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STRATIGRAPHY AND SEDIMENTOLOGY OF THE RAGING RIVER FORMATION (EARLY? AND MIDDLE EOCENE), KING COUNTY, WASHINGTON

by

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ABSTRACT

The lower? and middle Eocene Raging River Formation is the oldest Tertiary stratigraphic unit exposed in the east-central Puget Lowland, Washington, and provides key information for reconstructing regional paleogeography and tectonic history. Three informal stratigraphic units (designated 1 to 3 from base to top) are here recognized in the Raging River Formation based on distinctive sedimentary facies and lithologies. A fourth unit (unit 0) might either represent the lowest exposed part of the Raging River Formation or semi-lithified Quaternary(?) colluvium. Unit 1, approximately 230 m thick, consists of interbedded sandstone, mudstone, and conglomerate of inferred nonmarine (lower part) and transgressive shallow-marine (upper part) origin. Unit 2, approximately 185 m thick, consists of interbedded conglomerate, sandstone, and mudstone, and is inferred to be of mainly alluvial origin. A significant transgression is recorded by Unit 3 (about 300 m thick), which consists of gray silty mudstone and lesser sandstone, and was deposited in a marine shelf (lower part) and bathyal slope (upper part) setting. This transgression reflects local tectonism and not fluctuating eustasy. The Raging River Formation is overlain by prodelta(?) marine shelf deposits in the lower part of the Tiger Mountain Formation. The Raging River Formation may provide a surface analog for conductive rocks that underlie a large part of the southern Washington Cascade foothills.

Three sandstone petrofacies were identified in the Raging River Formation and lower part of the Tiger Mountain Formation. These petrofacies reveal an upward evolution in sediment source from Mesozoic basement rocks of oceanic affinity (petrofacies 1), to lower Tertiary volcanic rocks (petrofacies 2), to a mixed provenance including Mesozoic oceanic rocks, lower Tertiary volcanic rocks, and more distal plutonic or crystalline rocks (petrofacies 3).

INTRODUCTION

The lower? and middle Eocene Raging River Formation is the oldest Tertiary stratigraphic unit exposed in the east-central Puget Lowland, Washington (figs. 1, 2), and provides key information for reconstructing regional paleogeography and tectonic history. The base of the Raging River Formation is not exposed; it is overlain by the sandstone and mudstone of the Tiger Mountain Formation, which is in turn overlain by and interfingers with the volcanic and volcaniclastic Tukwila Formation (fig. 3). The Raging River Formation was named by Vine (1962) for patchy outcrops that comprise a ~8 km^2 northwest-trending belt on the forested east and north sides of Tiger Mountain and on the north flank of Taylor Mountain (fig. 2). Vine (1962, 1969) described the lithology, petrology, and clay mineralogy of the unit, measured two partial stratigraphic sections, and reported extensive invertebrate and foraminiferal fossil data. Vine (1962, 1969) interpreted the Raging River Formation as entirely marine, and suggested a marine-to-nonmarine transition occurs at the base of the overlying Tiger Mountain Formation. Since Vine (1962, 1969) conducted his research, the outcrop of the Raging River Formation has been significantly modified by the combined effects of logging and log-road construction, rapidly growing vegetation, and resedimentation of unconsolidated Quaternary deposits. Some of the exposures Vine (1962, 1969) examined are now completely covered, and some new outcrops are present. Core from a 514 m (1686 ft) borehole (fig. 2) that penetrates the upper Raging River and lower Tiger Mountain Formations drilled in 1983 by AMOCO Production Company is now also available for study. The purpose of this report is to supplement Vines (1962, 1969) work with new information on the stratigraphy, sedimentology, petrology, and tectonic significance of the Raging River Formation. This material will ultimately be combined with data collected from studies of heavy minerals, thermal maturation, and organic geochemistry in preparation of a formal report.

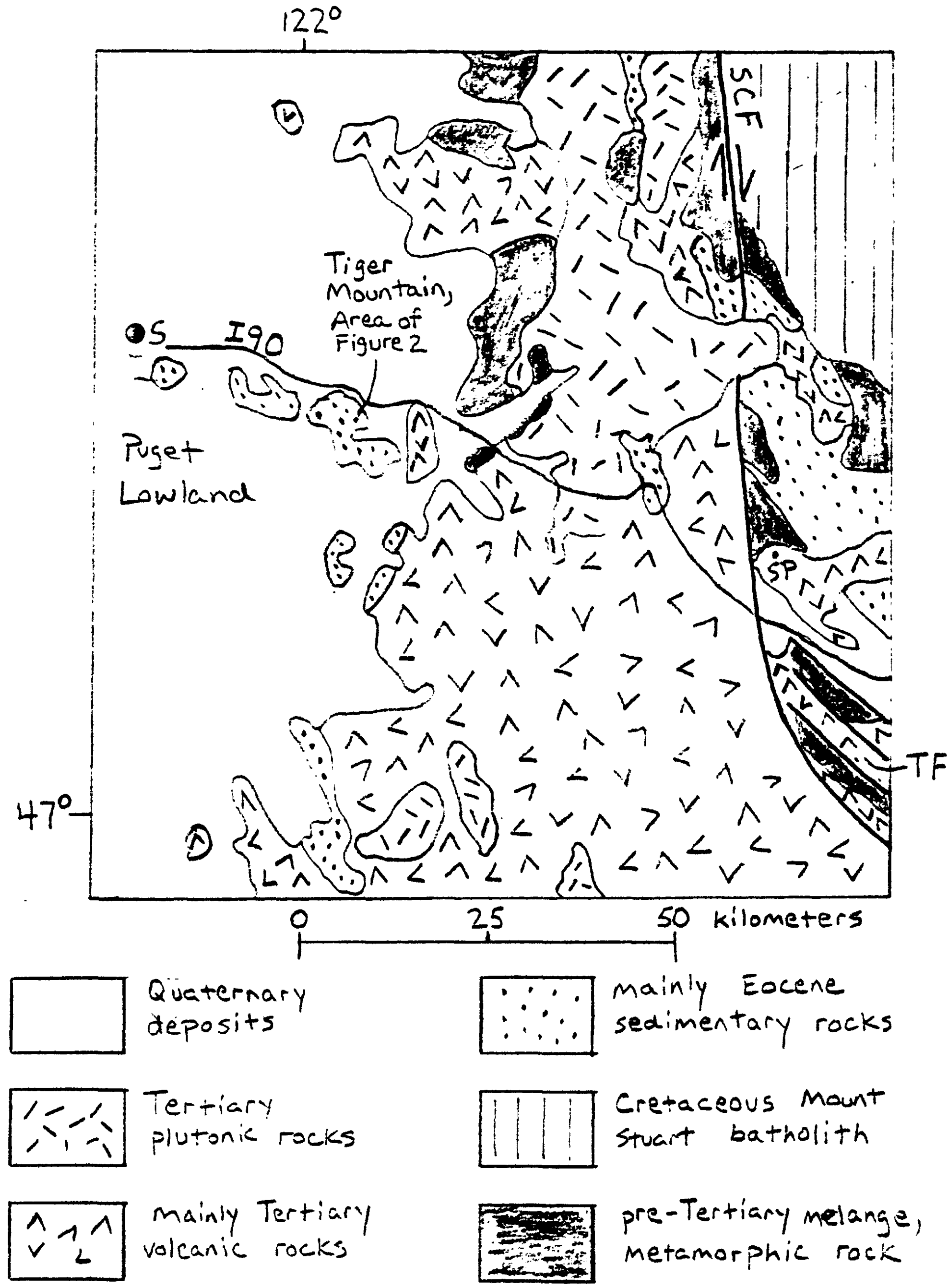


Figure 1. Schematic geologic map showing location of the Tiger Mountain area and surrounding area. S = Seattle; SCF = Straight Creek fault; SP = outcrop area of Silver Pass Volcanic Member of Swauk Formation; TF = area of outcrop of Taneum Formation. Modified from Frizzell and others (1984), Tabor and others (1982, 1984), Walsh and others (1987), and Yount and Gower (1991).

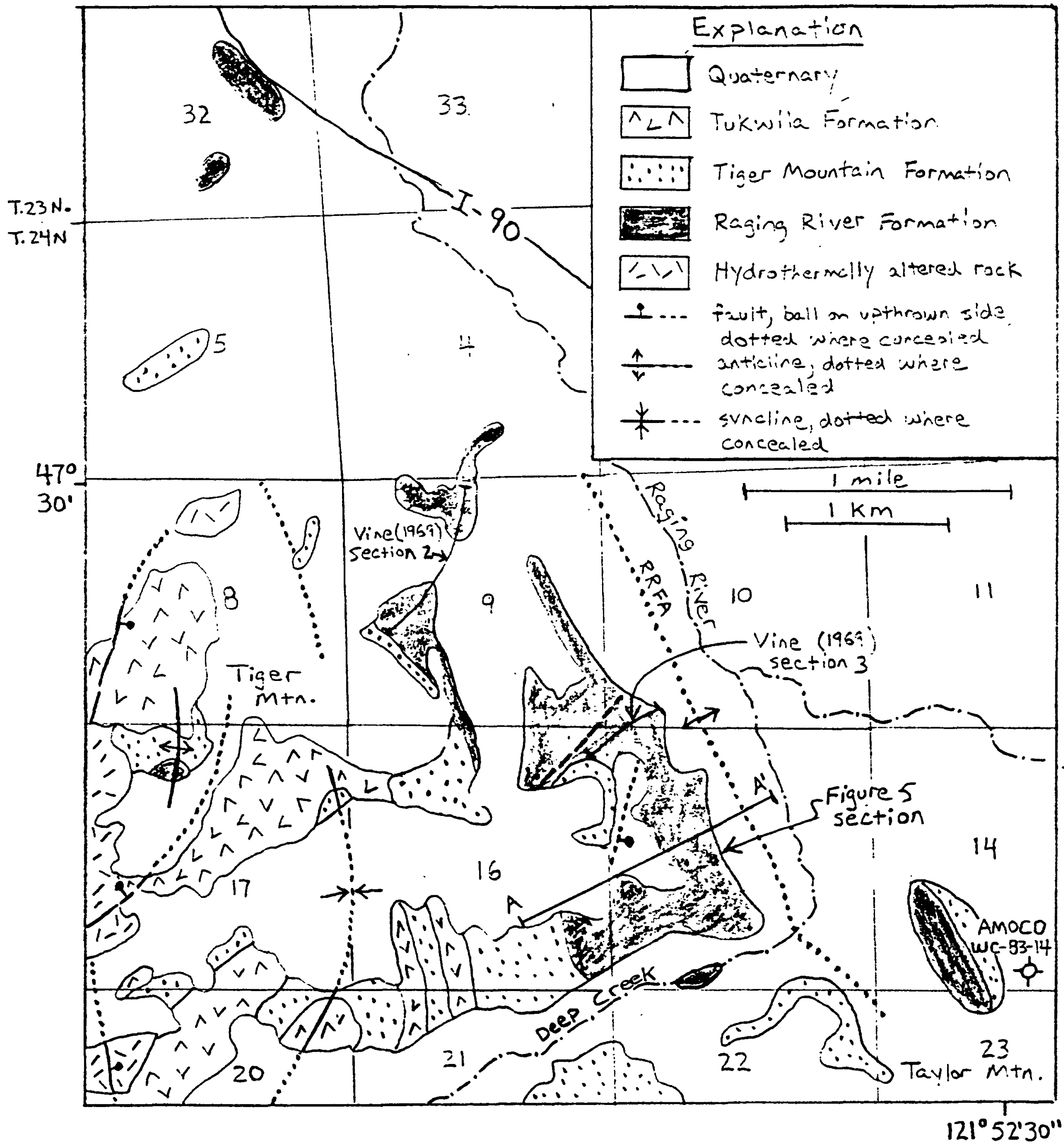


Figure 2. Schematic geologic map of the Tiger Mountain area showing locations of outcrops, Vine's (1969) measured sections cited in this text, structure, and the AMOCO WC-83-14 borehole. Line A-A' is the line of section used by Vine (1969) to determine thickness of Raging River Formation. RRFA = Raging River fault and anticline. Numbers indicate sections in T. 23, 24 N., R. 7 E. Modified from Vine (1969), Tabor and others (1982) and Frizzell and others (1984).

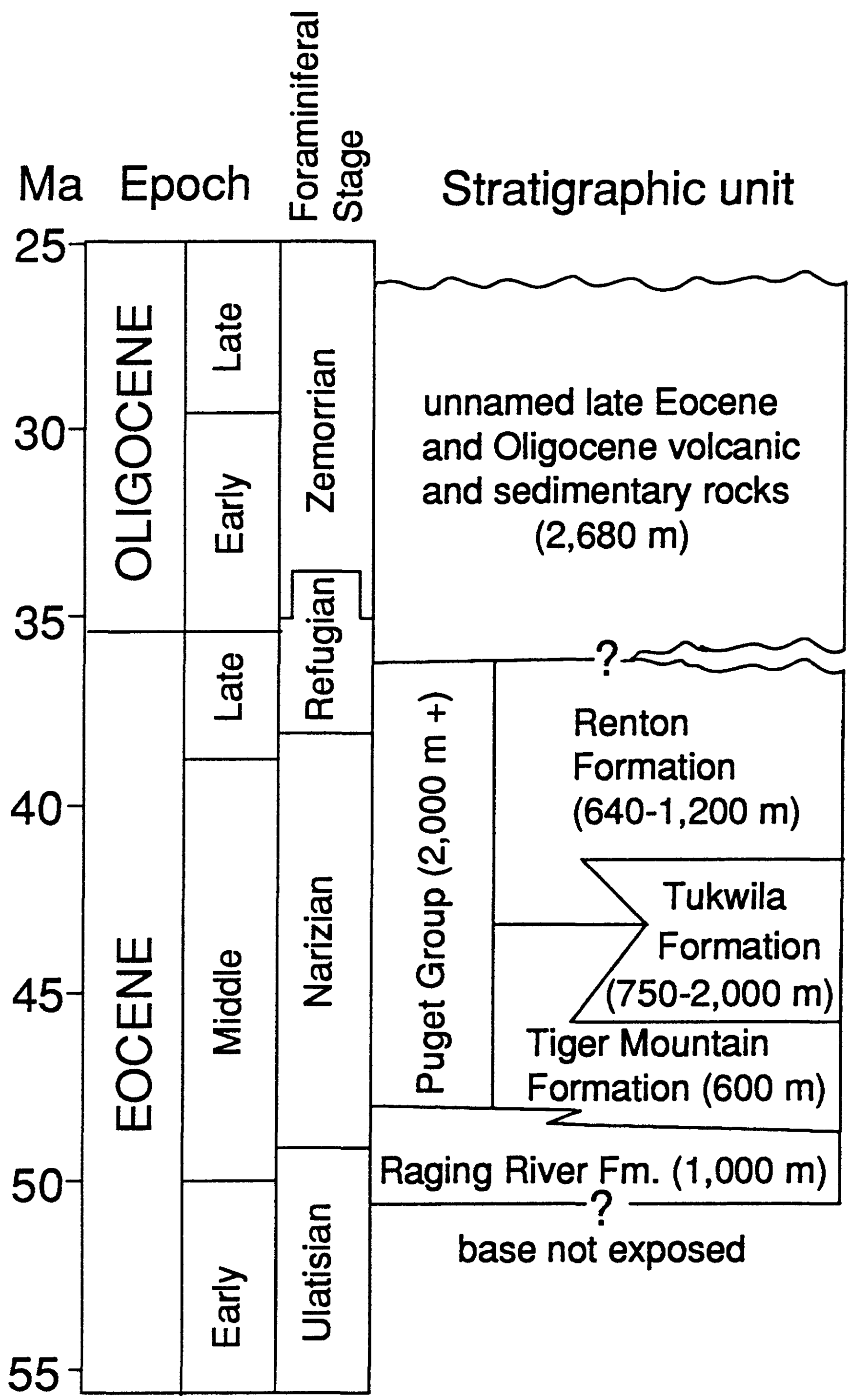


Figure 3. Schematic stratigraphic column showing Eocene and Oligocene stratigraphy of the Seattle-Tiger Mountain area (after Vine, 1969; Armentrout and others, 1983; Yount and Gower, 1991). Time scale is after Harland and others, 1990). Correlation with foraminiferal stages is based on Almgren and others (1988) and Niem and Niem (1992).
4. Schematic diagram showing composite section of the Raging River Formation. All locations are in T. 23 N., R. 7 E. Unit 0 could either represent the lowest exposed part of the Raging River Formation or semi-lithified Quaternary(?) colluvium. See text for discussion.

STRATIGRAPHY AND SEDIMENTOLOGY

The Raging River Formation forms patchy outcrops in a ~8km^2, northwest-trending outcrop belt on the east and north flanks of Tiger Mountain in the east-central Puget Lowland (figs. 1, 2). This area is heavily forested and covered by significant Quaternary glacial drift. Outcrops are generally of poor quality and occur mainly in the beds of small creeks and along former logging roads. Vine (1969) measured two partial stratigraphic sections of the Raging River Formation, including (1) a 560 m (1,836 ft)-m-thick section between elevations of 357 m (1,170 ft) to ~564 m (~1,850 ft) in the bed of a small tributary in W 1/2 sec. 9, T. 23 N., R. 7 E, and (2) a 410 m (1,345 ft) thick section exposed in the bed of a small tributary in secs. 10, 15, and 16, T. 23 N, R. 7 E. (fig. 2). Each of these two measured sections included about 48 percent cover. Based on traverses conducted in the summer of 1991, my estimate is that the amount of cover in each tributary is now much greater. Although the limited creek exposures still provide important sedimentologic, structural, and stratigraphic data, they are no longer suitable localities for measured sections. However, there is now a short section exposed on a logging road that is suitable for detailed analysis, and many other modern exposures were probably not present or were of poor quality when Vine conducted his research.

Vine (1969) suggested that the cumulative thickness of the Raging River Formation is as much as 915 m (3,000 ft) based on projection of outcrop attitudes onto a generalized cross section (line A-A' of fig. 2). This projection extends from the contact with the overlying Tiger Mountain Formation (figs. 2, 3) to the axis of the faulted, south-plunging, Raging River anticline (Vine, 1969, p. 38), which is mantled by glacial drift (fig. 2). Because the base of the Raging River Formation is not exposed (fig. 3) and Vine's section extends only to the anticline axis where it intersects the surface (fig. 2), the actual thickness of the unit may be greater than Vine's estimate.

As a result of field work and core description conducted in the summer of 1991, I recognized three informal stratigraphic units within the Raging River Formation (fig. 4). A fourth unit (designated unit 0) could either represent the lowest part of the Raging River Formation or (more likely) semi-lithified Quaternary(?) colluvium. Vine's (1969) sections were also used in developing this framework, but it is re-emphasized that much of the rock in the sections that Vine measured is no longer exposed. The four units were recognized on the basis of distinctive sedimentary facies and lithologies, and are described below. Because of limited exposure, the thickness of the different units is based largely on map projections of bedding-plane attitudes.

W.W. Rau (in Vine, 1969, p. 16) identified benthic foraminifera from the upper Raging River Formation (unit 3 of this report, fig. 4) and referred them to the late Ulatisian or possibly early Narizian stage of the middle Eocene (fig. 3; Armentrout and others, 1983). Rau (written commun., 1991) subsequently restricted these foraminifera to the early Narizian, and identified a comparable fauna in core of the upper Raging River Formation (see discussion of unit 3 below) from the AMOCO WC-83-14 borehole. Strata underlying the foraminifera localities are undated, and are probably early? to early middle Eocene in age. The overlying Tiger Mountain Formation (fig. 3) has not been dated. Turner and others (1983) reported late middle Eocene fission-track and K-Ar dates (41.3 ± 2.3 Ma and 42.0 ± 2.4 Ma, respectively) from the upper part of the volcanic Tukwila Formation, which overlies and interfingers with the Tiger Mountain Formation (fig. 3).

Unit 0

Unit 0, which is questionably part of the Raging River Formation, consists of massive breccia-conglomerate. This unit is exposed only in discontinuous outcrops at elevations between 238 m (780 ft) and 251 m (840 ft) in the bed of a tributary to the Raging River in SE 1/4, sec. 4., T. 23 N., R. 7 E (fig. 2). There is approximately 5 m (change in

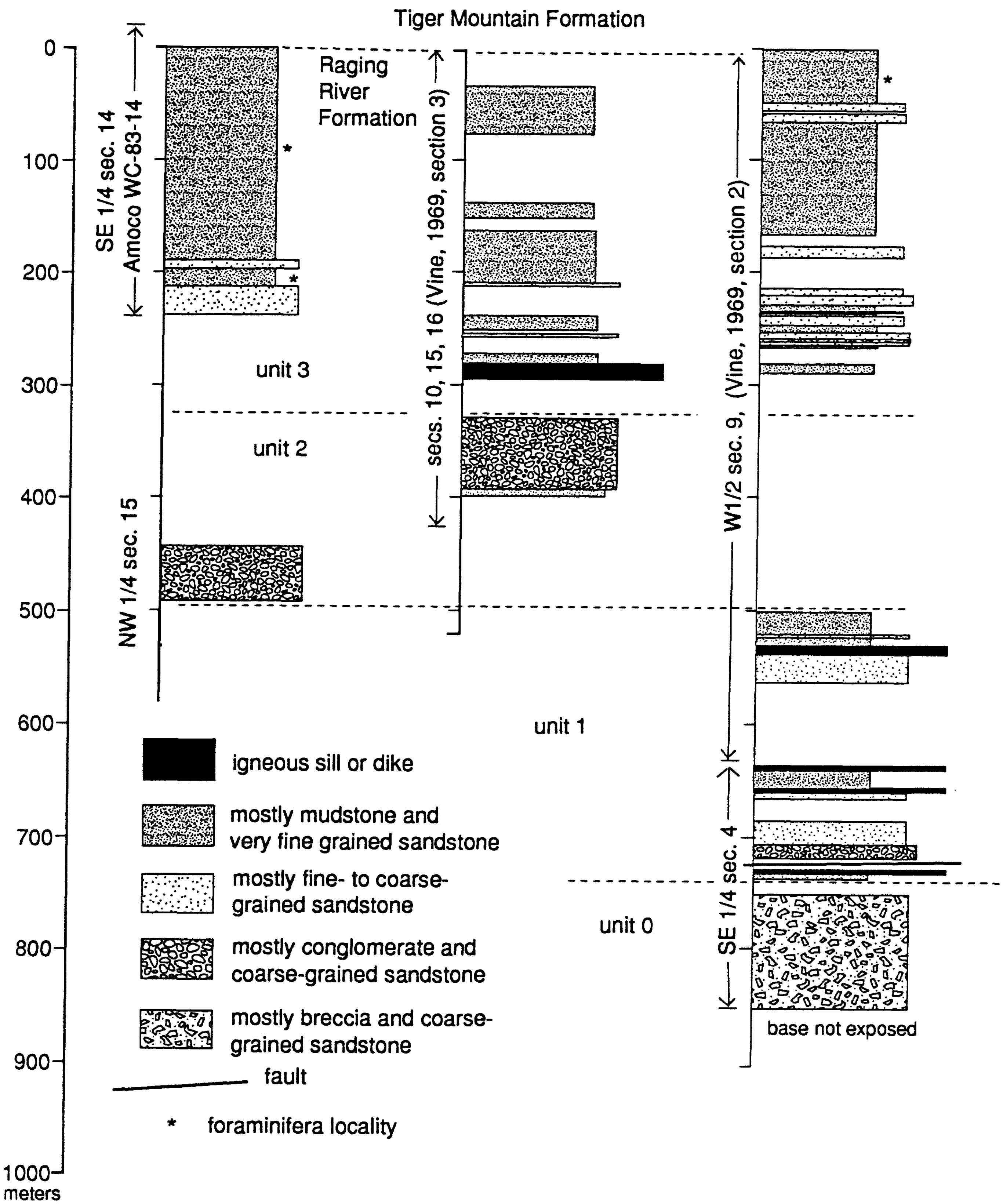


Figure 4. Schematic diagram showing composite section of the Raging River Formation. All locations are in T. 23 N., R. 7 E. Unit 0 could either represent the lowest exposed part of the Raging River formation or semi-lithified Quaternary(?) colluvium. See text for discussion.

elevation) of cover between the highest outcrops of unit 0 and the lowest outcrops of well-stratified unit 1. This is the same tributary in which Vine (1969) measured his 560-m-thick section. Vine chose not to measure or describe strata lower in the tributary (units 0 and 1 of this study) because of the effects of faulting and intrusions (see below). Because of its massive character, bedding-plane attitudes in the unit 0 breccia-conglomerate could not be determined. If it is part of the Raging River Formation and has the same attitude as that of the lowest exposures of overlying unit 1 that are clearly not affected by faulting or slumping, then unit 0 has a thickness of about 95 m. Unit 0 outcrops are resistant and underlie a 3-m-high waterfall. Boulders of unit 0 breccia-conglomerate are present near unit 0 stream outcrops but are not present at higher elevations in the stream bed.

No textural variations, fabric, or other features suggestive of primary bedding are discernible in outcrops of unit 0 that are as large as 3 m in mean dimension. Clasts are poorly sorted, angular to subrounded, and dispersed in a matrix of mud and lithic coarse-grained to granular sand. Clasts are as large as 80 cm in maximum dimension; the mean size of the ten largest clasts in an outcrop is generally 20-30 cm. Clasts are dominantly gray lithic sandstone, grayish-black mudstone, and minor chert and greenstone. All of these lithologies are found within the Raging River Formation, either as stratified rocks or as clasts in conglomerate (mainly unit 2, see below). The massive, coarse-grained, texturally immature character of this poorly exposed breccia-conglomerate indicates deposition proximal to source as colluvium or coarse-grained alluvium.

Unit 0 could either represent the lowest part of the Raging River Formation or semi-lithified Quaternary(?) colluvium. The resistant character of the unit (it underlies waterfalls and forms large subrounded boulders in the creek bed) is the strongest argument for inclusion in the Raging River Formation. Quaternary deposits (including texturally identical colluvium) are widespread on Tiger Mountain (Vine, 1969) but they are typically unconsolidated and highly weathered. The resistant, semi-lithified character of unit 0 and its local occurrence could, however, reflect early cementation by spring waters and(or) an anomalously high mud content in the rock matrix. Origin as locally derived Quaternary(?) colluvium is consistent with the clast lithologies, all of which could have been derived from local outcrops of the Raging River Formation. Alternatively, these lithologies also occur in and could have been derived from the Mesozoic melange belts (Frizzell and others, 1987) that presently crop out less than 10 km east of Tiger Mountain (fig. 1, also see "Provenance" section below). If derived from this Mesozoic source, a nearby Eocene uplift (fault-bounded?) of considerable relief would be required to account for the coarse texture of unit 0.

Although there is no conclusive evidence to distinguish between the hypotheses discussed above, I consider a Quaternary(?) colluvial origin more likely. Because of the uncertainty, I have not considered unit 0 below in the discussions that concern the Eocene paleogeography of the Tiger Mountain area and the Puget Lowland.

Unit 1

Unit 1 (fig. 4) also crops out in in the bed of the tributary to the Raging River that passes through secs. 4 and 9, T. 23 N., R. 7 E (fig. 2). In this creek, the lower part of unit 1 (from about 560 to 740 m in the column of figure 4) occurs from elevations of 256 m (840 ft) to 357 m (1170 ft) and is also below the base of the 560-m-thick section measured by Vine (1969, section 2) in this tributary. This lower interval is poorly and discontinuously exposed, intruded by dikes and (or) sills, and cut by faults that disrupt bedding-plane attitudes. As a result, the lithologies and thicknesses shown in the stratigraphic column in fig. 4 are at best approximations. The upper part of unit 1 (fig. 4) was plotted from Vine's (1969) section 2 descriptions of rocks cropping out between elevations of 357 m (1170 ft) and 396 m (1300 ft) in this creek bed. The only bedrock exposed in the creek bed in this interval (in the summer of 1991) was an igneous sill (elevation of 343 m) and a few small, poor outcrops of silty sandstone. Strata in the upper part of unit 1 also crop out in a few roadcuts and one borrow pit along a logging road in SE

1/4, sec. 9 and NW 1/4, sec. 15, T. 23 N., R 7 E. Based on map patterns, unit 1 is about 230 m thick.

Strata of unit 1 consist of interbedded sandstone, mudstone, and conglomerate. Outcrops in the creek bed at an elevation of 256 m (840 ft) consist of grayish-black, massive to flat-bedded mudstone and minor very fine-grained sandstone. Bed thickness is about 10 to 20 cm. At approximately 264 m (865 ft) in the creek bed, there are fair exposures of pebble and granule conglomerate and fine to very coarse-grained sandstone. Beds form 20- to 100-cm-thick fining-upward sequences separated by scour surfaces with as much as 20 cm of erosional relief within 100 cm of lateral exposure. The fining-upward sequences are internally massive or are characterized by crude horizontal stratification. Conglomerate pebbles are typically subrounded, moderately well sorted, less than 5 cm in diameter, and consist mainly of lithic sandstone, mudstone, and chert.

Outcrops of unit 1 in the creek bed at elevations of 274 m (900 ft), 287 m (940 ft), 293 m (960 ft), 297 m (975 ft), and 305 to 326 m (1,000 to 1,070), consist of gray, interbedded and interlaminated, very fine to medium grained sandstone and mudstone. Beds are typically structureless or are characterized by diffuse and disrupted plane lamination, less commonly hummocky bedding and wavy bedding, and possibly wave-ripple lamination. Small (< 1 cm) mudstone rip-up clasts are dispersed in a few sandstone beds. Locally strata are intensely bioturbated. Burrow forms resemble *Thalassanoides* and are typically straight to branching (at angles of 90° or 120°), horizontal to subhorizontal, 1-2 cm in diameter, as long as 10 cm, and have no obvious internal structure. Burrowed horizons are commonly tightly cemented by calcite. This interval also includes a few thin (< 10 cm) concretionary layers that contain dispersed, broken gastropod and pelecypod shell fragments.

Medium to dark gray, generally aphanitic, igneous sills or dikes intrude the unit 1 section at elevations of about 259 m (850 ft), 287 m (940 ft), and 308 m (1010 ft) in the creek bed. These igneous bodies disrupt stratification on outcrop scale and have planar to irregular margins.

Roadcut exposures are typically massive and badly weathered. The best exposures are in a borrow pit in NW 1/4, sec. 15 (fig. 2). Strata are structureless or less commonly have poorly preserved parallel stratification highlighted by thin laminations of plant debris. Isolated plant fragments are present on many bedding planes and coalified logs as large as 13 cm in length and 5 cm in diameter are also present. Strata are extensively bioturbated. The most common trace fossils are vertical *Skolithos* burrows that are as long as 18 cm and have typical diameters of 1-2 cm. Gastropod (mainly *Turritella*) and pelecypod shells and shell fragments are dispersed in many beds.

The more fine-grained, extensively burrowed, fossiliferous strata of the upper part of unit 1 are inferred to be of shallow marine origin on the basis of stratification styles, extensive bioturbation, and fossil content. The limited exposures of the graded conglomerate-sandstone facies in the lower part of unit 1 are not sufficient for reliable interpretation. Based on their stratigraphic association with overlying shallow-marine rocks, they might represent gravity-flow deposits of a shallow-marine fan delta (Nemec and Steel, 1988). Alternatively, the lack of evidence of marine reworking and the scale of erosion surfaces between units is consistent with a fluvial origin, as inferred for conglomerate of unit 2.

Unit 2

Unit 2 (fig. 4) consists of interbedded conglomerate, sandstone, and mudstone. At the base of his section 3 (secs. 10, 15, and 16, T. 23 N., R. 7 E ; fig. 2), Vine (1969) described about 60 m of mainly medium-grained to conglomeratic sandstone in the bed of a tributary to the Raging River that are here considered the upper part of unit 2. Unit 2 strata also form fair outcrops along the logging road in NW 1/4 sec. 15, about 750 m south of Vine's section 3 (fig. 2). A 49-m-thick section of these roadcut outcrops (fig. 5) projects

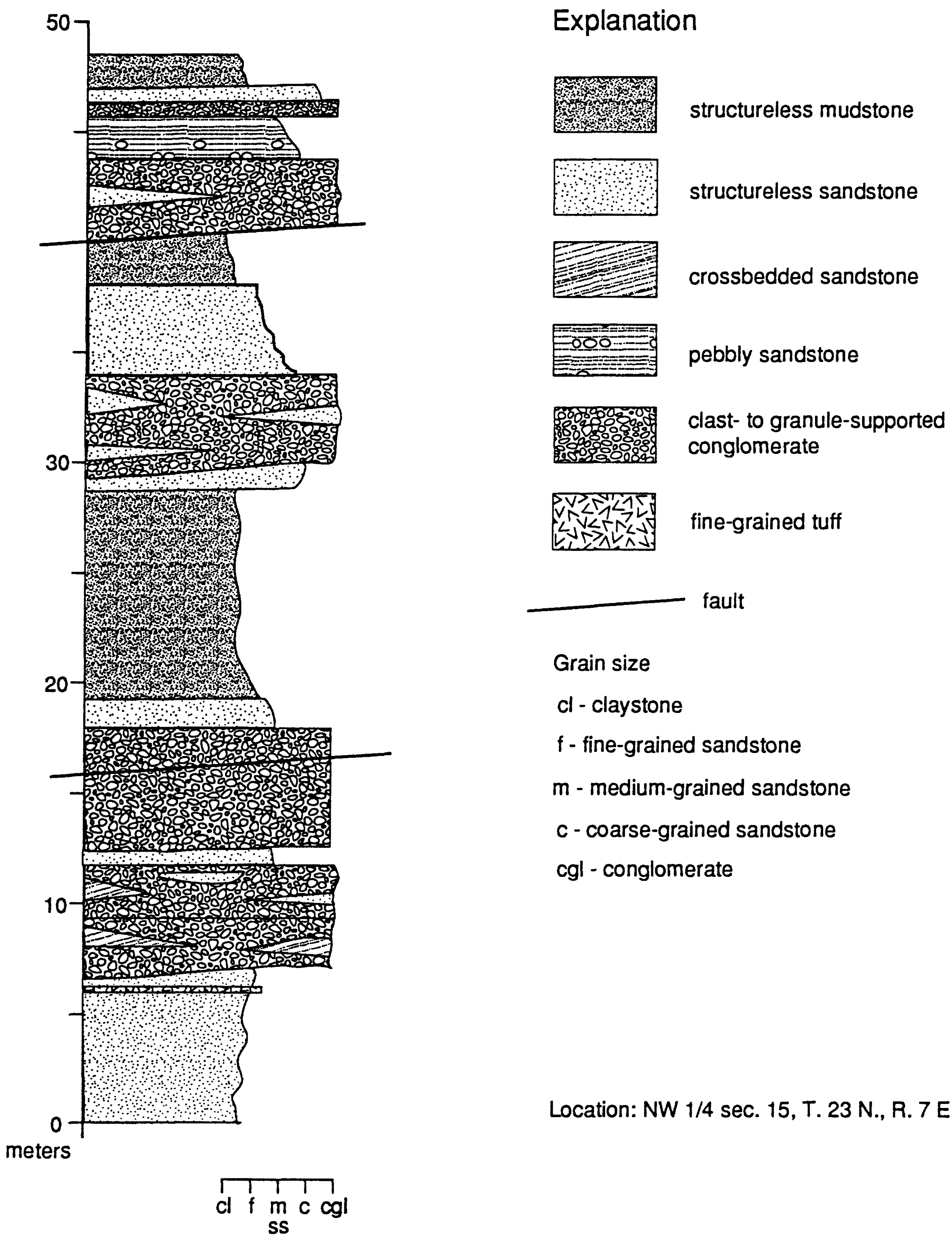


Figure 5. Measured section of the lower part of unit 2, described in outcrops along logging road in NW 1/4 sec. 15, T. 23 N., R. 7 E.

onto the line of generalized cross section used by Vine (1969) at a slightly lower stratigraphic level than the tributary exposures. Using the base of these roadcuts as the base of unit 2 and the top of the conglomeratic interval in the tributary section as its top, unit 2 is approximately 185 m thick. The isolated northern exposures of the Raging River Formation (fig. 2; E 1/2 sec. 32, T. 24 N., R. 7 E.) are included in unit 2 based on similarly distinct lithologies and sedimentary structures, however given the poor exposures, stratigraphic continuity between the two outcrop areas cannot be positively demonstrated. Strata at the same stratigraphic level as unit 2 (measuring down from the contact with the overlying Tiger Mountain Formation) are covered in Vine's (1969) section 2 (fig. 2).

The stream-bed outcrops of unit 2 measured by Vine (1969, section 3) are now poorly exposed. They include gray to yellowish-brown, poorly sorted, massive to crudely stratified conglomerate and low-angle bedded sandstone. Conglomerate beds are as thick as several meters. Clasts include abundant chert and aphanitic volcanic rock. Plant fragments are common. The maximum clast size in beds is typically about 6 cm. Low-angle bedded sandstone outcrops at an elevation of 325 m (1065 ft) in the creek bed and are inferred to represent the uppermost part of unit 2. These outcrops contains scattered organic debris, mudstone rip-up clasts, and locally contain abundant vertical *Skolithos?* burrows.

The 49-m-thick measured section of unit 2 (fig. 5) includes approximately 42 percent silty mudstone, 38 percent conglomerate, and 20 percent sandstone. Conglomerate beds are 60 to 545 cm thick, have low-angle erosional bases, and generally fine upward. Internally beds are poorly to moderately sorted, structureless, or exhibit crude low angle stratification, including scour surfaces. Pebbles are typically subrounded, commonly imbricate, and are clast-supported or dispersed in granular sandstone. The maximum size of pebbles in conglomerate beds ranges from 5 to 8 cm. Plant fragments are common. Several conglomerate beds include lenses of massive to crossbedded coarse-grained sandstone that are as thick as 30 cm and more than 100 cm wide (fig. 5). Restored paleocurrent directions determined from pebble imbrications, channel axes, and crossbeds indicate sediment transport to the west (fig. 6).

Sandstone and silty mudstone beds in the measured section are typically poorly exposed, structureless, contain dispersed plant fragments, and weather gray to olive green. These beds have common fracture planes lined with clay skins, a characteristic typical of paleosols (Retallack, 1988). A 20-cm-thick bed of fine-grained, grayish-orange, lithic tuff occurs in the lowest mudstone (fig. 5). The tuff bed includes contains scattered plant fragments and small (length < 1 cm, width < 1mm) root structures.

The isolated northern outcrops of unit 2 along Interstate 90 is intruded by several dikes and is relatively indurated. These strata consist of gray pebble conglomerate and interbedded sandstone. Conglomerate beds are as thick as a few meters and are bounded by low-angle (< 10°) erosional surfaces. Beds are internally structureless or crudely stratified, and uncommonly graded. Conglomerate clasts are subrounded to rounded, poorly to moderately sorted, generally dispersed in a granular matrix, and uncommonly imbricate. The mean size of the largest clasts in a bed is typically about 12 cm. Several large blocks of conglomerate were collected and slabbed for pebble counting. A count of 1180 clasts (fig. 7) indicates that lithic sandstone, chert, and aphanitic green or black volcanic rocks are the most common clast types.

Unit 2 strata are interpreted as mainly alluvial deposits. Poorly to moderately sorted, imbricate conglomerate and conglomeratic sandstone generally forms thick bodies overlying scour surfaces (fig. 5) and was deposited as coarse bedload in fluvial channels. Abundant internal scours and low-angle stratification suggest deposition occurred mainly on low-relief gravel bars characteristic of braided rivers. Uncommon crossbedded sandstone formed by migration of dunes or sand waves. Massive greenish-gray mudstones with scattered plant fragments and evidence of paleosol formation are characteristic of floodplain deposits found in Eocene alluvial sequences elsewhere in

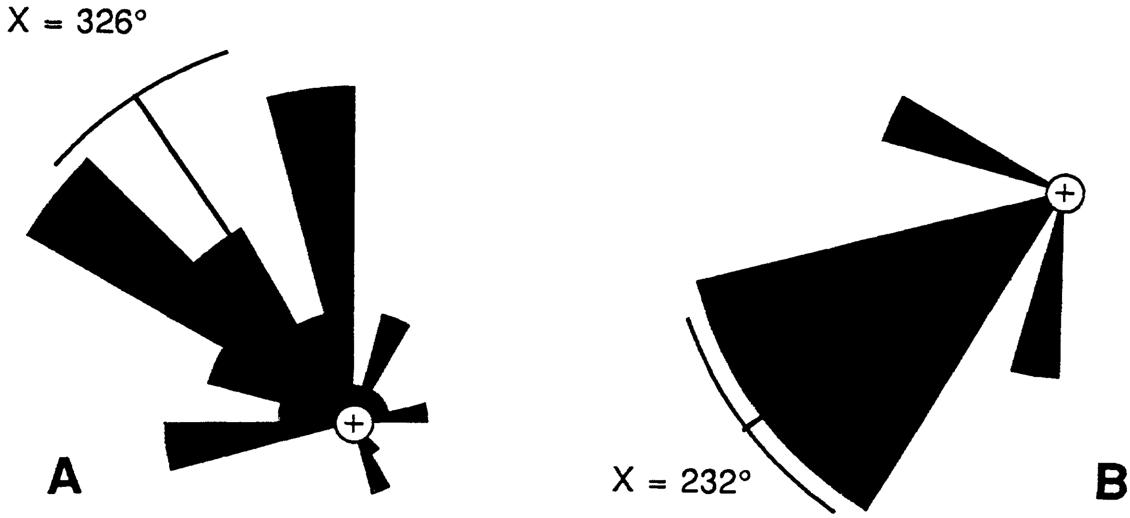


Figure 6. Rose diagrams showing restored paleocurrent data with vector mean and confidence angle from unit 2 based on (A) pebble imbrications (51 measurements), and (B) crossbeds (4 measurements) and channel axes (4 measurements). All data collected from the measured section of Figure 5 except 3 pebble imbrications from the isolated northern exposures in SE 1/4 sec. 32, T. 23 N., R 7 E (fig. 1).

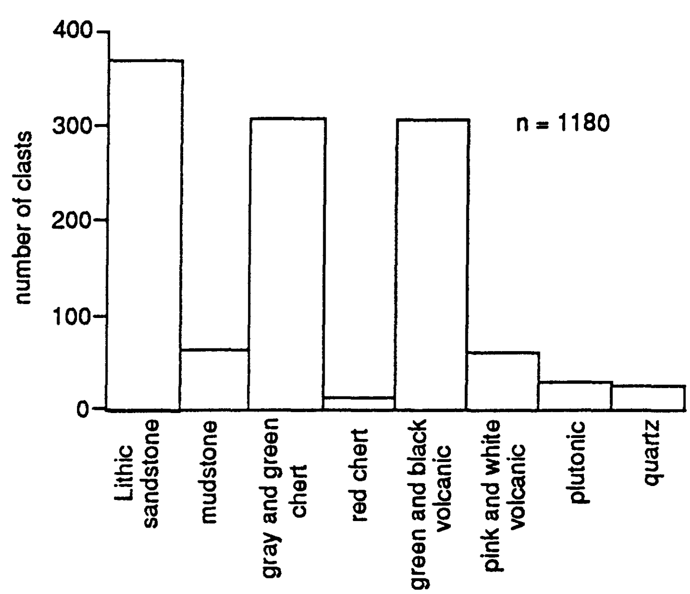


Figure 7. Histogram showing lithologies in conglomerate clasts from the inferred unit 2 conglomerate in SE 1/4 sec. 32, T. 24 N., R 7 E.

western Washington (for example, Johnson, 1984a), and are notably different from the medium to-dark gray, commonly bioturbated mudstone of clearly marine origin in overlying unit 3. The bioturbated sandstone that occurs at the top of unit 2 (see above) is probably shallow marine in origin and represents the transition to the marine rocks of unit 3.

Unit 3

Unit 3 consists of gray silty mudstone and lesser sandstone. Vine (1969) measured two partial stratigraphic sections through unit 3 (figs. 2, 4). The quality of exposure is now so poor along each creek-bed traverse that only a few small outcrops in each could be described. Along the traverse for Vine's (1969) section 2 (fig. 2), small outcrops between the elevations of 494 m (1620 ft) and 537 m (1760 ft) consist of gray, massive to parallel stratified silty mudstone and very fine to fine grained sandstone Along the traverse for Vine's (1969) section 3 (fig. 2), an igneous sill that crops out at an elevation of 323 m (1090 ft) represents the lowest unit 3 exposure (measured as 50 ft thick by Vine). There are poor discontinuous outcrops above this sill in the creek bed up to an elevation of about 360 m (1180 ft), after which outcrops largely disappear. These outcrops consist of parallel, wavy, and hummocky bedded very fine to fine grained sandstone. Hummocks have heights of about 3 cm and wavelengths of 20-25 cm. Beds are locally bioturbated.

The best outcrops of unit 4 occur in a large borrow pit at the end of a spur off the Kerriston-Echo Lake Road on the north flank of Taylor Mountain (SE 1/4 of SW 1/4, sec. 14., T. 23 N., R. 7 E.). About 10 m of section are exposed in this pit, consisting of medium to dark gray, very fine to medium-grained sandstone and brownish gray to dark gray silty mudstone. Sandstone is parallel bedded and less commonly ripple laminated, bioturbated, and contains common pelecypod and gastropod (*Turritella*) shell fragments. Burrows are most commonly horizontal to subhorizontal.and include circular tubes (diameter ~ 1 cm and length ≤ 5 cm) and 2-3 cm long meandering forms. Vertical and inclined burrows are much less common. Mudstone is typically massive and is best exposed adjacent to a dike on the east side of the borrow pit.

The best opportunity to study the sedimentology of unit 3 is in the core collected from the AMOCO WC-83-14 borehole. The borehole was drilled to a depth of 534 m (1752 ft) and cored nearly continuously from 150 ft to total depth (fig. 8). The mean dip of beds encountered by the borehole was about 50°, thus the amount of section represented is only about 310 m. Of this section, the lower 234 m are assigned to the upper part of unit 3 of the Raging River Formation, and the upper 76 m to the overlying Tiger Mountain Formation.

Strata in the WC-83-14 core consist mainly of medium to dark-gray silty or sandy mudstone and light to medium gray very fine to medium grained sandstone. The sandstone:mudstone ratio is approximately 1:4. Mudstone is typically massive but markedly fissile horizons are also present. Primary parallel lamination is rare. The massive character probably reflects at least partial deposition by suspension and extensive bioturbation. Trace fossils are abundant in many horizons of silty and sandy mudstone. *Helminthoida* sp. traces occur between depths of about 338 and 213 m (1109 and 700 ft), and *Teichichnus*, *Chondrites*, *Ophiomorpha*, and other trace fossils occur at several horizons. Thick intervals of mudstone uncommonly include thin (< 10 cm) interbeds of very fine to medium grained sandstone. Where not extensively bioturbated, these beds are typically parallel laminated, and have sharp bases marked by load casts and rare rip-up clasts. Rare gastropod (*Turritella*) and pelecypod shells and shell fragments occur in the mudstone at depths of 431, 419, 288, and 250 m (1415, 1374, 944, and 819 ft), and shell fragments occur at several intervals. Shells and shell fragments have variable orientations and were clearly redeposited.

Weldon Rau (written commun., 1991) identified sparse foraminiferal faunas from two intervals in the well and suggested that, although small, they are reasonably diagnostic of an early Narizian age. In a composite sample between 516.2 and 518.3 m (1693-1700 ft), Rau reported *Plectofrondicularia packardi packardi* Cushman and Schenck, *Pseudoglandulina* cf. *P. pyrula* d'Orbigny, and *Dentalina* sp. Based primarily on the presence of *Plectofrondicularia* and comparison to the biofacies outlined by Ingle (1980) for California Cenozoic paleobathymetry, Rau suggested a probable middle bathyal depositional environment for this assemblage. D. R. McKeel (oral commun., 1992), however, suggested that *Plectofrondicularia* is more characteristic of an outer shelf environment, which is more consistent with sedimentologic observations (see below) for the lower part of unit 3. In a composite sample from the interval 382.6 and 385.1 m (1255-1263 ft), Rau reported *Dentalina* sp., *Gyroidina* sp., *Quinqueloculira* cf. *Q. Triangularis* d'Orbigny, *Amphimorphina* cf. *A. californica* Cushman and McMasters, and ?*Pseudoglandulina* sp. Rau (in Vine, 1969, p. 16) reported a more extensive foraminifera species list for the upper part of unit 3 from a locality in Vine's section 2 (fig. 2), about 49 m below the base of the Tiger Mountain Formation (equivalent to a depth of about 775 ft in the WC-83-14 borehole). Rau (written commun., 1992) suggested a middle bathyal depositional environment for this assemblage, which is consistent with the sedimentologic interpretations described below.

Sandstone-rich strata in the WC-83-14 core are most abundant at depths of 534-502, 468-459, 283-279, and 276-254 m (1752-1648, 1535-1504, 927-916, and 906-835 ft). Strata are typically fine to medium-grained and well sorted. Beds in the lower two sandstone-rich horizons are structureless, parallel laminated, or extensively burrowed with relict parallel lamination. Sandstone beds with inclined laminations (recognized by intersections and truncations at angles as large as 30°) occurs at depths of about 511 m (1676 ft), 504 m (1654 ft), and 465 m (1525 ft). Rare wave?-ripple-lamination (ripple height < 2 cm) is present at 507 m (1663 ft). Chert-pebble conglomerate (maximum clast diameter < 2 cm) forms a 14-cm-thick interbed at a depth of 465 m (1524 ft). In the upper two sandstone-rich horizons, beds are similarly massive to parallel laminated. Massive beds are characterized by subtle vertical grain size-changes suggesting amalgamation on internal erosion surfaces. Parallel-laminated beds are commonly bounded by or include low-relief (< 1 cm) erosion surfaces overlain by mudstone rip-up clasts. Grading is rare, but a few thin (< 20 cm) beds fine upward. Convolute lamination is present in a few beds.

Unit 3 represents a transition from shelf to slope deposition. Hummocky bedded sandstone in creek-bed outcrops of the lower part of unit 3 indicate deposition above wave base in a shallow marine or shelf setting. The lower two sandstone-rich horizons in the WC-83-14 core include low-angle laminated and ripple-laminated sandstone that probably also reflect wave reworking. The dominance in overlying rocks of structureless silty mudstone suggests a slope depositional environment (for example, Mutti and Ricci Lucchi, 1972), consistent with the middle-bathyal paleobathymetry (500-2,000 m; Ingle, 1980) inferred from the foraminifera. The upper two sandstone-rich horizons in the WC-83-14 core were probably deposited by turbidity currents in channels cut into the slope. Massive and parallel-laminated facies represent the Bouma A and B turbidite divisions, respectively.

Lower Tiger Mountain Formation

Strata of the lower part of the Tiger Mountain Formation were examined only in core from the AMOCO WC-83-14 borehole (fig. 8). Approximately 118 m (386 ft) of the Tiger Mountain were cored, representing (correcting for structural dip) about 75 m of section. The contact between the Tiger Mountain Formation and the underlying Raging River Formation is characterized by an abrupt increase in grain size from dominantly mudstone to mainly sandstone, and by a marked change in the color of sandstone from light or medium gray to yellowish gray. The contact occurs in a gouge zone between 164.3 and 163.9 m (539.0 and 537.5 ft) in the core. Although this gouge zone does not appear to be a significant fault, structural displacement resulting in stratigraphic offset on this feature provides an explanation for the very abrupt facies transition at the contact, and is considered possible.

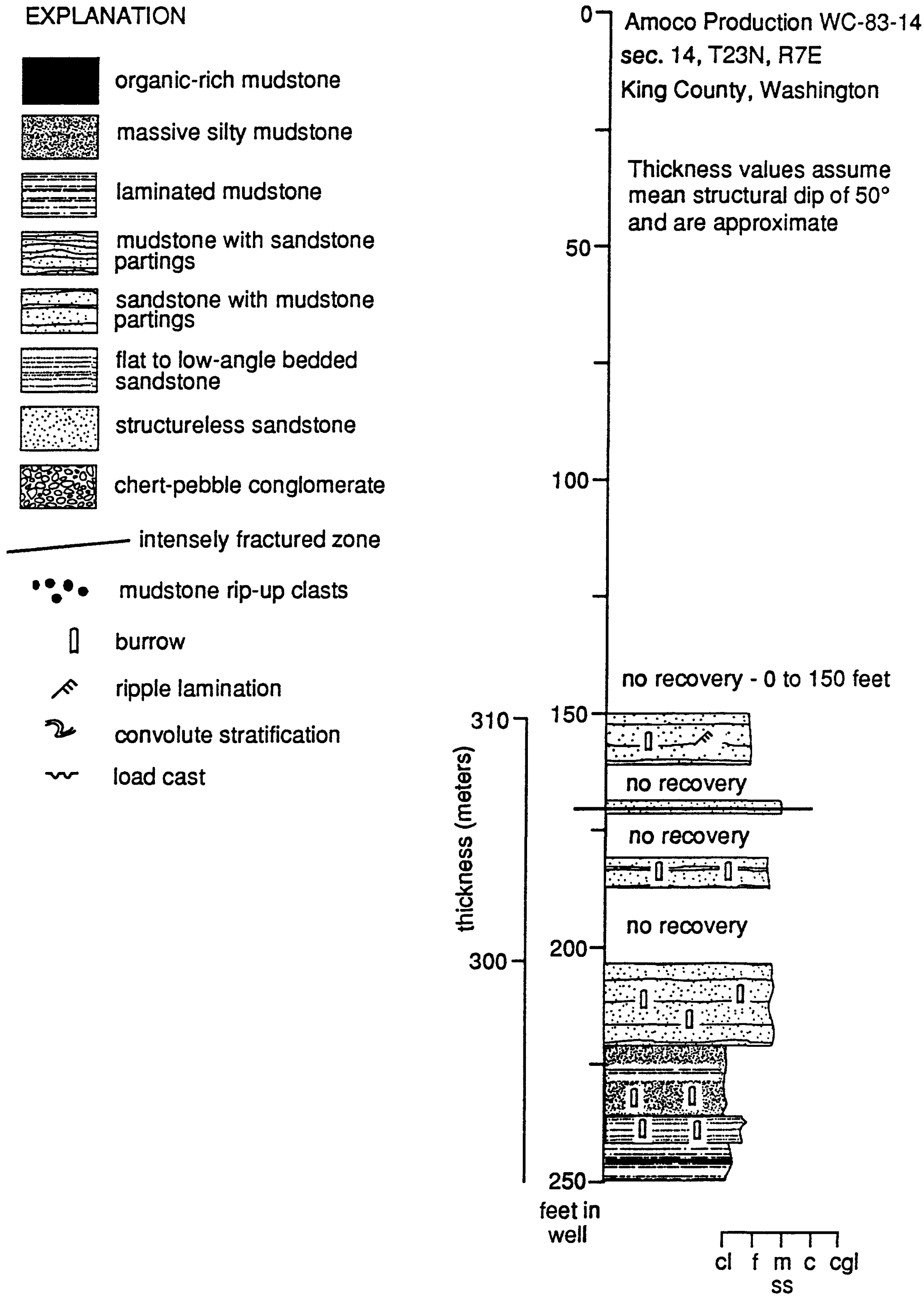


Figure 8. Sedimentologic log of core from the AMOCO WC-83-14 borehole, SE 1/4 sec. 14., T. 23 N., R. 7 E. The mean dip of bedding planes encountered by the borehole was about 50°, thus the thickness of the section (shown in meters) penetrated is significantly less than total depth.

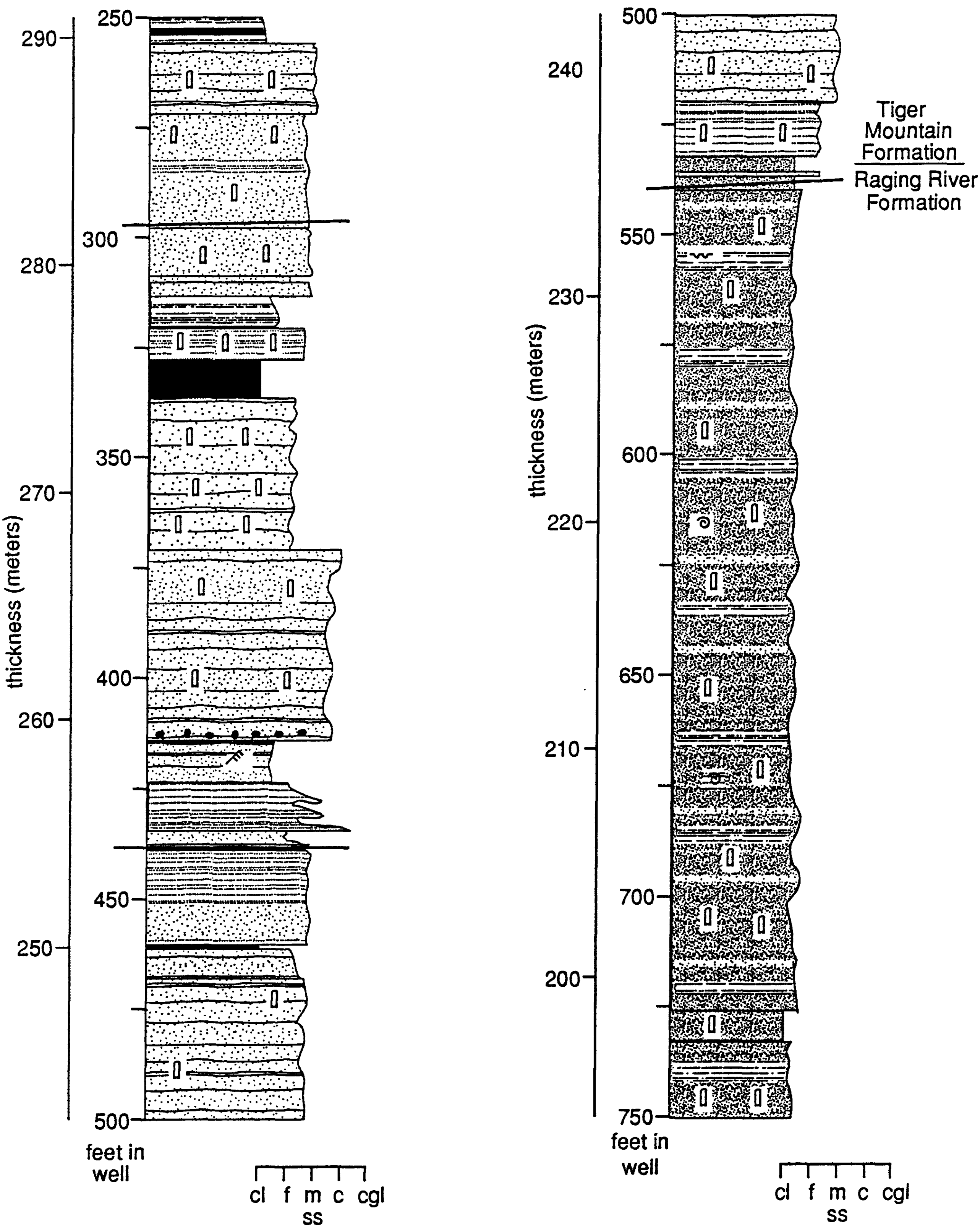


Figure 8 (continued).

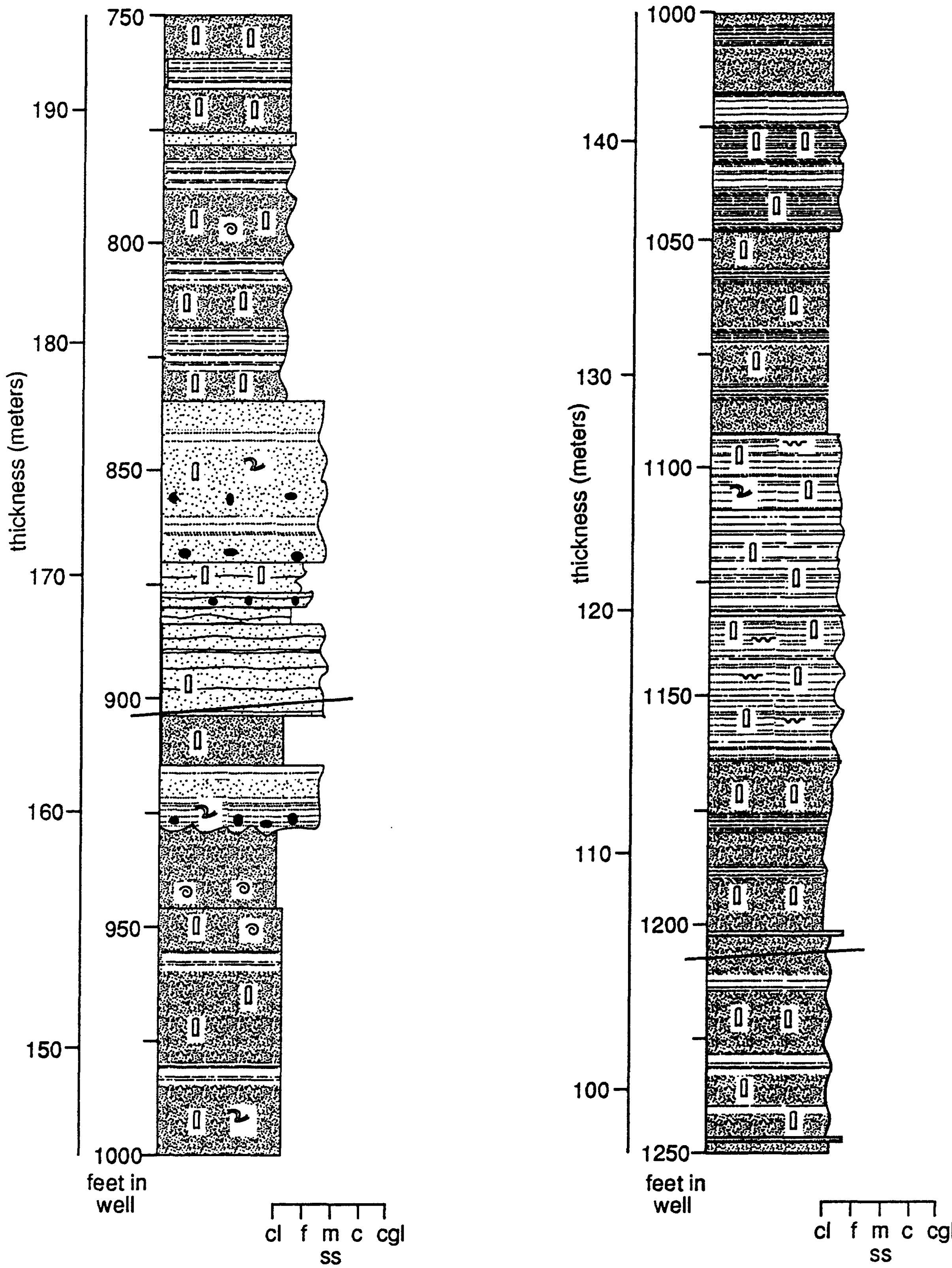


Figure 8 (continued).

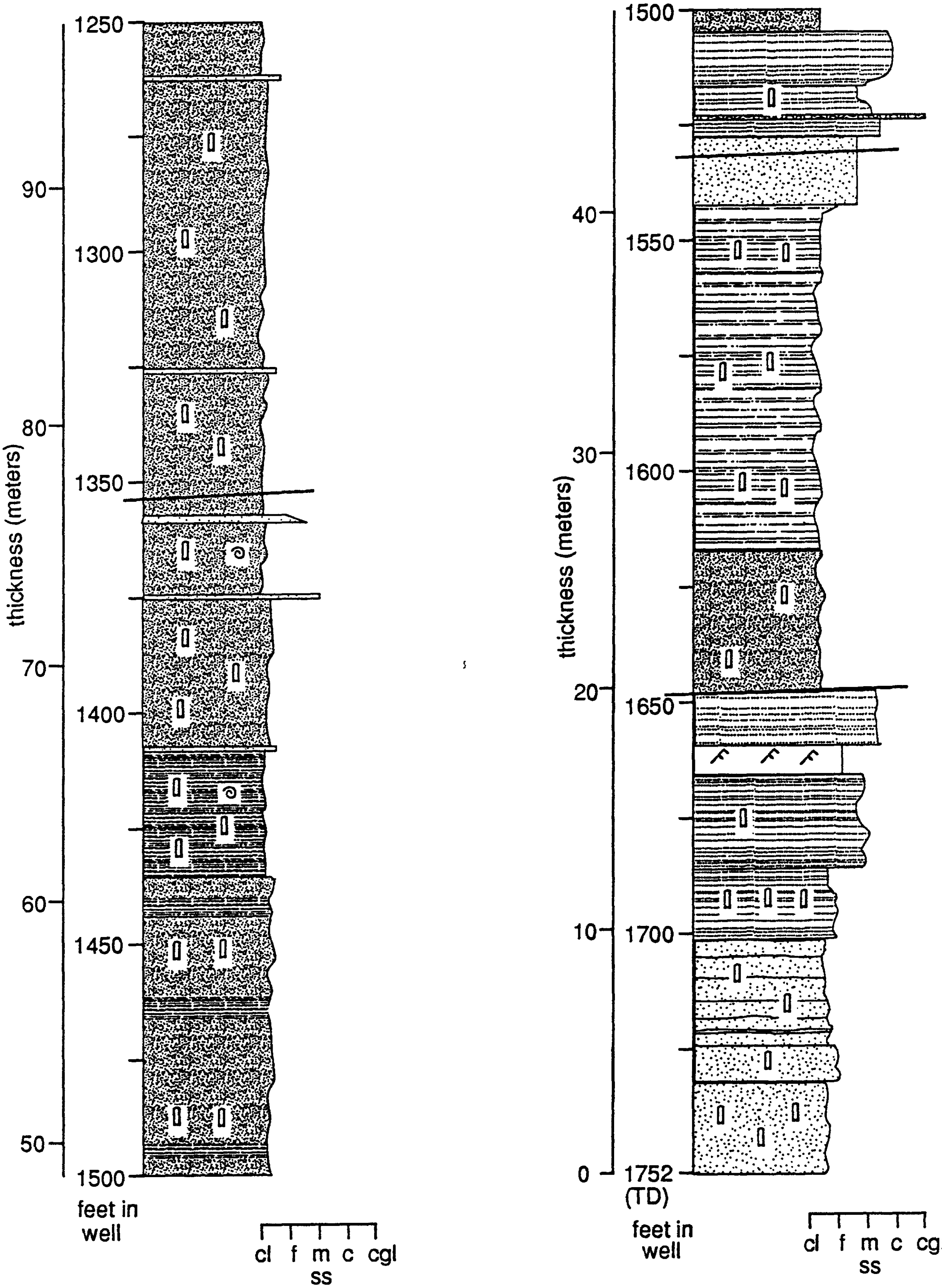


Figure 8 (continued).

The lower part of the Tiger Mountain Formation consists of interbedded yellowish-gray sandstone and medium-gray to grayish-black silty mudstone. The sandstone:mudstone ratio is about 5-6:1. Sandstone is typically moderately sorted, fine to medium grained, and forms beds several meters thick. Primary stratification is mainly parallel lamination; low-angle lamination and wave-ripple lamination are uncommon. Many sandstone beds overlie erosion surfaces lined with small mudstone rip-up clasts. Upper bed contacts are both graded and abrupt. An anomalous interval from 132.5 to 129.2 m (434.5-423.7 ft) consists of ten thin graded beds that fine upward from massive coarse-grained or granular sandstone to commonly parallel-laminated, fine-grained sandstone. More subtle vertical grain-size variations and inversions are common within many thicker sandstone beds and similarly indicate episodic deposition. Trace fossils, mainly vertical to horizontal lined burrows (*Skolithos* and *Scoyenia*), are present in most sandstone beds and range from rare to abundant. Where abundant, primary stratification is poorly preserved. Silty mudstone and carbonaceous mudstone lamina commonly form thin (< 1 cm) layers within thick sandstone beds. Fossil plant fragments are common in carbonaceous mudstone partings.

Silty mudstone in the upper part of the Tiger Mountain Formation ranges from parallel laminated and fissile to massive. Parallel-laminated beds commonly include very thin (< 1 cm) lenticular layers of very fine grained sandstone. These sandstone layers were probably also present in massive beds, but have been mixed with bounding fine-grained sediment by bioturbation. A ~1.5-m-thick bed of medium to dark gray organic-rich mudstone occurs between 102.4 m and 100.2 m (336 and 328.5 ft).

The fine- to medium-grained sandstone of the lower part of the Tiger Mountain Formation represents deposition in a marine shelf environment, possibly in a prodelta setting. Parallel and less common low-angle and wave-ripple laminated beds must in part reflect deposition by storm processes. These strata might be hummocky bedded, but the limited lateral perspective provided by the core and the extensive sediment mixing by bioturbation make this determination difficult. The more coarse-grained, graded beds formed as turbidites (Bouma A and in some cases B divisions) that were probably transported by density underflows at a delta front. Deposition of these turbidites below storm-wave base by storm-generated currents (as in Hamblin and Walker, 1979) is unlikely given their coarse grain size relative to adjacent strata. Preservation of turbidite features probably mainly reflects rapid removal from the zone of bioturbation by burial. Given the evidence for some turbidite deposition, it seems likely that many other massive bioturbated sandstone beds also had a turbidite origin. The variable amount of bioturbation in sandstone beds indicates variable sediment accumulation rates. Thick intervals of bioturbated sand indicate slow sediment accumulation whereas the presence of graded sandstone beds, sandstone beds with only moderate sorting, and abundant mudstone partings indicates minimal winnowing and relatively rapid accumulation. This inferred variation in sediment supply is consistent with a position in front of a laterally migrating delta.

A prodelta shelf setting for the lower part of the Tiger Mountain Formation is consistent with its stratigraphic position. As discussed above, underlying rocks near the top of the Raging River Formation (unit 3) were deposited at bathyal depths. Strata higher in the Tiger Mountain Formation described by Vine (1969) contain large-scale crossbedded sandstone and pebble conglomerate, siltstone with abundant plant fragments, and coal, clearly indicating nonmarine deposition.

SANDSTONE PETROGRAPHY

Vine (1962, 1969) provided a brief description of the sandstone petrology of the Raging River Formation. He stated that samples are unsorted and that it is commonly difficult to distinguish clast and chloritic matrix. Vine also noted that plagioclase is typically abundant, that quartz and potassium feldspar are rare or absent in some samples, and that proportions of quartz, chert, mafic minerals, and opaque minerals are variable. For this study, fourteen sandstone samples from units 2, 3, and 4 of the Raging River Formation and six samples from the overlying lower Tiger Mountain Formation were examined and point counted (Table 1, Appendix). Sandstone compositions were then plotted on ternary provenance diagrams (figs. 9, 10) after Dickinson (1985). Results are described below.

Unit 1

Five moderately sorted, medium- to coarse-grained sandstone samples of unit 1 were examined petrographically. Grains are typically moderately sorted and subrounded. These sandstones are are classified as lithic arenites (Dott, 1964). Monocrystalline quartz and volcanic lithic fragments are the most common grain types, but plagioclase feldspar (albite based on optical determination), sedimentary lithic fragments, polycrystalline quartz, and chert grains are also present in significant amounts (Table 1; Appendix). At least some of the albite in this unit and overlying units no doubt may result from alteration of calcic plagioclase. Potassium feldspar is very rare. Volcanic lithic fragments have lathwork to microlitic textures and less common felsitic textures, and commonly include chlorite, epidote, and other low-grade metamorphic minerals. Sedimentary lithic fragments range from microgranular quartzite grains to matrix-rich siltstone. Polycrystalline quartz grains are typically equigranular and nonfoliated. Non-framework grains include epidote, chlorite, hornblende, pyroxene, and opaque mafic minerals. Bent lithic fragments, calcite cement, and clay pseudomatrix (Dickinson, 1970) have resulted in the loss of all primary porosity.

On ternary provenance diagrams (Dickinson, 1985; fig. 9), the mean of unit 1 sandstones plots in the more "oceanic" portion of the recycled orogen field on a QFL diagram, in the more chert-rich portion of the recycled orogen field on a QmFLt diagram, and in a mixed provenance field on a QpLvLs diagram,

Unit 2

Only two sandstones were examined from conglomerate-rich unit 2. These samples are also lithic arenites (Dott, 1964) and consist of poorly to moderately sorted, medium-grained sandstone (Table 1, Appendix). The samples were collected from localities about 5 km apart (SJ-91-32 from the east flank of Tiger Mountain; SJ-92-200 from the north flank of Tiger Mountain) and have variable compositions.

Sample SJ-91-32 is from the upper part of unit 2 contains more than 50 percent volcanic lithic fragments, which have mainly lathwork and microlitic textures. Plagioclase (albite based on optical determinations) is abundant and ranges from fresh to highly altered. Potassium feldspar is absent. Monocrystalline quartz forms about 10 percent of the rock; polycrystalline quartz is rare and chert is absent.

Sample SJ-91-200 contains about 25 percent volcanic lithic fragments and 23 percent sedimentary lithic fragments. Volcanic lithic fragments have lathwork, microlitic, and felsitic textures. Sedimentary lithic fragments range from quartzite to matrix-rich siltstone. Polycrystalline quartz (including chert) and monocrystalline quartz form about 13 and 16 percent of the rock, respectively. Plagioclase feldspar (about 20 percent) is albite (based on optical determination) and variably altered to clays; potassium feldspar is absent. Primary porosity in both unit 2 samples has been completely filled by bent lithic fragments, clay pseudomatrix (Dickinson, 1970), and minor calcite cement.

The two unit 2 samples plot in the magmatic arc field on both QFL and QmFLt ternary provenance diagrams (Dickinson, 1985; fig. 9). The two samples plot at the two extremes of the arc orogen field on a QpLvLs diagram. The compositional variation between the two unit 2 samples could reflect (1) different local source terranes for sediments deposited 5 km apart at the same approximate stratigraphic level, (2) sampling

Table 1. Composition of sandstone of the Raging River Formation and lower Tiger Mountain Formation

Stratigraphic unit	unit 1, RRF		unit 2, RRF		unit 3, RRF		lower Tiger Mtn. Formation	
	X	SD	X	SD	X	SD	X	SD
Monocrystalline quartz	25.8	10.7	11.7	1.8	14.1	13.1	27.5	2.1
Polycrystalline quartz	9.7	2.3	5.1	6.1	2.5	1.8	3.4	1.5
Chert	4.9	1.3	3.4	4.8	0.2	0.5	2.8	1.8
Plagioclase feldspar	10.9	7.3	26.1	9.1	30.9	18.5	29.0	5.4
Potassium feldspar	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.2
Sedimentary lithic	10.4	2.6	11.6	15.6	1.3	1.6	7.7	1.9
Volcanic lithic	26.8	3.1	38.7	18.9	41.5	8.2	22.0	6.0
Metamorphic lithic	0.8	0.9	0.4	0.6	0.8	1.2	1.2	1.1
Mica	0.7	0.5	1.0	0.9	1.3	1.6	2.3	1.4
Accessories	2.7	2.1	0.3	0.0	2.3	2.8	0.3	0.3
Matrix and cement	7.4	2.3	2.0	1.7	5.3	4.6	4.0	1.6
Number of samples	5		2		7		6	
Plagioclase/total feldspar	1.00	0.01	1.0	0.0	1.0	0.0	1.0	0.01
QFL	45,12,42		21,27,52		19,34,48		36,31,34	
QmFLt	29,12,59		12,27,61		16,34,50		29,31,40	
QmPK	70,30,0		32,68,0		28,72,0		51,49,0	
QpLvLs	28,52,20		13,69,18		7,87,6		15,62,25	

Notes: Percentage of grain types (not normalized) is presented as a mean (X) and standard deviation (SD). Statistical parameters calculated after Dickinson (1985). Percentages based on point counts of more than 300 framework grains (quartz, feldspar, lithic fragments) per thin section or grain mount using the "Gazzi-Dickinson" method (Ingersoll and others, 1984). Raw petrographic data used in constructing this table is presented in the Appendix, table 2. Units 2, 3, and 4 of the Raging River Formation (RRF) are informal, following usage in this text.

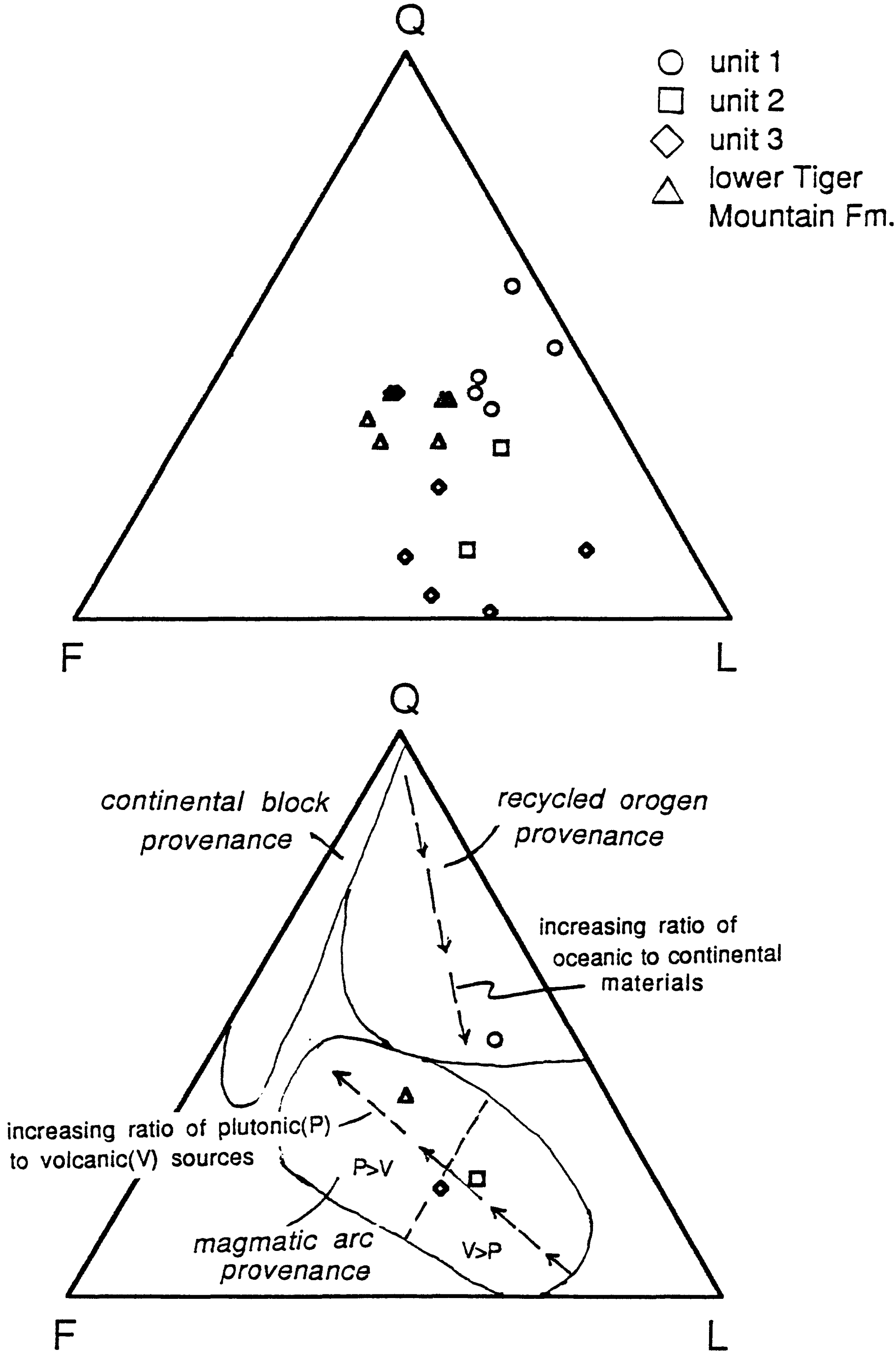


Figure 9. Ternary provenance diagrams showing range (upper diagrams) and mean (lower diagrams) of (A) QFL, (B) QmFLt, (C) QmPK, and (D) QpLvLs parameters for units 2, 3, and 4 of the Raging River Formation and the lower part of the Tiger Mountain Formation. Sandstone compositional data are summarized in Table 1. Raw petrographic data are presented in the Appendix. Provenance fields on the diagrams are from Dickinson (1985).

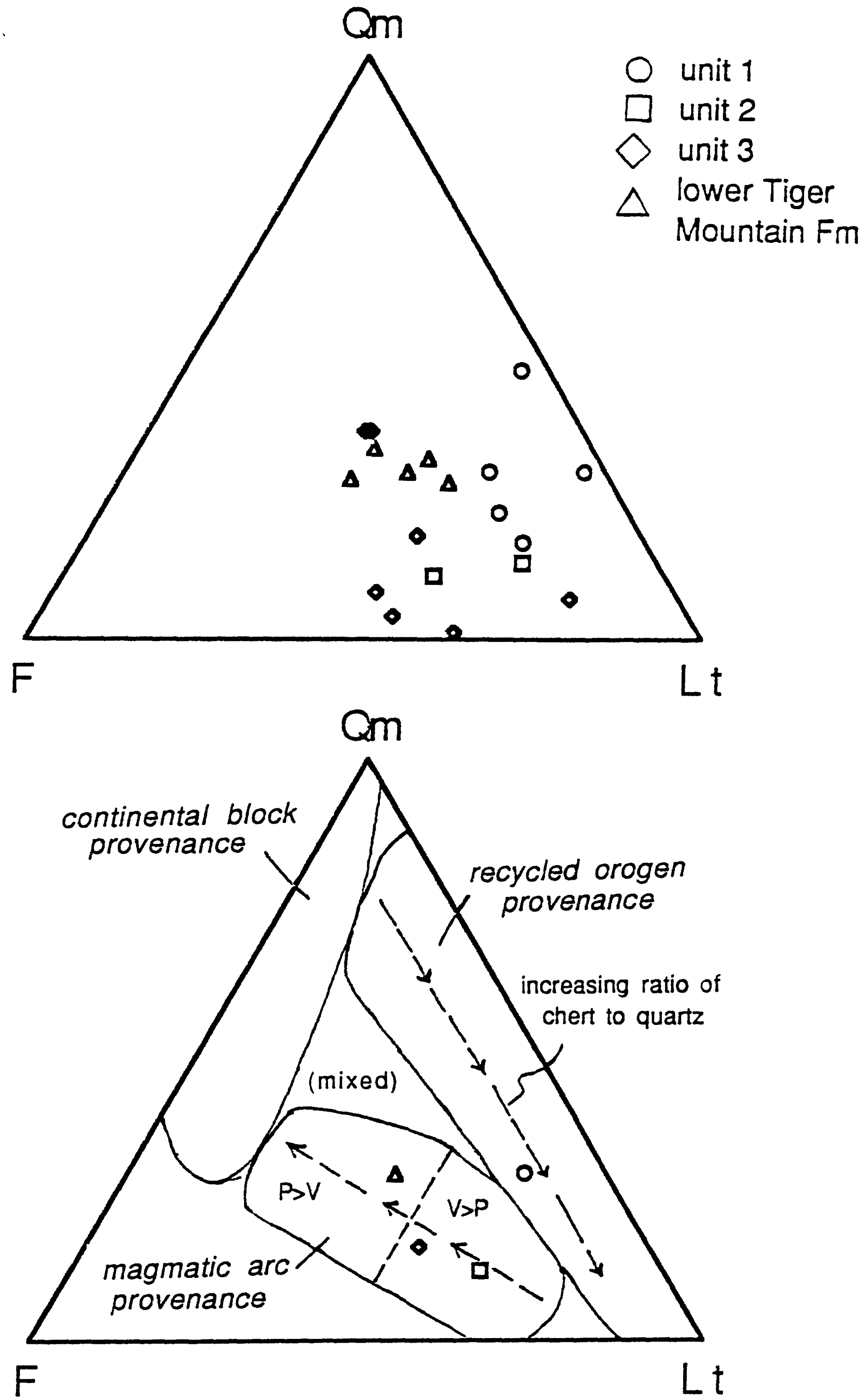
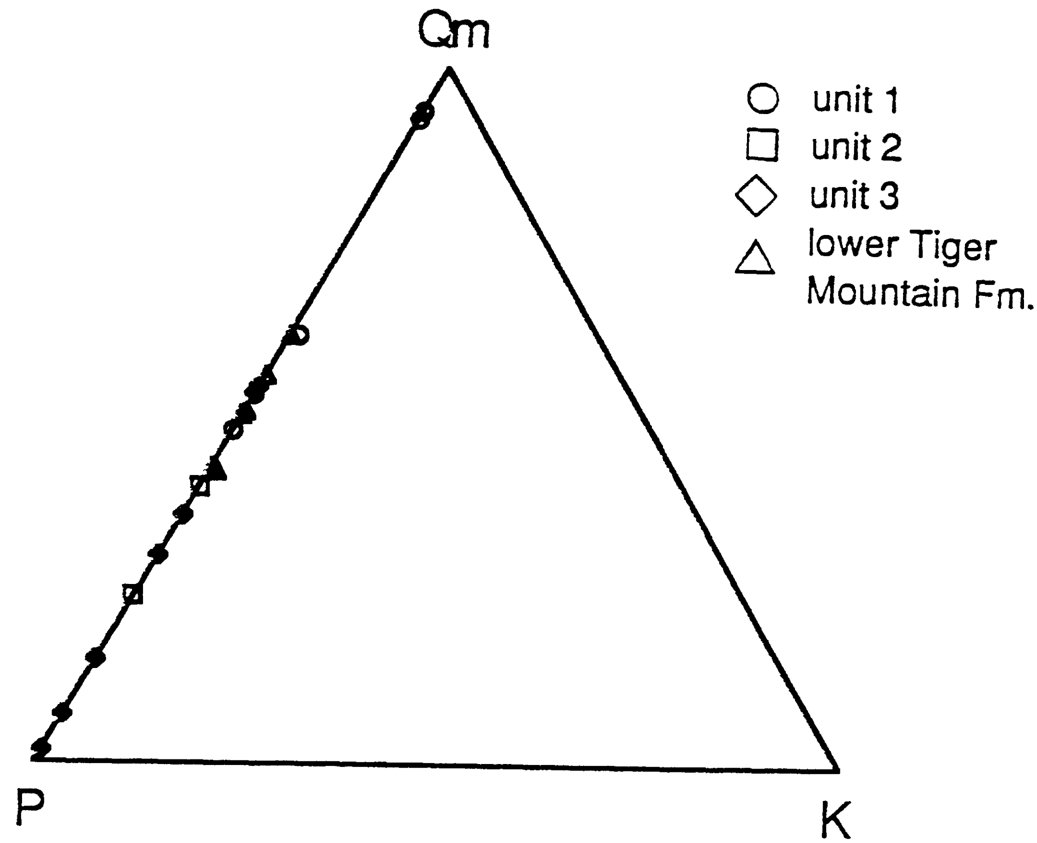

Qm
unit 1
unit 2
unit 3
lower Tiger
Mountain Fm.
F
Lt
Qm
continental block
provenance
recycled orogen
provenance
increasing ratio of
chert to quartz
(mixed)
P>V
V>P
magmatic arc
provenance
F
Lt

Figure 9B.


Qm
unit 1
unit 2
unit 3
lower Tiger Mountain Fm.
P
K

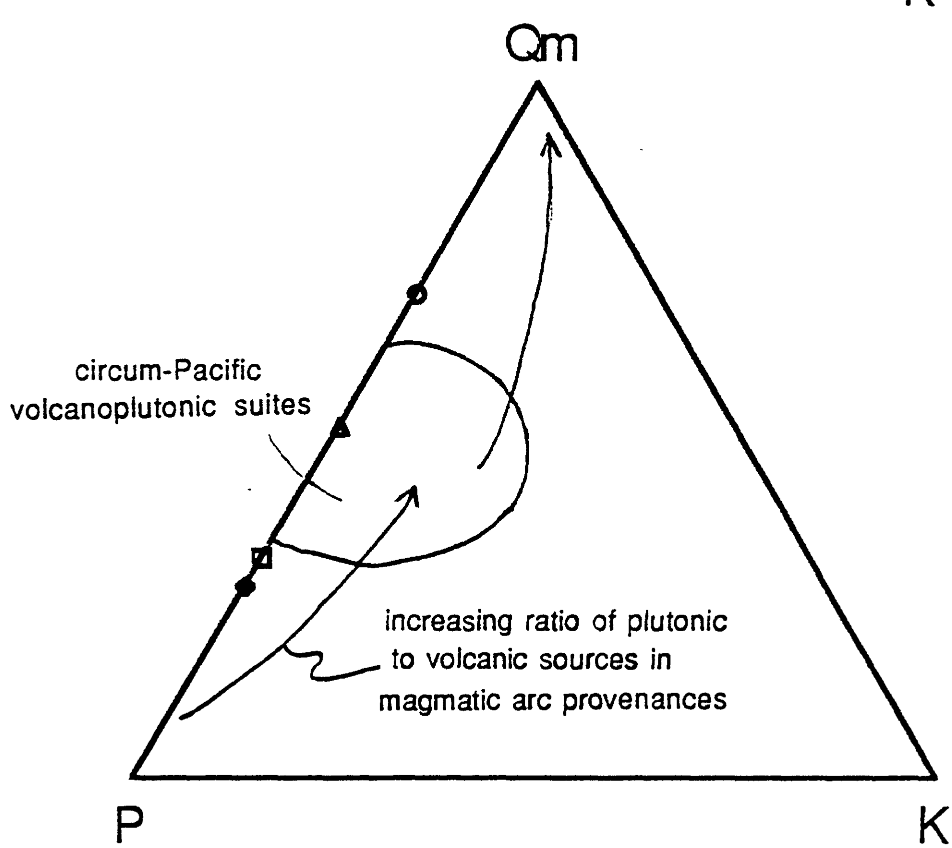

Qm
circum-Pacific volcanoplutonic suites
increasing ratio of plutonic to volcanic sources in magmatic arc provenances
P
K

Figure 9C.

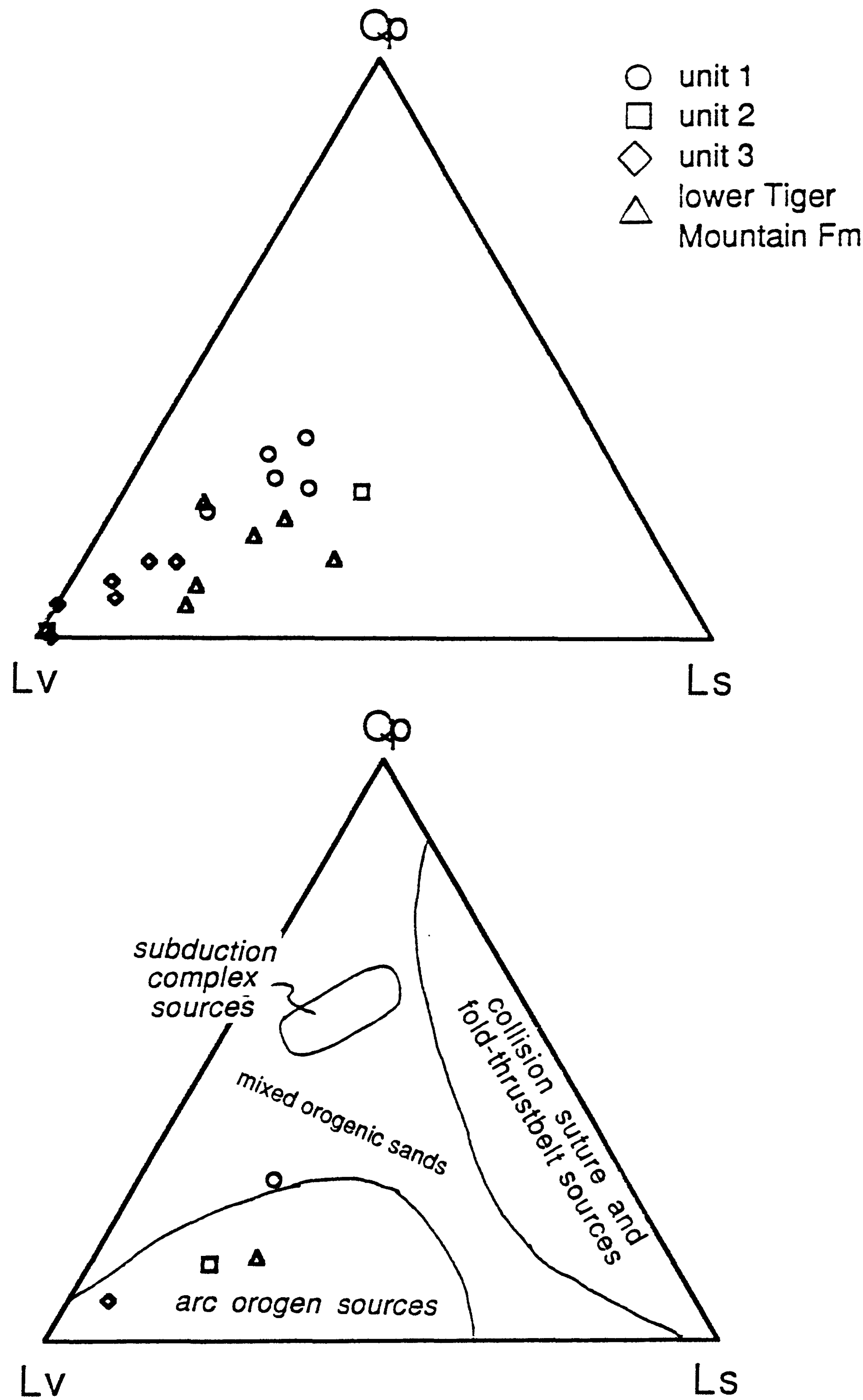

Qp
unit 1
unit 2
unit 3
lower Tiger Mountain Fm.
Lv
Ls
Qp
subduction complex sources
mixed orogenic sands
collision suture and fold-thrustbelt sources
arc orogen sources
Lv
Ls

Figure 9D.

from different stratigraphic levels within unit 2 or (3) incorrect correlation of the two different outcrop areas (see above discussion).

Unit 3

Seven samples of poorly to moderately sorted, fine- to coarse-grained sandstone from unit 3 were examined petrographically (Table 1, Appendix). The stratigraphically lowest five samples are lithic arenites; the upper two samples have slightly more feldspar than lithic fragments and are considered arkosic arenites (Dott, 1964). Volcanic lithic fragments are the largest component (37 to 67 percent) of the lowest five samples, and form about 20 percent of each of the upper two samples. In most samples, lathwork textures in volcanic lithic fragments are dominant; microlitic and felsitic textures are common in a few samples. Other types of lithic grains (including polycrystalline quartz and chert) form less than 10 percent of most samples. Monocrystalline quartz ranges from 1 to 18 percent in the lower five samples and is about 30 percent in the upper two samples. Plagioclase feldspar (albite based on optical determination) ranges from 15 to 41 percent (26 and 29 percent in the upper two samples), and potassium feldspar is absent. Chlorite, epidote, and opaque minerals are common accessory minerals. Biotite, which is rare in underlying units and most of unit 3, forms more than 3 percent of the stratigraphically highest sample. Primary porosity has been eliminated (to varying degree in different samples) by bent lithic fragments, pseudomatrix (Dickinson, 1970), calcite cement, and fibrous phylosilicate cement. Unit 3 samples plot in the magmatic arc provenance fields on QFL and QmFLt ternary provenance diagrams, and in the arc orogen field on a QpLvLs diagram (Dickinson, 1985; fig. 9).

Lower Tiger Mountain Formation

Six samples of moderately sorted, medium-grained sandstone from the lower Tiger Mountain Formation in the AMOCO WC-83-14 core were examined (Table 1, Appendix). These samples are classified as both lithic arenites (3) and arkosic arenites (3) and have fairly uniform compositions (fig. 9). Plagioclase feldspar (albite based on optical determinations) is the most abundant framework component (23-35 percent) followed by monocrystalline quartz (26-31 percent). Volcanic lithic fragments (14-29 percent) have lathwork, microlitic, and felsitic textures. Sedimentary lithic fragments (6-11 percent), polycrystalline quartz (2-4 percent), and chert (1-6 percent) occur in lesser amounts. Biotite (1-4 percent) is the most common accessory mineral. Primary porosity was eliminated (to varying degree in different samples) by bent lithic fragments, pseudomatrix (Dickinson, 1970), and calcite cement. Samples plot in the magmatic arc provenance fields on QFL and QmFLt ternary provenance diagrams, and in the arc orogen field on a QpLvLs diagram (Dickinson, 1985; fig. 9).

Provenance

Petrographic data indicate variable sources for the Raging River Formation and the lower part of the Tiger Mountain Formation. These sources are difficult to precisely identify because of the abundant cover of younger rocks and because of probable large-scale, Eocene displacement on the Straight Creek fault (fig. 1). The Straight Creek fault experienced approximately 85 to 190 km of right-lateral slip, probably mainly of Eocene age (Misch, 1977; Vance and Miller, 1981, 1992; Tabor and others, 1984; Johnson, 1985; Ague and Brandon, 1990; Coleman and Parrish, 1991); thus sediment source terranes east of the Straight Creek fault have been displaced at least several tens of kilometers following deposition of the Raging River Formation.

There appears to be three stratigraphically controlled sandstone petrofacies in the section that includes units 1, 2, and 3 of the Raging River Formation, and the lower part of the Tiger Mountain Formation (fig. 10). Petrofacies 1 includes unit 1 sandstones and the northern sample of unit 2. This petrofacies is distinguished on the basis of relatively equal amounts of monocrystalline quartz and volcanic lithic fragments, and significant amounts

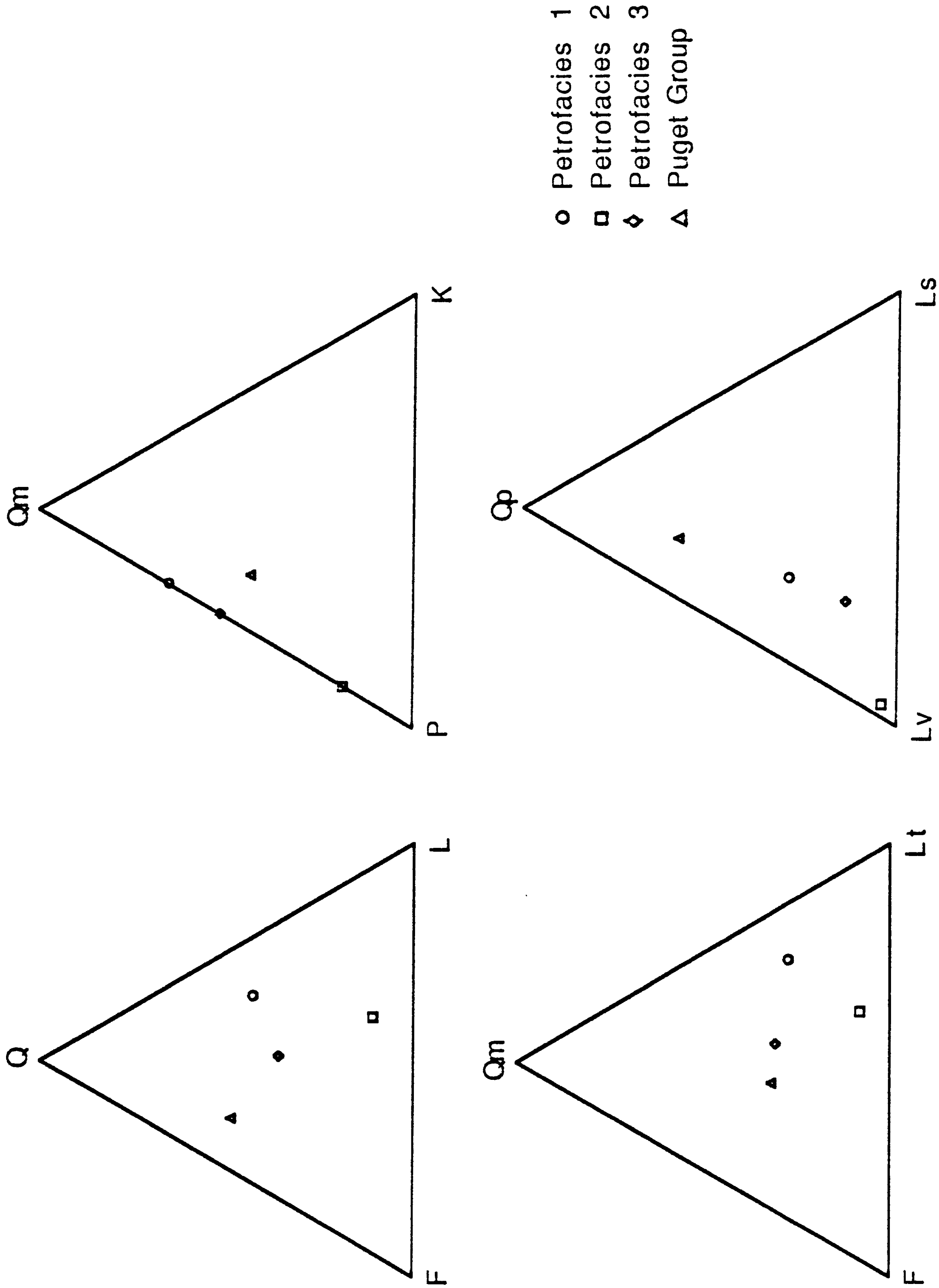


Figure 10. Ternary provenance diagrams (Dickinson, 1985) showing the mean of QFL, QmFLt, QmPK, and QpLvLs parameters for the three petrofacies recognized in the Raging River Formation (raw data in Appendix) and the lower part of the Tiger Mountain Formation, and for the younger Puget Group (data from Frizzell, 1979).

of plagioclase, sedimentary lithic fragments, polycrystalline quartz, and chert. On ternary provenance diagrams (fig. 10), the mean composition plots in the oceanic or chert-rich portions of the recycled orogen field, or in the mixed source field. The probable source for petrofacies 1 was nearby uplifts of Mesozoic rock of oceanic affinity, probably the western and eastern melange belts mapped by Frizzell and others (1987) less than 10 km east of Tiger Mountain (fig. 1). These oceanic basement rocks occur regionally (for example, Frizzell and others, 1987: Miller, 1989) and contain abundant chert, graywacke, and greenstone. The variable sedimentology and texture of Petrofacies 1 rocks must reflect a combination of variable relief in the source, sediment supply, and relative sea level.

Recognition of this Mesozoic basement terrane as an early(?) and early middle Eocene sediment source is important for understanding the paleogeography of correlative rocks deposited farther west on the eastern Olympic Peninsula. Based largely on a significant component of sedimentary, metasedimentary, chert, and volcanic lithic fragments, Melim (1984) suggested that the lower middle Eocene sandstone of Scow Bay (Armentrout and Berta 1977) must have been derived from rocks in the San Juan Islands to the north (Brandon and others, 1988), an area largely underlain by terranes similar to those in the melange belts mapped by Frizzell and others (1987). Einarsen (1987) similarly suggested a source in the San Juan Islands for a chert-rich petrofacies in the early Eocene Blue Mountain unit (sedimentary interbeds in the Crescent Formation). There is no independent evidence, however, that the main part of the San Juan Islands were uplifted during the Eocene. For example, the western part of the main outcrop belt of the Chuckanut Formation, less than 10 km from the eastern San Juan Islands, is relatively fine grained, dominantly arkosic,and was derived from sources to the east and north, not the west (Johnson, 1984b). In contrast, there is now compelling evidence that lithologically similar source rocks were exposed and eroding in the western Cascade foothills in the early(?) and early middle Eocene.

Petrofacies 2 includes the eastern sample of unit 2 and the stratigraphically lower 5 samples from unit 3. This petrofacies is distinguished on the basis of the large proportion of volcanic lithic fragments and plagioclase. The mean composition plots in the more volcanic portion of the magmatic arc field on provenance diagrams (fig. 10), indicating a volcanic source terrane. The minor proportion of low-grade metamorphic minerals in sandstones and lithic fragments suggests that the volcanic source was probably early Tertiary in age (pre-48 Ma) and not the Mesozoic greenstone inferred to be a partial source of petrofacies 1. This petrofacies was at least partly deposited at bathyal depths, making a nearby source of volcanic sediment unlikely (possible sources nearby would have also been submerged). It may be that the change of source from petrofacies one to petrofacies two reflects submergence of the petrofacies one source by the relative transgression reflected in the unit 3 sedimentology. Suitable lower Tertiary volcanic rocks, the Taneum Formation and Silver Pass Volcanic Member of the Swauk Formation (Tabor and others, 1984), are presently exposed east of the Tiger Mountain area on the east side of the Straight Creek fault (fig. 1). However, since most of the southern Washington Cascades is covered by rocks younger than the Raging River Formation (fig. 1; Walsh and others, 1977), the likelihood that the volcanic source of petrofacies 2 has been buried by younger volcanic rocks must also be considered a strong possibility.

Petrofacies 3 includes the upper two samples of the Raging River Formation and the lower part of the Tiger Mountain Formation. This petrofacies is distinguished on the basis of relatively equal amounts of quartz (including polycrystalline quartz and chert), plagioclase feldspar, and lithic fragments (mainly volcanic and sedimentary). The mean composition for petrofacies 3 plots in the more plutonic portion of the magmatic arc field on provenance diagrams (fig. 10), and is easily distinguished from petrofacies 2 on the basis of a smaller proportion of volcanic lithic fragments. Petrofacies 3 was probably derived from a mix of sources, including the Mesozoic oceanic rocks and lower Tertiary volcanic rocks inferred for petrofacies 1 and 2, and plutonic or crystalline rocks. Plutonic and crystalline rocks are the main sources for Eocene sandstones in the Puget Lowland and

Cascade Range (for example, Frizzell, 1979; Johnson, 1984b, 1985; Taylor and others, 1988), including the Puget Group which overlies the Raging River Formation. Possible plutonic or crystalline sources include the Mount Stuart batholith (fig. 1), high-grade metamorphic rocks now exposed in northeastern Washington, and the Idaho batholith. Petrofacies 3 was thus deposited in a transitional period when drainages were reorganizing so that more eastern sources could be tapped.

In summary, the petrofacies reveal an evolution in source terranes for lower(?) and middle Eocene sediments deposited in the central Puget Lowland. The oldest strata represented by petrofacies 1 were derived primarily from Mesozoic basement rocks of oceanic affinity. Stratigraphically higher petrofacies 2 was probably derived from lower Tertiary volcanic rocks. The stratigraphically highest rocks examined in this study, represented by petrofacies 3, were probably derived from a mix of sources that include Mesozoic oceanic rocks, lower Tertiary volcanic rocks, and regional plutonic or crystalline rocks. Petrofacies 3 represents a transition from oceanic and volcanic sediment sources to more plutonic and crystalline sources represented by the overlying Puget Group (Frizzell, 1979).

DISCUSSION

Sedimentologic and petrologic data on the Raging River Formation and lower part of the Tiger Mountain Formation (see above) provide important data for regional paleogeographic reconstruction. Paleocurrent data (fig. 6) were collected from only a small area but suggest a west-dipping paleoslope, which is consistent with other studies in the Cascade foothills and with petrologic data (for example, Buckovic, 1979; Johnson, 1984a, b, 1985, and unpublished data). The rapid transition in the Raging River Formation from unit 2 nonmarine deposits to unit 3 middle bathyal (depths of 500 to 2,000 meters) deposits provides evidence for abrupt subsidence and submergence of this paleoslope in the early middle Eocene (early Narizian, about 48 Ma). This dramatic pulse of basin subsidence is not seen in the correlative Chuckanut Formation farther north in the Puget Lowland/Cascade foothills (Johnson, 1984b) and thus appears to be related to local differential tectonism and not a regional transgression. Furthermore, global sea level curves (Haq and others) do not show a major rise in sea level at this time. Correlative rocks to the south in the Puget Lowland/Cascade foothills (Armentrout and others, 1983) are either not exposed or have not been well studied, and it is not clear at this time whether the southern Puget Lowland/Cascade foothills experienced this pulse of rapid subsidence.

Fine-grained marine rocks of inferred early and early middle Eocene age are apparently widespread in the subsurface in the southern Washington Cascade foothills. Stanley and others (1987, 1992) have described a major conductivity anomaly in the southern Washington Cascade foothills that underlies upper middle Eocene to Oligocene rocks and is inferred to consist mainly of fine-grained marine strata. The Tiger Mountain-Taylor Mountain exposures of the Raging River Formation (figs.1,2) and the AMOCO WC-83-14 (fig. 8) core provide the only known window or analogue for this anomaly. Stanley and others (1992) suggested these rocks could be a significant petroleum source rock. Rock-eval pyrolysis (S.Y. Johnson, unpublished data) indicates that unit 3 bathyal mudstone from the AMOCO WC-83-14 core are now overmature with respect to hydrocarbon generation (T_{max} = 533° - 542° for three samples) and thus cannot be reliably evaluated as petroleum source rocks (Peters, 1986). However, there is still as much as 0.8-0.9 percent total organic carbon in these rocks, an indication that they were once more organic rich and may have generated hydrocarbons in the past.

Significant vertical tectonism in the Tiger Mountain area is also recorded by the abrupt transition from the middle bathyal deposits of unit 3 of the Raging River Formation to the inferred shelf deposits of the lower part of the Tiger Mountain Formation. This transition (provided there is no section cut out at the contact, see above) requires at least several hundred meters of shoaling but occurs within a few tens of meters of section (fig. 8). Thus the basin floor must have been rising during deposition of the lower Tiger Mountain Formation. A comparison of the subsidence history of the Tiger Mountain area and other sites in the Puget Lowland will provide important data for reconstructing the tectonic and sedimentary history of the region.

CONCLUSIONS

Three informal stratigraphic units are recognized in the lower(?) and middle Eocene Raging River Formation based on distinctive sedimentary facies and lithologies. A fourth unit (unit 0) consisting of breccia-conglomerate, could either represent the lowest part of the Raging River Formation of, more likely, lithified Quaternary(?) colluvium. Unit 1, approximately 230 m thick, consists of interbedded sandstone, mudstone, and conglomerate of inferred nonmarine (lower part) and shallow-marine (upper part) origin. Unit 2, approximately 185 m thick, consists of interbedded conglomerate, sandstone, and mudstone, and is interpreted as mainly alluvial deposits. A major transgression is recorded by Unit 3 (about 300 m thick), which consists of gray silty mudstone and lesser sandstone, and was deposited in a marine shelf (lower part) and bathyal slope (upper part) setting. This transgression reflects local tectonism and not eustatic fluctuations. The Raging River Formation is overlain by prodelta(?) marine shelf deposits in the lower part of the Tiger Mountain Formation.

Three sandstone petrofacies were identified in the Raging River Formation and lower part of the Tiger Mountain Formation. These petrofacies reveal an upward evolution in sediment source from Mesozoic basement rocks of oceanic affinity (petrofacies 1), to lower Tertiary volcanic rocks (petrofacies 2), to a mixed provenance including Mesozoic oceanic rocks, lower Tertiary volcanic rocks, and more distal plutonic or crystalline rocks (petrofacies 3).

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APPENDIX

Raw petrographic data on point counts of 20 fine- to coarse-grained sandstones from the Raging River Formation and the lower part of the Tiger Mountain Formation are presented below. Point counts were conducted using the Gazzi-Dickinson method (Ingersoll and others, 1984). All thin sections were stained for potassium feldspar. Petrographic data are plotted in figures X-X and summarized in table 1.

Codes for tables of petrographic data.

1. Stratigraphic unit: R2 = unit 1 of Raging River Formation; R3 = unit 2 of Raging River Formation; R4 = unit 3 of Raging River Formation; TM = lower part of Tiger Mountain Formation.

2. Localities: 1 (1509') = Amoco Production WC-83-14 borehole (footage); 2 = outcrops in drainage in S 1/2 sec. 4, N 1/2 sec. 9, T. 23 N., R.7E (fig.X); 3 = roadcut outcrops in W. 1/2, sec. 15, T. 23 N., R. 7E; 4 = roadcut outcrops in SW 1/4 sec. 32, T. 24 N., R. 7 E.

3. Grain size of sample: F = fine-grained sandstone; M = medium-grained sandstone; C = coarse-grained sandstone.

4. Number of points counted.

5. Number of framework grains counted.

6-22. Modal percent of composition (not normalized to 100.0%).

6. Monocrystalline quartz.

7. Foliated polycrystalline quartz.

8. Undifferentiated polycrystalline quartz.

9. Chert.

10. Plagioclase feldspar.

11. Potassium feldspar.

12. Sedimentary rock fragment.

13. Volcanic rock fragment.

14. Quartz-mica tectonite rock fragment.

15. Low-grade metamorphic rock fragment.

16. Biotite, muscovite, and chlorite.

17. Epidote, amphibole, and pyroxene.

18. Opaque minerals, garnet, sphene, and other heavy minerals.

19. Matrix and hematite cement

20. Calcite cement.

21. Porosity.

22. Plagioclase/total feldspar.

23. QFL (total quartz, feldspar, lithic fragments).

24. QmFLt (monocrystalline quartz, feldspar, lithic fragments).

25. QmPK (monocrystalline quartz, feldspar, lithic fragments).

26. QpLvLs (polycrystalline quartz, volcanic lithic fragments, sedimentary lithic fragments)

For calculating Ternary ratios QFL, QmFLt, QmPK, QpLvLs:
Q = 6 + 7 + 8 + 9; Qm = 6; F = 10 + 11; L = 12 + 13 + 14 + 15; Lt = 7 + 8 + 9 + 12 + 13 + 14 + 15; Qp = 2 = 3 = 4; Lv = 8; Ls = 7.

TABLE 2 (Page 1). PETROGRAPHIC DATA

SAMPLE NUMBER	SJ-91-10A	SJ-91-12	SJ-91-13B	SJ-91-15	SJ-91-16
Code					
1	R2	R2	R2	R2	R2
2	2	2	2	2	2
3	C	M-C	M	M	M
4	407	358	380	384	390
5	347	333	334	355	348
6	14.5	20.1	25.3	43.0	26.2
7	0.5	0.6	0.8	0	0.3
8	9.8	10.6	8.2	6.0	11.6
9	6.4	5.9	3.2	3.9	5.1
10	15.7	17.9	14.7	3.4	2.6
11	0	0	0.3	0	0
12	9.6	10.6	12.6	6.3	12.8
13	26.5	26.5	22.1	27.9	30.8
14	0.5	0.3	0.8	0	0
15	1.7	0.6	0	0	0
16	1.5	0.8	0.6	0	0.8
17	5.1	1.1	0	0	0.5
18	1.2	1.4	2.4	0.8	1.0
19	0	0	6.8	0	0.5
20	6.9	3.6	2.4	8.9	7.9
21	0	0	0	0	0
22	1.0	1.0	0.98	1.0	1.0
23	37,18,45	40,19,41	43,17,40	59,4,37	48,3,49
24	17,18,65	22,19,59	29,17,54	46,4,50	29,3,68
25	48,52,0	53,47,0	62,37,1	93,7,0	94,6,0
26	32,50,18	31,49,20	26,47,27	22,63,14	28,51,21

TABLE 2 (Page 2). PETROGRAPHIC DATA

SAMPLE NUMBER	SJ-91-200	SJ-91-32	SJ-91-22	SJ-91-27	SJ-91-41
Code					
1	R3	R3	R4	R4	R4
2	4	3	3	3	1(1733')
3	M	M	M	M-C	F-M
4	380	384	392	387	389
5	371	370	370	368	370
6	12.9	10.4	3.3	0.8	17.5
7	1.8	0	0	0	0.3
8	7.6	0.8	0	0.3	4.1
9	6.8	0	0	0	0
10	19.7	32.6	41.3	34.1	31.4
11	0	0	0	0	0
12	22.6	0.5	1.0	0.5	0
13	25.3	52.1	48.7	59.4	37.3
14	0.8	0	0	0	0.5
15	0	0	0	0	1.5
16	1.6	0.3	0.5	0	0.5
17	0	0.3	0	0	3.1
18	0	0.3	0.5	2.6	1.0
19	0	2.9	2.6	2.1	1.0
20	0.8	0.3	2.0	0.3	1.8
21	0	0	0	0	0
22	1.0	1.0	1.0	1.0	1.0
23	30,20,50	12,34,54	4,44,53	1,36,63	23,33,44
24	13,20,67	11,34,55	4,44,53	1,36,63	18,33,49
25	40,60,0	24,76,0	7,93,0	2,98,0	36,64,0
26	25,39,35	1,98,1	0,98,2	1,99,1	10,84,6

TABLE 2 (Page 3). PETROGRAPHIC DATA

SAMPLE NUMBER	SJ-91-42	SJ-91-44	SJ-91-48	SJ-91-48A	SJ-91-51
Code					
1	R4	R4	R4	R4	TM
2	1(1676')	1(1509')	1(918')	1(839.5')	1(526')
3	M-C	M-C	M	M	M
4	383	376	417	383	383
5	357	353	345	356	350
6	7.0	6.7	29.5	33.7	26.4
7	0	0	0.2	0.3	0
8	1.8	4.0	3.1	3.1	1.6
9	1.3	0.3	0	0	0.8
10	38.4	15.4	26.6	29.2	28.7
11	0	0	0	0	0
12	3.4	0.3	0.2	3.9	7.0
13	38.4	67.0	20.1	19.8	28.7
14	0	0.3	0.5	2.9	0.3
15	0	0	0	0	0
16	0.6	0.3	3.1	4.0	3.7
17	0	1.1	0	0.5	0.3
18	0.8	0.3	1.2	0.5	0
19	5.0	1.9	0.2	1.3	0.3
20	0.5	2.7	15.1	0.8	4.4
21	0	0	0	0	0
22	1.0	1.0	1.0	1.0	1.0
23	11,44,45	12,16,72	40,32,28	40,31,29	31,29,40
24	8,44,48	7,16,77	36,32,32	36,31,33	29,29,42
25	15,85,0	30,70,0	53,47,0	54,46,0	50,50,0
26	7,85,8	6,94,0	13,77,10	13,73,14	6,75,19

TABLE 2 (Page 4). PETROGRAPHIC DATA

SAMPLE NUMBER	SJ-91-52	SJ-91-53	SJ-91-54	SJ-91-58	SJ-91-58A
Code					
1	TM	TM	TM	TM	TM
2	1(497')	1(450')	1(389')	1(213')	1(168')
3	M	M	M-C	F-M	M
4	382	372	363	422	383
5	357	349	353	383	353
6	26.2	31.2	26.7	25.6	28.7
7	0.3	0	0.6	0	0.5
8	3.4	4.0	4.4	1.4	3.1
9	2.9	2.7	5.8	1.2	3.1
10	35.3	29.6	23.1	34.6	22.7
11	0.5	0	0	0	0
12	10.7	8.3	5.8	5.7	8.9
13	14.1	17.2	28.9	20.9	22.2
14	0	0.8	1.9	1.4	2.9
15	0	0	0	0	0
16	0.5	2.4	1.1	4.2	2.1
17	0	0	0	0	0
18	0	0.5	0.3	0.9	0
19	0	0.5	1.4	1.4	0.3
20	5.0	2.7	0	2.6	5.5
21	0	0	0	0	0
22	0.99	1.0	1.0	1.0	1.0
23	35,38,27	40,32,28	39,24,38	31,38,31	39,25,37
24	28,38,34	33,32,35	27,24,49	28,38,34	31,25,44
25	42,57,1	51,49,0	62,38,0	43,57,0	56,44,0
26	14,49,37	21,53,26	24,64,13	9,72,29	18,59,23