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NEW CONCEPTS OF REGIONAL GEOLOGY AND URANIUM EXPLORATION IN NORTHEASTERN WASHINGTON

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ABSTRACT

Many uranium showings plus one future and two operating mines occur in northeastern Washington. The regional geology is generally considered to consist of Mesozoic (Shuswap) gneiss domes and Mesozoic to Tertiary plutons that are cut by Tertiary grabens that were basins of deposition for local formations. I (1980b) have suggested that the sillimanite-grade rocks are not gneiss domes but pre-Beltian(?) cores of Tertiary anticlines and that regionally extensive Tertiary rocks are preseved in fault-bounded synclines adjacent to the anticlines = metamorphic core complexes.

Accordingly, stratigraphic or sandstone-type uranium deposits probably are localized by regionally extensive facies changes, not by facies changes in local basins. The recognition of regional unconformities and facies changes is, therefore, critical to exploration. Deposits of probable supergene origin, such as the Midnite deposit, may be related to a specific Tertiary regional unconformity (which could be post-Eocene) or to multiple regional unconfomrities. Unfortunately the regional facies of the Tertiary strata, the location of Tertiary unconformities, and their ages with respect to ages of known uranium deposits are still only poorly known.

Most pegmatitic deposits in the metamorphic rocks are too small or low grade to be commercial Rössing-type deposits. However, the uranium from such pegmatites may have been reconcentrated in Tertiary strata, below Tertiary unconformities, or in the cataclastic zones peripheral to the core complexes. Structurally controlled deposits in the cataclastic zones may have formed in a manner similar to the unconformity-vein deposits of Saskatchewan or in zones of hydrothermal alteration. Thus, the margins of the core complexes deserve to be intensively prospected.

References

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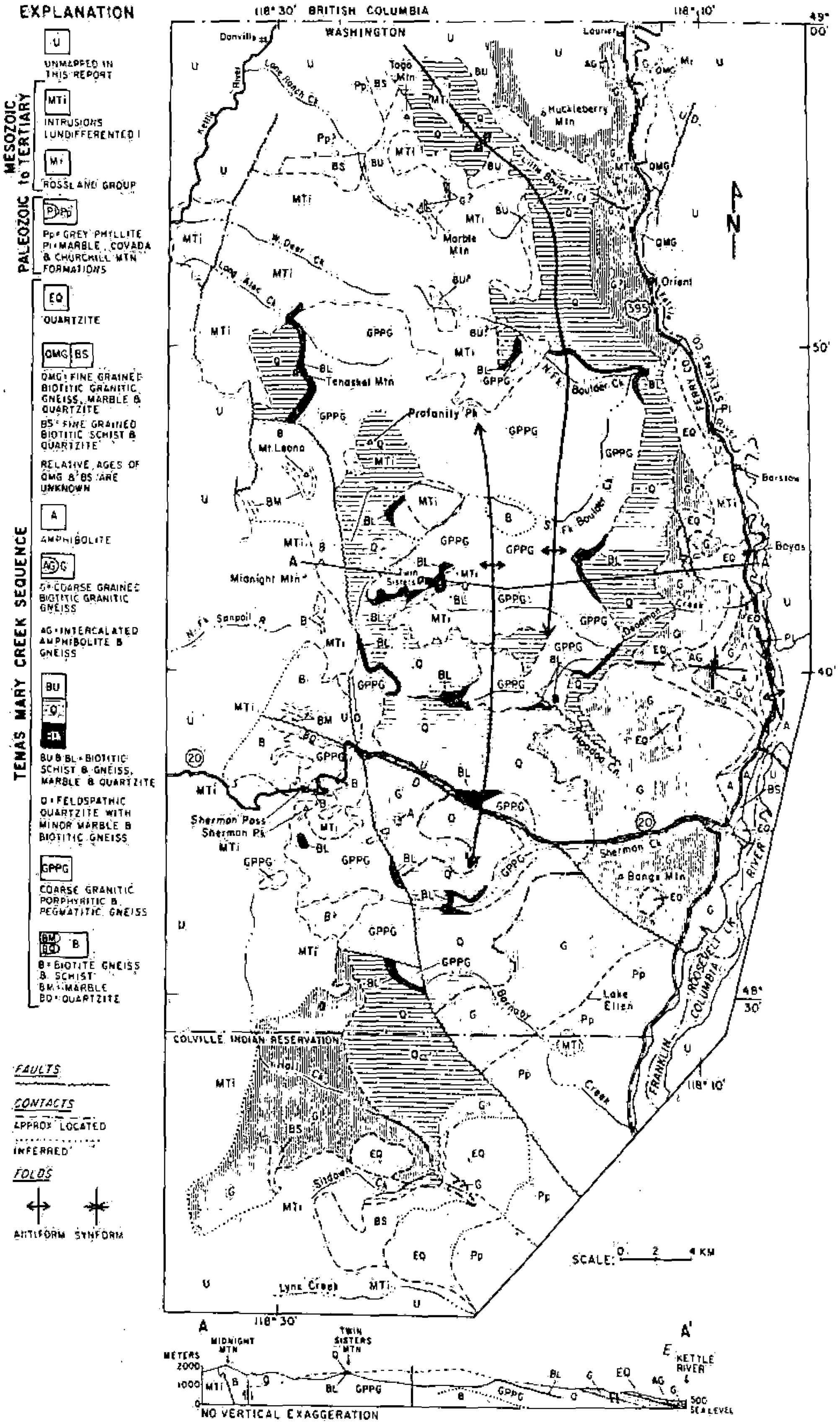


Figure 2. Preliminary geologic map of the Kettle dome, Ferry County, Washington.

TABLE 1. CRITERIA FOR DISTINGUISHING BETWEEN INTERVALS DOMINATED BY BIOTITIC SCHIST AND GNEISS IN THE KETTLE DOME

Map unit*	Approximate thickness (m)	Apparent geographic restriction	Distinctive lithologies and mineralogies	Thickness of marble and quartzite (m)	Amount of pegmatite
BS	200 to 600	Northeast quarter of Togo Mountain and north half of Twin Lakes quadrangle	Fine-grained biotitic schist, calc-silicate schist, minor amphibolite, no sillimanite	No marble <30	None
QMG	>600	Southwest third of Laurier quadrangle	Fine-grained biotitic gneiss, calc-silicate gneiss	<15	None?
BU	0 to 300	North half of Togo Mountain quadrangle	Medium-grained biotitic, sillimanite-bearing schist and gneiss; phlogopitic marble, quartzite	<60	Little
BL	100 to 150	Sherman Peak and south third of Togo Mountain quadrangle	Medium-grained biotitic, sillimanite-bearing schist and gneiss, phlogopitic marble, quartzite	<15	Common
B	800(?)	Mount Leona to Sherman Pass	Medium-grained, biotitic, sillimanite-bearing schist and gneiss, phlogopitic marble, quartzite	<60	Very common

*These map units are shown in Figure 2.

Granitic, Porphyritic, Pegmatitic Gneiss. The lowest widespread unit is a granitic, porphyritic, pegmatitic gneiss (GPPG in Fig. 2, hereafter "pegmatitic gneiss") that commonly has no compositional layering. The megacrysts are potassium feldspar. The pegmatitic portions are dikelets <1 m thick and irregular clots about a metre in diameter that grade outward into nonpegmatitic gneiss. Some of the irregular clots are remnants of dikelets that were disrupted along foliation planes or dismembered by folding. The foliation is sufficiently weak that some previous investigators included the pegmatitic gneiss in adjacent intrusions. This gneiss is one of the thickest (>850 m) and most extensive of all of the Tenas Mary Creek units, extending from the crest of the range on the west to the valley bottoms on the east. Small outcrops of biotitic gneiss and marble along the North Fork of Deadman Creek suggest that the lower contact of the pegmatite gneiss may be exposed. This interpretation is shown in the cross section of Figure 2.

The stratiform map pattern of the thin unit of biotitic schist, gneiss, and rather pure marble in the quartzite-dominated sequence above the pegmatite gneiss led Parker and Calkins (1964) to suggest that the pegmatite gneiss itself is a metasedimentary unit. However, Pearson (1967) was impressed by the lack of compositional layering and suggested that it is an orthogneiss and that the unit of biotitic schist and gneiss and marble was nonconformably deposited upon it.

An alternative interpretation is that the protolith of the pegmatite gneiss originally was a prekinematic or synkinematic pluton intruded into the pelitic rocks. Indeed, near the mouth of the South Fork of Boulder Creek large outcrops of quartzite and of biotitic schist occur within the pegmatitic gneiss. Furthermore, well-foliated, 1- to 2-m-thick concordant bodies of orthogneiss are ubiquitous in the overlying metasedimentary rocks; these orthogneisses are compositionally similar to the pegmatitic gneiss but lack the augen of feldspar and the pegmatitic bodies. Similar concordant bodies occur in the Grand Forks area (Preto, 1970) and in the Curlew area, where they are as much as 12 m thick (Parker and Calkins, 1964). In addition, the biotitic schist and gneiss that overlie the pegmatitic gneiss are so similar to the biotitic schist and gneiss below the pegmatitic gneiss (Table 1) that they may be the same unit. In the Grand Forks area (Table 2), the apparent absence of pegmatitic gneiss plus the presence of 2,000 m of biotitic and associated metasedimentary rocks underlying the quartzite also support the interpretation that the protolith of the pegmatitic gneiss was intrusive into the pelitic rocks.

Preto (1970) correlated Daly's Cascade gneiss (1912) with the pegmatitic gneiss of the Curlew area. However, the Cascade gneiss in the Grand Forks area consists of several bodies only a few square

TABLE 2. CORRELATION AND THICKNESS OF THE TENAS MARY CREEK SEQUENCE AND PALEOZOIC UNITS IN NORTHERN WASHINGTON AND ADJACENT BRITISH COLUMBIA

Kettle Dome (this paper)	Curlew quadrangle (Parker and Calkins, 1964)	Bodie Mountain quadrangle (Pearson, 1967)	Grand Forks, British Columbia (Preto, 1970)	Republic and Aeneas quadrangles (Muessig, 1967)	Bald Knob quadrangle (Staatz, 1964)	Buckhorn Mountain district (McMillen, 1979)
Covada and Churchill Mountain formations	Phyllite assigned to rocks of Tenas Mary Creek	Metamorphic rocks of Buckhorn Mountain; phyllite and marble assigned to the metamorphic rocks in the southwest corner of quadrangle	3	Rocks near Sheep Mountain	Graywacke, phyllite, black shale, and probably, quartzite of Permian or Triassic rocks	Anarchist group
Eastern quartzite, <300 m	Absent	Absent	Absent	Absent	Quartzite within Permian or Triassic rocks?	Absent
Fine-grained biotite schist, 600 m	Schist in rocks of Tenas Mary Creek, 2,750 m	Metamorphic rocks in southwest corner of quadrangle	Part of V(?), >200 m?; IV	Metamorphic rocks near Golden Harvest Creek	Phyllitic quartzite, 1850 m; schist in Permian or Triassic rocks	Goat Ranch metamorphic complex
Amphibolite, 200 m	Hornblende schist in rocks of Tenas Mary Creek?	Amphibolite in rocks of Tenas Mary Creek	IV?, <1100 m; V?	Absent	Absent	Absent
Eastern granite gneiss, >800 m	Quartz-plagioclase gneiss in rocks of Tenas Mary Creek, 500 to 1,000 m	Quartz-feldspar gneiss in rocks of Tenas Mary Creek	IX	Absent	Absent	Absent
Biotitic schist and gneiss with minor quartzite and marble, <300 m	Absent	Metamorphic rocks of Tonata Creek	III, <1200 m	Absent	Absent	Absent
Feldspathic quartzite with minor biotitic schist and marble, >650 m	Quartzite in rocks of Tenas Mary Creek and of St. Peter Creek, 970 m	Quartzite in rocks of Tenas Mary Creek	II, <430 m	Absent	Absent	Absent
Biotitic schist and gneiss with minor quartzite and marble, <150 m	Marble and associated rocks in rocks of Tenas Mary Creek, 3 to 240 m	Marble in rocks of Tenas Mary Creek	I	Absent	Absent	Absent
Granitic, porphyritic, pegmatic gneiss, >850 m	Orthoclase-quartz-oligoclase gneiss in rocks of Tenas Mary Creek, >1,100 m	Granitic gneiss in rocks of Tenas Mary Creek	VII?	Assigned to quartz monzonite east of Sherman fault	Absent	Absent
Biotitic schist and gneiss with minor quartzite and marble, >700 m	Quartz-biotite schist, calc-schist, and quartzite of rocks of St. Peter Creek	Absent	I, 2,000 m	Metamorphic rocks east of Sherman fault	Absent	Absent

kilometres in area. The body about 7 km east of Grand Forks, the only one I have examined, lacks the feldspar megacrysts and pegmatitic patches representative of pegmatitic gneiss. Perhaps the Cascade gneiss and the smaller concordant bodies of gneiss above the pegmatitic gneiss in the Kettle dome were satellitic stocks, sills, and dikes of the pluton from which the pegmatitic gneiss formed.

Quartzite-dominated Sequence. Overlying the pegmatitic gneiss are heterogeneous units (sillimanitic biotitic schists and gneiss with minor quartzite and marble) above and below >650 m of feldspathic quartzite (Table 1). The lower heterogeneous unit is so thin that it was not always encountered during reconnaissance mapping; thus, it is not shown as a continuous unit in Figure 2. It is present in the Tenas Mary Creek and Grand Forks areas (Table 2), and more detailed mapping (Pearson, 1977) shows that it is continuous in the southern part of the Togo Mountain quadrangle.

Rusty- to white-weathering quartzite >650 m thick overlies the lower heterogeneous unit. The quartzite has 5% to 10% white-weathering feldspar 1 to 5 mm in diameter. The feldspar is more commonly orthoclase than plagioclase (Parker and Calkins, 1964; Preto, 1970). The quartzite generally is nonmicaceous, but does contain intercalated biotitic schists and gneisses >20 m thick. On the southern side of Profanity Peak, coarse white marble 30 to 60 m thick occurs within the quartzite. The heterogeneous unit above the quartzite appears to be restricted to the northern part of the Togo Mountain quadrangle and the Grand Forks area.

Eastern Granitic Gneiss. Above the quartzite-dominated sequence on the eastern limb of the dome are >800 m of coarse-grained, very well foliated, unlayered to indistinctly layered, granodioritic orthogneiss. The gneiss generally is not pegmatitic but does have some plagioclase megacrysts as much as 1 cm long. The basal part of this gneiss commonly is more leucocratic and has inclusions of feldspathic quartzite similar to those in the underlying rocks. Amphibolites and thin quartzites along U.S. Route 395 in the Laurier quadrangle are of uncertain origin; they may have been either xenoliths or intercalated sediments. In the Curlew quadrangle (Parker and Calkins, 1964) and in the Boyds quadrangle on the eastern limb of the Kettle dome, the upper part of the gneiss contains stratiform amphibolites. The regionally discordant contacts of this gneiss shown in Figure 2 may indicate the intrusive origin of its protolith.

This unit has caused considerable confusion. Pardee (1918) and Campbell (1938, 1946) included it within the Colville batholith. Still more confusing is the similarity of this unit to the pegmatitic gneiss, especially in the few places where the latter is not particularly pegmatitic or the eastern gneiss has 1-cm plagioclase megacrysts. In these places the >650-m quartzite above or below a gneissic unit is diagnostic. Judging from the description of Parker and Calkins (1964) and Pearson (1967), the pegmatitic gneiss contains more potassium feldspar and less hornblende than the eastern gneiss. Bowman (1950), Campbell and Thorsen (1966), Lyons (1967), and Pearson (1977) lumped the two gneisses as a single unit. Bowman (1950) correlated the eastern orthogneiss at Laurier on the Canadian border with the Cascade gneiss. However, the Cascade gneiss 7 km east of Grand Forks is neither as hornblende-rich nor as well foliated as the eastern gneiss.

The remarkable areal extents of the eastern granitic gneiss and the pegmatitic gneiss deserve comment. Both gneisses occur throughout the Kettle dome (Fig. 2). Both also are present as far northwest as the bend in the Kettle River in the Curlew quadrangle (Parker and Calkins, 1964), and both probably occur in the Grand Forks area of British Columbia mapped by Preto (1970). Thus the pegmatitic gneiss has a minimum distance of outcrop of 50 km and the eastern gneiss a minimum of 70 km. Because both gneisses are overlain or intruded by other units, their total length could be greater. How much of their present form was caused by attenuation of the original plutons during metamorphism is not known.

Amphibolite. On the eastern limb of the dome, a 200-m thick, black amphibolite overlies the eastern granitic gneiss; similar stratiform amphibolites occur within the gneiss. On the basis of elemental ratios, Preto (1970) concluded that similar amphibolites of the Grand Forks area originally were mafic intrusions, but Donnelly (1978) noted that metasomatism may make these results inconclusive. The presence of blue-green hornblende accompanied by oligoclase or andesine suggests that the amphibolite is not of sillimanite grade (Donnelly, 1978).

Fine-Grained Biotitic Rocks. Fine-grained, biotitic, granitic gneiss with intercalated calc-silicate units, quartzite, and amphibolite overlie the eastern granitic gneiss in the Laurier quadrangle; these are labeled QMG in Figure 2. Compositionally similar rocks (labeled BS) in the northwestern and southeastern margins of the dome are schistose to almost phyllitic instead of gneissic (Table 1). Correlation of QMG with BS cannot be demonstrated because the two belts of outcrop cannot be traced into each other. Because neither unit crops out near Boyds, their position relative to the 200-m-thick amphibolite is not known.

The schistose rocks are similar to the fine-grained biotitic schist and biotitic quartzite with intercalated fine-grained amphibolite and calc-silicate schist mapped by Staatz (1964), Muessig (1967), and McMillen (1979) in the Okanogan dome (Table 2). The fine-grained schist does not seem to be sillimanite-bearing (Parker and Calkins, 1964; Staatz, 1964; Muessig, 1967; Preto, 1970; McMillen, 1979), except adjacent to plutons in the Okanogan dome.

Eastern Quartzite. A slabby, slightly rusty weathering, fine-grained quartzite with micaceous partings occurs along the southeastern margin of the Kettle dome. Muscovite and minor biotite on the partings and the presence of isoclinal recumbent folds (outlined by the micaceous partings) suggest that metamorphism of the rocks in the Kettle dome is younger than this quartzite. Sillimanite has yet to be found in this quartzite, even in the schistose partings (Donnelly, 1978). Because the quartzite overlies the 200-m amphibolite, the eastern gneiss, and the fine-grained biotite schists (Fig. 2), the basal contact of the quartzite may be a major unconformity.

Because this quartzite occurs on both sides of the Columbia River near the bridge at Kettle Falls, it must be >200 m thick. Along U.S. Route 395 in the unmapped area between Boyds and Orient, where calc-silicate gneisses of unknown affinity appear to overlie the quartzite, the quartzite appears to be about 300 m thick.

I have suggested (Cheney, 1977) that the eastern quartzite might be equivalent to the 580 to 910 m of thin platy quartzite with sericitic partings near the top of the basal Cambrian Gypsy quartzite described by Park and Cannon (1943) in northeasternmost Washington. However, the eastern quartzite, which seems to have a higher metamorphic grade than all known examples of the Gypsy, could equally well not be Gypsy.

Because the >650-m quartzite within the dome contains intercalated units of biotitic gneiss and marble as much as 60 m thick but the eastern quartzite does not, these two quartzites probably are not correlative. All known examples of Beltian Revett Quartzite in Stevens County are gray and occur in lower grade rocks, so that this correlation may not be likely. Because Donnelly (1978) observed that the eastern quartzite has the same recumbent and other folds as the underlying amphibolite and the other rocks of Tenas Mary Creek described by Lyons (1967), the eastern quartzite is provisionally included within the Tenas Mary Creek sequence.

Paleozoic and Younger Rocks

Black argillite, gray phyllite, dark limestone, and white marble of late Paleozoic age, together with greenstone of reputed Triassic age, overlie the high-grade metamorphic rocks of the dome. In the Orient district, Bowman (1950) called these the Churchill formation; in the Colville Indian Reservation, Pardee (1918) used the name Covada group. Table 2 and Figure 3 indicate tht similar rocks have been described elsewhere. These formations may not be strictly correlative, but all are inferred to be Pennsylvanian to Triassic in age. The next youngest unit is the Jurassic Rossland Group of volcanic rocks. The Tertiary rocks are described later.

Although the fine-grained biotitic schist is compositionally similar to the late Paleozoic phyllitic rocks, the two probably are not the same unit subjected to different grades of regional metamorphism. For example, the late Paleozoic phyllitic rocks contain thick pods of quite pure limestone and marble, whereas fine-grained biotitic schists have only thin calc-silicate schists. Furthermore, the eastern quartzite occurs between the fine-grained schists and the phyllites on the southeastern limb of the dome, and the fine-grained biotitic schist is locally absent along margins of the dome that are overlain by phyllite. Parker and Calkins (1964) suggested that in the Curlew quadrangle an unconformity exists between fine-grained biotitic schist and the overlying phyllites. Such an unconformity would explain the relationships seen in the Kettle dome.

Age and Correlation of the Rocks of the Tenas Mary Creek Sequence

Bowman (1950) applied the name Boulder Creek Formation to the metamorphic rocks in the small part of the Kettle dome that he mapped. However, the sequence is better exposed and described as several mappable units in the area of the Tenas Mary Creek. Hence, the name Tenas Mary Creek sequence proposed by Parker and Calkins (1964) is preferred. However, the basal heterogeneous unit of biotitic gneiss, marble, and quartzite does not crop out in the type area. Furthermore, Parker and Calkins included phyllite in the top part of the Tenas Mary Creek sequence. Because the phyllite has a much lower metamorphic grade (greenschist) and may be unconformable on the rocks of the Tenas Mary Creek, I believe it should be excluded. Until more extensive stratigraphic and petrographic studies are available, the fine-grained biotitic schists, amphibolite, and the eastern quartzite are provisionally included in the Tenas Mary Creek sequence.

The age and regional correlation of the rocks of Tenas Mary Creek are poorly known. Engels and others (1976) listed K-Ar dates on individual minerals of 50 and 67 m.y. for amphibolites. R. L. Armstrong (1977, personal commun.) has obtained preliminary whole-rock Rb-Sr dates of 600 to 1,200 m.y. B.P. on the pegmatitic gneiss and the eastern gneiss of the Kettle dome. He regards the dates as typical of the Shuswap terrane.

Parker and Calkins (1964), Pearson (1967), Preto (1970), and Donnelly (1978) correlated the rocks of Tenas Mary Creek with the Shuswap terrane of southern British Columbia. The mantling metasedimentary rocks in the Shuswap have been regarded as probably mostly Precambrian and Paleozoic but with some as young as Triassic-Jurassic (Wanless and Ressor, 1975; Okulitch and others, 1977). The thick quartzites in the Shuswap terrane were regarded as possibly Lower Cambrian (Okulitch and others, 1977); thus, by analogy, the >650-m quartzite in the Tenas Mary Creek or the eastern quartzite in the Kettle dome might be Lower Cambrian. However, the Shuswap now appears to include metasedimentary rocks as much as 3,000 m.y. old that were intruded by 1,960-m.y.-old granitic rocks and then metamorphosed 935 m.y. ago (Duncan, 1978).

If the rocks of Tenas Mary Creek are Precambrian, they could be equivalent to Windermere, Beltian, or pre-Beltian rocks. The Beltian rocks closest to the Kettle dome are in southeastern Stevens County and have been described by Miller and Clark (1975). These and other known examples of Beltian rocks in Washington and adjacent Idaho are of much lower metamorphic grade (the pelitic rocks are still black argillites). Furthermore, the 950-m Beltian Revett Quartzite weathers gray and is not as feldspathic as quartzite of the Tenas Mary Creek, and marbles of the Tenas Mary Creek rocks do not resemble the carbonate rocks of the Belt. These same arguments could be applied to the Windermere-Deer Trail rocks which, in addition, have thick greenstones that have no analogues, except possibly the amphibolites, in the rocks of the Tenas Mary Creek.

Lithologically and structurally, the most probable correlatives of the Tenas Mary Creek sequence are sillimanite-grade rocks in the Spokane area (Fig. 3). These rocks include the cataclastic Newman

Lake orthogneiss with 5-cm potassium feldspar megacrysts (Miller, 1974d; Weissenborn and Weis, 1976) and a feldspathic quartzite near Freeman (Weis, 1968) that appears to be at least as thick as the quartzite of Tenas Mary Creek. Furthermore, Griggs (1973) showed that these rocks define a flat-topped dome, herein called the Spokane dome. The northeasternmost rocks of this terrane in Idaho also are domal and yield ages of about 1,500 m.y. (Clark, 1973). The Pb-α ages of 1,150 m.y. for the Hauser Gneiss (Weis, 1968) are, of course, suspect but are suggestive of a correlation with the Tenas Mary Creek.

Most workers (Griggs, 1973; Clark, 1973; Miller, 1974b; Miller and Clark, 1975; Weissenborn and Weis, 1976) have suggested that the rocks of the Spokane dome are high-grade portions of the Belt Supergroup. However, Armstrong (1975) suggested that paragneiss, quartzite, marble, schist, amphibolite, and orthogneiss in central Idaho and the Spokane dome are part of a pre-Beltian metamorphic terrane. Because Griggs (1973) and Miller and Clark (1975) showed that on a regional scale the Spokane dome is conformably surrounded on the southern and western sides by Beltian strata, the abrupt change in metamorphic grade could be due to an unrecognized, gently domed sub-Beltian unconformity or low-angle fault. I prefer this alternative and believe that the high-grade rocks of the Spokane dome probably are pre-Beltian.

Initial strontium isotopic ratios of Mesozoic plutons in northern Washington also suggest that the rocks of the Tenas Mary Creek may be Precambrian. Plutons as far west as long. 121°W have initial ratios >0.704, which implies that the magmas were contaminated by radiogenic strontium from a Precambrian basement (Armstrong and others, 1977). Thus, the rocks of the Tenas Mary Creek could be part of such a basement. If so, the lithologic similarity of the rocks of the Tenas Mary Creek to those in the Spokane dome would support the suggestion of Armstrong and others (1977) that on the basis of these initial strontium isotopic ratios, the Precambrian basement of pre-Mesozoic North America extended westward into northern Washington.

In summary, meager stratigraphic and radiometric evidence, including a comparison with the Shuswap rocks, favor but do not prove a Precambrian age for the rocks of the Tenas Mary Creek in the Kettle dome. Regional structural interpretations, in turn, favor a pre-Beltian age for the high-grade metamorphic rocks in the Spokane dome and, by analogy, the rocks of the Tenas Mary Creek in the Kettle dome. However, because the Spokane dome is east of the Kootenay arc and Kettle dome is west of it, such a correlation is, admittedly, unconventional.

Plutons

A number of Mesozoic and Tertiary granitic plutons intrude the Tenas Mary Creek, Paleozoic, and Mesozoic rocks. The plutons vary from biotite dominated to hornblende dominated, from fine and medium grained to coarse grained, and from foliated to unfoliated phases. At present it is not known how many discrete plutons there are. All are shown as a single unit in Figure 2.

STRUCTURE OF KETTLE DOME

Kettle Dome

The antiformal nature of the rocks underlying the Kettle River Range was first recognized by Campbell (1946). He noted that near and south of State Route 20 the foliation forms a dome "12 miles wide" elongated to the northeast. He also realized that the cataclasis of the rocks is similar to that of the Okanogan dome.

The antiformal pattern of the Kettle dome is best shown by the map pattern of the >650-m quartzite

(Fig. 2) and by the antiformal dips of this quartzite. Rocks of the Tenas Mary Creek sequence on the eastern and southeastern limbs of the dome form prominent dip slopes near Orient, Kettle Falls, and Lake Ellen. The best-preserved dip slope on rocks of the Tenas Mary Creek sequence defining the western limb of the dome is Tenasket Mountain.

The dome is >65 km long north-south and 27 km wide. The structural relief is only about 3 km (Fig. 2). The northern end of the dome is a northwest-trending antiform, defined by opposing dips in the >650-m quartzite and biotitic rocks on Huckleberry Mountain and on Togo and Marble Mountains.

The dips of bedding and of foliation within the Tenas Mary Creek units crudely define two en echelon north-trending, gently antiformal axes within the dome. Dips generally are <25°, and locally foliation and bedding are nearly horizontal, forming flat-topped ridges in the center of the dome. However, contacts are unusually steep to vertical along the northwesternmost margin of the dome and near Profanity Peak along the north-trending fault on the western side of the dome.

The simple domal structure could be part of a larger, more complex structure. For example, detailed mapping might show that the domal structure is the upper limb of a large recumbent fold similar to the small folds commonly seen in outcrops. Furthermore, if the eastern quartzite could be shown to be correlative with, or older than, the >650-m quartzite within the dome, the structure is more complex than shown in Figure 2. When the reconnaissance nature of the mapping is considered, such possibilities should not be ignored.

Structures within the Dome

Folds larger than those in outcrops but with map patterns smaller than several kilometres are difficult to recognize in reconnaissance mapping. A gently eastward-plunging synform may exist in the eastern gneiss and amphibolites south of Deadman Creek in the Boyds quadrangle. The amphibolite north of the mouth of Sherman Creek in the Bangs Mountain quadrangle may mark a similar synform. An east-trending antiform brings the lowest units of Tenas Mary Creek to the surface along the Kettle River in Canada (Preto, 1970), and this fold could account for the east-trending salient of the eastern gneiss at the Canadian border near Laurier in Figure 2. Gentle northwest-trending folds in the eastern quartzite along the eastern margin of the dome may be minor folds associated with formation of the dome.

A north-trending fault in the western part of the Sherman Peak and Togo Mountain quadrangles juxtaposes structurally higher rocks on the east against structurally lower rocks on the west. The ≥2-km vertical separation on this fault shown on the cross section in Figure 2 could produce the 10 km of apparent left-lateral separation shown on the map in Figure 2. The fault does not seem to offset the hornblende quartz dioritic pluton in the valley of the North Fork of Sherman Creek.

A west-northwest–trending fault with the northeast side up occurs in Hoodoo Canyon. A similar fault in the Sherman Peak and Bangs Mountain quadrangles may offset the north-trending fault mentioned above. Such a northwest-trending fault would explain why marble and quartzite in the biotitic unit north of Sherman Pass dip toward each other. It would also explain the apparent juxtaposition of the eastern gneiss and pegmatitic gneiss along State Route 20 northeast of Sherman Pass. The same fault would account for the northward termination of the upper Paleozoic phyllites along the southeastern edge of the dome, as well as the straight courses of Sherman Creek and of Donaldson Draw on Bangs Mountain. Smaller faults within Tenas Mary Creek rocks probably are more numerous than reconnaissance mapping can resolve. Small northwest-trending faults do cut the eastern quartzite and eastern gneiss in the Boyds quadrangle.

The maps of Parker and Calkins (1964) and Muessig (1967) indicate that neither of the large faults offset the faults that bound Tertiary rocks to the west of the dome. Thus, the large faults within the

Kettle dome probably are pre-Tertiary. On the eastern side of the Kettle River in the Orient quadrangle, pyroxenites and other mafic rocks mark the contact between the rocks of the Tenas Mary Creek and upper Paleozoic phyllites and Tertiary rocks (Bowman, 1950). Perhaps this is a postdome fault (like the serpentinite-bearing Sherman fault west of the dome, shown in Fig. 3).

The contact between the rocks of the Tenas Mary Creek sequence and the overlying low-grade rocks along the eastern margin of the dome appears to be tectonic. Campbell (1938, 1946) described cataclasis in the eastern gneiss on the southeastern limb of the dome. Locally, chloritic fractures and brecciation are well developed along the northeastern margin of the dome (Bowman, 1950; Lyons, 1967; Donnelly, 1978), especially in the small plutons near Orient (Bowman, 1950). Cataclasis (microshears and microbrecciation) in the metasedimentary rocks is parallel to but later than the foliation that outlines the recumbent folds (Lyons, 1967; Donnelly, 1978). Furthermore, unmetamorphosed nonrecrystallized, but brecciated limestone (presumably of late Paleozoic age) overlies rocks of Tenas Mary Creek in three places: just west of the confluence of the Kettle and Columbia Rivers, on the Kettle River 3.3 km northwest of Barstow, and on U.S. Route 395 2 km northwest of Barstow. The granitic gneisses of the Tenas Mary Creek below the limestone of the Kettle River locality are extensively chloritized. It seems likely that detailed mapping would show that the limestone in the Orient and Boyds quadrangles overlies a gently eastward-dipping tectonic zone.

REGIONAL GEOLOGY

Terranes Equivalent to the Kettle Dome

The cataclastic and domal nature of the gneisses between the Republic area and the Okanogan River have been described by Waters and Krauskopf (1941), Snook (1965), and Fox and others (1976, 1977). Although this dome is structurally similar to the Kettle dome, it is predominantly composed of Mesozoic(?) orthogneiss and granitic plutons.

The dioritic gneisses in the western part of the Okanogan dome were regarded as paragneisses by Snook (1965). Fox and others (1976) proposed that Snook's name of Tonasket Gneiss be applied to all such rocks (Fig. 3). My preliminary mapping suggests that virtually all of the Tonasket Gneiss in the central part of the dome is derived from a pluton grading inward from diorite to quartz diorite to porphyritic granodiorite.

The age of the Tonasket Gneiss is not too well known. On the southeastern margin of the dome, upper Paleozoic hornfelsic phyllite occurs adjacent to an orthogneiss that is similar to the interior porphyritic granodioritic phase of the Tonasket Gneiss. Fox and others (1976) reported U-Pb ages of 87 and 100 m.y. and a Th-Pb age of 94 m.y. from a euhedral zircon from hornblende-rich Tonasket Gneiss.

The eastern part of the Okanogan dome is dominated by biotitic quartz monzonitic to granodioritic plutons that intrude the Tonasket Gneiss and the late Paleozoic phyllitic rocks. Portions of these plutons have been described by Waters and Krauskopf (1941), Parker and Calkins (1964), Staatz (1964), Muessig (1967), and Pearson (1967). In general, the plutons are texturally zoned, becoming coarser grained and more porphyritic inward, weakly to moderately foliated, and locally cataclastic. The western contacts of the westernmost plutons that I have mapped in the dome commonly dip $\leqslant 25^\circ$ eastward. Pardee (1918) named various crystalline rocks, including such plutons at the southern ends of both the Kettle and Okanogan domes, the Colville batholith. The term "Colville batholith" probably should be reserved for these variably foliated, leucocratic quartz monzonitic to granodioritic Mesozoic plutons as Staatz (1964) suggested.

Studies of the Okanogan dome have led to three theories of origin that might be applicable to the other domes as well. Waters and Krauskopf (1941) considered the cataclasis of the Tonasket Gneiss to be the protoclastic border, or carapace, of the Colville batholith. Snook (1965) demonstrated the metamorphic nature of the Tonasket Gneiss and pointed out that cataclasis postdates the mylonitization that cuts the foliation within the Tonasket Gneiss. He concluded that the increasingly cataclastic nature of the gneiss adjacent to the border of the dome could be attributed to later folding of an originally flat thrust in the gneisses, rather than to batholithic emplacement. The presumed paragneissic origin of the Tonasket Gneiss and 66- to 46-m.y. ages determined by K-Ar and fission-track measurments led Fox and others (1976, 1977) to suggest that the rocks were emplaced as an Upper Cretaceous gneiss dome that cooled through the Eocene.

As noted above, rocks similar to those in the Kettle dome occur in the Spokane dome. At present, cataclasis (Fig. 3) has been reported only in the coarse Newman Lake Orthogneiss and the Mesozoic Loon Lake batholith (Weissenborn and Weis, 1976; Miller, 1974d). Mylonitic rocks are known at two localities on the eastern edge of the dome between Coeur d'Alene and lat 48°N (Miller and Engels, 1975, p. 524).

Regional Extent of Tertiary Formations and Folding

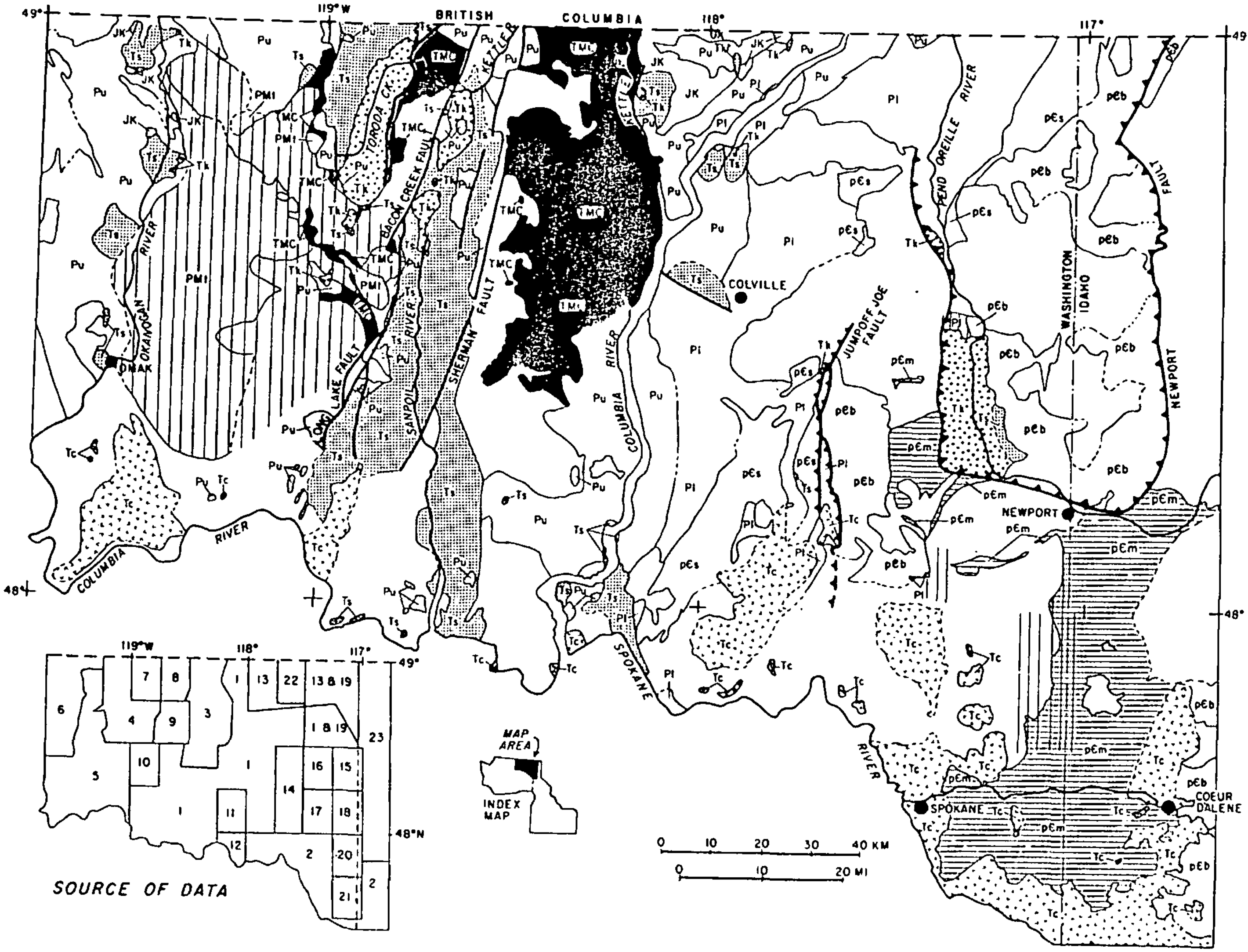
An understanding of the regional geology (Fig. 3) is helpful in determining the origin and the age of the Kettle dome. The maps of Parker and Calkins (1964), Muessig (1967), and Staatz (1964) demonstrate that a syncline occurs west of the Kettle dome. This fold was recognized by Wright (1949) and named the "Sanpoil syncline" by Muessig. In the center of the fold is the Eocene Klondike Mountain Formation; successively outward (down the section) are the Eocene Sanpoil volcanic rocks, the Eocene O'Brien Creek Formation, and the upper Paleozoic to Triassic rocks. The synclinal map pattern is discernible on Figure 3.

Another north-trending synclinal inlier of the same three Eocene formations occurs near Orient on the northeastern margin of the dome (Fig. 3). Dips as great as 50° occur in the lower part of the Klondike Mountain Formation (Pearson and Obradovich, 1977).

Discordant K-Ar dates similar to those reported by Fox and others (1976, 1977) in the Okanogan dome are common in northeastern Washington and adjacent British Columbia (Miller and Engels, 1975; Armstrong and others, 1977). An alternative explanation to a cooling gneiss dome is that these dates were caused by Eocene volcanism and plutonism (Armstrong and others, 1977). As noted below, the Eocene volcanic rocks (Sanpoil Volcanics and Klondike Mountain Formation) were of regional extent, and Eocene plutons are common; the quartz monzonite of Long Alec Creek (K-Ar age of 51.7 ± 1.6 m.y., according to Engels and others, 1976) in the northern end of the Kettle Dome (Figs. 2, 3) even has batholithic dimensions.

Because the Kettle dome is bounded on the west and the northeast by Tertiary synclines, its present antiformal structure also is most likely Tertiary (Cheney, 1976, 1977). Furthermore, the length, trend, and structural relief of the Sanpoil syncline are similar to those of the dome. The axis of the Kettle dome is not parallel to the axis of the Sanpoil syncline, but this difference may be due to the combined effect of Tertiary folding and older structures within the rocks of the Tenas Mary Creek sequence. The high-grade metamorphism and related folding within the Tenas Mary Creek probably is pre-Tertiary (and probably pre-Beltian), and much of the uplift of the Tenas Mary Creek from the depths at which sillimanite forms probably was pre-Tertiary.

The regional extent of Tertiary folding is best appreciated after recognition of the regional extent of the Tertiary formations. Pearson and Obradovich (1977) have shown that the Eocene O'Brien Creek Formation, the dacites of the Sanpoil Volcanics, and the volcanic and volcaniclastic rocks of the Klondike Mountain Formation in the Republic area (Meussig, 1967) extend across northeastern Washington. The regional presence of the same three unconformity-bounded Tertiary formations suggests that they were not deposited in local basins as most authors—including Parker and Calkins



49°
119°W
BRITISH
COLUMBIA
118°
117°
49°
48°
48°
TORODA CK.
BACON CREEK FAULT
KETTLE
SHERMAN FAULT
SANPOIL RIVER
LONG LAKE FAULT
OKANOGAN RIVER
OMAK
COLUMBIA RIVER
KETTLE
COLUMBIA RIVER
COLVILLE
JUMPOFF JOE FAULT
PEND OREILLE RIVER
WASHINGTON
IDAHO
NEWPORT FAULT
NEWPORT
SPOKANE RIVER
SPOKANE
COEUR DALENE
Pu
PMI
TMC
Ts
Tk
JK
Tc
Pl
pЄs
pЄb
pЄm
0 10 20 30 40 KM
0 10 20 MI
MAP AREA
INDEX MAP
119°W
118°
117°
49°
48°N
1
2
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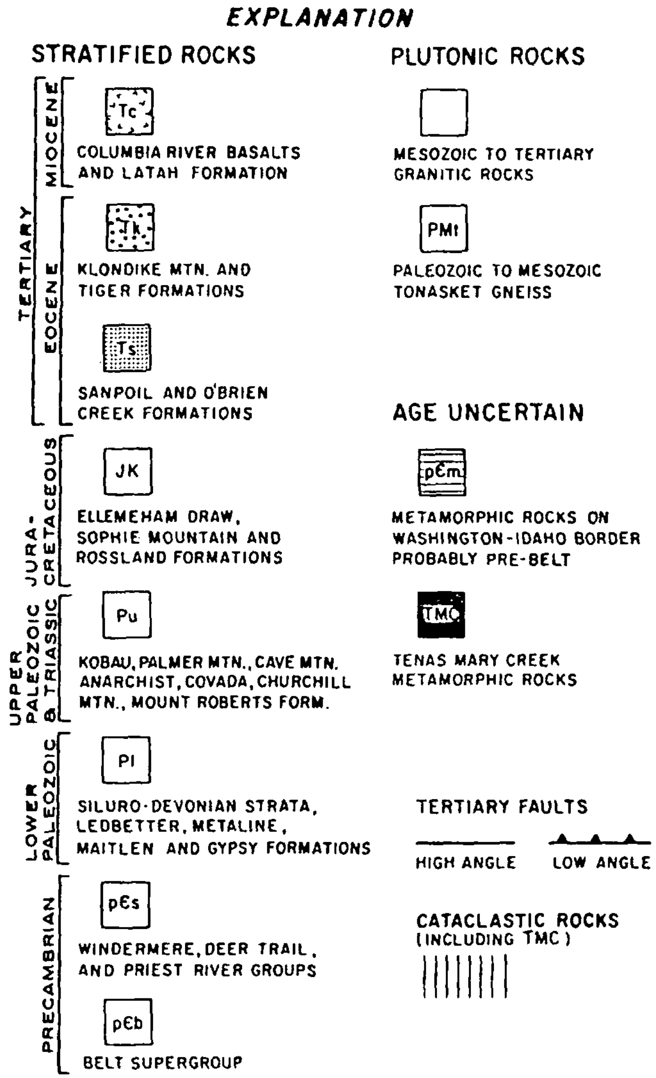

Figure 3. Geologic map of northeastern Washington and adjacent Idaho. For cartographic clarity, small stocks and the letter designations of Tertiary and Mesozoic plutons have been omitted from the map. Data sources are (1) Huntting and others (1961); (2) Griggs (1973); (3) Cheney (this paper); (4) Cheney (unpub. mapping); (5) Fox and others (1977); (6) Rinehart and Fox (1972); (7) Pearson (1967); (8) Parker and Calkins (1964); (9) Muessig (1967); (10) Staatz (1964); (11) Campbell and Raup (1964); (12) Becraft and Weis (1963); (13) Yates (1971); (14) Miller and Clark (1975); (15) Miller (1974a); (16) Miller (1974b); (17) Miller (1974c); (18) Miller (1974d); (19) Miller and Engels (1975); (20) Weissenborn and Weis (1976); (21) Weis (1968); (22) Yates (1964); (23) Bond (1978).

(1964), Muessig (1967), and Pearson and Obradovich (1977)—suppose.

The Klondike Mountain Formation as shown in Figure 3 is more extensive than shown by Pearson and Obradovich (1977). The map of Fox (1970) suggests that the Klondike Mountain Formation may exist in the Okanogan Valley. East of the Columbia River the mafic, olivine-bearing flows that locally lie above the Sanpoil immediately east of long. 118°W (Yates, 1971) might correlate with Muessig's (1967) basaltic upper member of the Klondike Mountain Formation. Pearson and Obradovich (1977) gave the following minimum ages: O'Brien Creek, 53 m.y.; Sanpoil, 50 m.y.; and Klondike Mountain, 41 m.y.

For simplicity, the conglomerates and sandstones of the Tiger Formation that unconformably overlie Sanpoil lavas in the Pend Oreille Valley (Pearson and Obradovich, 1977) are shown in the same pattern in Figure 3 as the Klondike Mountain Formation. However, no evidence presently exists as to whether these formations are correlative or not. Indeed, because the Tiger Formation varies greatly in provenance and appearance, it may have been deposited in more than one epoch of the Tertiary (Miller, 1971, 1974b). Additionally, although some parts of the Tiger appear to dip westward into the Newport fault, Miller (1971) pointed out that other parts of the Tiger appear to overlie the fault and no part of the formation is known to show the effects of proximity to such a major fault as the Newport fault. Thus, at least part of the Tiger may be correlative with at least one of the two unconformity-bounded epiclastic units described by Muessig (1967) and Pearson and Obradovich (1977) in the lower part of the Klondike Mountain Formation.

The Sanpoil syncline and the syncline near Orient already have been noted. The regional map of Rinehart and Fox (1972) shows two synclinal remnants of the Eocene formations along the western border of the Okanogan dome near Tonasket. The inliers of Eocene rocks just east of the Columbia River are partly synclinal and partly fault bounded (Yates, 1971; Pearson and Obradovich, 1977) and are aligned along a north-northeast trend. Perhaps the inliers west of the Okanogan dome and east of the Columbia River are remnants of formerly more extensive north-northeast–trending synclinal belts of Tertiary rocks similar to the Sanpoil syncline.

The inlier of Eocene formations on the Canadian border northwest of the Sanpoil syncline has been named the "Toroda Creek graben" by Pearson and Obradovich (1977). This inlier may also be synclinal, but, admittedly, the number of westward-dipping flow structures in the eastern edge of the Klondike Mountain Formation are few (Pearson, 1967), unconformities obscure a synclinal map pattern in the Tertiary rocks, and the eastern edge of the Klondike Mountain Formation is faulted (Pearson, 1967).

Tertiary Faults and Cataclasis

The synformal Newport fault zone in northeastern Washington and northwestern Idaho (Fig. 3) may cut the Tertiary Tiger Formation (Miller, 1974b) and does cut a 45- to 51-m.y.-old pluton (Miller and Engels, 1975). The fault separates structurally lower muscovite-biotite schist, micaceous quartzite, gneiss, and batholithic rocks from Tertiary rocks and only mildly metamorphosed Paleozoic and Beltian rocks (Miller, 1971, 1974b, 1974c, 1974d). The fault is a gently northward-plunging, synformal, cataclastic zone 300 m wide. Figure 3 shows areas of cataclasis beyond the fault described by Miller (1974b, 1974c, 1974d); detailed petrographic studies might enlarge these areas. K-Ar dates of plutons peripheral to the fault are typically 45 to 51 m.y. B.P. (Miller and Engels, 1975). Miller and Engels suggested that the preservation of much older K-Ar dates (typically 93 to 101 m.y. B.P.) in the plutonic rocks 8 to 25 km from the fault and in the upper plate of the fault indicates lateral displacement of 70 to 100 km.

A smaller Newport-type fault may bound the belt of Tertiary rocks of the so-called Toroda Creek graben. Along the northeastern margin of this belt, between the Canadian border and the Kettle River, Parker and Calkins (1964) described a fault with a 400-m-wide zone of sheared breccia; this fault separates rocks of the Tenas Mary Creek in their type area from the Tertiary rocks to the west. Along this contact southwest of the Kettle River, Pearson (1967) described westward-dipping sheets of breccia as much as 30 m (locally 300 m) thick below and within the Klondike Mountain Formation. Although he suggested that these breccias were debris flows, Pearson also interpreted the eastern contact of the Tertiary rocks as a fault dipping 20° to 30° westward. Pearson and Obradovich (1977) extended this fault southward toward Granite Creek in the Aeneas quadrangle. In the valley of Granite Creek, a very poorly sorted and poorly stratified breccia consisting mostly of granitic fragments in an arkosic matrix occurs beneath the Klondike Mountain volcanic rocks. Muessig (1967) and Pearson and Obradovich (1977) regarded these breccias as sedimentary, but my mapping indicates that (1) locally some of the clasts are "smeared out" in a well-foliated matrix; (2) matrix-filled fractures down to hairline width extend into a few clasts, and (3) the underlying granites have mylonitic seams. Thus, the breccia may be tectonic. If, like the Newport fault, a western limb of this fault does exist, it may explain the juxtaposition of low-grade upper Paleozoic strata against garnet-staurolite mica schist at Wauconda Summit in the northwestern corner of the Aeneas quadrangle. This fault would be on strike with the fault that Pearson (1967) mapped just to the north and would separate the Tertiary volcanic rocks to the east from schist, phyllite, amphibolite, and marble to the west. Because additional mapping is necessary to determine whether these faults are segments of a single system analogous to the Newport fault, a single fault is not shown on Figure 3.

Although the faults on the western side of the Sanpoil syncline (Fig. 3) clearly are regarded as the western boundary faults of the Republic graben (Parker and Calkins, 1964; Muessig, 1967; Staatz, 1964), a number of anomalies exist (Cheney, 1979). Firstly, the traces of these faults are more sinuous than can be shown on Figure 3. Secondly, Wright (1949) concluded that most of the epithermal gold ore in the Sanpoil Volcanics in the Republic district adjacent to the Bacon Creek fault is in thrust faults that dip 55° to 65° eastward. He illustrated (1949, Figs. 3, 4b, 7) the Bacon Creek fault as a major break along which an anticline involving the Sanpoil and Klondike Mountain units was thrust westward over Colville granitic rocks. Furthermore, highly sheared and veined phyllite with concordant rhombic tectonic clasts of limestone dips 20° eastward in an adit in sec. 32, T. 37 N., R. 32 E., where Muessig (1967) interpreted the junction of the Bacon Creek and Scatter Creek faults; the location is virtually on strike with Wright's (1949) cross section showing the Bacon Creek fault.

On Figure 3, the Scatter Creek fault is the unlabeled segment between the Bacon Creek and Long Lake faults. Muessig noted (1967) that in one adit the Scatter Creek fault is horizontal. Two of the three western boundary faults in the Bald Knob quadrangle to the southwest dip gently eastward (Staatz, 1964). In Figure 3, the King Creek and Nespelem River faults are the first and second faults, respectively, east of the Long Lake fault. Staatz showed the King Creek fault as a thrust and only assumed normal movement on the Long Lake fault. He also showed the high-angle Nespelem River fault as up on the eastern side (not the western side as one might expect for a western-bounding fault of a graben).

Another thrust exists at least locally on the eastern limb of the Sanpoil syncline. Muessig (1967) mapped a "major thrust fault," the Lambert Creek thrust, cutting Sanpoil flows and the younger quartz monzonite of Herron Creek. Parker and Calkins (1964) did not recognize such a fault in the neighboring Curlew quadrangle, but the sinuous St. Peter fault, which is cut by the Sherman fault, is a likely candidate. The Sherman fault east of the Sanpoil syncline does appear to be a high-angle fault (Staatz, 1964; Meussig, 1967).

In summary, the so-called Toroda Creek and Republic grabens may be synclinely folded allochthons rather than grabens. Alternatively, if they are bounded only on one side by thrusts, they are only half-grabens. In any case they are not grabens in which the Tertiary rocks were deposited.

Available mapping (Campbell, 1938, 1946; Waters and Krauskopf, 1941; Snook, 1965; Petro, 1970;

Weissenborn and Weis, 1976) indicates that cataclasis within the crystalline rocks of the three domes increases in intensity toward the margins of each dome. Furthermore, the intensely cataclastic marginal zones, including the previously discussed northeastern margin of the Kettle dome, have sinuous traces suggestive of low dips. Snook (1965) has already suggested that the cataclastic zone along the western margin of the Okanogan dome is due to folding of an originally flat thrust and that erosion has removed the cataclastic zone from the crest of the dome.

Although cataclasis is easier to detect in coarse-grained crystalline rocks, the greatest shearing probably occurred in the incompetent rocks (such as the upper Paleozoic argillites) above the crystalline rocks. The Osoyoos and Whiskey Mountain plutons within upper Paleozoic strata peripheral to the northwestern margin of the Okanogan dome do become more cataclastic toward the dome (Fox and others, 1976; Rinehart and Fox, 1972). An intensely shattered and hydrothermally altered pluton occurs in phyllitic rocks south of Lake Ellen on the southeastern margin of the Kettle dome, and Campbell (1938) described cataclastic sills and quartzite in the Paleozoic phyllites in this area. In fact, Campbell (1938) probably was the first to suggest that intense shearing in the phyllitic rocks and the intense cataclasis in the adjacent gneiss were similar to the effects of major thrust faults, but he discarded this idea in favor of a protoclastic border of what he inferred was the Colville batholith.

If these cataclastic zones are antiformal analogues of the synformal Newport fault, a westward-dipping fault zone should occur between the Newport fault and the Kettle dome. A possible candidate is the gently westward-dipping Jumpoff Joe fault in the Chewelah area. Miller and Clark (1975) suggested that thrusting on the Jumpoff Joe fault might be extensive enough to explain the structural and stratigraphic contrasts between the Deer Trail group west of the fault and the Belt rocks to the east. Where the fault cuts 100-m.y.-old plutons, Miller and Clark reported that it forms a cataclastic zone as much as 150 m wide; south of Chewelah, upper Miocene Columbia River Basalt overlies the fault (Miller and Clark, 1975). Miller and Clark also suggested that northeast-striking faults that pass a few kilometres northwest of Chewelah might be the major structures in the area.

If the Jumpoff Joe fault and the imbricate zone beneath it that involves lower Paleozoic strata are equivalent to the Newport fault, the lower Paleozoic and the Precambrian Deer Trail–Windermere–Priest River strata are restricted to the upper plate. Units of the Belt Supergroup in the Chewelah area (Miller and Clark, 1975) would be in the lower plate, but east of the Pend Oreille River (Miller, 1974a), such units are in the upper plate of the Newport fault.

The Newport fault, the low-angle faulting in the Toroda Creek area, the faults bordering the western limb of the Sanpoil syncline, and the Lambert Creek fault may be similar in age. All cut Eocene rocks. The Newport fault cuts a 45- to 51-m.y.-old pluton (Miller and Engels, 1975). The Lambert Creek thrust cuts the quartz monzonite of Herron Creek, which is similar to the Long Alec Creek batholith that has been dated at 53 m.y. B.P. (Pearson and Obradovich, 1977). Furthermore, the 48- to 49-m.y.-old Swimptkin Creek and Coyote Creek plutons in the Okanogan dome are slightly cataclastic (Fox and others, 1977). Whether these faults are portions of a single regional fault, a series of related faults, or merely local zones of decoupling is not yet known.

TIMING OF STRUCTURAL EVENTS

Mylonites and brecciated rocks have been described in the crystalline rocks of each of the three domes. Snook (1965) stressed that, although both commonly occur in the same rocks on the western margin of the Okanogan dome, the directionless microbreccias formed later than the schistose mylonites and that in most mylonites the biotite did not change to chlorite, whereas, chlorite, epidote, and zeolites are prominent in the microbreccias. The same relationships occur on the northern margin of the Okanogan dome in the contact metamorphic aureole of the Mount Bonaparte pluton (one of the Colville plutons) and as discrete sericitic phyllonite zones within the Cretaceous(?) Buckhorn Mountain pluton a few kilometres north of the dome (McMillen, 1979). As McMillen (1979) has stresed, the petrographic descriptions of Campbell (1938), Parker and Calkins (1964), Lyons (1964), and Donnelly (1978) suggest that mylonitization and later brecciation accompanied by retrograde metamorphism also are common on the margins of the Kettle dome.

Thus, although the mylonites and the cataclastic zones characterized by brecciated rocks commonly are coincident, they differ in age. Mylonitization is Cretaceous(?) or younger (McMillen, 1979) but has not been observed in Eocene rocks; whereas, cataclasis is Eocene or younger. Thus, mylonitization in the crystalline rocks of the domes is not related to the Tertiary faults and cataclasis described above. If the Jumpoff Joe fault near Chewelah, which is overlain by Columbia River basalt, is related to the other low-angle faults marked by cataclastic zones, these faults are pre-late Miocene. A study of that part of the Tiger Formation that appears to overlie the Newport fault might provide a better age for the faulting.

The antiformal nature of the cataclastic zones around the margins of the domes indicates that the cataclastic zones have been folded. The age of this folding is not well known. The map and cross section C–C′ of Weissenborn and Weis (1976) suggest that the erosion surface beneath the Columbia River Basalt and the interlayered Latah formation dips southwesterly off the Spokane dome; thus, at least part of the doming may be older than the basalt. However, because the greater structural relief of the larger north-trending Cascade arch to the west is younger than the Columbia River Basalt (McKee, 1972), it is tempting to speculate that the present structural relief of the north-trending Spokane, Kettle, and Okanogan domes also may be due to folding younger than the basalt.

CONCLUSIONS

In summary, northeastern Washington is characterized by north-northeast–trending Tertiary folds tens of kilometres long but with amplitudes of only a few kilometres. The synclines are marked by remnants of Tertiary strata that once were regionally extensive. Instead of being diapiric gneiss domes, I believe that the Okanogan dome, the Kettle dome, the Paleozoic and Precambrian rocks near Chewelah between the Pend Oreille and Columbia Rivers, and the Spokane dome are the anticlines. The cores of the Kettle and Spokane domes consist of high-grade metamorphic rocks that probably are pre-Beltian in age. The high-grade rocks near Chewelah probably are pre-Beltian also. Mylonites within the domes probably are Cretaceous in age.

At present, any relationship between the Newport, the Jumpoff Joe, and other low-angle faults must be regarded as speculative, and no unequivocal physical evidence exists for significant displacement along any of them or on the cataclastic zones rimming the domes. Until physical evidence of significant displacement is available and until the ages of most of the cataclastic zones are known, the cataclastic zones should be regarded as local zones of Tertiary decoupling between the crystalline batholithic and metamorphic basement and the stratified cover rocks. Only additional investigations can determine whether the low-angle faults and cataclastic zones are a major folded Tertiary thrust, a series of thrusts, or purely local phenomena. The folding that caused the present distribution of faults and the present structural relief of the domes may be Miocene or younger.

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