

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY


**GEOLOGIC MAP OF THE OMAK LAKE 15' QUADRANGLE,
OKANOGAN COUNTY, WASHINGTON**

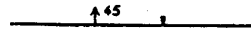
By John W. Goodge and Vicki L. Hansen


GEOLOGIC QUADRANGLE MAP
Published by the U.S. Geological Survey, 1994


GEOLOGIC MAP SYMBOLS

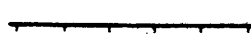
COMMONLY USED ON MAPS OF THE UNITED STATES GEOLOGICAL SURVEY
(Special symbols are shown in explanation)


 Contact – Dashed where approximately located; short dashed where inferred; dotted where concealed


 Contact – Showing dip; well exposed at triangle


 Fault – Dashed where approximately located; short dashed where inferred; dotted where concealed


 Fault, showing dip – Ball and bar on downthrown side


 Normal fault – Hachured on downthrown side


 Fault – Showing relative horizontal movement


 Thrust fault – Sawteeth on upper plate

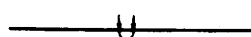
 Anticline – Showing direction of plunge; dashed where approximately located; dotted where concealed


 Asymmetric anticline – Short arrow indicates steeper limb


 Overturned anticline – Showing direction of dip of limbs

 Syncline – Showing direction of plunge; dashed where approximately located; dotted where concealed

 Asymmetric syncline – Short arrow indicates steeper limb





 Overturned syncline – Showing direction of dip of limbs

 Monocline – Showing direction of plunge of axis




 Minor anticline – Showing plunge of axis

 Minor syncline – Showing plunge of axis




Strike and dip of beds – Ball indicates top of beds known from sedimentary structures

 ⁷⁰ Inclined  Horizontal
 ⁴⁰ Vertical  Overturned




Strike and dip of foliation

 ²⁰ Inclined  Vertical  Horizontal




Strike and dip of cleavage

 ¹⁵ Inclined  Vertical  Horizontal

Bearing and plunge of lineation

 ¹⁵ Inclined  Vertical  Horizontal

Strike and dip of joints



 ⁴⁰ Inclined  Vertical  Horizontal


Note: planar symbols (strike and dip of beds, foliation or schistosity, and cleavage) may be combined with linear symbols to record data observed at same locality by superimposed symbols at point of observation. Coexisting planar symbols are shown intersecting at point of observation.

Shafts



 Vertical  Inclined

Adit, tunnel, or slope

 Accessible  Inaccessible

 Prospect









Quarry

 Active  Abandoned

Gravel pit

 Active  Abandoned

Oil well

 Drilling  Shut-in  Dry hole
 Gas  Show of gas  abandoned
 Oil  Show of oil

GEOLOGIC MAP OF THE OMAK LAKE 15' QUADRANGLE, OKANOGAN COUNTY, WASHINGTON

By John W. Goodge and Vicki L. Hansen

INTRODUCTION

The Omak Lake 15' quadrangle, located about 2 km east of the town of Omak in northeastern Washington, lies mostly within the Colville Indian Reservation east of the Okanogan River. Geologic mapping was completed in conjunction with regional geologic mapping of the Colville reservation, which was compiled at a scale of 1:100,000 (Atwater and Rinehart, 1984).

Rocks of the Omak Lake 15' quadrangle lie within the Omineca crystalline belt (Monger and others, 1972), whose plutonic and high-grade regional metamorphic rocks extend from British Columbia southward into north-central Washington (fig. 1; on map sheet). Several structural culminations of crystalline rocks, referred to as metamorphic core complexes (Crittenden and others, 1980; Armstrong, 1982) or gneiss domes (Reesor, 1965; Fox and others, 1977), punctuate the Omineca belt; the southwesternmost of these is the Okanogan metamorphic core complex of Washington. The Omak Lake quadrangle contains rocks of the southwestern part of the Okanogan metamorphic core complex; these rocks are continuous, both lithologically and in metamorphic grade, with high-grade crystalline rocks of the Shuswap Metamorphic Complex in southern British Columbia (Okulitch, 1984). To the east and southeast, Tertiary volcanic and clastic sedimentary rocks within the en echelon Toroda Creek, Republic, and Keller grabens separate the Okanogan metamorphic core complex from the Kettle and Lincoln metamorphic core complexes (fig. 2; on map sheet). The Okanogan Valley and Omak Lake fault zones (Snook, 1965) mark the western boundary of the Okanogan metamorphic core complex in the Omak Lake quadrangle; these low-angle faults are part of a major structural décollement that separates lower-plate rocks of the Okanogan and other metamorphic core complexes from structurally higher, Tertiary and older, metamorphic, plutonic, and volcanic rocks. Chief within this upper-plate sequence is the Quesnellia terrane (figs. 1, 2; on map sheet), which consists of upper Paleozoic to Lower Jurassic volcanic-arc and oceanic rocks (Tipper, 1981; Monger and others, 1982). These rocks were accreted to the western margin of North America in the Middle Jurassic (Read and Wheeler, 1976; Tipper, 1981; Parrish and Wheeler, 1983). The Quesnellia-North American terrane suture is an important struc-

tural boundary that may have been the locus of younger deformation (Okulitch, 1984). In the southwest corner of the quadrangle, Miocene basalt of the Columbia River Basalt Group overlies these other rocks. Quaternary deposits, chiefly glacial drift, conceal both upper- and lower-plate rocks in at least one-third of the quadrangle.

Rocks of the Okanogan metamorphic core complex exhibit a low topographic profile between the Okanogan River (fig. 3) and the Sanpoil River (located about 40 km east of the quadrangle), particularly when viewed eastward from the Okanogan River valley. The present homoclinal form of the complex is a direct result of structural and plutonic tectonism that raised high-grade, mylonitically deformed crystalline rocks from depth to their present position. Prominent west-sloping flanks of the complex result from preferential erosion along foliation planes of west-dipping mylonitic gneiss.

Pardee (1918) originally assigned the crystalline rocks within the quadrangle to the "Colville batholith," which is his reconnaissance field term for the diverse granitoid rocks found on the Colville reservation. Both Pardee (1918) and Waters and Krauskopf (1941) described a broad zone of deformation that fringes the western and southwestern borders of the Colville batholith. Waters and Krauskopf (1941) suggested that this zone represents a protoclastic border that formed adjacent to wallrocks during intrusion of the batholith. Snook (1965) reinterpreted this zone of deformation as a system of steeply dipping faults. More recent studies of crystalline rocks within this region include those by Fox and others (1976, 1977), Cheney (1980), Goodge (1983a, b), Goodge and Hansen (1983), Hansen (1983a, b), Atwater (1985), Parkinson (1985), Volk (1986), Fox and Rinehart (1988), and Holder and Holder (1988). Additionally, Hansen and Goodge (1988) reviewed ideas about the origin of the Okanogan metamorphic core complex and proposed a new model of its evolution. Reviews of correlative rocks in British Columbia have been presented by Okulitch (1984) and Parrish and others (1988).

OKANOGAN METAMORPHIC CORE COMPLEX

The Okanogan metamorphic core complex in the Omak Lake 15' quadrangle consists of, in order from

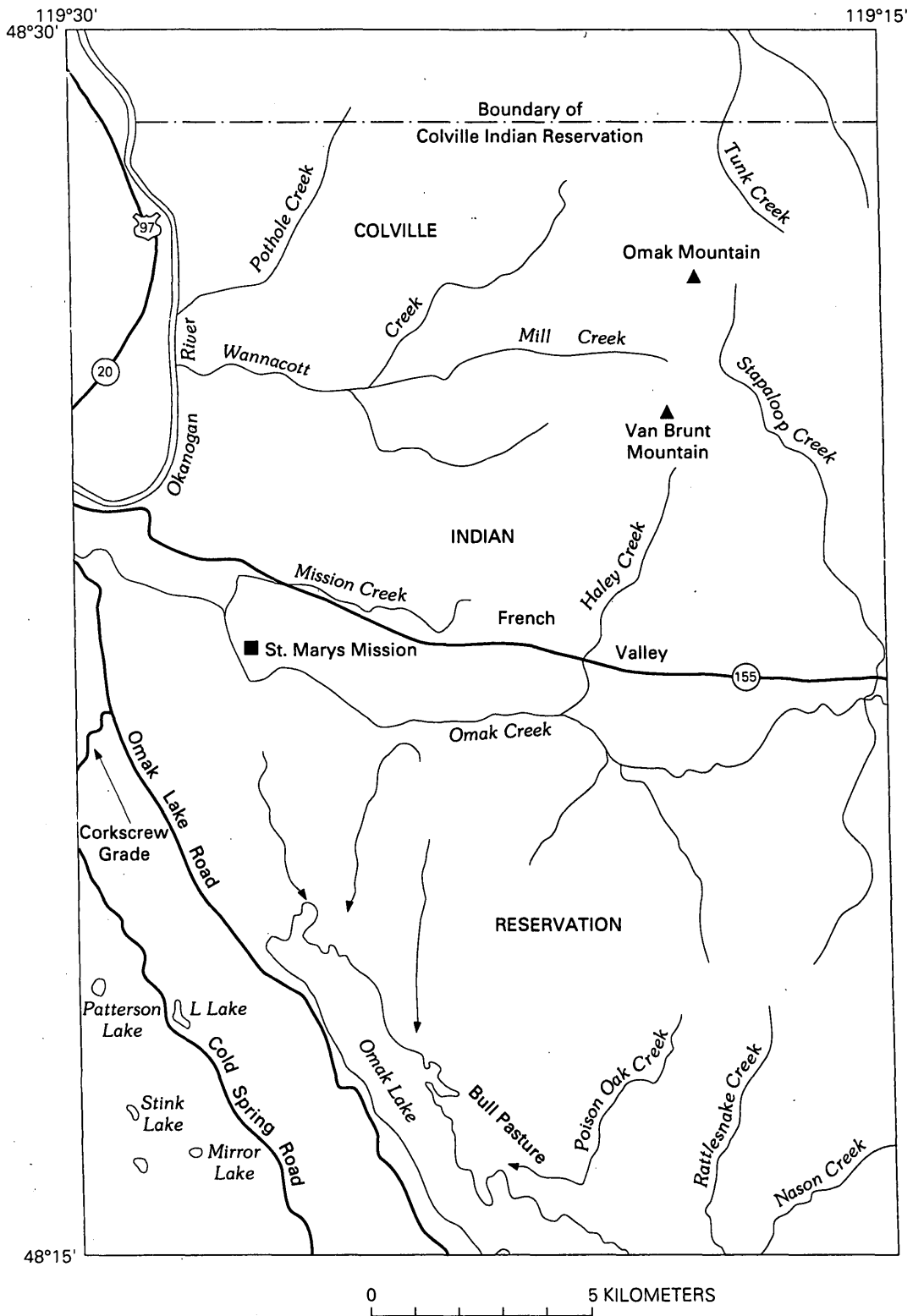


Figure 3. Geographic features referred to in text. Note that on 1953 edition of Omak Lake 15' quadrangle, used as base for map sheet, Route 155 is shown as Route 10A, and Route 20 is shown as Route 10. Arrowhead indicates downstream terminus of creek. See figures 1 and 2 (on map sheet) for location of quadrangle.

oldest to youngest: high-grade layered paragneiss (the Tonasket Gneiss); hornblende-biotite granodioritic gneiss that is commonly layered; two units of orthogneiss (the Mission Creek and the French Valley Granodiorites); biotite granite and granodiorite (the Coyote Creek pluton); and microdiorite dikes. The dominant structural feature of the Okanogan metamorphic core complex is a zone of penetrative ductile mylonite (as defined by Bell and Etheridge, 1973), which is bounded on the west and southwest by the Okanogan Valley and Omak Lake fault zones. Deformation within this zone produced a pervasive and penetrative mylonitic fabric in the Tonasket Gneiss, the hornblende-biotite granodioritic gneiss, and the Mission Creek and French Valley Granodiorites; an incipient fabric is evident in the granitic rocks of the Coyote Creek pluton. Nonmylonitized microdiorite dikes cut rocks that display well-formed mylonitic fabrics.

TONASKET GNEISS

The Tonasket Gneiss (Fox and others, 1976) is a high-grade, layered paragneiss that exhibits evidence of polyphase deformation. It has the oldest protolith of any unit in the Okanogan metamorphic core complex. The Tonasket is exposed in the northern third of the quadrangle, and it also extends northward and eastward outside of the quadrangle across much of the Okanogan complex, where it includes layered amphibolitic gneiss and calc-silicate rocks.

Hornblende-biotite gneiss and biotite gneiss make up the major part of the Tonasket Gneiss, and potassium-feldspar augen gneiss, pelitic schist, amphibolite, biotite quartzite, calc-silicate gneiss, and garnet-bearing alaskite gneiss are minor constituents. Compositional layering and the presence of calc-silicate, pelitic, and quartzite layers indicate a sedimentary protolith, possibly a sedimentary sequence that contains abundant volcanic rocks and minor impure carbonate rocks, sandstone or chert, and shale.

No geochronometric or paleontological data exist that provide age constraints on formation of the Tonasket protoliths. However, in southern British Columbia, contiguous paragneisses of the Okanogan metamorphic core complex are intruded by granitic plutons that are approximately 100 Ma or older (Parkinson, 1985). Also, the Tonasket is similar in metamorphic grade and structural style to rocks of the Shuswap Metamorphic Complex in southern British Columbia, which were metamorphosed during crustal-shortening events in Middle Jurassic time (Archibald and others, 1983; Parrish and others, 1988). Thus, the protoliths of the Tonasket may be older than Middle Jurassic(?) if the age of Tonasket metamorphism is similar to the age of metamorphism of rocks in parts of the Shuswap Metamorphic Complex.

Metamorphism of the Tonasket Gneiss reached the sillimanite-muscovite zone of the amphibolite facies; textures in the pelitic schist indicate that sillimanite is in equilibrium with muscovite. Metamorphic tem-

peratures probably did not exceed those of the sillimanite-orthoclase zone because sillimanite and orthoclase do not occur in equilibrium grain contact; however, this lack of contact may simply be a function of primary compositional layering observed in the particular rocks we sampled for thin section. Metamorphic temperature-pressure conditions probably did not exceed those at which muscovite breaks down to form aluminum silicate.

Structural features of the Tonasket Gneiss reflect two distinct periods of deformation and metamorphism: in the first, metamorphic fabrics and fold structures formed during high-grade regional metamorphism and synmetamorphic folding; in the second, ductile-shear fabrics, which indicate synkinematic recrystallization of older metamorphic fabrics, formed during postmetamorphic mylonitization, as discussed below. Events of similar tectonic style and sequence have also been interpreted from high-grade rocks of the Shuswap Metamorphic Complex (Reesor, 1965; Fyles, 1970; Read and Brown, 1981; Brown and Read, 1983; Brown and others, 1986).

Deformation related to high-grade regional metamorphism of the Tonasket Gneiss is shown by a well-developed foliation and mineral lineation. The foliation consists of parallel compositional layering and schistosity. The metasedimentary rock types described above are thinly layered, having thicknesses of millimeters to as much as several centimeters. Rocks containing abundant mica and amphibole display a planar schistosity parallel to these thin compositional layers. Most rocks, particularly from fine-grained mafic units, contain a mineral lineation formed by recrystallized biotite or hornblende; this lineation, evenly distributed on schistosity surfaces, is formed by the grain-shape preferred orientation of undeformed biotite and hornblende. Pelitic rocks contain a similar lineation formed by the alignment of phyllosilicates and sillimanite. The mineral lineation can be distinguished from a younger mylonitic lineation by the lack of stretched quartz rods, aggregates of biotite, and plagioclase augen. In thin section, the Tonasket rocks exhibit highly recrystallized, hypidioblastic metamorphic textures, which include foliated but crystallographically undeformed biotite, hornblende, and sillimanite (0.5–3.0 mm), as well as garnet porphyroblasts (2–3 mm) with no detectable rotation, unstrained plagioclase, and weakly undulose to unstrained, serrate quartz (0.25–3.0 mm).

The Tonasket Gneiss in the Omak Lake quadrangle is here divided into two textural or fabric domains: the first domain, present east of the hachured line on the map, is marked by a metamorphic foliation fabric; a second domain, developed at a higher structural level nearer the core-complex border, is defined by mylonitic fabrics superimposed on older metamorphic fabrics. The mylonitic fabric, which consists of a shear foliation and a mineral elongation lineation, is texturally similar to and continuous with mylonitic fabrics evident in the orthogneiss of the Mission Creek and French Valley Granodiorites to the south. Toward the inte-

rior of the complex, the mylonitic fabric is progressively more difficult to distinguish from the low-shear-strain metamorphic foliation and the grain-shape lineation. In the biotite- and hornblende-rich schists and layered gneisses, however, mylonitic foliation and lineation appear markedly different from the preexisting metamorphic fabrics. The mylonitic foliation is anastomosing in form (see section entitled "Mylonitic Fabric"), whereas the metamorphic foliation is planar and continuous; the mylonitic elongation lineation consists of smeared, rod-shaped quartz-plagioclase-biotite aggregates, whereas the metamorphic lineation consists only of a biotite, hornblende, or sillimanite mineral lineation. The metamorphic fabric is increasingly deformed within the mylonite zone toward the core-complex margin, where the mylonitic fabric dominates.

HORNBLLENDE-BIOTITE GRANODIORITIC GNEISS

The hornblende-biotite granodioritic gneiss, which is locally layered and characteristically contains a mylonitic fabric, crops out on the northeast shore of Omak Lake and in the area surrounding Bull Basture (fig. 3) in the southern part of the quadrangle. This gneiss, although mylonitic, is contiguous with nonmylonitic rocks mapped as the plutonic complex of Boot Mountain by Atwater and Rinehart (1984) in the Boot Mountain 15' quadrangle south of Omak Lake. The granodioritic gneiss is intruded by pegmatitic and granitic phases of the Coyote Creek pluton in the southeast corner of the quadrangle near Nason Creek; in that area, it is also cut by microdiorite dikes. The protolith of the granodioritic gneiss seems unrelated to, and is probably older than, the Mission Creek and French Valley Granodiorites, because the granodioritic gneiss is compositionally dissimilar to them and is texturally inhomogeneous; it also extends well south of the Okanogan metamorphic core complex and appears to reflect a polyphase history.

ORTHOgneiss

Foliated and lineated mylonitic orthogneiss, the most abundant rock type in the quadrangle, crops out in a broad belt northeast of Omak Lake. Mylonitic fabrics characteristic of the Okanogan metamorphic core complex are well defined in this orthogneiss near border areas of the complex but diminish in intensity with structural depth towards the east. The orthogneiss is here subdivided into two formally named units, both mylonitic, on the basis of composition and texture: (1) the Mission Creek Granodiorite, a porphyritic biotite granodiorite that contains megacrysts of potassium feldspar believed to be relict igneous phenocrysts; and (2) the French Valley Granodiorite, an equigranular biotite granodiorite that resembles the Mission Creek except that it lacks potassium-feldspar megacrysts.

The Mission Creek Granodiorite is here named for exposures along Mission Creek in the Omak Lake

quadrangle. It crops out over a broad area in the quadrangle and also extends northward and eastward into the adjoining Tonasket and Disautel 15' quadrangles. Exposures in a quarry about 0.8 km north of Route 155 (fig. 3) and about 4.8 km east of the town of Omak (SW¹/₄ sec. 32, T. 34 N., R. 27 E.) are here designated as the type locality of the unit.

The French Valley Granodiorite is here named for exposures found in the vicinity of French Valley (fig. 3). The unit crops out in several separate but extensive locales, which are primarily in the central part of the Omak Lake quadrangle but also extend eastward into the Disautel 15' quadrangle. Exposures in roadcuts along Route 155, about 0.5 km west of where Route 155 crosses Haley Creek (SE¹/₄ sec. 7, T. 33 N., R. 28 E.), are here designated as the type locality of the unit.

Contacts between the orthogneiss units and the Tonasket Gneiss are concordant with mylonitic foliation over great distances, indicating substantial postemplacement shear deformation. As a result, original intrusive relations are difficult to interpret; however, the contact between the French Valley and the Tonasket appears gradational over a width of several hundred meters, possibly reflecting a combination of intricate intrusive relations and synemplacement metasomatism. The contact between the Mission Creek and the Tonasket is also gradational but is more abrupt, spanning a width of several meters to a few tens of meters.

Contact relations suggest that the Mission Creek and French Valley Granodiorites probably represent contemporaneous phases of a composite pluton. These units have relatively sharp contacts with one another (contact zones less than 10 m wide); however, these contacts are also parallel to mylonitic foliation, hence they were probably modified by postintrusive ductile shear. The French Valley contains inclusions of the Mission Creek, yet apophyses of the Mission Creek cut the French Valley, providing equivocal age relations. Both the French Valley rocks and the granodioritic gneiss contain potassium-feldspar megacrysts near contacts with the Mission Creek, although it is not clear whether these crystals are xenocrysts or whether they formed by metasomatism or late-stage crystallization adjacent to the feldspar-rich Mission Creek body.

Snook (1965) proposed a metasomatic origin for the orthogneiss in the southwestern part of the Okanogan metamorphic core complex. Five properties of the Mission Creek and French Valley Granodiorites, however, support the view of Waters and Krauskopf (1941) and Fox and others (1976) that these units are solely of igneous parentage: (1) compositional homogeneity; (2) primary igneous textures, including abundant euhedral sphene, well-twinned plagioclase, and perthitic orthoclase; (3) inclusions of the Mission Creek in the French Valley; (4) widespread mafic inclusions and dikes of aplite and pegmatite; and (5) invariant major-element geochemical composition of the Mission Creek rocks. Most samples of the Mission Creek show linear major-element compositional trends between 69 and 72 weight percent

SiO₂ (table 1; fig. 4); these trends are within the compositional ranges typical of unmodified primary igneous rocks, and they do not indicate geochemical change during postmagmatic ductile and brittle deformation.

Field evidence indicates that the Mission Creek and French Valley Granodiorites were emplaced during or after high-grade metamorphism of the Tonasket Gneiss but before mylonitization. Although the Tonasket Gneiss was regionally metamorphosed to the amphibolite facies, we have not observed evidence of superimposed contact metamorphism adjacent to the granodiorites, and, therefore, we infer that high-grade metamorphism of the Tonasket preceded or accompanied intrusion of the Mission Creek and French Valley bodies. Additionally, dikes within the Mission Creek and French Valley units are not folded, nor are contacts between the Tonasket and the orthogneiss units, indicating that intrusion of these units must chiefly postdate high-grade dynamothermal metamorphism of the Tonasket, although rheologically homogeneous granodioritic intrusions may be resistant to folding. The protoliths of the Mission Creek and French Valley units must in part predate the mylonitization, because the rocks now contain penetrative mylonitic fabrics; however, mylonitization is not likely related to intrusion, as suggested by Waters and Krauskopf (1941), because paragneisses in the quadrangle, as well as to the north throughout much of the Okanogan metamorphic core complex, contain the same mylonitic fabrics (Ross, 1973, 1981; Ross and Christie, 1979; Bardoux, 1985; Parkinson, 1985).

A potassium-argon age of 47.2±1.4 Ma for biotite in the Mission Creek Granodiorite (Fox and others, 1976; table 2) probably denotes postcrystallization cooling below the argon-closure temperature for biotite (about 280°C; Parrish and Roddick, 1985). We

regard this age to be a reflection of Eocene or older regional heating rather than original crystallization. Unpublished uranium-lead data of D.L. Parkinson (written commun., 1987) on the French Valley Granodiorite include discordant zircon analyses that indicate a lower intercept of about 55 Ma, which provides a minimum age estimate of crystallization. These data also include a concordant uranium-lead sphene analysis that probably represents cooling of the unit through 550°C by 50 Ma. These uranium-lead data are, however, statistically poor and probably reflect a complicated polygenetic history (D.L. Parkinson, written commun., 1987). Therefore, we consider the intrusive ages of the Mission Creek and the French Valley Granodiorites to be poorly constrained at this time, and we provisionally assign an age of Cretaceous or Eocene to both of these units.

GRANITIC ROCKS

The southeast part of the Omak Lake quadrangle contains the westernmost exposures of the Eocene Coyote Creek pluton, which is composed of light-colored, porphyritic biotite granite and granodiorite that forms several other plutons within the Colville reservation (Holder and Holder, 1988). The unit is lithologically and probably genetically equivalent to the Keller Butte Granite mapped by Carlson (1993) in the Nespelem 15' quadrangle. Although its contacts are often indistinct because of petrographic similarity, cross-cutting relations indicate that the Coyote Creek pluton intruded the Mission Creek and French Valley Granodiorites. The Coyote Creek also intrudes the hornblende-biotite granodioritic gneiss as wide zones of sharply defined pegmatitic dikes of varying thickness. Coarse potassium-feldspar phenocrysts (less than or equal to

Table 1. Whole-rock major-element analyses of lower-plate (mylonitic) Mission Creek Granodiorite and upper-plate (nonmylonitic) Omak Lake Granodiorite

[Results in wt. %, normalized to 100% minus H₂O and CO₂. Analyses performed by X-ray fluorescence at Washington State University in Pullman (Hansen, 1983b). Data plotted in figure 4]

| Sample No. | Mission Creek Granodiorite (mc) ¹ | | | | | | | | | | | | Omak Lake Granodiorite (ol) | | | |
|--------------------------------|--|-------|--------|--------|--------|--------|-------|--------|--------|--------|--------|--------|-----------------------------|-------|--------|-------|
| | 2A | 4A | 6A | 8A | 10A | 2B | 4B | 6B | 7B | 2C | 4C | 6C | 8C | 31 | 39 | 41 |
| SiO ₂ | 69.99 | 68.57 | 70.68 | 70.31 | 72.10 | 70.35 | 71.03 | 70.24 | 70.05 | 69.60 | 70.65 | 70.17 | 71.37 | 67.87 | 72.83 | 69.04 |
| Al ₂ O ₃ | 17.54 | 18.35 | 17.42 | 17.27 | 16.62 | 17.55 | 16.83 | 17.14 | 17.26 | 17.75 | 17.17 | 17.38 | 16.82 | 16.96 | 15.18 | 16.59 |
| TiO ₂ | 0.36 | 0.37 | 0.32 | 0.34 | 0.28 | 0.34 | 0.33 | 0.33 | 0.35 | 0.36 | 0.35 | 0.33 | 0.31 | 0.53 | 0.27 | 0.39 |
| ² FeO | 1.93 | 1.93 | 1.69 | 1.95 | 1.24 | 1.89 | 1.83 | 1.80 | 2.01 | 2.01 | 1.96 | 2.04 | 1.67 | 3.26 | 1.59 | 2.40 |
| MnO | 0.05 | 0.05 | 0.04 | 0.05 | 0.03 | 0.04 | 0.05 | 0.05 | 0.05 | 0.04 | 0.05 | 0.05 | 0.05 | 0.07 | 0.05 | 0.06 |
| CaO | 3.47 | 3.73 | 3.18 | 3.45 | 2.91 | 3.29 | 3.34 | 3.35 | 3.30 | 3.40 | 3.32 | 3.28 | 3.25 | 3.37 | 2.18 | 2.63 |
| MgO | 0.29 | 0.44 | 1.69 | 0.25 | 0.25 | 0.27 | 0.32 | 0.31 | 0.37 | 0.52 | 0.36 | 0.33 | 0.32 | 1.21 | 0.38 | 0.96 |
| K ₂ O | 1.79 | 1.86 | 1.82 | 1.76 | 2.59 | 2.18 | 1.99 | 2.33 | 2.42 | 2.01 | 1.93 | 2.06 | 2.02 | 3.02 | 4.11 | 4.30 |
| Na ₂ O | 4.46 | 4.52 | 3.09 | 4.47 | 3.88 | 3.96 | 4.11 | 4.31 | 4.03 | 4.20 | 4.04 | 4.22 | 4.09 | 3.49 | 3.29 | 3.46 |
| P ₂ O ₅ | 0.13 | 0.17 | 0.08 | 0.16 | 0.11 | 0.13 | 0.16 | 0.14 | 0.16 | 0.12 | 0.17 | 0.15 | 0.10 | 0.21 | 0.13 | 0.16 |
| Total | 100.01 | 99.99 | 100.01 | 100.01 | 100.01 | 100.00 | 99.99 | 100.00 | 100.00 | 100.01 | 100.00 | 100.01 | 100.00 | 99.99 | 100.01 | 99.99 |

¹Samples from traverses A, B, and C show progressively stronger mylonitic fabrics with increasing sample number.

²All Fe as FeO.

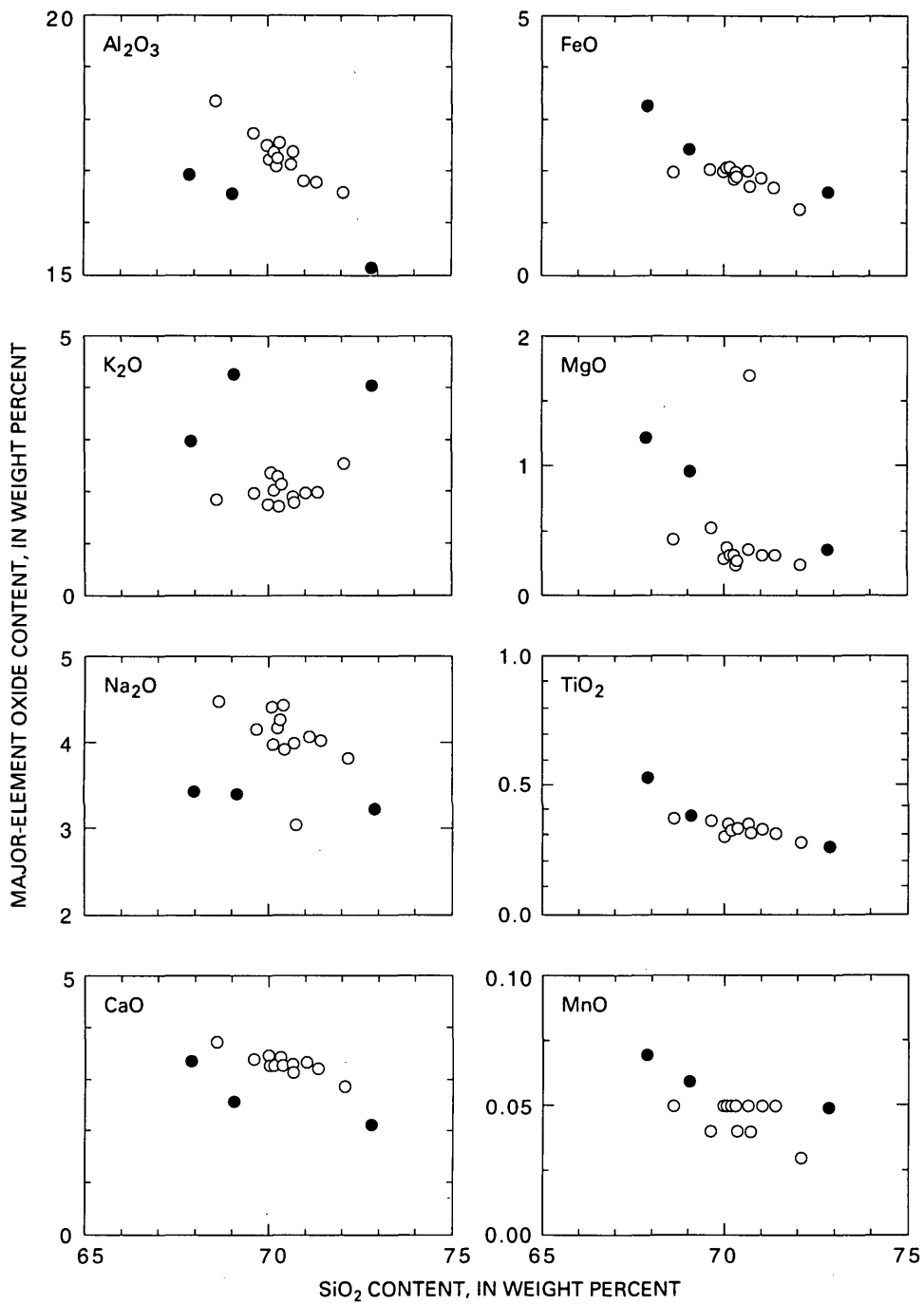


Figure 4. Major-element oxides with respect to SiO₂ for samples of granodioritic rocks from two units within quadrangle. Circles, chemical compositions of lower-plate (mylonitic) Mission Creek Granodiorite; dots, chemical compositions of upper-plate (nonmylonitic) Omak Lake granodiorite. Whole-rock analyses given in table 1.

Table 2. Potassium-argon ages and analytical data from rock units in quadrangle

[Sample location, age, and mineralogy shown on map sheet]

| Sample No. | Latitude | Longitude | Mineral | K ₂ O (wt.%) | Radiogenic ⁴⁰ Ar (10 ⁻¹⁰ mol/g) | (% of total ⁴⁰ Ar) | Age (Ma) |
|---|-----------|------------|------------|-------------------------|---|-------------------------------|----------|
| Mission Creek Granodiorite | | | | | | | |
| ¹ O-425 | 48°23.45' | 119°26.52' | Biotite | 9.45 | 6.50 | 82.9 | 47.2±1.4 |
| Omak Lake Granodiorite | | | | | | | |
| ² HOL-39 | 48°17.63' | 119°25.43' | Biotite | 9.53 | 7.44 | 75 | 53.4±1.3 |
| Reed Creek Quartz Dioritic Orthogneiss of Menzer (1983) | | | | | | | |
| ² HOL-276 | 48°16.71' | 119°26.09' | Biotite | 9.22 | 7.77 | 80 | 57.4±1.4 |
| | | | Hornblende | 1.35 | 1.50 | 57 | 75.2±1.9 |
| Hornblende-biotite granodiorite | | | | | | | |
| ² HOL-277 | 48°19.59' | 119°29.14' | Biotite | 9.42 | 6.71 | 52 | 48.9±1.2 |
| | | | Hornblende | 1.32 | 1.39 | 59 | 72.1±1.8 |

¹Fox and others (1976); age recalculated by Atwater and Rinehart (1984) on the basis of new decay constants.²Atwater and Rinehart (1984).

12 cm), which are characteristic of the Coyote Creek rocks, commonly make up half or more of a dike.

A sample from the Coyote Creek pluton east of the Omak Lake quadrangle yields biotite potassium-argon ages of 50.4±1.5 Ma (Fox and others, 1976; recalculated with new decay constants by Atwater and Rinehart, 1984) and 51.1±1.3 Ma (Atwater and Rinehart, 1984), which are similar to ages from other leucocratic granitic plutons within the Okanogan metamorphic core complex. Although these ages have been interpreted as igneous crystallization ages (Fox and others, 1976, 1977; Atwater and Rinehart, 1984), it is important to consider that they represent only the time at which the rocks cooled below the argon-retention temperature in biotite.

Locally in the Omak Lake 15' quadrangle, and also in the adjoining Boot Mountain and Alameda Flat 15' quadrangles to the south and southeast (Atwater, 1985), rocks of the Coyote Creek pluton display a weak elongation lineation parallel in trend to the mylonitic lineation within the hornblende-biotite granodioritic gneiss. If the elongation lineation in the Coyote Creek rocks resulted from the same mylonitic event that affected other rocks in the Okanogan metamorphic core complex, then the potassium-argon ages from the Coyote Creek pluton indicate that mylonitization took place before 50 Ma.

DIKES

Porphyritic microdiorite dikes, ranging in thickness from 0.5 to 10 m, intrude the hornblende-biotite granodioritic gneiss, the Mission Creek Granodiorite, and the Coyote Creek pluton in the southern part of the quadrangle. The dikes strike north-northeast and generally dip steeply northwest, which is parallel to a regional joint trend and normal to the mylonitic lineation. Chilled contacts and lack of mylonitic

deformation indicate relatively late emplacement of the microdiorite dikes into low-temperature wallrocks after mylonitic deformation. Concordance with regionally developed joints, which probably formed during mylonitic extension, indicates that dike injection occurred along an established fracture system. The dikes are probably magmatically related to the Tertiary volcanic rocks exposed in the Okanogan River valley on the basis of their shallow level of intrusion and postkinematic age of emplacement relative to the ductile deformational event.

ROCKS WEST AND SOUTHWEST OF THE OKANOGAN METAMORPHIC CORE COMPLEX

Rocks west and southwest of the Okanogan metamorphic core complex in the Omak Lake 15' quadrangle are herein subdivided into five lithologic types, from oldest to youngest: (1) high-grade layered paragneiss, presumably correlative with the Salmon Creek Schists and Gneisses of Menzer (1983) and referred to as such herein; (2) hornblende-biotite granodiorite; (3) felsic granitoid rocks, which include the Reed Creek Quartz Dioritic Orthogneiss of Menzer (1983), the granodiorite of Cook Lake, the Omak Lake Granodiorite, and the Coyote Creek pluton; (4) intermediate-composition to felsic volcanic rocks of Eocene age; and (5) the Grande Ronde Basalt of Miocene age.

The paragneiss and the felsic granitoid rocks lithologically resemble rocks within the Okanogan metamorphic core complex and, except for mylonitic deformation, share a common sequence of geologic events. Injection of the hypabyssal microdiorite dikes may have accompanied brittle faulting that produced breccia at the margin of the complex during or soon after mylonitization. After faulting had ceased, Miocene basalt

filled a valley that probably had been cut into one of the fault zones.

PARAGNEISS

In the Omak Lake quadrangle, the Salmon Creek Schists and Gneisses of Menzer (1983) contains layered gneiss, amphibolite, pelite, quartzite, hornblende, and minor metamorphic(?) dunite. Hornblende-biotite gneiss dominates the paragneiss assemblage of the unit. Layers of distinct lithologies range in thickness from 10 to 100 m. A well-developed metamorphic foliation, locally with a mineral lineation, parallels thinner compositional layers. Tight, similar folds¹, ranging in amplitude from 5 cm to 5 m, are found locally, particularly in the schistose rocks. Axial planes parallel both the foliation and the compositional layering along attenuated limbs; fold axes parallel the mineral lineation.

Lenses of dunite, varying in length from tens to hundreds of meters, strike parallel to the foliation of the enclosing rocks. Although the dunite-host contacts are not exposed, the dunite observed nearest to the paragneiss appears unchilled, and the paragneiss lacks contact effects. Therefore, the dunite was probably emplaced as solid serpentinite or dunite before or during metamorphism (Misra and Keller, 1978; Desmarais, 1981).

The Salmon Creek unit may be the less-deformed equivalent of the Tonasket Gneiss within the Okanogan metamorphic core complex; this correlation is based on similarity of lithologic variation within the two units, as well as regional metamorphic grade and style of premylonitic deformation. The Salmon Creek is regionally metamorphosed to the sillimanite zone of the amphibolite facies, and the rocks lack only the penetrative mylonitic fabric present in parts of the Tonasket Gneiss.

FELSIC GRANITOID ROCKS

Five distinct felsic granitoid units intrude the Salmon Creek Schists and Gneisses; the oldest of these units is the hornblende-biotite granodiorite. Intermediate in age are the Reed Creek Quartz Dioritic Orthogneiss of Menzer (1983), the granodiorite of Cook Lake, and the Omak Lake Granodiorite. The youngest granitoid unit, the Coyote Creek pluton, is present both within and outside of the Okanogan metamorphic core complex.

The hornblende-biotite granodiorite, which is the lateral equivalent of rocks mapped previously as the (migmatitic) plutonic complex of Boot Mountain in the Boot Mountain 15' quadrangle to the south (Atwater and Rinehart, 1984), intrudes the Salmon Creek unit along broadly gradational contacts that are subparallel to metamorphic foliation. The rocks are nonlayered to well layered; locally a mineral lineation is developed.

¹Similar fold—A fold in which the layers maintain a constant thickness when measured parallel to the axial plane.

Within the 0.5-km-wide gradational contact zone, both the ratio of hornblende to biotite and the sphene content increase toward the schistose Salmon Creek rocks. The granodiorite commonly includes xenoliths or schlieren, within which foliation parallels the contact with the Salmon Creek. This broad, structurally concordant, partly migmatitic contact zone suggests that the granodiorite intruded the Salmon Creek at a deep crustal level, and probably did so during the final stages of deformation of the Salmon Creek. Discordant potassium-argon ages on the granodiorite of 72.1 ± 1.8 Ma on hornblende and 48.9 ± 1.2 Ma on biotite (table 2) probably record postcrystallization cooling following a Late Cretaceous to early Tertiary thermal event. Nowhere in the quadrangle is the granodiorite in contact with the other felsic granitoid units outside the complex, although it forms xenoliths in the Coyote Creek pluton within the Omak Lake fault zone. These nonmylonitic granodiorite rocks present outside the Okanogan metamorphic core complex appear to us to be lithologically equivalent to the protolith of the mylonitic hornblende-biotite granodioritic gneiss unit within the complex, although the nonmylonitic rocks outside the complex are generally equigranular in texture.

In the Omak Lake quadrangle, the Reed Creek Quartz Dioritic Orthogneiss consists of medium-grained, massive to foliated, subequigranular granodiorite that displays a distinctive bimodal size distribution of biotite grains. It crops out as a large body northeast of the Corkscrew Grade fault zone and as smaller bodies southwest of the fault zone near Patterson Lake. Foliation in the Reed Creek generally parallels the north-northwest-trending metamorphic foliation of the Salmon Creek, as do thin septa of Reed Creek rocks within the Salmon Creek; in addition, the Reed Creek locally grades into the Salmon Creek. These features indicate that the Reed Creek, like the hornblende-biotite granodiorite, was emplaced during the late stages of deformation of the Salmon Creek. Also like the granodiorite, discordant potassium-argon ages of 75.2 ± 1.9 Ma and 57.4 ± 1.4 Ma (table 2) on hornblende and biotite, respectively, probably record Late Cretaceous to early Tertiary cooling of the Reed Creek to temperatures below those required for argon retention in biotite and hornblende (Parrish and Roddick, 1985) rather than original crystallization. Although the Reed Creek is not in contact with the granodiorite, we infer that these two units may possibly be coeval, because they have similar structural trends and internal fabrics, as well as similarly discordant ages.

The granodiorite of Cook Lake crops out only in poorly exposed roadcuts in the southwest part of the quadrangle. The Cook Lake presumably intrudes the Salmon Creek Schists and Gneisses; it also intrudes the Reed Creek Quartz Dioritic Orthogneiss in the Boot Mountain 15' quadrangle to the south (Atwater and Rinehart, 1984). The Cook Lake body appears to be younger than the Salmon Creek, the Reed Creek, and the hornblende-biotite granodiorite units, because the Cook Lake lacks the foliation or compositional layer-

ing indicative of postemplacement strain.

The Omak Lake Granodiorite is here named for exposures at Omak Lake in the Omak Lake 15' quadrangle. The unit crops out along the southwestern shore of the lake in a large, northwest-trending belt adjacent to the Salmon Creek and Reed Creek units. Exposures in roadcuts along the west side of the Omak Lake Road (SW¹/₄ sec. 3, and E¹/₂ sec. 4, T. 32 N., R. 27 E.), which runs along the west shore of Omak Lake (fig. 3), are designated as the type locality of the unit. The Omak Lake unit, which concordantly intrudes the Salmon Creek Schists and Gneisses in the quadrangle, is a coarse-grained rock that contains pink to gray potassium-feldspar megacrysts (1–6 cm) that make up about 5 percent of the rock. Inclusions of hornblende-biotite amphibolite commonly parallel the primary igneous flow foliation, which is marked by elongate but not recrystallized quartz and plagioclase, as well as aligned potassium-feldspar megacrysts and biotite (table 3). This igneous flow foliation parallels the Omak Lake-Salmon Creek contact. Hornblende is present only near amphibolite inclusions, and the sphene content increases near the inclusions. Medium-grained equigranular alaskite that cuts the Omak Lake rocks may be a related border-zone plutonic phase, for it is found primarily along the Omak Lake-Salmon Creek contact. Pegmatite veins as wide as 0.5 m, which contain graphic intergrowths, coarse (2–4 cm) biotite laths, and rare red garnet, intrude both the Omak Lake body and the alaskite.

The Omak Lake Granodiorite is both lithologically and chemically similar to the Mission Creek Granodiorite present within the Okanogan metamorphic core complex; however, it differs texturally from the Mission Creek in that the Omak Lake lacks a mylonitic fabric. The Omak Lake shows only slight major-element differences from the Mission Creek (table 1), and it also exhibits similar variations relative to SiO₂ (fig. 4). The Omak Lake is slightly enriched in K₂O, FeO, MgO, and MnO, and it is depleted in Al₂O₃, Na₂O, and CaO. The Omak Lake and the Mission Creek Granodiorites also have similar potassium-argon ages on biotite of 53.4±1.3 Ma and 47.2±1.4 Ma (table 2), respectively. These ages probably do not record the time of primary igneous crystallization; rather, they record the time of cooling through the argon-retention temperature of biotite (Parrish and Roddick, 1985). Thus, we provisionally assign an age of Cretaceous or Eocene to the Omak Lake Granodiorite.

The Coyote Creek pluton is found both inside and outside of the Okanogan metamorphic core complex. In the Bull Pasture area, located just inside the margin of the complex in the southernmost part of the quadrangle (fig. 3), the Coyote Creek rocks display elongate quartz eyes in discrete, nonpenetrative mylonitic bands; in these bands, the mylonitic foliation and lineation parallel the structural fabrics of the complex. Elsewhere in the southern part of the complex outside of the quadrangle, the Coyote Creek rocks generally lack a ductile-shear fabric; however, as far south

as the Columbia River, located about 15 km south of the quadrangle, the rocks contain shear bands that are found chiefly within 1 to 2 km of a fault zone that is approximately tangent to the pluton margin (Atwater, 1985). Within the Omak Lake valley, as well as in the Bull Pasture area, the Coyote Creek rocks are thoroughly brecciated along fault zones that mark the southwest boundary of the Okanogan metamorphic core complex. Additionally, the rocks contain inclusions of the hornblende-biotite granodiorite in both of these areas. Within the complex, the Coyote Creek body lacks the strong mylonitic fabrics of the other units that it intrudes, as was outlined earlier; in addition, the pluton is strongly brecciated along the Okanogan Valley fault system which marks the boundary of the complex. Thus, the Coyote Creek pluton probably intruded after the peak of mylonitization that is recorded within the Okanogan metamorphic core complex but before the termination of brittle faulting along the margin of the complex.

VOLCANIC ROCKS

Volcanic rocks, consisting of flows and flow breccias, are surrounded by Quaternary gravel deposits in the Okanogan River valley. These rocks are lithologically similar to other intermediate-composition and silicic Tertiary volcanic rocks that are exposed outside the quadrangle toward the west and further north along the Okanogan River. The flows may be correlative with flows mapped as the Eocene dacite of Carter Mountain (Rinehart and Fox, 1976) in the Conconully 15' quadrangle. The age of eruption of these volcanic rocks relative to that of the brittle deformation along the Okanogan fault zone is unclear.

Flood basalts of the Columbia River Basalt Group cover bedrock in the southwestern corner of the map area. Swanson and others (1979) assigned these flows to the Grande Ronde Basalt, which is chiefly tholeiite of early and middle Miocene age. The flows are horizontal and apparently undeformed, and they presumably cover Miocene topography; locally, the flows incorporate poorly consolidated terrigenous sand at their bases. Thus, the finger of basalt that is present west of Omak Lake may occupy a paleovalley that formed along the Corkscrew Grade fault zone. The basalt here lies parallel to concealed parts of the Corkscrew Grade fault zone, and it lies at topographic levels that are equivalent to or higher than the glacial drift that covers the fault zone.

SURFICIAL DEPOSITS

Holocene alluvium fills a number of river and creek drainages and is also found along the northeast side of Omak Lake. Coalesced alluvial fan deposits are common along the east side of the Okanogan River valley, where they either form aprons that slope up eastward against steeply west dipping foliated rocks

Table 3. Summary of mineral modes for plutonic and metaplutonic rocks in quadrangle
[Modes counted on stained slabs; Q, quartz; K, potassium feldspar; P, plagioclase; M, mafic minerals]

| Sample No. | Q | K | P | M | Number of points | Sample No. | Q | K | P | M | Number of points |
|---------------------------------|------|------|------|------|------------------|--|------|------|------|------|------------------|
| Coyote Creek pluton (Tcc) | | | | | | Mission Creek Granodiorite (mc) | | | | | |
| OL-85-31 | 23.2 | 17.1 | 56.9 | 2.8 | 1124 | SS-328 | 21.1 | 17.9 | 53.0 | 8.0 | 498 |
| O-85-8 | 24.0 | 17.9 | 55.6 | 2.6 | 1006 | SS-149 | 20.8 | 19.6 | 53.9 | 5.7 | 336 |
| OL-85-32A | 27.3 | 25.1 | 42.7 | 4.9 | 990 | O-85-1-1 | 26.5 | 20.8 | 50.4 | 2.4 | 1096 |
| OL-85-32B | 27.0 | 5.9 | 59.3 | 7.8 | 1063 | O-85-1-2 | 28.4 | 24.5 | 45.9 | 1.2 | 1050 |
| OL-85-32C | 20.4 | 14.5 | 60.6 | 4.5 | 1031 | OL-85-20A | 25.7 | 11.6 | 57.6 | 5.0 | 1034 |
| OL-85-18 | 21.8 | 9.2 | 64.6 | 4.4 | 912 | OL-85-20B | 28.1 | 13.6 | 54.2 | 4.2 | 1084 |
| AF-85-1 | 16.4 | 10.8 | 68.3 | 4.4 | 1042 | SM-1 | 22.9 | 8.4 | 63.3 | 5.4 | 1112 |
| Average | 22.9 | 14.4 | 58.3 | 4.5 | | HOL-92 | 25.3 | 8.8 | 64.5 | 1.4 | 1015 |
| Omak Lake Granodiorite (ol) | | | | | | HOL-18 | 24.6 | 10.4 | 62.3 | 2.7 | 1082 |
| HOL-34A | 25.5 | 28.8 | 34.0 | 11.7 | 1134 | OL-85-1 | 23.8 | 12.4 | 59.0 | 4.8 | 1081 |
| HOL-39 | 28.0 | 22.1 | 40.8 | 9.1 | 1098 | OL-85-33 | 20.9 | 11.4 | 64.9 | 2.8 | 1015 |
| HOL-72 | 26.7 | 48.8 | 21.0 | 3.5 | 1000 | OL-85-24 | 24.5 | 9.5 | 60.7 | 5.4 | 1009 |
| HOL-129A | 27.9 | 38.4 | 29.5 | 4.2 | 1000 | OL-85-23 | 25.2 | 14.4 | 57.8 | 2.6 | 1008 |
| OL-85-21 | 23.7 | 18.2 | 46.4 | 11.6 | 939 | OL-85-6 | 25.0 | 8.7 | 59.2 | 7.1 | 1062 |
| Average | 26.4 | 31.3 | 34.3 | 8.0 | | OL-85-28B | 21.1 | 12.4 | 62.3 | 4.2 | 1018 |
| French Valley Granodiorite (fv) | | | | | | OL-85-16 | 19.9 | 19.0 | 57.6 | 3.5 | 991 |
| OL-85-13A | 24.4 | 21.6 | 52.4 | 1.6 | 1058 | OL-85-12 | 23.0 | 16.7 | 57.6 | 2.7 | 1051 |
| OL-85-13B | 22.5 | 14.2 | 58.6 | 4.6 | 1035 | OL-85-11 | 25.0 | 16.4 | 55.6 | 3.0 | 1005 |
| HOL-20 | 25.7 | 5.6 | 62.9 | 5.8 | 1034 | OL-85-14 | 22.9 | 33.8 | 42.3 | 1.1 | 1045 |
| GCS-69 | 29.7 | 9.7 | 56.4 | 4.2 | 1018 | OL-85-10 | 24.2 | 24.2 | 49.1 | 2.5 | 1078 |
| OL-85-2 | 19.6 | 3.4 | 70.9 | 6.1 | 1131 | OL-85-9 | 20.9 | 14.1 | 60.1 | 4.9 | 1015 |
| OL-85-25 | 24.7 | 2.1 | 66.8 | 6.4 | 1064 | OL-85-8 | 25.4 | 19.3 | 49.9 | 5.4 | 980 |
| OL-85-3 | 22.7 | 5.5 | 65.9 | 5.8 | 1048 | OL-85-7 | 24.7 | 10.4 | 62.4 | 2.5 | 1049 |
| OL-85-4 | 24.1 | 17.1 | 55.5 | 3.2 | 1027 | HPH-1 | 26.2 | 12.8 | 59.3 | 1.7 | 1010 |
| OL-85-5-1 | 21.8 | 15.5 | 58.2 | 4.4 | 1013 | Average | 24.0 | 15.5 | 56.8 | 3.8 | |
| OL-85-5-2 | 18.0 | 5.0 | 69.9 | 7.1 | 1003 | Hornblende-biotite granodioritic gneiss (gg) | | | | | |
| OL-85-30 | 26.2 | 22.2 | 48.7 | 2.9 | 971 | HOL-90 | 21.4 | 21.5 | 52.8 | 4.2 | 1018 |
| OL-85-26 | 23.9 | 6.6 | 62.1 | 7.5 | 1005 | OL-85-17 | 31.5 | 26.9 | 40.5 | 1.1 | 1040 |
| OL-85-27 | 24.9 | 22.4 | 47.8 | 4.9 | 1021 | BM-85-1 | 13.9 | 7.3 | 62.9 | 15.9 | 1017 |
| OL-85-28A | 28.4 | 12.7 | 55.3 | 3.6 | 1018 | Average | 22.3 | 18.6 | 52.1 | 7.1 | |
| OL-85-29A | 22.0 | 17.9 | 57.7 | 2.4 | 983 | Hornblende-biotite granodiorite (ggd) | | | | | |
| OL-85-29B | 10.8 | 3.7 | 77.9 | 7.5 | 1079 | HOL-118A | 18.8 | 23.3 | 46.5 | 11.4 | 996 |
| Average | 23.1 | 11.6 | 60.4 | 4.9 | | HOL-118B | 26.0 | 22.0 | 43.5 | 8.5 | 1093 |
| | | | | | | Average | 22.4 | 22.7 | 45.0 | 10.0 | |

of the Okanogan metamorphic core complex or are inset below glacial terraces. Small bodies of cemented alluvium border parts of the northeast edge of Omak Lake; bedding in this alluvium has a primary shallow southwest dip toward the lake (NE $\frac{1}{4}$ sec. 3, T. 32 N., R. 27 E.). Glacial drift covers much of the quadrangle and consists of four principal kinds of deposits: (1) lodgement till, mainly in the area between Omak and Mission Creeks; (2) glaciofluvial deposits, mostly sand and gravel along the present course of the Okanogan River; (3) thinly bedded and laminated lacustrine silt

and clay found in broad valleys of streams such as Tunk, Wannacott, Omak, and Nason Creeks; and (4) recessional-moraine deposits, which consist of poorly sorted sand and gravel that form elongate ridges in the areas near Omak and Mission Creeks, as well as above Miocene basalt in the Mirror Lake area in the southwest part of the quadrangle. Along the east side of the Okanogan River, the glaciofluvial deposits form pronounced terraces that may represent relict ice-marginal deposits formed along the eastern edge of the Okanogan lobe of the Cordilleran ice sheet (Pine, 1985). Surficial

deposits in the northwest part of the quadrangle are partly generalized from the detailed mapping of Minard (1985).

METAMORPHISM

Metamorphism is one of the most significant aspects of the petrotectonic evolution of the rocks that make up the Okanogan metamorphic core complex in the Omak Lake 15' quadrangle. In the view of Fox and others (1977), high-grade metamorphism and concomitant plutonism culminated in the emplacement of the complex by largely diapiric processes. Hansen and Goodge (1988) proposed that metamorphism of crystalline rocks within the complex accompanied midcrustal, east-directed overthrusting and crustal thickening during accretion of parautochthonous terranes, whereas younger magmatism accompanied tectonic unroofing of the crystalline complex.

Rocks that are chiefly a product of high-grade metamorphism lie in the northern third of the quadrangle (Tonasket Gneiss) and also west of Omak Lake (Salmon Creek Schists and Gneisses). The sections that follow briefly outline key phase relations and textural observations that constrain the grade and conditions of metamorphism in the Tonasket and Salmon Creek lithologic assemblages. The petrology and significance of the rocks of the Tonasket Gneiss are discussed in greater detail by Waters and Krauskopf (1941), Snook (1965), Fox and others (1976, 1977), and Hansen and Goodge (1988), although these interpretations differ as to the relation between metamorphism and the formation of the Okanogan metamorphic core complex. A more thorough treatment of the metamorphism of the Salmon Creek rocks is provided by Menzer (1983).

TONASKET GNEISS

The Tonasket Gneiss is composed largely of biotite gneiss and hornblende-biotite layered gneiss and has subordinate pelitic, amphibolitic, and calc-silicate lithologies (metamorphic phase assemblages present in these various lithologies are summarized in figure 5). The dominant intermediate-composition gneiss rock type typically contains hornblende+biotite+plagioclase+quartz, in addition to sphene and an iron-titanium oxide. Mafic rocks, generally amphibolites, typically contain pargasitic hornblende+plagioclase±diopside±garnet±biotite, in addition to quartz, sphene, and an iron-titanium oxide. Pelitic schists contain quartz+potassium feldspar+albite+biotite+sillimanite+garnet±muscovite+iron-titanium oxide, where muscovite most commonly has reacted to form sillimanite+potassium feldspar. Calc-silicate gneisses contain quartz+calcite+plagioclase+diopside ±meionitic scapolite±idocrase. These high-grade peak metamorphic assemblages are to a variable degree overprinted by lower-grade assemblages that formed during postmetamorphic ductile and brittle deformation along the margin of the

| PHASE \ UNIT | TONASKET GNEISS | SALMON CREEK SCHISTS AND GNEISSES |
|--|-----------------------|-----------------------------------|
| Amphibolites | | |
| Quartz | — | — |
| Plagioclase | — | — |
| Clinopyroxene | — | — |
| Ca-amphibole | — | — |
| Garnet | — | — |
| Biotite | — | — |
| Sphene | — | — |
| Fe-Ti oxide | — | — |
| Hornblende-biotite granodioritic gneiss | | Lithology not present |
| Quartz | — | |
| Plagioclase | — | |
| Orthoclase | — | |
| Ca-amphibole | — | |
| Biotite | — | |
| Fe-Ti oxide | — | |
| Pelitic rocks | | |
| Quartz | — | — |
| Plagioclase | — | — |
| Orthoclase | — | — |
| Muscovite | — | — |
| Biotite | — | — |
| Garnet | — | — |
| Sillimanite | — | — |
| Fe-Ti oxide | — | — |
| Calc-silicate rocks | | |
| Quartz | — | — |
| Calcite | — | — |
| Plagioclase | — | — |
| Clinopyroxene | — | — |
| Wollastonite | — | — |
| Ca-amphibole | — | — |
| Ca-garnet | — | — |
| Zoisite | — | — |
| Scapolite | — | — |
| Idocrase | — | — |
| Ultramafic rocks | Lithology not present | |
| Olivine | — | — |
| Orthopyroxene | — | — |

Figure 5. Metamorphic phase-assemblage diagram of different lithologies in the Tonasket Gneiss and the Salmon Creek Schists and Gneisses of Menzer (1983) (data compiled from: Goodge, 1983b; Hansen, 1983b; Menzer, 1983; this study). Solid line indicates that phase is ubiquitous; dashed line indicates trace abundances. All phases listed for a given lithology do not necessarily all coexist.

Okanogan metamorphic core complex (Hansen and Godge, 1988).

Peak metamorphism of the Tonasket Gneiss in the quadrangle reached upper amphibolite-facies conditions, as suggested by the presence of: (1) sillimanite and muscovite in equilibrium with biotite and garnet in pelitic schist; (2) hornblende in equilibrium with biotite and intermediate-composition plagioclase in hornblende-biotite gneiss; and (3) hornblende in equilibrium with intermediate-composition plagioclase in thin amphibolite units. Plagioclase compositions generally vary from oligoclase to andesine. These criteria suggest minimum metamorphic temperatures of about 600°C and metamorphic pressures unconstrained (Apted and Liou, 1983).

Snook (1965), citing mineralogical evidence in rocks he termed "basic gneisses," inferred that the Tonasket Gneiss just north of the quadrangle was metamorphosed to the granulite facies before an amphibolite-facies metamorphism. Within the quadrangle, however, we have found no evidence of a predecessor granulite-facies metamorphism, such as the presence of orthopyroxene in phase assemblages of basaltic rocks (Miyashiro, 1973).

SALMON CREEK SCHISTS AND GNEISSES

The Salmon Creek Schists and Gneisses of Menzer (1983) is chiefly composed of hornblende-biotite gneiss and also contains amphibolite, pelitic schist, and marble or calc-silicate gneiss. These rocks contain metamorphic phase assemblages that resemble those of the Tonasket Gneiss (fig. 5). Mineral assemblages in the Salmon Creek rocks indicate peak metamorphic conditions in the amphibolite facies (Miyashiro, 1973; Hyndman, 1985). Metamorphic fabrics include a well-developed foliation, which consists of parallel compositional layering and schistosity, and a mineral lineation, which is defined by amphibole, biotite, and sillimanite. Locally, this lineation is parallel to the axes of tight to isoclinal, similar folds, suggesting that deformation occurred, at least, in part during metamorphism.

Overall, the rock types, metamorphic mineral assemblages, and synmetamorphic structures in the Salmon Creek rocks are very similar to those in the Tonasket Gneiss within the Okanogan metamorphic core complex. We interpret these features to be an indication of a similar origin and evolution of the high-grade metamorphic rocks, now represented by the Tonasket and Salmon Creek units, in deep parts of a crystalline Okanogan terrane prior to Tertiary crustal extension. This high-grade terrane was subsequently dismembered during uplift of the Okanogan metamorphic core complex; during this later event, ductile (mylonitic) flow and brittle normal faulting displaced the Salmon Creek rocks westward relative to the Tonasket Gneiss, which remained in a lower-plate position within the complex.

STRUCTURE

Diverse structural features within the rocks of the

Omak Lake 15' quadrangle record a complicated, multistage deformational history related to evolving regional tectonic events. Structural features discussed in this report include the following (inferred from oldest to youngest): (1) mesoscopic folds in the layered Tonasket Gneiss, interpreted to have formed during high-grade metamorphism; (2) ductile normal faults; (3) mylonitic fabrics, which were formed during simple-shear-dominated ductile deformation; (4) map-scale upright folds that warp the mylonitic fabrics; (5) fault zones, which mark the western boundary of the Okanogan metamorphic core complex, that formed by brittle fracturing and brecciation; and (6) subvertical joints, which strike perpendicular to the inferred direction of tectonic transport during extension of the crystalline rocks in the core of the complex.

SYNMETAMORPHIC FOLDS

Mesoscopic folds in the Tonasket Gneiss formed during amphibolite-grade regional metamorphism. These outcrop-scale folds are found chiefly in the layers of hornblende-biotite gneiss, but they are also found locally throughout the rest of the Tonasket exposures and are well displayed in the vicinity of Omak Mountain. They are similar folds that generally have amplitudes varying from several centimeters to several meters. Typically, the fold axes plunge gently east and the axial planes dip steeply south. These mesoscopic fold profiles indicate a northeast direction of fold vergence not otherwise discernable from larger scale fold patterns.

Folding of metamorphic foliation and schistosity, as well as the formation of fold axes perpendicular to mineral lineation, indicate that folding accompanied metamorphism. However, some rocks contain microscopic recrystallized polygonal arcs of biotite around fold hinges; some also contain a weak axial-plane schistosity. These features indicate that regional metamorphism partly outlasted the latest stages of folding.

Mesoscopic folds are also present in upper-plate rocks of the Salmon Creek Schists and Gneisses west of Omak Lake. These tight, similar folds have steep axial surfaces, and their fold axes, which plunge moderately north-northwest, are colinear with a mineral lineation.

DUCTILE NORMAL FAULTS

Ductile normal faults deform the Tonasket Gneiss at structural levels below the most strongly formed mylonite in the Okanogan metamorphic core complex. These ductile structures are found mainly in Tonasket rocks east of Omak Mountain, although they are not shown on the map sheet. They strike east-northeast and dip steeply southward, forming narrow (1-4 cm) shear bands that offset metamorphic layering and mineral foliation. Ductile normal faults in the quadrangle consistently show south-side-down movement, as inferred from the asymmetry of shear bands (Platt and Vissers, 1980) and the presence of southeast-downdropped am-

phibolite boudins in hornblende-biotite gneiss. In most cases, continuity of thin layers is preserved across the shear bands, although individual layers may be extremely attenuated. Locally, ductile normal faults disrupt limbs of similar folds, indicating that ductile normal faulting postdates the folding that accompanied high-grade metamorphism.

We know of no field observations that relate ductile normal faulting to the formation of postmetamorphic mylonitic fabrics. Although both the ductile normal faults and the mylonitic fabrics discussed below probably formed at midcrustal conditions, we found no compelling evidence that the two types of structures formed at the same time.

MYLONITIC FABRIC

A penetrative mylonitic-gneiss fabric dominates the structural form of rocks within the Okanogan metamorphic core complex. A zone of mylonitic gneiss, 1.0 to 1.5 km thick, conforms to the perimeter of the complex and forms "flat-iron"-like aprons that dip westward into the Okanogan River valley. Intensity of mylonitic deformation decreases from the border to the interior of the complex and also southward along that border near the south end of Omak Lake. The shaded line on the map sheet identifies the lowest structural level at which mylonitic fabric is recognizable in the field; this boundary is gradational between mylonitic rocks west of its trace and nonmylonitic rocks to the east. We believe the mylonite zone continues as a westward-flattening structure beneath nonmylonitic upper-plate rocks exposed toward the west.

Mylonitic orthogneiss in the Mission Creek and French Valley units contains a moderately well developed foliation and a strongly developed lineation. Zones rich in quartz alternating with layers of biotite and feldspar define a penetrative, planar, compositional mylonitic foliation (S). Within the foliation plane, streaks of quartz, biotite, and plagioclase define a penetrative stretching lineation (L_1), which trends approximately N. 60° W. throughout the quadrangle. Blocky, elongate potassium-feldspar megacrysts commonly display quartz-filled, subvertical fractures oriented normal to L_1 in the plane of foliation.

In the mylonitic Tonasket Gneiss, subequant to elliptical feldspar grains (2–8 mm) exhibit augenlike shapes, which are particularly apparent where wrapped by fine-grained biotite sheaths that pinch out in tails within the foliation plane. This texture is quite distinct from the blastic mineral textures shown in the nonmylonitic Tonasket Gneiss toward the interior of the complex. The geometric relation between mylonitic fabric and mesoscopic folds also differs. In the mylonitic domain, the mylonitic foliation forms a strong axial-plane schistosity that crosses fold-hinge profiles, and mineral lineation lies parallel to fold axes, whereas in structurally deeper nonmylonitic gneisses, schistosity and layering are most commonly folded in the absence of an axial-plane schistosity. Thus, fold geometry in

mylonitic gneisses is controlled by the orientation of shear fabrics, whereas the fabrics of nonmylonitic gneisses (mostly restricted to mineral alignment) are dependent on fold geometry.

Microscopic textures common to mylonitic rocks in the quadrangle include the following: rounded and fractured feldspar grains, commonly displaying tails of recrystallized feldspar or quartz pressure shadows; very fine grained (less than 0.25 mm), disaggregated and attenuated biotite; and fine-grained undulose quartz showing both grain-shape and lattice preferred orientation, as well as recrystallized grains and ribbon textures locally. In sections normal to S and parallel to L_1 , traces of variably developed, nonpenetrative shear planes (C) cross the mylonitic foliation (fig. 6). C strikes parallel to S but consistently dips more steeply northwestward by 15° to 45°, defining a fabric asymmetry; the intersection of C and S is normal to L_1 . Aligned and smeared, very fine grained biotite coats C and marks a second, nonpenetrative slickenside lineation (L_2), which is parallel in trend to L_1 although it plunges more steeply west. The mylonitic fabric is uniformly monoclinic: the plane of symmetry is perpendicular to foliation S and contains both the pen-

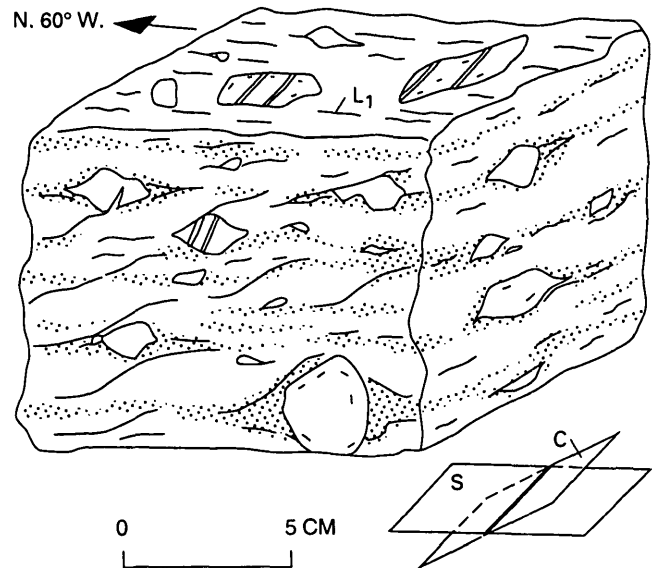


Figure 6. Generalized S-C fabric relations in mylonitic orthogneiss of Okanogan metamorphic core complex. Primary planar fabric elements are semicontinuous compositional layers (S) and discontinuous, discrete shear planes (C); each contains a mineral elongation lineation (L_1 and L_2 , respectively), but only L_1 is shown within S. In mylonitic gneisses, C consistently dips more steeply northwest than S. S is defined by alternating layers that are rich in quartz (white) and mica (stippled) and that also contain coarse-grained, blocky potassium-feldspar megacrysts; in addition, megacrysts may contain quartz-filled fractures (parallel lines), which are oriented normal to L_1 .

etrative and the slickenside lineations; the monoclinic 2-fold axis of rotation is perpendicular to the mylonitic lineation and parallel to the mylonitic foliation. The monoclinic fabric geometry is consistent throughout the quadrangle where S and C planes are found.

In mylonite of the Okanogan metamorphic core complex, S is the most conspicuous foliation; rocks generally fracture along this subplanar, penetrative foliation. C planes, commonly spaced 3 to 20 mm apart, are more difficult to observe in the field; they are sharp, discrete, nonpenetrative, biotite-coated surfaces, commonly 1 to 5 cm long as seen in sections perpendicular to S and parallel to lineation. C is best developed high in the structural sequence where mylonitic fabric is strongest. The French Valley and Mission Creek units best display S-C fabrics, which are distinguishable in the Tonasket Gneiss only locally.

The relative orientations of S and C provide a reliable indication of shear sense during formation of the mylonitic fabric (Berthé and others, 1979; Simpson and Schmid, 1983; Lister and Snoke, 1984). The sense of movement is that by which C deforms S, or in which shear along C is concurrent with stretching in S. (Locations where kinematic interpretations were made using S-C methods are shown on the map sheet). S-C planes in the Okanogan metamorphic core complex consistently indicate top-to-the-west tectonic movement that is parallel to the elongation lineation L_1 during mylonitic deformation. Therefore, mylonite exposed in the Omak Lake quadrangle formed when upper-plate rocks were displaced in a direction of N. 60° W. relative to lower-plate rocks, with respect to present geographic coordinates. Locally, other kinematic indicators, such as mica fish, shear bands, and quartz grain-shape preferred orientation (Simpson and Schmid, 1983; Lister and Snoke, 1984) record a similar shear sense.

UPRIGHT MEGASCOPIC FOLDS

The mylonite zone as defined by mylonitic foliation S is warped into shallowly northwest plunging, upright folds (shown on the map sheet and on cross section A-A' as a large-scale antiform and synform). Plunge of these broad warps is less than 10°. Fold axes parallel regional trends of the unidirectional mylonitic lineation and, hence, may be "A" folds (Mattauer, 1975), if they formed during mylonitization with axes parallel to the direction of tectonic transport.

FAULT ZONES

Snook (1965) mapped two large faults, the Okanogan Valley and Omak Lake faults, that border the Okanogan metamorphic core complex in the western part of the quadrangle. Our mapping shows these structures to be prominent, 250- to 900-m-thick fault zones that contain tectonic breccia. We delineate three principal zones, the Okanogan Valley, the Omak Lake, and the Corkscrew Grade fault zones, which, although partly covered locally, probably make up a single fault sys-

tem that bifurcates to the south in the vicinity of Corkscrew Grade. This fault system forms a continuous zone of extensive fracturing, brecciation, and chloritic alteration and defines the southwestern and western margins of the Okanogan metamorphic core complex. The degree of brecciation varies considerably; locally, blocks of coherent undeformed rocks as large as 1 km by 0.25 km crop out within a brecciated, light-pink to green matrix of unknown protolith. Both hanging wall and footwall rock units are pervasively brecciated within the wide zones shown on the map sheet.

Breccias of the Okanogan Valley fault zone crop out near the western border of the complex along the axis of the northwest-plunging synform located near the mouth of Wannacott Creek. Within the synform, the rocks grade structurally upward from coherent mylonitic granodiorite to microfractured, brecciated, and chloritized rocks of the same protolith. The zone of brecciation and alteration in the Wannacott Creek synform is subparallel to the mylonitic foliation, which dips gently west.

Breccias and discrete faults of the Omak Lake fault zone are exposed in both the valley northwest of Omak Lake and along the northeast shore of Omak Lake northwest of Poison Oak Creek. Northeast of Omak Lake in the Bull Pasture area (fig. 3), the Omak Lake fault zone passes through nonmylonitic rocks of the hornblende-biotite granodiorite and the Coyote Creek pluton. Northwest of Omak Lake, the fault zone cuts mylonitic orthogneiss of the Mission Creek Granodiorite and nonmylonitic granite of the Coyote Creek pluton. An elongate exposure of nonbrecciated rock that is surrounded by Quaternary valley fill contains tectonically mixed rocks of the Coyote Creek pluton and the hornblende-biotite granodiorite unit (labeled on map sheet as "Tcc+ggd"). We interpret this exposure as a domain of relatively coherent rocks that is enveloped by more strongly tectonized fault-zone breccias; in this sense, it is analogous to a fault horse.

Brecciation and mineral alteration indicate that deformation along Omak Lake fault zone occurred in a brittle, low-temperature environment. Orientations of the most prominent, parallel, gouge-filled fractures, as well as the trace of the fault zone over topography, indicate that the zone strikes northwest and dips 45° to 60° to the southwest. In field exposures, however, the randomly oriented slickensides, which are ubiquitous, convey neither a consistent sense of offset nor measure of movement within the fault zone.

Quaternary glacial deposits of sand and gravel, which are mapped northeast of the flood-basalt exposures near Mirror and Patterson Lakes, fill a valley along Cold Spring Road that probably conceals a zone of brecciation that extends southward from fault-zone exposures along the Corkscrew Grade. The Corkscrew Grade fault zone postdates intrusion of the Coyote Creek pluton but is older than eruption of the Miocene basalt that flowed into the eroded fault valley farther south. In several locations (for example, near the mouth of Wannacott Creek and in the valley northwest of Omak

Lake), fault-zone breccias contain mylonitic clasts, indicating that mylonitic deformation predates brecciation.

A large valley extends from the northern end of Omak Lake northward to St. Marys Mission. The valley is marked by steep walls, particularly on the west side, and it trends generally parallel to the Omak Lake fault zone. No significant breccias have been observed along this valley, and the Mission Creek-French Valley contact does not appear to be offset across it. It is likely that this valley represents a structural zone, either a small-displacement fault or a joint, that has been preferentially scoured by glacial ice.

In the Omak Lake quadrangle, the system of fault zones that marks the western border of the Okanogan metamorphic core complex forms a structural detachment between lower-plate mylonitic rocks within the complex and nonmylonitic upper-plate rocks outside the complex. Structural relations of the type described in the quadrangle also continue northward along the western border of the Okanogan metamorphic core complex from Washington into British Columbia (Tempelman-Kluit and Parkinson, 1986); seismic evidence suggests that this regionally extensive detachment zone dips moderately west beneath upper-plate rocks (Potter and others, 1986).

JOINTS

Many north-northeast-trending, steep tension fractures and joints cut the mylonitic fabric of the Okanogan metamorphic core complex approximately normal to the mylonitic lineation. At outcrop scale, tapered tension gashes are typically less than 0.5 cm wide and commonly contain chlorite, epidote, quartz, and zeolite. Joints, mapped mostly from aerial photographs but also verified in the field, are deeper and wider at the surface toward the western edge of the complex and become less prominent in the interior to the east, suggesting either greater extension or more brittle deformation toward the margin of the complex. Like mylonitic foliation, joints are better exposed on southwest-facing slopes. Many joint surfaces are slickensided; one shows a small amount of displacement, having a west-side-downdropped sense of offset. Some joints are intruded by microdiorite dikes, none of which display mylonitic fabrics. Consistently oriented approximately perpendicular to the mylonitic lineation, the joints may represent the latest stages of deformation as a result of extension parallel to mylonitic lineation.

GEOLOGIC HISTORY

INTERPRETATION OF POTASSIUM-ARGON AGES

A great number of potassium-argon ages have been reported for plutonic, volcanic, and metamorphic rocks of the region that surrounds and includes the Okanogan

metamorphic core complex (Fox and others, 1976, 1977; Armstrong and others, 1977; Atwater and Rinehart, 1984); several of these ages are included in this report (table 2). Previous interpretations that potassium-argon ages on the plutonic and metamorphic rocks of this region record ages of emplacement or crystallization are suspect; recent documentation has shown that the potassium-argon system was thermally disturbed in nearby regions at least in early Tertiary time (Mathews, 1983; Archibald and others, 1984). Not only is the potassium-argon system easily reset or disturbed, but different minerals exhibit closure to loss of argon over a wide range of temperatures (Parrish and Roddick, 1985; Ghent and others, 1988). Therefore, cooling ages in minerals such as biotite probably best reflect a nonlinear average of time over which the mineral began to retain, and finally completely retained, argon.

Discordant biotite and hornblende ages on plutonic and metaplutonic rocks of the Okanogan metamorphic core complex most likely reflect differences in the argon-closure temperature for each of these minerals and, in addition, manifest the thermal complexities noted above. The significance of these ages is questionable, but, in general, the ages may indicate a Late Cretaceous to early Tertiary period of cooling from elevated temperatures that resulted from magmatism and (or) crustal thickening. If the potassium-argon system was not disturbed, Eocene ages on metamorphic rocks may either reflect reheating by plutons or simply cooling from midcrustal temperatures during Eocene uplift. Therefore, these potassium-argon ages should probably not be considered as the age of an early Tertiary metamorphism, but rather that they collectively point to a general period of thermal subsidence.

SUMMARY OF GEOLOGIC EVENTS

The oldest units exposed in the quadrangle, in terms of both their protolith ages and the timing of formation of their characteristic structures, are the Tonasket Gneiss and the Salmon Creek Schists and Gneisses of Menzer (1983). The variation in lithology as well as the presence of minor pelitic schist, quartzite, and calc-silicate rocks indicate that the major parts of the Tonasket and the Salmon Creek are of sedimentary origin. Metamorphic dunite, present locally in the Salmon Creek unit, probably is not a part of the original sequence of rocks but may reflect the tectonic incorporation of deep-crustal material during metamorphism and deformation. In view of their similarities in lithology, especially in metamorphic grade and fabric, we speculate that both paragneiss units belong to an initially coherent sequence of metamorphic rocks that have the same sedimentary ancestry; their age of deposition is pre-Cretaceous, possibly as old as pre-Middle Jurassic(?).

Deformation of the Tonasket and Salmon Creek units coincided with and also followed upper amphibolite-facies metamorphism. Synmetamorphic deformation

is defined by a well-developed foliation and mineral lineation, and its latest stages produced tight folding of foliated gneiss throughout the region. The grade of metamorphism, style of folding, and sense of vergence of folds are consistent with the many east-vergent structures that developed in parts of the Shuswap Metamorphic Complex during Middle Jurassic time (Reesor, 1965; Wheeler, 1965; Hyndman, 1968; Fyles, 1970; Reesor and Moore, 1971; Brown and Tippett, 1978; Read, 1980; Read and Brown, 1981; Brown and others, 1986; Parrish and others, 1988).

Several large, hornblende- and (or) biotite-bearing, chiefly granodiorite plutons intruded the Tonasket and Salmon Creek paragneisses during or after the peak of regional metamorphism and folding. These plutons include those of the hornblende-biotite granodiorite and granodioritic gneiss units as well as those of the Reed Creek Quartz Dioritic Orthogneiss of Menzer (1983), the granodiorite of Cook Lake, the Omak Lake Granodiorite, the Mission Creek Granodiorite, and the French Valley Granodiorite units. A single granite body, the Coyote Creek pluton, subsequently intruded all other granodiorite bodies.

Rocks of the Okanogan metamorphic core complex were penetratively deformed in a wide, subplanar, ductile mylonite zone; the resulting mylonitic fabric increases in intensity westward and structurally upward. We believe the mylonitic deformation took place in latest Mesozoic to early Cenozoic time, although it has not yet been possible to establish the age of mylonitization in the quadrangle by isotopic dating methods. Recent geochronologic studies of mylonitic rocks from the westernmost part of the Okanogan metamorphic core complex in British Columbia and also from the easternmost part of the Valhalla metamorphic core complex in British Columbia (Parkinson, 1985; Carr and others, 1987; Parrish and others, 1988) indicate that ductile fabrics related to extension formed as late as Eocene time. The Tonasket Gneiss, as well as all plutonic rocks that contain a well-developed mylonitic fabric, were clearly involved in the ductile mylonitization. The Coyote Creek pluton as observed in the complex exhibits only an incipient mylonitic fabric, which cannot be unambiguously attributed to this particular episode of deformation. Ductile shear-band fabrics are only locally formed in the Coyote Creek pluton, and these ductile structures cannot be continuously traced into the penetrative fabrics of other lower-plate units. Thus, on the basis of available evidence, we believe it is possible that ductile fabrics in the Coyote Creek rocks may represent either (1) deformation during magmatic emplacement, perhaps associated with coeval, higher level brittle deformation along the Okanogan Valley and related fault zones, or (2) weak shear deformation at the structurally lowest levels of the Okanogan mylonite zone. The lack of clear textural relations between the Coyote Creek shear bands and the penetrative mylonitic fabrics of the Okanogan metamorphic core complex, as well as the uncertainty of potassium-argon ages as an indication of the Coyote Creek crystallization age,

leave unresolved the age of penetrative ductile-shear deformation.

A difference between temperatures of peak metamorphism and mylonitization of as much as 350°C (Hansen and Goodge, 1988) suggests that the timing of these two events may have been separated by as few as several million years. An uplift of between 5.4 and 7 km (corresponding to a temperature difference of 350°C and using average geothermal gradients of between 50 and 65°C/km) could have occurred during a timespan of between 0.54 and 7.0 m.y., depending on the rate of uplift (we used maximum and minimum denudation rates of 1 and 0.1 cm/yr, respectively). Geothermal gradients of between 50 and 65°C/km are typical for geologic terrains characterized by active arc magmatism, as was probably the case for the Okanogan region during Late Cretaceous and Eocene times. However, because no structural evidence exists to link high-grade metamorphism and mylonitization to the same tectonic event, these estimates may reflect the minimum time required to uplift the high-grade metamorphic rocks to higher structural levels in the crust during mylonitization.

Subsequent Eocene events such as brittle faulting, joint formation, microdiorite dike emplacement, and regional volcanism are the cumulative effects of extension and doming of rocks of the Okanogan metamorphic core complex. The combined effects of these events also caused the juxtaposition of mylonitized metamorphic and plutonic Okanogan rocks with their nonmylonitized equivalents. Mylonitization and brecciation probably took place during the same period of protracted extension that tectonically raised the interior of the complex; these deformational events are interpreted to have resulted from mechanisms consistent with a model of an evolving extensional shear zone (Davis and others, 1986; Hansen and Goodge, 1988).

Uplift probably was further aided by the emplacement of large volumes of leucocratic granite (Fox and others, 1976, 1977), which possibly includes the Coyote Creek pluton, that helped lift the Okanogan mylonite zone upward to its present level of exposure along the western flank of the complex because of the low density of the granite at the time of emplacement. During thermal rise of high-grade crystalline rocks in the complex, cooler rocks above the mylonite zone tectonically denuded the core rocks by moving westward, causing shear within the mylonite zone and brecciation within the Okanogan Valley and Omak Lake fault zones. The brecciation of ductile mylonite fabric along these brittle fault zones, as well as the lower temperature estimates for the formation of breccia-zone alteration as shown by mineral parageneses (Hansen and Goodge, 1988), indicate that the faults formed later than did the mylonite that they cut, and they probably did so at shallower crustal depths. Thus, brittle deformation near the surface along the margin of the complex coincided with ductile shear at greater crustal depth, but it most likely outlasted formation of the mylonitic fabrics at the present level of exposure. Such a model is generally similar to that which

was proposed by Fox and others (1977), in which both the ductile and brittle deformation along the margin of the Okanogan metamorphic core complex are the result of the rise of crystalline Okanogan rocks caused by voluminous pluton emplacement. However, in our view, the uplift of crystalline rocks of the complex is largely a result of regional tectonic extension. Fox and Beck (1985) hold a similar view of extension by concurring with a model of upper-crustal necking and dilation invoked by Price (1980). Parrish and others (1988) regard this extension as a result of Eocene gravitational spreading of tectonically thickened crust (postulated as a result of earlier Mesozoic regional thrusting), where extension was induced in part by a change in North American-Kula plate interactions.

Eocene to early Miocene erosion exposed the mylonitic and plutonic rocks of the Okanogan metamorphic core complex, probably leaving them topographically higher than adjacent rocks to the west. The Miocene Grande Ronde Basalt then flowed onto this landscape, covering downdropped rocks to the west and lapping against the uplifted crystalline complex.

In Pleistocene time, the Okanogan lobe of the Cordilleran ice sheet carved valleys and ice-marginal channels, scraped dip-slope flat-irons along the western flank of the crystalline complex, and deposited subglacial, glaciofluvial, and glaciolacustrine sediments over much of the quadrangle.

SUMMARY

The Omak Lake 15' quadrangle covers an area that straddles the southwestern margin of the Okanogan metamorphic core complex, one of a number of similar tectonic elements within the North American Cordillera. The principal geologic and structural features of rocks within the quadrangle are the result of tectonism related to formation of the complex.

The major part of the quadrangle is underlain by high-grade metamorphic and plutonic rocks that make up the lower-plate Okanogan metamorphic core complex. These rocks have a complicated structural and metamorphic history related to early metamorphism, deformation, and magmatism, after which followed structural unroofing of the complex caused by regional crustal extension. Both ductile strain, which resulted in the formation of mylonites, and brittle deformation, which formed hydrothermally altered fault-zone breccias, have played important roles in accommodating this large-scale extension. The structural relation between the early-formed mylonite and the younger fault-zone breccias is controversial, and additional study (particularly geochronology) is needed to resolve the existing problems. However, current evidence indicates that extension took place over a geologically short period, in latest Mesozoic to Eocene time, by the development of a regional-scale structural detachment composed of ductile mylonite and superimposed parallel brittle fault zones. Deformation is believed to have transferred to progres-

sively higher levels within the extending crust by changing from deep-level ductile flow to higher level brittle faulting, as in a model for an evolving extensional shear zone.

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