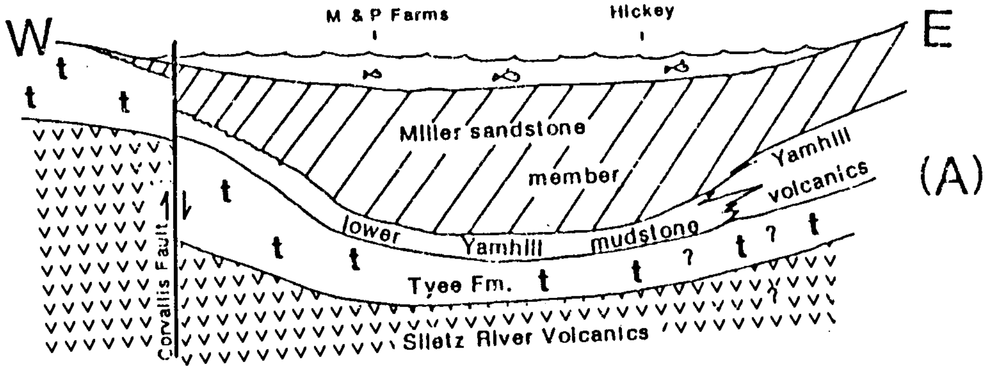
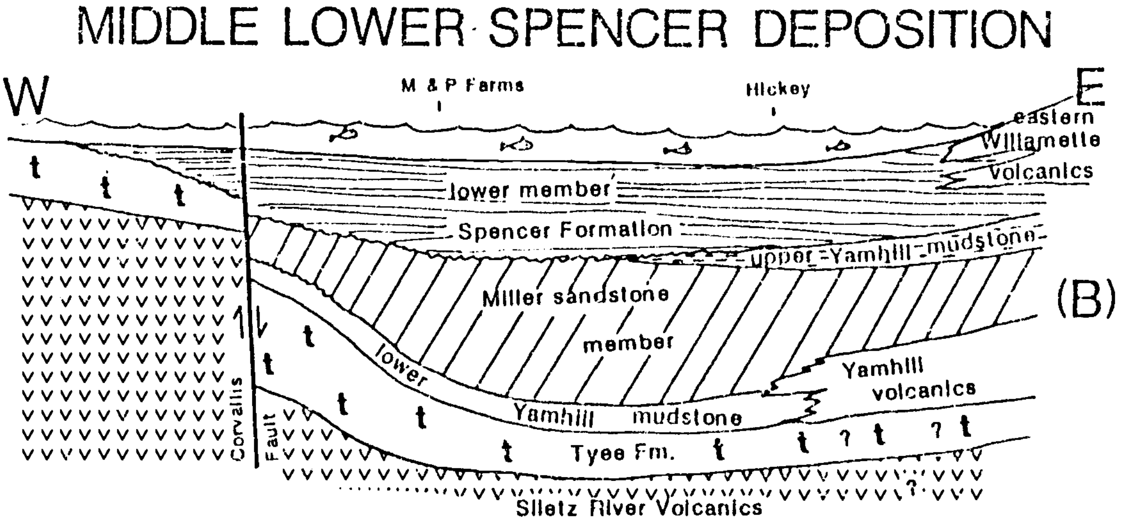


Figure 36: Schematic cross-sections through Hickey and M & P Farms wells, extending eastward across the Corvallis Fault. Shows interpreted fault movement and effects on sedimentation: (A) late in Miller sandstone deposition; (B) during the middle of lower Spencer deposition; (C) present day, after uplift of the Coast Range during the Miocnene (Snavely and others, 1980). Approximate vertical exaggeration 10:1.



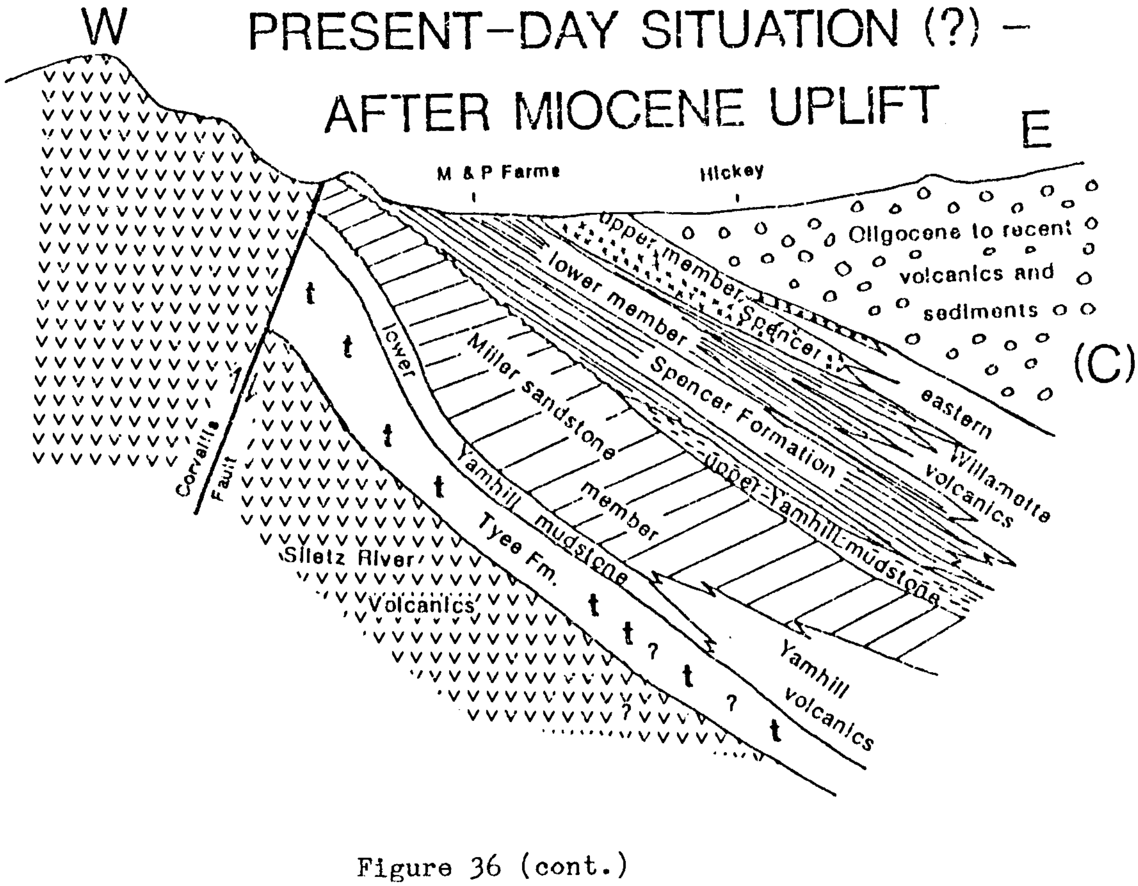


Figure 36 (cont.)

unconformity between the Spencer and underlying Tyee(?) strata adjacent to the fault zone.

The Spencer Formation shows a significantly lesser amount of thinning towards the Corvallis fault as compared to the Miller sandstone (Fig. 12). This suggests diminished movement on the fault during Spencer deposition. Assuming that substantial offset on the Corvallis fault occurred prior to Spencer deposition and during Yamhill deposition, the upthrown block may have been a high during Spencer time (probably during Yamhill time also; Fig. 36). This high could have acted as a barrier within the Spencer basin. The Yamhill mudstones, Miller sandstone, Tyee Formation and Siletz River volcanics may have been successively unroofed from the upthrown block providing detritus to the Spencer basin.

Pre-Spencer offset and the existence of a high within the basin is further supported by marked lithologic differences in the Spencer sandstones north and south of the fault (Fig. 37). The change in sandstone composition could also be caused, in part, by later transgression in the south, after increased volcanic activity. Tentative interpretations of stratigraphy and depositional environments also suggest shallower water settings in the area of the fault as compared to farther eastward (i.e., the Porter well; see depositional environment discussion: Starr Creek-Belfountain-Monroe Area).

Erosion has removed stratigraphic evidence of post-Spencer movement on the Corvallis fault. The Corvallis fault is primarily defined by the presence of steeply dipping strata. No steep dips are found in the Spencer Formation along the projected northward extension of the fault. Well correlations indicate only a slight increase in dip

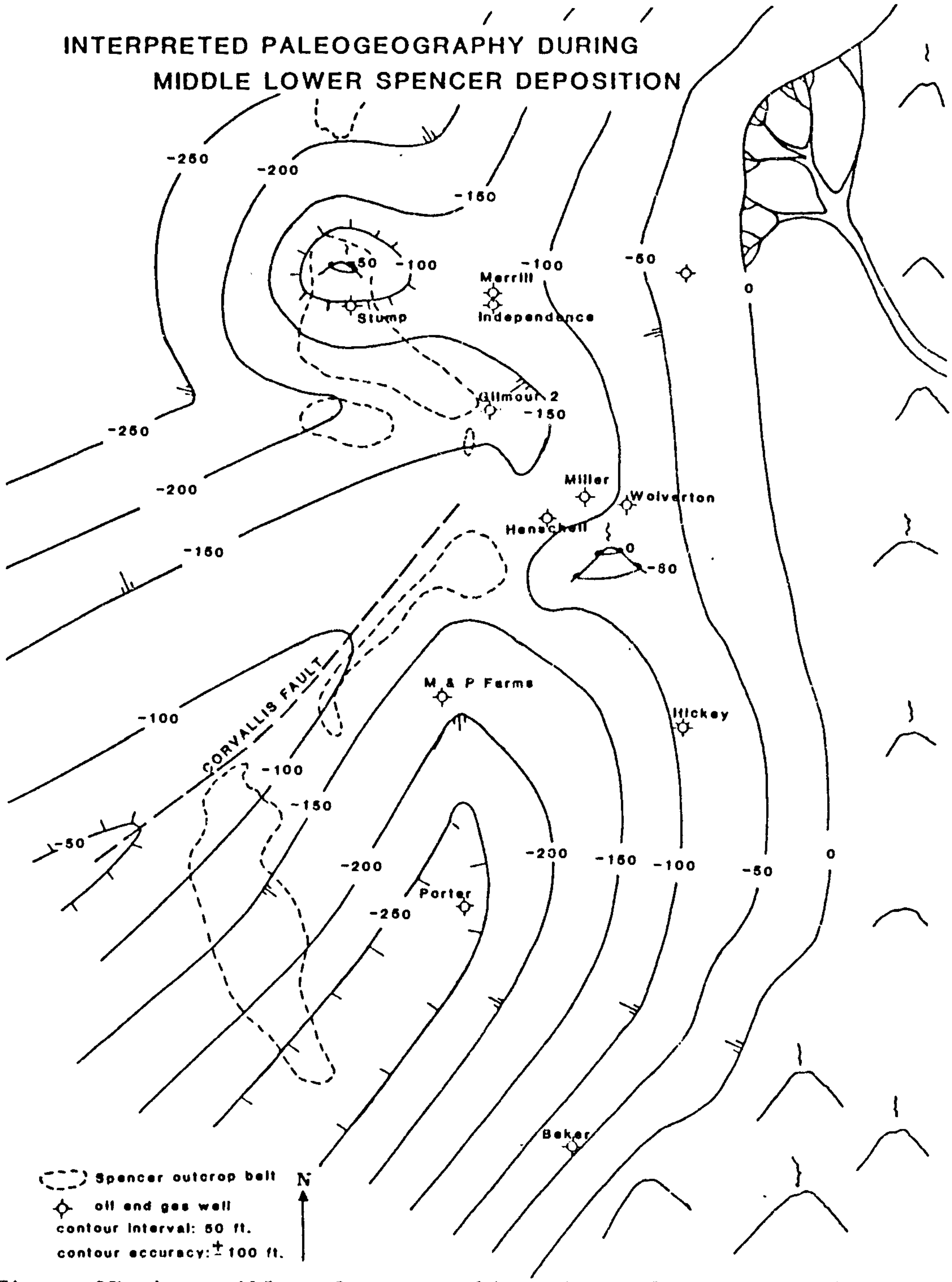


Figure 37: A possible paleogeographic setting during deposition of the middle part of the lower member of the Spencer. A broad shelf existed in the northern part of the study area. A high within the basin along the trend of the Corvallis fault, combined with a volcanic center at the northern end of this high, forms a protected basin in the south. Volcanism is active along the shoreline to the east and southeast, and at local centers within the basin.

across this projected fault extension. Therefore, offset on any northward extension of the Corvallis fault was minimal after Spencer deposition. Emplacement of Oligocene intrusives into pre-existing planes of weakness associated with the Corvallis fault may have limited further movement. Later offset could have stepped out to the east and been accomodated on younger, adjacent structures such as the Albany fault. Alternatively, post-Spencer movement may have occurred along the Corvallis fault, but must have been terminated abruptly northward, with movement possibly translated eastward to the Albany fault. However, poor surface exposures in the intervening Albany/Spring Hill area do not appear to be structurally complex.

The Albany fault, defined by offset at the base of the Spencer in wells, is interpreted to parallel the Corvallis fault (Fig. 14). The Miller sandstone, upper Yamhill mudstone, and the lower Spencer do not show substantial thickness changes across the Albany fault. Therefore, movement along the Albany fault is thought to have occurred sometime after lower Spencer deposition.

Volcanism was apparently active to the east and southeast during Yamhill and Spencer deposition. Yamhill strata grade eastward into tuffs, welded tuffs, and basaltic to dacitic flows (the Yamhill volcanic facies; Fig. 13). To the east and southeast, Spencer sedimentary strata are more tuffaceous and volcanic flow interbeds are more common. Volcanics also existed within the Spencer basin. For example, in the Mount Pisgah area southeast of Dallas, an accumulation of late Eocene volcanics (Baldwin, 1964) could have created a local topographic high. Volcanic flows in wells (e.g. 350 to 500 foot interval in the Miller well; Plate II) suggest that other volcanic build ups may have been present within the basin.

STRATIGRAPHIC PROBLEMS

The lack of Miller sandstone and Yamhill mudstones along the outcrop belt in the southwestern part of the study area is thought to be caused, in part, by thinning as a result of fault activity. Periods of nondeposition and/or erosion on a high formed by uplift on the Corvallis fault, may have lessened the original Yamhill thickness (Fig. 36a, b). The Yamhill Formation is present to the north, where offset on the Corvallis fault is thought to die out (Plate I).

A thinner section of Yamhill strata may have been mistakenly mapped as Tyee or Spencer in the poorly exposed southern outcrop belt. Miller sandstones pinch out to the northeast into middle bathyal Yamhill mudstones (McKeel, 1984). Presumably, these very fine- to fine-grained sandstones have undergone a facies change to deeper water turbidites. If the same westward deepening occurred to the south, Miller sandstone strata could easily be mistaken for Tyee. Vokes and others (1954) believed upper Tyee beds in the Dawson and Monroe areas were equivalent to the Lorane siltstone, a possible Yamhill equivalent.

If the Miller sandstone did not undergo a facies change to deeper water deposits to the southwest, basal Spencer sandstones may instead be the Miller sandstone. A preliminary identification of a pre-Spencer macrofossil found in the basal Spencer sandstone east of Dawson supports this hypothesis (see Stratigraphy: Starr Creek-Belfountain--Monroe Area).

The thickness of the Spencer Formation was originally estimated as 4,500 feet in the study area (Vokes and others, 1954). This estimate may be high because of the stratigraphic problems discussed above. Lithologic similarities probably caused the Miller sandstone strata to be included in the Spencer Formation thickness when making this estimate. The Willamette-1 well southeast of Corvallis was drilled in 1934, prior to the mapping of Vokes and others (1954). In this well, the upper Yamhill mudstone is thin or absent, and the resulting Miller-Spencer sandstone is very thick. Revised estimates of Spencer thickness in the central Willamette Valley are 1,000 feet in the northern part of the study area, to 1,500 feet in the central part, to 1,200 feet in the south.

YAMHILL FORMATION: DEPOSITIONAL ENVIRONMENTS

The Yamhill is a regressive-transgressive sequence in the central Willamette Valley. The primarily bathyal, volcanic-rich lower Yamhill mudstones and siltstones grade upwards into the Miller sandstone. Continued regression is indicated as depositional depths in the Miller sandstone decreased from outer neritic/middle bathyal to marginal marine/nonmarine (Plates II, III). The basin is thought to deepen westward; the sandstones pinch out to the northeast, undergoing a facies change to deeper water mudstones and siltstones. The volcanic content of both the lower Yamhill mudstones and the Miller sandstone increase to the southeast, towards the Yamhill volcanic facies. Volcanism to the southeast probably supplied abundant sediment, and small-scale deltas may have prograded into the subsiding basin. Shoaling was followed by transgression, as indicated by the deposition of bathyal upper Yamhill mudstones and siltstones (McKeel, 1984, 1985).

SPENCER FORMATION: DEPOSITIONAL ENVIRONMENTS

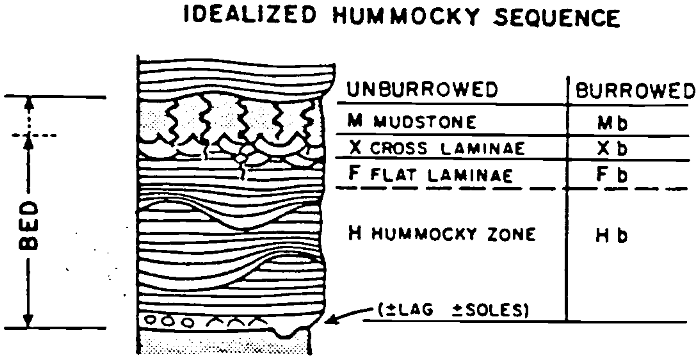
Previous interpretations of the depositional environment of the Spencer Formation included shallow marine shelf to nearshore settings. North of the study area in the Tualatin Valley, a shoaling upwards sequence, from middle/outer shelf into the nearshore zone, is inferred for Spencer sandstones (lower member). The overlying Spencer mudstones (upper member; Stimson Mill beds) represent deepening to upper bathyal depths (Al-Azzaby, 1980; Thoms and others, 1983). To the south in Lane County, intertidal to nearshore environments, including strandline, estuary, delta, and coal swamp settings, have been proposed for Spencer sandstones (Gandera, 1977). A shelf to nearshore environment is also proposed for Spencer sandstones which crop out in the central Willamette Valley. The sandstones of the lower member of the Spencer Formation grade eastward (in the subsurface) into shallower water facies. Mudstones of the upper Spencer were deposited at middle to upper bathyal depths, and grade eastward into the eastern Willamette volcanics.

The basal Spencer sandstones are thought to lie unconformably on older rocks throughout the study area (Vokes and others, 1954; Baldwin, 1964). However, it is not clear whether this unconformity formed during transgression or regression after structural activity in the basin. In the southern and central parts of the study area, a transgressive unconformity is suggested by subsurface data, including thinning and absence of underlying Yamhill strata, and abrupt lithologic changes in well logs (Plate II, Fig. 13). At the outcrop belt, coarse basal sandstones are overlain by a fining, and deepening upwards sequence supporting this hypothesis. In the north, the base of the Spencer is not exposed. Van Atta (1986) suggested that the base of the

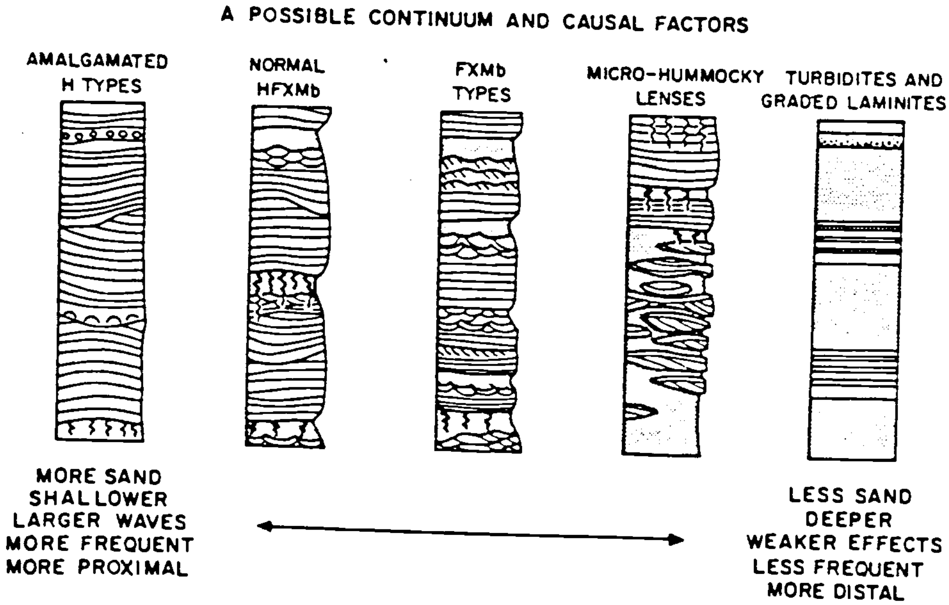
Spencer Formation is conformable in the western Tualatin Valley. The sea which deposited Yamhill strata may also not have completely withdrawn from the northern study area. The base of the Spencer may be a regressive unconformity in the deeper parts of the Spencer basin (e.g., Bruer well; Plate II).

Monmouth-Buena Vista Area

The stratigraphically lowest beds in the northern area, exposed at the "clay" pit (Fig. 16) were probably deposited at shoreface to inner shelf depths. In the lower part of the outcrop, hummocky to parallel laminations are present. Hummocky cross-stratification is discussed in more detail in Appendix IV. The hummocky bedding at the "clay" pit is generally amalagmated (H or HF types; Fig. 38; Dott and Bourgeois, 1982). However, rare HFXM hummocky sequences are preserved. In these sequences, hummocky cross-strata flatten upwards and are overlain by ripple cross-beds which are draped by thin mudstones. Amalgamated hummocky cross-stratification is thought to form on a storm wave-dominated shallow shelf to lower shoreface. At innermost shelf depths, lower wave heights associated with more frequent, smaller storms can generate hummocky cross-stratification. The relatively thinner fair weather deposits accumulating between storms would generally be eroded at the beginning of the next storm event (Bourgeois, 1980; Dott and Bourgeois, 1982). The abundance of parallel laminae relative to hummocky cross-strata may be explained by deposition primarily in the zone of shoaling storm waves (innermost shelf). At this location oscillatory flow could dominate over unidirectional coastal currents and parallel laminae would commonly be formed (Nottvedt and Kreisa, 1987). Dott and Bourgeois (1982) report similar flat



A



B

Figure 38: Hummocky sequences: (A) the idealized hummocky sequence showing notation used to describe component zones; (B) a proposed continuum of different hummocky sequence types (from Dott and Bourgeois, 1982).

laminations, rare localized swales, and very low angle truncations associated with hummocky cross-strata in the Coaledo Formation. They suggest these structures are a hybrid type of hummocky sequence.

Trough cross-stratification, which overlies the parallel to hummocky-laminated beds at the "clay" pit (Fig. 16), is more characteristic of higher energy shoreface deposits. Trough cross-stratification is commonly produced in the lower to middle shoreface (the outer rough facies of Clifton and others, 1971; Fig. 39). Interbedded mud laminae indicate a continued variability in current intensity. The sequence is capped by a bioturbated silty sandstone. The increase in bioturbation may represent increased depth of deposition because bioturbation generally increases with depth (Howard, 1972). Alternatively, this sandstone may have been deposited in a zone of intense bioturbation. For example, in the Ventura-Port Hueneme area of California, a dense community of sand dollars causes a local zone of bioturbation in the seaward part of the high energy nearshore zone (Howard and Reineck, 1981).

Trace fossils from the "clay" pit (Skolithos, Ophiomorpha, Chondrites, and Thalassinoides?) are found in both shoreface and inner shelf deposits (Chamberlain, 1978). Binary plots relating sediment texture to depositional environment suggest a shelf setting for the lower beds. The interpreted upsection change from inner shelf to shoreface settings at the "clay" pit indicates deposition during a regressive episode early in Spencer deposition.

The strata exposed at Helmick Hill (Fig. 18) are thought to be deposited at middle shelf to middle shoreface depths. The bedding sequence is more variable than at the "clay" pit. The basal beds

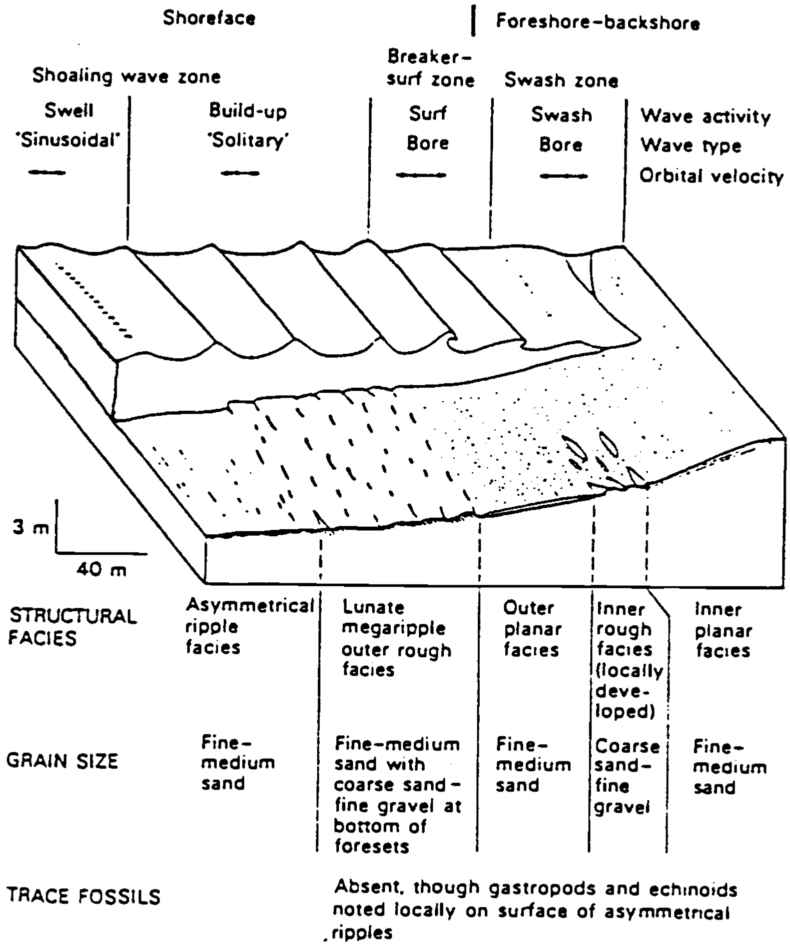


Figure 39: Processes, bedforms, and facies from the non-barred, high wave energy shoreface (after Clifton and others, 1971; from Elliott, 1984).

consist of partially to completely bioturbated hummocky sequences, with thick fair weather siltstone to mudstone layers. Hummocky sequences were thin enough, and the time between storms long enough, that units could be completely reworked (Dott and Bourgeois, 1982). The intense bioturbation, finer grained nature (very fine-grained sand to silt), presence of small macrofossils and crabs, along with a higher content of plant debris suggest somewhat lower energy, decreased storm frequency, and deeper, probably middle shelf deposition.

The degree of bioturbation in these lower beds decreases upwards, and the bioturbated unit is overlain by a well sorted, fine- to medium-grained arkosic sandstone. The contact is not exposed, but is thought to be sharp. Trough and ripple laminations within this dominantly massive sandstone, together with sediment texture, suggest higher energy shoreface deposition. Inner shelf deposits could have been removed by shoreface erosion during regression. Bioturbated silty sandstones are similar to the upper bioturbated silty sandstone at the "clay" pit. They may represent deepening to quieter water or deposition in a zone of high biogenic activity as suggested earlier. This bioturbated silty sandstone passes upward into a well sorted, fine- to medium-grained sandstone connoting increased physical reworking of the sediment. Very fine-grained hummocky bedded sandstones which cap the sequence indicate a return to inner shelf deposition along a storm wave-dominated coastline. The sequence of bioturbated, fine-grained shelf deposits overlain by shoreface sands and then again by shelf sandstones suggests a regressive episode during Spencer transgression.

The poor exposures in the Monmouth area are thought to be the middle part of the lower member of the Spencer Formation. The arkosic sandstones with siltstone interbeds are believed to be hummocky sequences, deposited in a storm wave-dominated shelf setting during periods of volcanic quiescence. The interfingering basaltic sandstones and conglomerates were rapidly deposited during volcanic activity in the Mount Pisgah area, then reworked to some degree by storm wave activity and shelf currents.

Near the top of the lower member of the Spencer Formation, the Independence and Merrill well logs show several coarsening upward sequences (Plate II). One of these sequences crops out in the bluffs immediately south of Buena Vista (Fig. 21), where several types of hummocky sequences are excellently exposed. The lowermost fine sandstones and siltstones show ripple cross-lamination, and parallel to hummocky laminae. These units resemble the FXMb hummocky deposits described by Dott and Bourgeois (1982; Fig. 38). This bedding type is thought to form in a more distal setting with weaker currents and a sufficient sediment supply. The bedding sequence changes upsection to normal HFXMb types and then to amalgamated H types. This progression of bedforms, along with the upsection thickening of sandstone beds/thinning of mudstone beds indicates a shoaling shelf (Dott and Bourgeois, 1982). Abundant burrows resembling Rosselia and Arenicolites support a shelf interpretation (Chamberlain, 1978). Farther upsection, amalgamated hummocky cross-strata grade into trough cross-bedding. This may indicate continued shallowing or, more likely, an extremely high energy event with strong currents (Nottvedt and Kreisa, 1987). Trough cross-beds pass laterally into convolute bedding, attesting to the rapid deposition of this unit (Dott and Bourgeois, 1982).

Stratigraphically higher exposures, farther north along the Willamette River, are finer grained. Thinning of sandstone beds/thickening of mudstone beds suggests renewed deepening of the shelf. The hummocky sequences immediately overlying the amalgamated sandstone change back to normal HFXMb types and then grade into FXMb types with abundant rippled beds.

The Buena Vista beds may have been deposited seaward of a major river mouth on a storm wave-dominated shelf. Sediment supply would be high and distributary channel cut-offs could account for the coarsening upwards cycles noted in wells (e.g., Merrill, Plate II). Alternatively coarsening upward cycles could be related to changing subsidence rates or sea level variations.

Beds exposed at the summit of Monmouth Road are interpreted to be more distal shelf storm deposits showing structures similar to the micro-hummocky lenses described by Dott and Bourgeois (1982; Fig. 38). A low sand supply would prevent formation of true hummocky cross-lamination. These beds probably were deposited in a storm wave-dominated shelf environment similar to the Buena Vista bluffs but at slightly greater depths and more distal from a major river source.

The abundance of hummocky cross-stratification in the Monmouth-Buena Vista area means that this area was a broad storm wave-dominated shelf during deposition of most of the lower member of the Spencer Formation. The extent of the shelf may have been related to local tectonics including uplift along the Corvallis fault before and possibly during Spencer deposition, and the presence of a local volcanic build-up in the Mt. Pisgah area. Short-term regressions/progradations were recorded. Tectonic activity may have caused regressions and shoaling to shoreface depths during early Spencer time. Small river mouth deltas supplying large amounts of sediment may have prograded and been abandoned depositing coarsening upwards sequences.

Subsurface Geology: Northern Area

The subsurface geology of the northern area supports the proposed broad shelf depositional environment. In the northernmost part of the study area (Bruer well), the lower Spencer is siltier than in wells to the east and southeast, and was probably deposited primarily in a middle shelf setting. The sandier units may represent progradation of the Spencer shoreline (or tectonic uplift) and deposition at slightly shallower depths. In the Merrill well, about 12 miles southeast, sand bodies within the lower Spencer section are better defined than in the Bruer well. Deposition was probably at shallower, inner shelf depths (inner to middle neritic; Oregon Natural Gas-Independence well; McKeel, 1984). The funnel-shaped spontaneous potential curves of the middle and upper sands in the Merrill well are characteristic of upward coarsening grain gradation typical of deltaic bar-fingers, shelf sand sheets, and other prograding bodies of sand (Conybeare, 1985). The medium-grained, well sorted parts of these sand units imply higher energy conditions and shallower, probably shoreface, depositional settings. A sand-rich unit is present at the top of the lower member of the Spencer in both the Bruer and Merrill wells. These sandstones are abruptly overlain by siltstones and mudstones of the upper member of the Spencer Formation, suggesting deepening and renewed transgression.

The lower member of the Spencer Formation in the northeastern part of the study area (Gath well), correlates closely with the Merrill well (Plates II, III). However, the Gath section contains more volcanic detritus, along with tuffs and basalt flows. A volcanic source apparently existed to the east or southeast. Little microfossil evidence is available, but abundant lignite chips and medium- to coarse-grained sands in well cuttings suggests inner shelf (inner neritic) to marginal marine deposition.

The upper member of the Spencer Formation is not present in the Gath well. Instead, the lower member grades upsection into the dominantly volcanic sequence with some sedimentary interbeds, included in the eastern Willamette volcanics. The depth increased to outer shelf to upper slope depths during deposition of the lower eastern Willamette volcanics (upper to middle bathyal; McKeel, 1984). Progradation of the Spencer shoreline, or tectonic uplift, apparently occurred during accumulation of these volcanics and associated sediments as depositional setting shallowed to the outer shelf (outer neritic; McKeel, 1984). During latest Narizian, as volcanic activity continued, the eastern Willamette volcanics reached as far west as the Merrill well.

Albany-Corvallis Area

The limited poor exposures in the Albany-Corvallis area prohibit a detailed interpretation of depositional environment. Although no fossils have been found in the arkosic sandstones of Logsdens Ridge and Spring Hill, they are thought to be marine, deposited at inner shelf to shoreface depths. Parallel to low angle laminations, with micas and organic debris concentrated on bedding planes, may be amalgamated hummocky cross-stratification. Thus an inner shelf depositional environment is suggested. Other medium-grained sandstones with coarser beds may have been deposited in the high energy shoreface.

The overlying basaltic beds in the Albany area are also thought to have been deposited at inner shelf to shoreface depths. Toredo wood borings, rounded volcanic pebbles, and robust pelecypod fossils suggest shallow, higher energy conditions (Keen and Coan, 1974; Bromley, Pemberton, and Rahmani, 1984). Bioturbated and laminated siltstones and mudstones indicate periods of quieter deposition, probably during fair weather periods.

The change from arkosic to basaltic sandstones is probably related to volcanic activity to the east. Basaltic flows and tuff beds are present at similar stratigraphic positions about seven miles east in the Miller well. A local volcanic build-up within the basin would have caused shoaling and a sudden input of volcanic detritus. The resulting high sedimentation rate may have allowed for rapid burial and preservation of fair weather siltstones and sandstones on the inner shelf or shoreface. The presence of fragile vesicular grains and an altered glassy matrix between basalt pebbles supports an active volcanic source rather than an uplifted Siletz River Volcanic source.

Poorly exposed fine- to medium-grained arkosic sandstones in the Corvallis area which may be the base of the Spencer are mapped as Spencer? in this study. Lithic arkoses having a volcanic character, overlie the questionable arkosic sandstones. Bioturbated and laminated fine-grained sandstones, along with normally graded coarse sandstone to siltstone units, suggest deposition in a zone of intermittent wave reworking, probably on the inner shelf between fair weather and storm wave base. Normally graded storm-generated units similar to those exposed near Corvallis have been described in many modern and ancient shelf deposits (e.g., Hayes, 1967; Kumar and Sanders, 1976; Howard and Reineck, 1981; Kreisa, 1981). These graded shelf storm layers consist of: (1) an erosive base; (2) a basal lag deposit of mud clasts, shells, plant debris, and/or rock fragments; (3) horizontal to low angle (hummocky) laminations; (4) wave ripple lamination; and (5) a burrowed interval (Fig. 40; Johnson and Baldwin, 1987).

Subsurface Geology: Central Area

The lower member of the Spencer Formation in the subsurface of the central area is thought to have been deposited primarily in inner shelf, nearshore, and nonmarine settings (inner neritic to nonmarine; McKeel, 1985). The amount of nonmarine section increases to the southeast. This thicker lower Spencer section is sandier than the northwestern area; sands have a more volcanic character, and the siltstones are highly tuffaceous. The volcanic content, including interbedded basalts and tuffs, increases upsection.

Well correlations suggest that the thickening of the lower member of the Spencer Formation in the east-central area is not the result of increased thickness of individual sand bodies (Plate II, Fig. 12). Extrusive volcanics have added to the thickness of the lower member in the east and central parts of the study area. Moreover, a build up of volcanics and volcanogenic sediments may have allowed the central part of the study area to remain high and in shallower water as the sea transgressed. The upper sandstones may have been deposited at the same time as upper Spencer siltstones and mudstones of the upper member of the Spencer to the northwest. Slower transgression or temporary

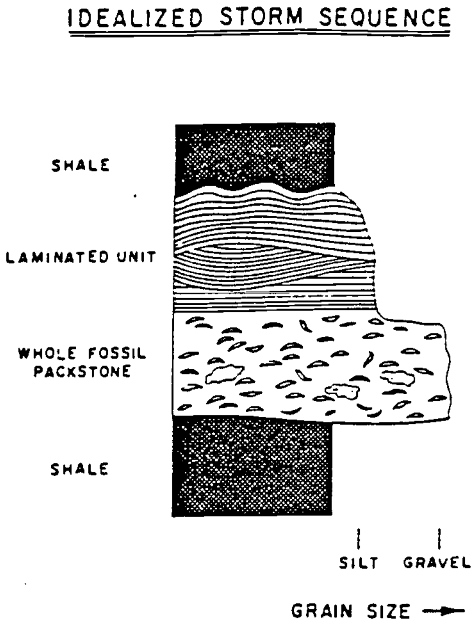


Figure 40: Idealized vertical succession of sedimentary structures and lithologies in normally graded shelf sequences, based on the Martinsburg Formation, southwestern Virginia (from Kriesa, 1981).

progradation may have occurred during the period when the coastline was near the east-central area. Erosion of an active volcanic highland would have provided a large sediment supply, possibly enough to build a delta into the subsiding basin. The abundant lignites and carbonaceous debris found through much of the Spencer section are common to marsh and distributary bay settings associated with deltas (Coleman and Prior, 1982).

With continued transgression, the volcanic-rich upper part of the lower member of the Spencer passed upward into the eastern Willamette volcanics in the east-central area, and into tuffaceous mudstones grouped in the upper member of the Spencer in the west-central area.

Starr Creek-Belfountain-Monroe Area

The basal arkosic lithic sandstones in the southern part of the study area differ from the overlying feldspathic litharenites. The basal sandstones are richer in sedimentary rock fragments, potassium feldspar, and quartz. They contain angular mudstone clasts which resemble the underlying Tyee mudstones. The basal sandstones are thought to be transgressive, derived in part from shoreface erosion of underlying sedimentary strata. The presence of rare robust pelecypods and gastropods, large-scale tangential cross-beds and coarse-grained sandstones suggest a shallow, nearshore environment of deposition. The overlying fine- to medium-grained sandstones have a more volcanic character and were probably deposited in nearshore to shelf settings as volcanic input began to dominate over shoreface erosion during transgression.

Gradual deepening upsection to shelf depths is indicated by an increase in bioturbation and fossil abundance, and a decrease in grain size to fine sand and silt. In the middle part of the lower Spencer, where bioturbation is intense, relict graded sandstones are present. These normally graded beds are thought to represent shelf storm deposits. Storm frequency must have been low enough for thick very fine-grained sandstones and siltstones to accumulate, and for deposits to be thoroughly bioturbated. A barrier to the west, or a deeper outer shelf setting could explain the decreased storm frequency versus deposits north of Albany.

Fossil abundance and the degree of bioturbation decrease near the top of the lower Spencer. The increase in physical versus biological structures could be related to shoaling of the basin, or a period of higher energy storms. The resulting deposits are similar to the storm wave-generated shelf deposits described in the Corvallis area; a concentration of shells and coarse debris near the base of the fining upward sequence and some parallel laminations are visible.

The Spencer Formation is lithologically different north and south of the Corvallis-Albany area. To the north, the sandstones contain a lower percentage of volcanic grains and generally more potassium feldspar. Storm-generated shelf deposits are common in both the north and south. However, in the north, storm deposits are characterized by hummocky sequences formed in fine sandstone and siltstone. To the south, storm deposits are normally graded sequences beginning with a coarse sand to pebble-sized fossil-rich basal lag and fine upwards to siltstone or mudstone. Hummocky bedding is not readily apparent. The significantly different character of the Spencer Formation north and south of Albany is related primarily to a closer proximity to the volcanic source, and possibly to the presence of a barrier or shoal within the basin (Fig. 37). Greater volcanic input in the south would dilute the quartz and potassium feldspar content. Volcanic granules and pebbles were supplied by nearby volcanic vents. A high within the basin, caused by uplift on the Corvallis fault prior to, and possibly during Spencer deposition, could alter hydrodynamic conditions in the southern part of the basin. The area behind the barrier may have been more protected, experiencing lower wave energy and lower storm-generated current intensity. The quieter setting and high input of finer volcanic probably favored biologic productivity, causing a higher abundance of macrofossils and bioturbation. The abundant fossils and coarse volcanic material were concentrated as a basal lag in storm deposits. The barrier may have caused storm-generated unidirectional shelf currents to be weaker in the south. Parallel laminations could have formed more commonly than hummocky cross-stratification because of the dominance of oscillatory flow during storms (Nottvedt and Kreisa, 1987). Alternatively, normally graded sandstones could be deposited as turbidite-like layers below storm-wave base by sand-laden storm surges (Hamblin and others, 1979; Wright and Walker, 1981).

As suggested earlier, interpretation of stratigraphy to the south also supports the presence of a high within the basin. Spencer sandstones closer to the Corvallis fault contain Brachiodontes (a mussel), and Venericardia aragonia (a pelecypod) in life position suggesting a intertidal to muddy shallow water deposition (Keen and Coan, 1974). These sandstones are interpreted to be the middle part of the lower Spencer. If so, they were probably deposited at shallower depths than equivalent strata, such as the middle part of the Belfountain Road outcrop to the east. Microfossils indicate upper to middle bathyal depths for all but the lowest 350 feet of the lower Spencer in the Porter well (Plate II). If subsurface-surface correlations are correct, then equivalent strata in the outcrop belt were deposited at shallower, inner to middle shelf depths.

In the south, the Spencer Formation records transgression during late Eocene, with at least one episode of shoaling. Deposition started at shoreface depths, increased to shelf depths for most of lower Spencer deposition, then increased again to bathyal slope depths during deposition of the upper Spencer.

Subsurface Geology: Southern Area

Subsurface information is limited from the south, but a deepening upwards sequence is indicated for both the Porter and Baker wells. In the south, the shelf was apparently not broad, but dropped off more steeply than the shelf in the north. Marginal marine to nonmarine sediments in the Baker well are thought to grade northwestward into the upper bathyal deposits of the Porter well (Plate II). As suggested above there may have been a shallowing to the west, towards the outcrop belt. The lower Spencer in the Porter well is silty; all but the lowermost section is thought to have been deposited at upper middle to upper bathyal depths (McKeel, 1985). A shorter period of shallow water deposition, associated with a later and more rapid transgression in the south may have contributed to the relatively thin neritic section in the Porter well.

The southward thinning of the lower member of the Spencer Formation (Fig. 12) is probably related to subaerial exposure and volcanism during deposition of lower parts of the lower Spencer in the north. The stratigraphic details of the volcanic units underlying the Spencer in the south are unknown. These volcanics have been included in the Yamhill volcanic facies in the cross-section (Plate II), but may actually be more closely associated with Spencer deposition. The southern province may have been a volcanic highland during earliest late Narizian, and the Spencer sea may not have trangressed across the area until later during lower Spencer deposition. This later period of transgression may have been more rapid, prohibiting accumulation of a thick sequence of sandstone and siltstone.

Periods of subaerial exposure and erosion/nondeposition may also have occurred intermittently during deposition of the lower member of the Spencer Formation. Many of the Spencer sandstones in the Baker well may be nonmarine. Conglomerates are common in the section. Marine microfossils have only been found at the top of the lower Spencer, and in one zone lower in the section (McKeel, 1985). The depositional depth increased near the top of the lower Spencer prior to the transition to volcanics.

Upper Spencer siltstones and mudstones in the Porter well are probably thicker because they are close to the volcanic source. The upper Spencer grades eastward into the eastern Willamette volcanics in the Baker well (Plate II). Lignite and conglomerates within the volcanics suggest progradation of the Spencer sea (tectonic uplift?), with shallowing to marginal marine depths.

Depositional History

Several inferences concerning the depositional history of the Spencer Formation can be made based on analyses of well logs and outcrops in the central Willamette Valley. The base of the Spencer is thought to lie on an unconformity throughout most of the study area.

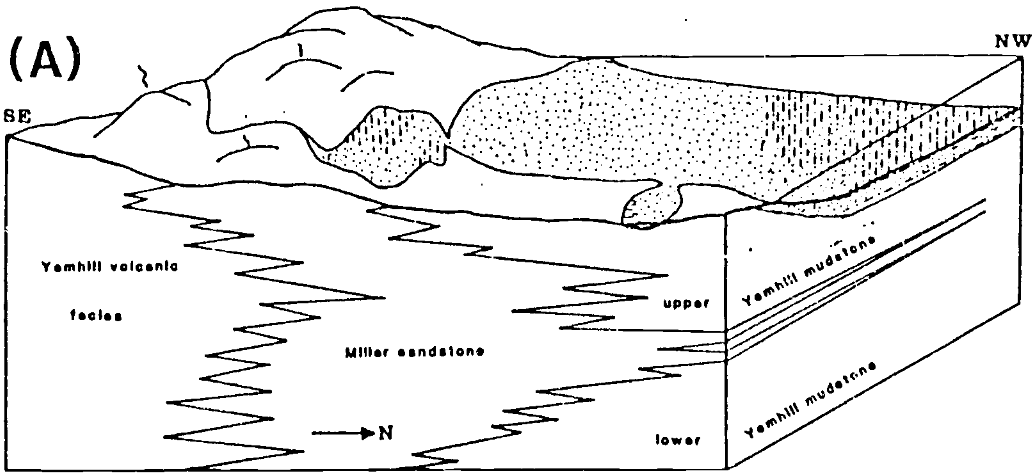
The Spencer sea advanced into the study area from a northwesterly direction. Local topography on the transgressive surface probably included a high in the area of the Corvallis Fault. During its initial transgression, sandstones and siltstones were deposited in coastal environments, primarily shelf and shoreface settings, but also coastal bays, estuaries, and marshes (Fig. 41a).

As volcanic activity increased to the east and southeast, small-scale deltas may have built out onto the shelf. Several episodes of progradation and abandonment of delta lobes may be recorded in the north and central parts of the basin. Tectonic activity in the forearc basin may also have caused some fluctuations in sea level. Slower transgression, and progradation during this period allowed a thick sequence of shallow water sands to accumulate in the central area. A broad storm wave-dominated shelf was present in the northern area. Localized volcanism (i.e., Mt. Pisgah) was probably occurring at this time (Fig. 41b). A shoal may have existed in the area of the Corvallis Fault. This shoal, combined with volcanism in the Albany area may have limited communication between the northern and southern parts of the study area.

The southern area may have been a topographic high during early Spencer deposition; transgression was delayed until the time of volcanism in the central area, about half way through deposition of the lower Spencer. During renewed transgression the shoreline advanced more rapidly across the southern area, resulting in a thin sequence of nearshore and shelf sands and silts (Fig. 41c).

As transgression continued, upper to middle bathyal silts were deposited to the northwest, while outer neritic to upper bathyal

Figure 41: Diagrammatic interpretations of paleogeography and depositional environments during Spencer deposition: (A) early in Spencer deposition -- transgression of the Spencer sea from the northwest and deposition of sand and silt in estuarine, coastal bay, shoreface and shallow shelf environments. Minor volcanism in the highland to the southeast; (B) middle Spencer deposition -- a period of stillstand/progradation during transgression. Volcanic activity in the southeast provides abundant detritus, and a delta is built into the subsiding basin. Lower member of Spencer sands and silts are deposited in a deltaic setting with mudstones deposited far to the northeast. Volcanic flows and tuffs are interbedded with sediments. Localized volcanic highs within the basin are sites of volcaniclastic deposition; (C) later in Spencer deposition -- renewed, rapid transgression causes deposition of a thinner lower member section in the south. Upper member silts and muds are deposited in the northwest. Volcanic activity is increasing in the southeast, and sediments are very tuffaceous with interbedded flows and tuffs; (D) uppermost Spencer/eastern Willamette volcanic deposition -- further transgression is followed by slight progradation during the build-up of eastern Willamette volcanics in the south and east. Muds of the upper Spencer are deposited in the north and west.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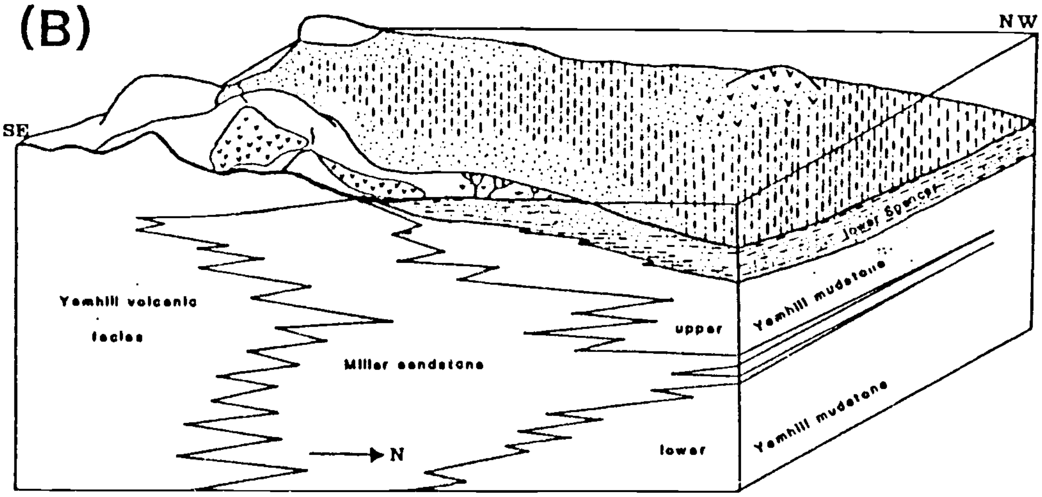
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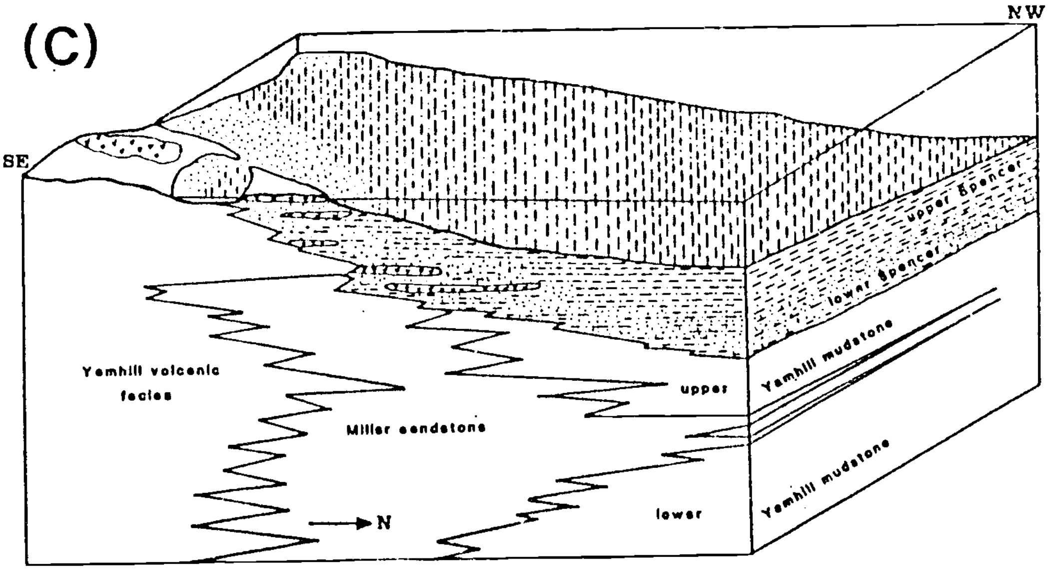
Figure 41



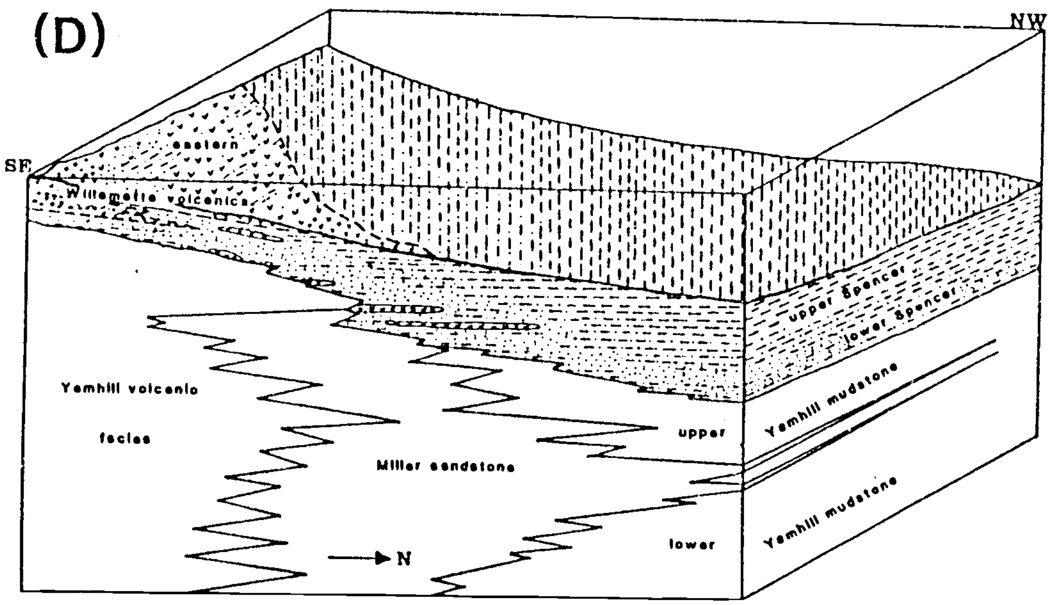


Figure 41 (cont.)

tuffaceous sands and silts, along with volcanics, were accumulating in the east and south. Volcanic activity, including flows and abundant pyroclastic eruptions increased in the east (the eastern Willamette volcanics). Shoaling in the eastern part of the basin was associated with the build up of volcanics (Fig. 41d). Nearshore to nonmarine sedimentary rocks were deposited in the southeast during this period of volcanic activity. Deposition continued at greater depths in the north, but slight shoaling is suggested by the upsection change from upper middle bathyal to upper bathyal foraminifera.

PROVENANCE

Analysis of Spencer sandstones in the central Willamette Valley supports the dual distal plutonic/metamorphic-proximal volcanic provenance proposed by earlier workers (Gandera, 1977; Van Atta, 1986; Cunderla, 1986). Sandstones from the study area plot primarily in the magmatic arc provenance zone on Dickinson and Suczek's (1979) triangle plot relating sandstone composition to tectonic setting (Fig. 42). Several samples, primarily from the northern part of the study area, plot in the transitional area between the continental block and magmatic arc provenances.

The abundance of zoned and twinned plagioclase, clear and unstrained monocrystalline quartz, and volcanic rock fragments supports a volcanic source (Dickinson, 1970; Folk, 1974). The preservation of soft and easily altered volcanic rock fragments and angular plagioclase suggests close proximity to the volcanic source. Rapid erosion, short transport and probable moderate to high relief in the source area were necessary to preserve these grains in the warm humid late Eocene

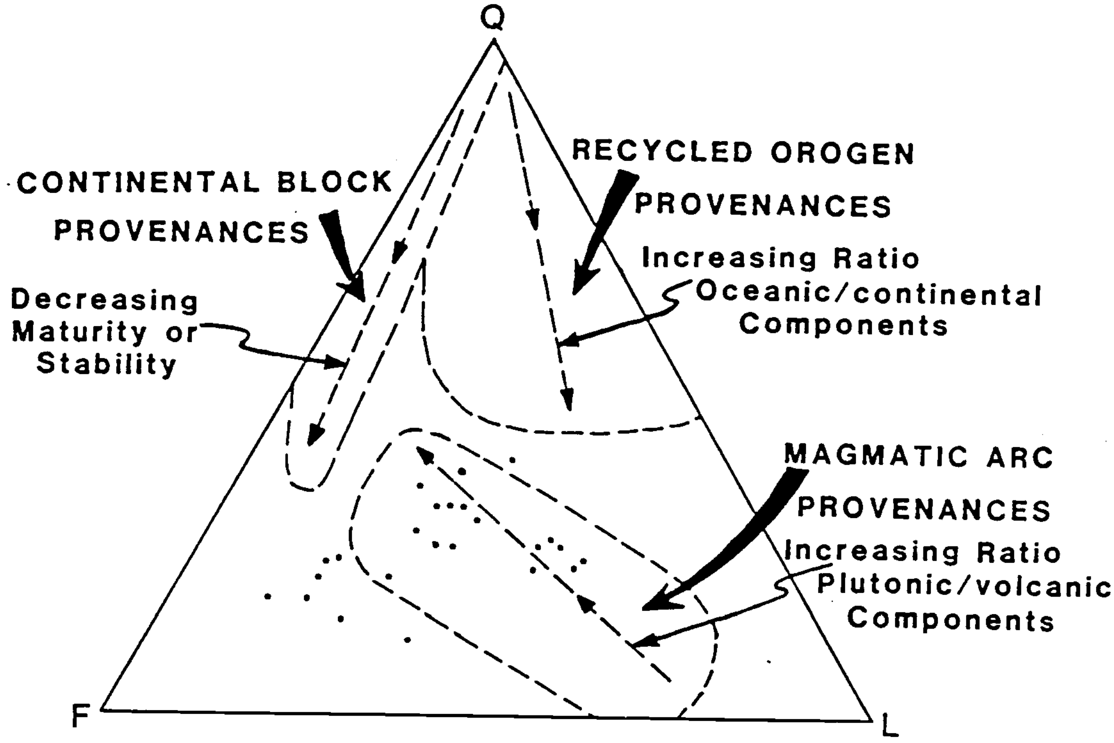


Figure 42: Triangular QFL plot showing the relationship between Spencer sandstone composition and the tectonic setting of the sandstone provenance (Q = total quartzose grains, F = total feldspar grains, and L = total unstable lithic fragments; after Dickinson and Suczek, 1979). Spencer sandstones plot primarily within the magmatic arc provenance. Some samples, particularly those from the northern study area plot in the transitional area between magmatic arc and continental block provenances. One sample from the basal Spencer sandstone in the south plots between the recycled orogen and magmatic arc provenances.

climate of western Oregon (Sandborn, 1935; Chaney, 1956; Dott, 1966; Folk, 1974).

A plutonic/metamorphic source is indicated by large amounts of quartz, potassium feldspar, plus the heavy mineral assemblage (Folk, 1974; Cunderla, 1986). Potential sources for this material are the North Cascades, other plutonics in northeastern and central Washington covered by the Columbia River Basalt flows, the Idaho batholith, and the Blue Mountains (Heller and Ryberg, 1983; Van Atta, 1986; Cunderla, 1986). An ancestral Columbia River has been suggested to carry these plutonic and metamorphic grains long distances (Van Atta, 1971; Niem and Van Atta, 1973). Their decrease in abundance to the south supports a northeastern source, with redistribution by longshore transport.

Uplifted and exposed blocks of Tertiary rocks within this tectonically active forearc basin may have been local sources. Sedimentary rock fragments, anomalously rounded quartz, and other recycled grains in the basal Spencer were probably derived from these local uplifted blocks and by shoreface erosion during transgression. One sample from the basal Spencer sandstone plots between the recycled orogen and magmatic arc provenances on Figure 42.

Potential sources of the abundant volcanic grains have been covered by younger Cascade volcanics and Columbia River Basalts. However, the volcanic units identified in wells, including the Yamhill volcanics and eastern Willamette volcanics, are likely sources. Cunderla (1986) and Gandera (1977) report dominantly andesitic composition of volcanic grains in the Spencer. The volcanics penetrated by wells have been primarily identified as basalt, but may very well be andesite. Uplifted blocks of Siletz River Volcanics within the basin may also have supplied some volcanic detritus.

A more prevalent volcanic source is indicated to the south in the study area. Late Eocene volcanic activity probably started earlier and/or at a more westward location to the south. If plutonic and metamorphic grains were primarily supplied by an ancestoral Columbia River and transported southward by currents, the northern area would receive more of this continental block type input. Dilution by volcanic grains would be limited because the source would be farther away. Time-transgressive Spencer sand deposition may also help explain the change in composition. Sands in the northern part of the basin may have been deposited earlier, during the proposed "volcanic gap" (Kadri and others, 1983). The sea may not have transgressed southward until volcanic activity had significantly increased.

DIAGENESIS

Mechanical compaction of the Spencer Formation has bent and warped micas. Volcanic and sedimentary rock fragments have been deformed around more rigid grains. A few feldspars have been fractured.

Chemical diagenetic processes observed in the Spencer include: (1) grain alteration, mainly of feldspars, volcanic rock fragments, and mafic minerals; (2) authigenic mineral formation; and (3) cementation. Feldspars have undergone sericitization, vacuolization, kaolinitization and calcite replacement. Plagioclase shows the highest degree of alteration; however, many potassium feldspars have been slightly altered. Pyroxene (augite) and hornblendes have been etched, and some biotite and hornblende has altered to chlorite. Biotite crystals also show bleaching to white mica and partial siderite replacement.

Many types and degrees of alteration are seen in volcanic rock fragments and glass. Rare glass shard outlines are filled with clay. The glassy matrix in many volcanic grains has been altered to clay. Some volcanic grains have been altered to brown, birefringent clays (smectite/illite?), while others altered to olive green clays. The green grains resemble glauconite except relict plagioclase laths can be identified. Some volcanic grains have been altered to chert-like microcrystalline aggregates. More rarely, volcanic grains show calcite replacement or a concentration of iron in the grains giving them a semi-opaque reddish appearance. Partial to complete replacement of volcanic grains is common in calcite-cemented sandstones, giving them an apparent low lithic volcanic content (e.g., sample 110h, Table 2).

Authigenic mineral formation within the Spencer was documented by Cunderla (1986) using a scanning electron microscope. He identified authigenic smectite coating grains and filling pores, authigenic potassium feldspar crystals and rhombs, and authigenic heulandite lining pores and forming euhedral crystals. Crystal growth is thought to have been the result of a high concentration of dissolved solids in formation water.

Several types of cement are present within the Spencer Formation. Clays are the most common, occurring as clay rims, clay coats, and pore filling. Calcite locally cements sandstones; it typically occurs in well sorted sandstones, those containing abundant organic matter, and locally around fossils. Calcite cement is generally impure and cloudy. Calcite replaces whole grains, and causes corrosion around the edges of other grains. Iron oxide cements also occur locally and are most commonly observed adjacent to intrusives. Authigenic silicate cements have been documented by Enlows and Oles (1966) and Cunderla (1986).

SUMMARY AND CONCLUSION

During the middle to late Eocene, western Oregon was a residual forearc basin floored by oceanic crust. Because of this tectonic setting, the basin was a major sediment repository, and contains a general shallowing upwards sedimentary sequence (Dickinson and Seely, 1979). Deep water turbidites of the Tyee and lower Yamhill Formations pass upwards into shelf or nearshore deposits of the upper Miller sandstone and Spencer Formation. The forearc basin deepened westward with the Spencer Formation grading into the deeper water Nestucca Formation to the west and northwest, respectively.

Study of both surface and subsurface data has permitted a more complete regional study of the poorly exposed late Eocene strata in the central Willamette Valley of western Oregon. The Spencer Formation stratigraphy, distribution, depositional environments and associated tectonic activity were examined. The depositional environment of the Yamhill Formation, and stratigraphic problems concerning its distribution were considered briefly.

In the subsurface of the central Willamette Valley, the Yamhill Formation consists of the Miller sandstone member enclosed by mudstones and siltstones (Fig. 13). The poorly defined lower Yamhill mudstone is tuffaceous, and grades upsection into the Miller sandstone. The Miller sandstone member is lens shaped, reaching a maximum thickness of approximately 2,000 feet (Fig. 10). The Miller sandstone consists of very fine- to medium-grained sandstones, with interbedded siltstones and mudstones. Foraminifera indicate an early Narizian age, and depositional shallowing from upper bathyal near the base, to marginal marine near the top (McKeel, 1984, 1985). The upper Yamhill mudstone ranges from absent to 750 feet thick in wells, thickening to the northwest as the Miller sandstone thins. Lower Narizian upper Yamhill mudstones and siltstones were depsosited at upper to middle bathyal depths (McKeel, 1984, 1985). The Yamhill Formation undergoes a facies change to volcanics towards the southeast. The basaltic to dacitic flows and tuffs are interbedded with sedimentary rocks of early Narizian age (McKeel, 1985). Yamhill strata have not been mapped at the outcrop belt to the southwest. Thinning as a result of erosion/nondeposition associated with Corvallis fault activity, or misidentification of strata may explain its non-recognition.

The Yamhill basin deepened to the northwest as indicated by Miller sandstones grading into deeper water Yamhill mudstones and siltstones. The upper parts of the Miller sandstone may represent the eastern shoreline of the Yamhill basin. Abundant sediment, supplied by the active volcanism, probably caused progradation of the shoreline into the subsiding Yamhill basin. Deposition in shelf, shoreface, and possibly in swampy deltaic settings is interpreted. With renewed transgression, bathyal upper Yamhill mudstones were deposited over the shallow water sandstones.

Thickening of the Miller sandstone parallel to and on the downthrown side of the Corvallis Fault, along with thinning of the Yamhill mudstone along the fault trace (Figs. 10, 11), indicates movement during and possibly after Yamhill deposition. Fault movement probably caused the area to be a local high during Spencer transgression. Decreased fault activity during Spencer deposition is indicated by a lesser degree of lower Spencer thinning towards the fault. No substantial thickness changes in the Yamhill and lower

Spencer are noted across the Albany Fault. Offset on the Albany Fault probably occurred sometime after early Spencer deposition.

The Spencer Formation is divided into a lower member, composed dominantly of sandstones and siltstone, and an upper mudstone member (Fig. 13). The upper mudstone member grades eastward into the eastern Willamette volcanics. Because of variations in petrology and stratigraphy, the study area is subdivided geographically into northwestern, southern, and east-central domains (Fig. 9). The Spencer crops out in the northwestern and southern areas; in the east-central area it is defined primarily in the subsurface. The lower member of the Spencer Formation is 600 to 700 feet thick in the northwestern and southern areas, and thickens to 1,000 feet in the east-central area. The sandstone to siltstone ratio and grain size increase eastward.

In the northwestern province, sandstones of the lower member of the Spencer Formation are primarily lithic arkoses. Volcanic-rich sandstones are found locally, close to volcanic vents (e.g., Mount Pisgah area). Abundant hummocky cross-stratification in northern outcrops suggests deposition on a broad storm wave-dominated shelf. Coarser grain sizes and trough cross-bedding in lower parts of the lower member indicate regressive episodes with shoaling to shoreface depths. In the upper part of the lower memberm coarsening upward sequences suggest progradation of the Spencer shoreline, possibly caused by increased volcanic input from the east. The sandstone to siltstone ratio decreases to the northwest indicating deepening in this direction. Middle bathyal mudstones of the upper member of the Spencer Formation were deposited late in Spencer deposition after further transgression. These mudstones grade eastward into the eastern

Willamette volcanics. The volcanics reached as far west as the northwestern area during latest Spencer time.

The lower member of the Spencer Formation in the east-central province contains a higher percentage of sandstone and larger grain sizes than other areas because it is closer to the proposed east-northeast-trending shoreline. Deposition was probably at inner shelf to shoreface depths, grading into nonmarine to the east. Interbedded volcanic flows and tuffs add to the thickness of the lower member in this area. They also may have allowed the area to remain a site of sand deposition at shelf depths as the Spencer sea transgressed. Volcanic flows and tuff beds became more abundant upsection, and sand composition becomes more volcanic. Lower sandstones in the area are generally more arkosic, coarser grained, and show a greater degree of reworking. In much of the eastern-central area the lower member of the Spencer passes directly upsection into eastern Willamette Volcanics. However, some very tuffaceous siltstones and mudstones are grouped in the upper Spencer.

In the southern area, sandstones of the lower member of the Spencer are generally arkosic litharenites. The basal sandstone contains more sedimentary rock fragments, quartz and potassium feldspar than overlying sandstones. Presumably these sediments were partially derived from shoreface erosion of the underlying strata during transgression and redeposited in nearshore environments. Overlying sandstones contain abundant plagioclase, and rock fragments are dominantly volcanic. Deepening to shelf depths is evidenced by an increase in bioturbation, abundant macrofossils, and normally graded shelf-storm deposits. With renewed transgression, very tuffaceous mudstones of the upper member of the Spencer were deposited. In wells to the southeast, the Spencer section consists of tuffs, volcanic flows and minor tuffaceous sandstones. The area around the Baker well may have been nonmarine during parts of Spencer deposition. The more volcanic nature of lower member sandstones in the south is a result of closer proximity to the volcanic source. Furthermore, transgression may have occurred later in the south, as volcanic activity was increasing. A barrier or shoal within the basin may also have contributed to the different sediment character. A shoal within the basin may have protected the southern area from reworking by strong shelf currents. And, as a result, the area was more favorable for biologic productivity and sediment bioturbation. Alternatively, the quieter deposition may have taken place at deeper, middle shelf depths.

The Spencer Formation records transgression during late Eocene time (late Narizian). As the Spencer sea advanced from the northwest, sandstones and siltstones were deposited in nearshore and shelf settings. Transgression was interrupted by several regressional/progradational episodes. Uplift and subsidence in the tectonically active forearc basin probably caused many fluctuations in relative sea level. Volcanic activity to the east and southeast may have supplied sediment fast enough that small-scale deltas were built into the basin. Well data indicate volcanic activity far to the east in the study area, and nearby to the southeast during lower Spencer deposition. Volcanism increased upwards through the Spencer deposition. Small volcanic centers within the Spencer basin may have generated local highs during deposition and thus produced volcanic sediments for the basin. With renewed transgression bathyal mudstones were deposited over much of the

Spencer basin. To the east, the mudstones grade into the eastern Willamette volcanics. The eastern Willamette volcanics are early Narizian in age, and probably represent early western Cascade volcanism. They may be equivalent to the Fisher Formation in the Eugene area, the undifferentiated Eocene and Oligocene sediments in the Salem area, and in part, to the Little Butte Volcanics in the Western Cascade foothills.

FUTURE WORK AND UNRESOLVED PROBLEMS

Further study is needed to better define the late Eocene stratigraphy, tectonic activity, and geologic history of western Oregon. One of the main problems in the central Willamette Valley is the presence of the thick Miller sandstone member of the Yamhill in the subsurface, and its apparent absence at the surface. A more detailed study of well cuttings and cores from the Miller sandstone would expand knowledge about its sedimentary character and facies changes. The Miller sandstones and Yamhill mudstones should be compared to surface exposures of the Yamhill, and to other Yamhill sandstones like the Clatskanie.

With a better understanding of Miller sandstone petrology and the use of paleontology (especially microfossils), strata around the Spencer/Tyee contact should be examined in as much detail as possible. Attempts should be made to determine if the Miller sandstone is completely absent, has been mistaken for the Spencer, and/or has undergone a facies change and resembles the Tyee. Furthermore, the Spencer/Tyee contact, as mapped, cuts nearly straight across valleys and hills, suggesting near vertical beds. However, measurements show shallower dips. Further study would help delineate the poorly exposed contact.

A detailed study of the Corvallis fault and other major structures within the area may also shed light on the Miller sandstone problem. The timing of fault activity and northward termination of the Corvallis fault are of particular interest. Determination of the trends of faults identified in the subsurface also is needed. Geophysical methods, such as seismic reflection, gravity and magnetic surveys, would help determine the northward termination of the Corvallis fault. Dipmeter logs may help define subsurface structures. Study of existing seismic lines within the area would provide more information on overall basin structure.

A detailed study of the eastern Willamette volcanics and the Yamhill volcanics is needed to determine if they represent early western Cascade volcanism or are more closely related to the Siletz River Volcanics. Age dating and chemical analysis of well cuttings and cores would shed more light on the volcanic evolution of western Oregon. Volcanics in the Mt. Pisgah area and the Miller well should also be studied to determine if these are indeed late Eocene volcanics correlative with those interbedded with the Nestucca and Cowlitz.

Detailed study of sedimentary structures in the northern part of the basin could tell more about the direction of sediment transport and smaller scale changes in depositional setting. This data would also add to the growing set of information on the existence, patterns and causes of hummocky cross-stratification.

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APPENDICES

APPENDIX I

FOLK AND WARD FORMULAS FOR CALCULATION OF GRAIN SIZE PARAMETERS

$$\text{MEAN} = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$\text{STANDARD DEVIATION} = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$\text{SKEWNESS} = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

$$\text{KURTOSIS} = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

where ϕ_x = the phi value for which x percent of the sample is coarser

APPENDIX II

GRAIN SIZE ANALYSIS DATA

Location
Sample#/figure 101#

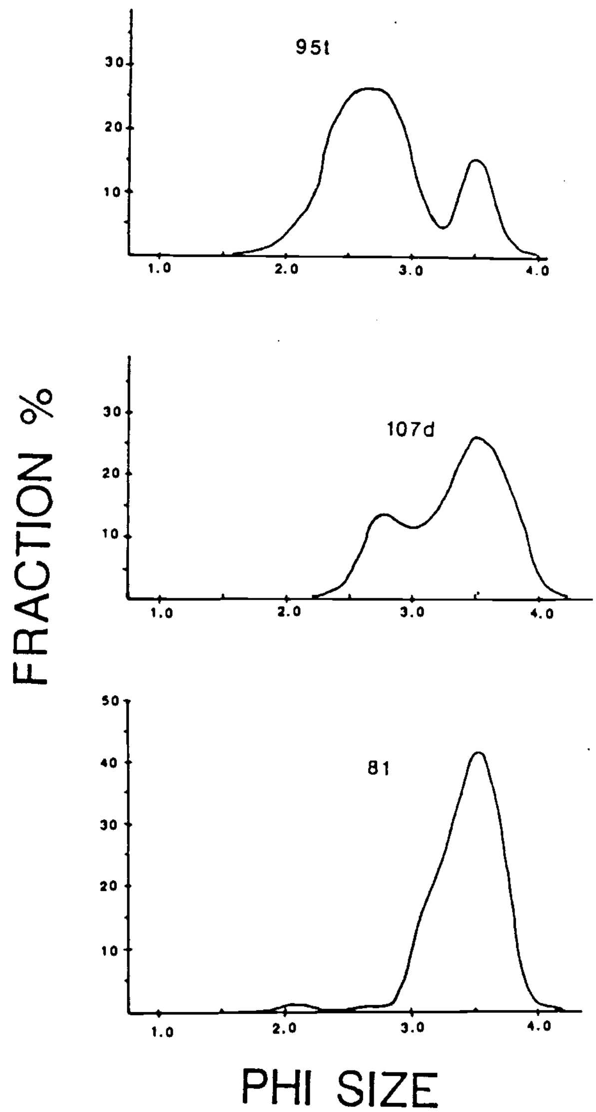
FRACTION WEIGHT %

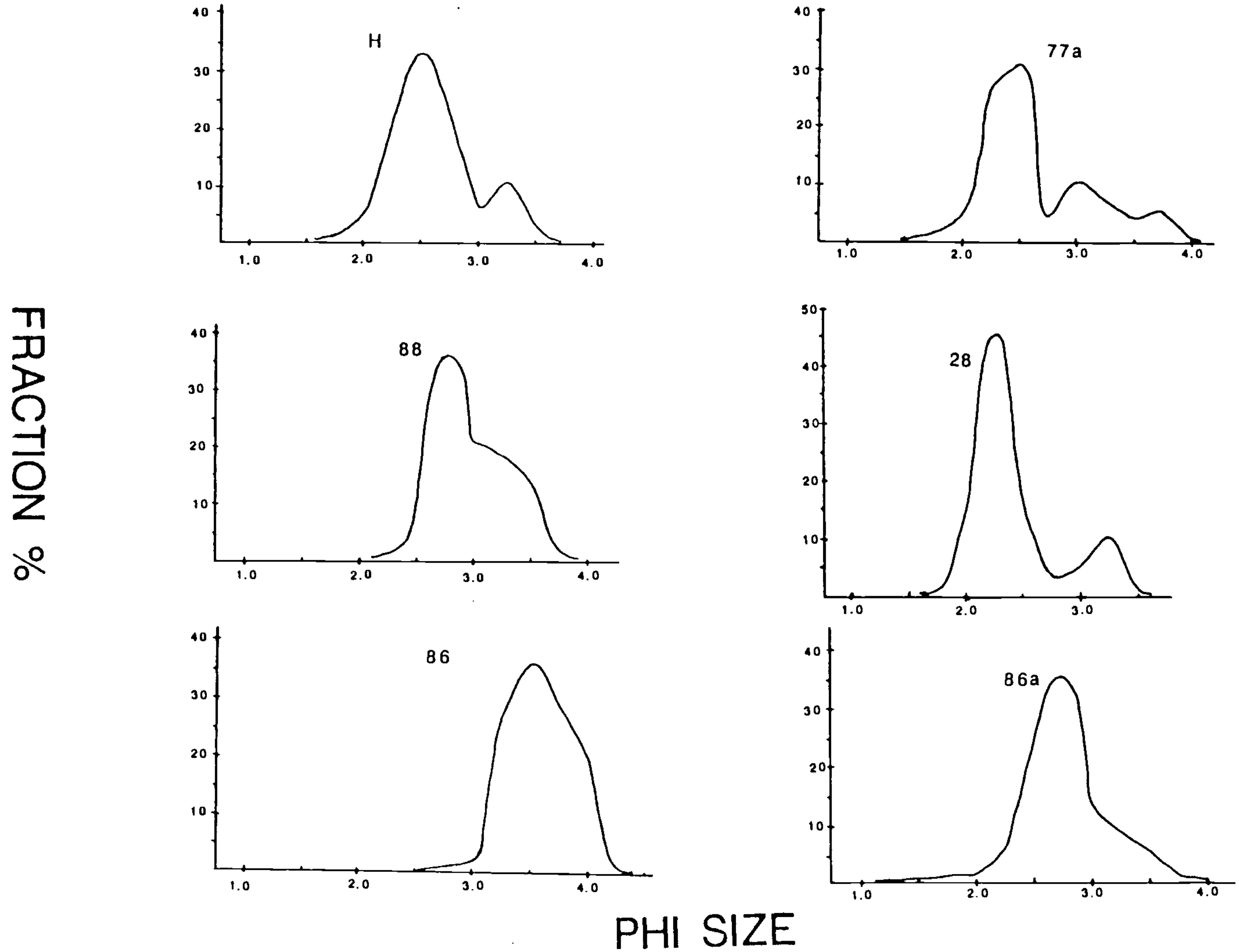
PHI SIZE	Lower Spencer Formation Northern Area	Helmick Hill 107/#10	Helmick Hill 104b/#10	Helmick Hill 88/#10	Helmick Hill 86/#10	Helmick Hill 86a/#10	"Clay" Pit 107b/#13	"Clay" Pit 107d/#13	Monmouth 96b/#7	Amer. Quasar Petrol. Independence (3450' depth)	Lower Spencer Formation Southern and Central areas	Belfountain Rd. 28/#61	Bruce Rd. 77/#62	Spring Hill (east) 48/#26	Logsdens Ridge 81/#29	Walunt Hill 95t/#35 (Spencer?)	Miller sandstone	Amer. Quasar Petrol. Henschell (1070' depth)
0.75		0.32																
1.00		0.62																
1.25		0.94				0.25												
1.50		1.55				0.25												
1.75		14.47										1.27	1.69			0.37		
2.00		28.97	3.28			1.19						15.57	7.31	2.68	0.93	3.61		5.98
2.25		26.97	30.83			7.89						46.07	27.28	15.21		10.40		22.39
2.50		16.62	50.45	11.20		24.76		4.16	4.30	6.45		16.42	30.07	30.42		25.07		32.83
2.75		3.04	7.47	35.66	1.61	35.44	4.62	16.15	18.87	13.96		3.55	4.90	21.63		21.17		21.63
3.00		1.81	2.83	20.29	2.16	14.21	20.30	14.09	21.38	20.40		5.37	11.07	3.73	13.44	14.30		6.73
3.25		0.94	1.41	18.77	12.91	8.86	30.79	17.99	21.31	16.10		10.50	7.44	12.08	25.91	7.25		10.44
3.50		1.81	3.73	13.98	36.28	5.62	27.70	26.40	22.15	10.73		1.24	4.72	4.47	42.11	15.04		
3.75		2.12			27.42	1.54	15.50	18.05	11.99	17.18			5.53	3.73	17.61	2.78		
4.00					19.62		1.09	3.17		15.18				6.05				

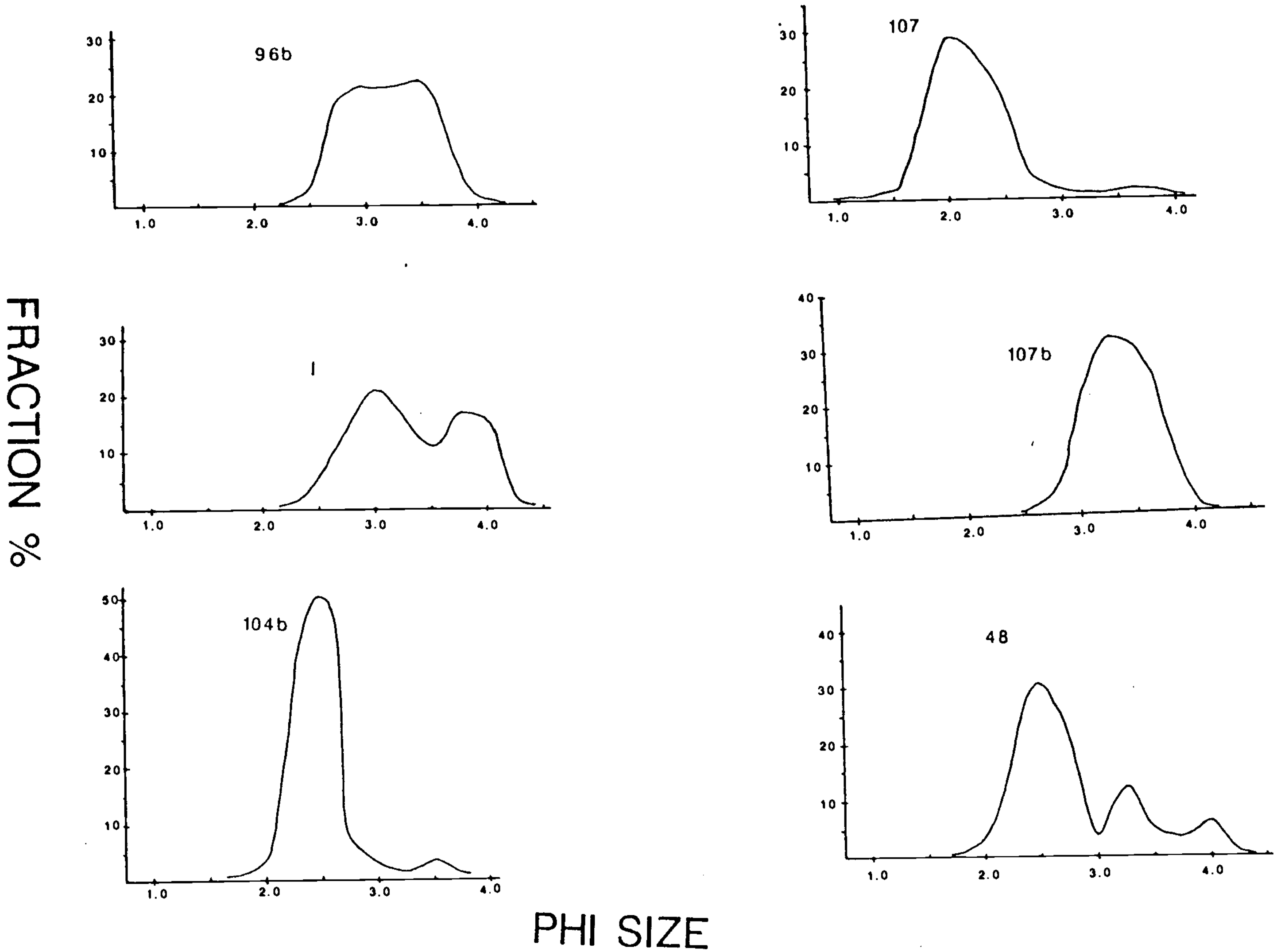
Location Sample#/figure 101#	COARSEST 1 %	MEDIAN	KURTO-SIS	SKEW-NESS	STAND. DEV.	MEAN
Lower Spencer Formation Northern Area						
Helmick Hill 107/#10	482	243	1.29	0.20	0.35	2.03
Helmick Hill 104b/#10	252	209	2.49	0.44	0.23	2.30
Helmick Hill 88/#10	179	141	0.60	0.24	0.29	2.84
Helmick Hill 86/#10	149	88	0.93	-0.09	0.24	3.48
Helmick Hill 86a/#10	265	161	1.19	0.26	0.34	2.64
"Clay" Pit 107b/#13	148	108	0.78	-0.03	0.27	3.22
"Clay" Pit 107d/#13	178	107	0.78	-0.21	0.40	3.15
Monmouth 96b/#7	178	120	0.71	-0.06	0.35	3.06
Amer. Quasar Petrol. Independence (3450' depth)	179	113	0.63	0.08	0.46	3.19
Lower Spencer Formation Southern and Central areas						
Belfountain Rd. 28/#61	300	225	1.69	0.59	0.39	2.32
Bruce Rd. 77/#62	300	192	0.93	0.43	0.48	2.50
Spring Hill (east) 48/#26	255	170	0.98	0.45	0.49	2.65
Logsdens Ridge 81/#29	150	99	1.63	-0.20	0.22	3.28
Walunt Hill 95t/#35 (Spencer?)	278	160	0.90	0.26	0.47	2.73
Miller sandstone						
Amer. Quasar Petrol. Henschell (1070' depth)	253	186	1.06	0.17	0.31	2.44

APPENDIX III

FRACTION PERCENTAGE PLOTS OF GRAIN SIZE DATA




FRACTION %
H
77a
88
28
86
86a
PHI SIZE
1.0
2.0
3.0
4.0
10
20
30
40
50



96b
107
I
107b
104b
48
FRACTION %
PHI SIZE
1.0
2.0
3.0
4.0
10
20
30
40
50

APPENDIX IV

HUMMOCKY BEDDING AND HUMMOCKY SEQUENCES

Hummocky cross-stratification is abundant in the northern part of the study area. The term "hummocky cross-stratification" was introduced by Harms and others (1975) to describe low-angle dipping cross-strata sets above low-angle erosional surfaces. Dips vary in direction, and generally do not intersect the erosional surface. Laminae may systematically thicken or thin within a set, but do not commonly intersect.

Dott and Bourgeois (1979, 1980, 1982) have defined an idealized hummocky sequence in which hummocky cross-stratification is a major component (Fig. 38a). This idealized sequence is deposited during storm conditions. The base of the sequence is a low angle erosional base overlain by hummocky cross-stratification (the hummocky zone; H). Hummocks and swales may be symmetric or asymmetric. The laminae draping the bedforms commonly thin over hummocks and thicken in swales. Due to this thinning and thickening, laminae tend to flatten upsection producing an indistinct flat laminated zone (F zone). As the storm wanes and flow intensity decreases, a thin zone of rippled and cross-laminated fine sand or silt is deposited above the flat laminated zone (X zone). The sequnece is capped by a mudstone (M zone) deposited during the last stages of the storm and the following fair weather period. The mudstone is generally partially to completely bioturbated (Dott and Bourgeois, 1982).

Complete HFXM sequences are rarely preserved. Depending on the depth, wave and current energy, storm frequency and rate of sediment input, variations of the idealized sequence are deposited (Fig. 38b). For example, frequent high energy storms may cause erosion of upper zones, leaving amalgamated sequences (e.g. "clay" pit, parts of Buena Vista). With a low sediment supply and weaker currents micro-hummocky lenses are thought to be deposited (Fig. 38b; e.g. Monmouth Road summit beds; Dott and Bourgeois, 1982).

Hummocky sequences are thought to form in storm wave-dominated lower shoreface and shelf settings, commonly between fair-weather and storm wave base. They typically develop in fine sand to coarse silt. During storms, fine sand derived from river floods and scouring of the shoreface is transported offshore. Wave oscillation may also resuspend sediment over shoals (Dott and Bourgeois, 1982). Deposition under a combination of oscillatory and unidirectional currents, developed during storms is thought to generate hummocky cross-stratification (Hunter and Clifton, 1982; Swift and others, 1983; Allen, 1985). If unidirectional currents are dominant over oscillatory flow, hummocky cross-stratification is thought to be transitional to trough cross-lamination; if high energy oscillatory flow is dominant, hummocky bedding may grade into parallel laminations (Fig. 43; Nottvedt and Kreisa, 1987).

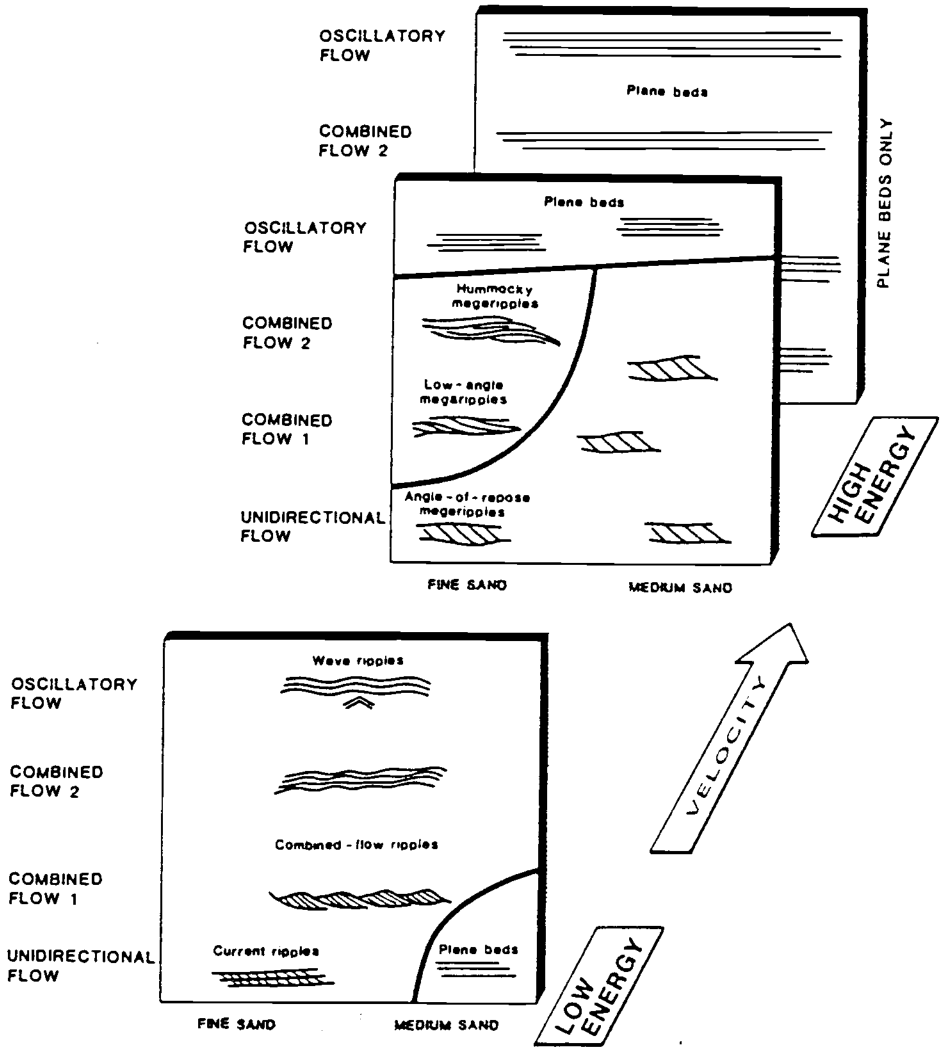


Figure 43: Conceptual bedform phase diagram. Schematic plot of bedforms as a function of current structure, current velocity, and grain size. Note transitional nature of hummocky bedding, megaripple bedding (trough cross-bedding), and plane beds (from Nottvedt and Kreisa, 1987).