GEOLOGY OF THE UPPER PROTEROZOIC TO LOWER CAMBRIAN THREE SISTERS FORMATION, GYPSY QUARTZITE, AND ADDY QUARTZITE, STEVENS AND PEND OREILLE COUNTIES, NORTHEASTERN WASHINGTON

by

KEVIN A. LINDSEY, DAVID R. GAYLORD, and LOUIS H. GROFFMAN

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES

REPORT OF INVESTIGATIONS 30

1990

WASHINGTON STATE DEPARTMENT OF
Natural Resources

Brian Boyle - Commissioner of Public Lands
Art Stearns - Supervisor

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Geology of the Upper Proterozoic to Lower Cambrian Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite, Stevens and Pend Oreille Counties, Northeastern Washington

by Kevin A. Lindsey[1], David R. Gaylord[2], and Louis H. Groffman[2]

ABSTRACT

The Upper Proterozoic Three Sisters Formation and Upper Proterozoic through Lower Cambrian Addy and Gypsy Quartzites are distinctive sedimentary units in northeastern Washington. In the areas studied the 930-m-thick Three Sisters Formation consists of coarse-grained to granular, cross-bedded quartzite and pebble conglomerate that is divided into a lower quartzite unit, a middle conglomerate unit, and an upper quartzite unit. In Washington, the Three Sisters Formation crops out only in northern Pend Oreille County, between Metaline Falls and the United States-Canada border. The overlying 1,400- to 1,750-m-thick Gypsy Quartzite crops out in northern Stevens and Pend Oreille Counties; its correlative, the 1,100 to 1,400-m-thick Addy Quartzite, crops out in central Pend Oreille, central and southern Stevens, and northern Lincoln Counties. The Gypsy Quartzite is composed of a cross-bedded, basal quartzite unit, a lower argillite unit, a purple quartzite unit, a coarse quartzite and argillite unit, and a fossiliferous upper argillite unit. The Addy Quartzite is divided into four units: a basal quartzite unit, a purple-banded unit, a cross-bedded, coarse quartzite unit, and a fossiliferous upper unit.

The Three Sisters Formation and Addy and Gypsy Quartzites lie near the base of the Cordilleran miogeocline and were deposited during and following Late Proterozoic rifting on the newly formed western margin of the North American craton. The Three Sisters Formation was deposited in localized rift basins during the final stages of rifting by a west-flowing (craton-to-basin) braided fluvial system. Following rifting, continental margin subsidence and associated transgression led to the deposition of the Addy and Gypsy sediments across much of northeastern Washington in braided fluvial, coastal, and shelf environments. Addy and Gypsy desposition ended as marine transgression displaced coarse terrigenous clastic depositional systems onto the craton, and shelf mud and carbonate deposition was established in northeastern Washington.

The quartz-rich strata of the Three Sisters Formation and Addy and Gypsy Quartzites are potentially important sources of silica. However, the scarcity of friable, easily mined outcrops limits economic development to only a few localities.

INTRODUCTION

The Upper Proterozoic to Lower Cambrian Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite are three of the most distinctive sedimentary units in northeastern Washington. They are the only thick quartzitic units in the region, and two of them, the Addy and Gypsy Quartzites, form easily recognized stratigraphic markers because they are the only post-Middle Proterozoic coarse terrigenous clastic units that extend across the entire region. Study of the nature and origin of the Addy and Gypsy Quartzites and Three Sisters Formation will lead to a better understanding of regional geology, Late Proterozoic to early Paleozoic tectonics and paleogeography of northeastern Washington, and correlations between Upper Proterozoic through Cambrian strata of northeastern Washington and those of surrounding areas.

Location of Study Areas

The Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite crop out in a discontinuous, 30- to 50-km-wide belt extending from Fort Spokane, Washington, north to the Canadian border (Fig. 1). In the United States the Three Sisters Formation is known to crop out only near Metaline Falls, Washington (Figs. 1 and 2) (Miller, 1982; Burmester and Miller, 1983). The Gypsy Quartzite is exposed in northern Stevens and Pend Oreille Counties (Miller and Yates, 1976; Yates, 1976), whereas the Addy Quartzite crops out in central and southern Stevens

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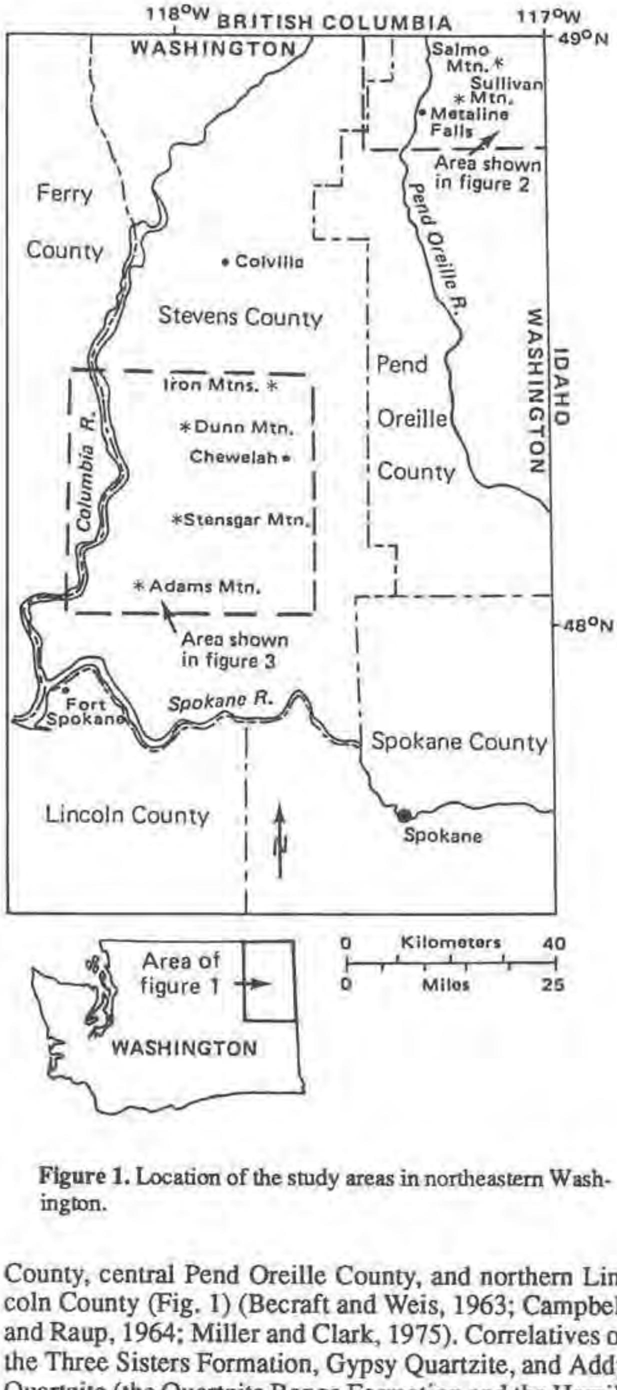


Figure 1. Location of the study areas in northeastern Washington.

County, central Pend Oreille County, and northern Lincoln County (Fig. 1) (Becraft and Weis, 1963; Campbell and Raup, 1964; Miller and Clark, 1975). Correlatives of the Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite (the Quartzite Range Formation and the Hamill Group) extend north into central British Columbia at least as far as the Caribou Mountains (Mansy and Gabrielse, 1978; Devlin and Bond, 1988). Just south of Fort Spokane, Upper Proterozoic to lower Paleozoic rocks are buried beneath the flows of the Miocene Columbia River Basalt Group.

The study areas for the report were chosen on the basis of accessibility, completeness, and quality of the exposures. Detailed studies of the Three Sisters Formation and the Gypsy Quartzite were undertaken by Groffman (1986) on Gypsy Peak and Salmo Mountain and to a lesser extent by Lindsey (1987) near Sullivan Mountain. The Addy Quartzite was examined in the central part of Stevens County on Adams Mountain, Huckleberry Mountain, Stensgar Mountain, Dunn Mountain, Quartzite Mountain, and in the Iron Mountains by Lindsey (1987) (Fig. 3).

Objectives of This Report

The objectives of this report are to: (1) describe the stratigraphy of the Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite; (2) examine correlations between them and other units; (3) propose formal stratotypes for the Addy and Gypsy Quartzites; (4) present a depositional history for the three units; and (5) review their economic potential. Stratigraphic descriptions of the Addy and Gypsy Quartzites and Three Sisters Formation are based on examination of measured stratigraphic sections coupled with detailed geologic mapping in the study areas and reconnaissance mapping outside the study areas. Correlations are based on recognition of distinct stratigraphic trends, sequences, marker beds, and paleontology. These data provided the framework upon which the type sections were designated and described. Analysis of sedimentary structures, lithofacies associations, paleocurrents, and paleontology allowed sedimentologic interpretations. Identification of major structural elements aided interpretation of large-scale tectonic features. Combining these observations provided a basis for the interpretation of the Late Proterozoic to Cambrian geologic history of northeastern Washington. Discussion of the economic geology of the Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite is based on the geology of active and inactive quarries in these units. Information in this report also indicates possible areas for future economic development.

REGIONAL GEOLOGIC SETTING

Stratigraphy

The Addy and Gypsy Quartzites and Three Sisters Formation are among the oldest rocks in the Cordilleran miogeocline in northeastern Washington; they lie near the base of the miogeoclinal section (Stewart and Suczek, 1977; Devlin and others, 1985). The Cordilleran miogeocline is a west-thickening wedge of Upper Proterozoic to lower Paleozoic sedimentary and basaltic volcanic rocks extending from the Yukon to northern Mexico (Fig. 4) and marking the western edge of the North American craton (Stewart, 1972; Stewart and Suczek, 1977). Formation of the Cordilleran miogeocline began during Late Proterozoic rifting, which formed or modified the western edge of the North American craton and initiated passive margin sedimentation (Burchfiel and Davis, 1975; Stewart, 1972; Stewart and Suczek, 1977; Sears and Price, 1978; Armin and Mayer, 1983; Devlin

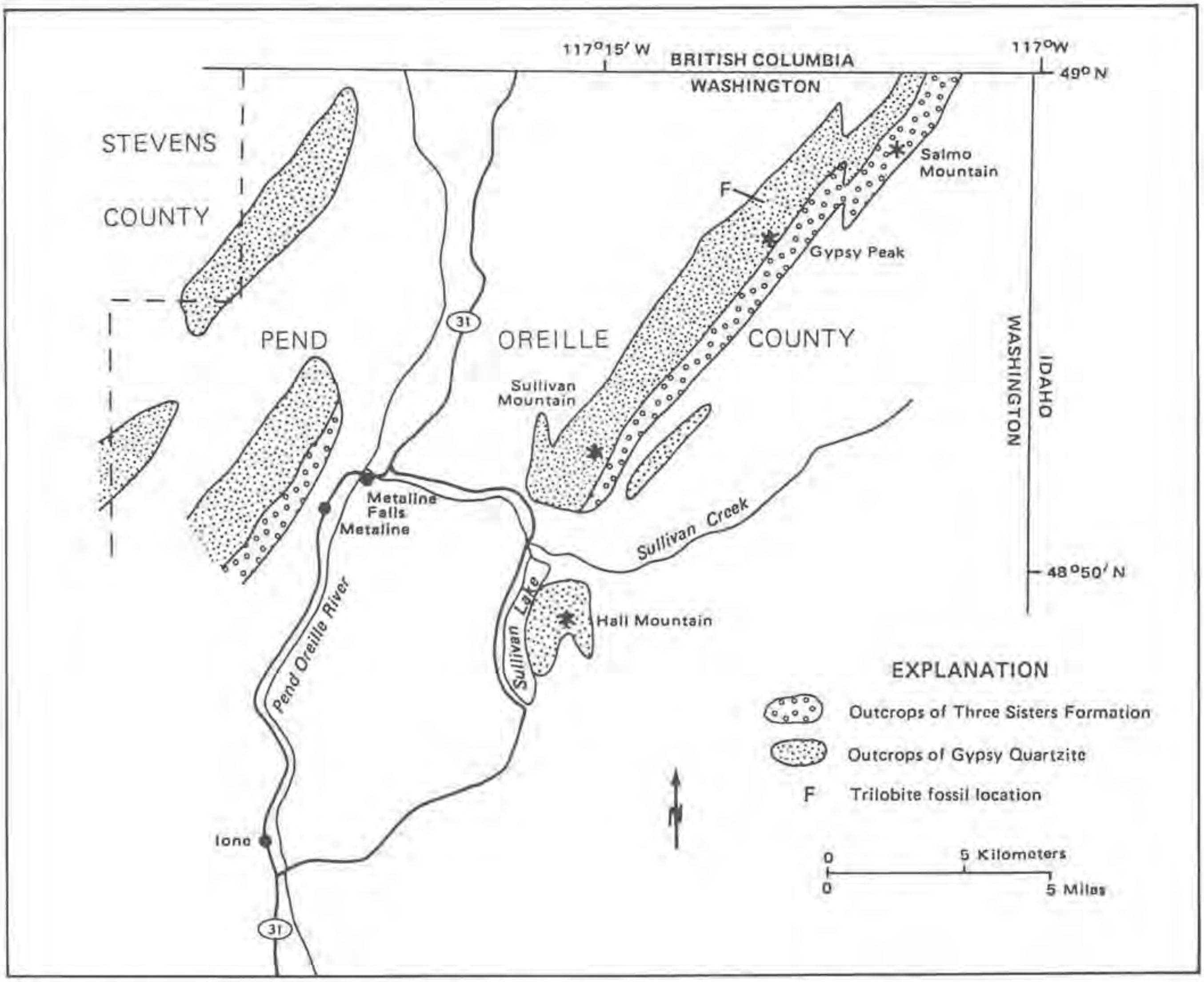


Figure 2. Outcrops of the Three Sisters Formation and Gypsy Quartzite, northern Pend Oreille County, Washington. Geology from Miller and Yates (1976), Miller (1982), Burmester and Miller (1983), and Groffman (1986).

and others, 1985; Harper and Link, 1986; Devlin and Bond, 1988).

Along the trend of the miogeocline, the outcrop belt of the Three Sisters Formation extends into southern British Columbia where it is overlain by the Quartzite Range Formation (Walker, 1934; Becraft and Weis, 1963; Mansy and Gabrielse, 1978), a unit that is thought to be correlative with the Addy and Gypsy Quartzites (Becraft and Weis, 1963). Farther north in the miogeocline, in central British Columbia, probable correlatives of the Three Sisters Formation and Addy and Gypsy Quartzites are the Gog and Hamill Groups (Mansy and Gabrielse, 1978). The miogeoclinal correlative of the Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite south of the study area is the Brigham Group of southeastern Idaho and northern Utah (Lochman-Balk, 1972; Stewart and Suczek, 1977). On the craton, units homotaxial with the Addy and Gypsy Quartzites include the Gold Creek Quartzite in northern Idaho (Vacher, 1969; Lochman-Balk, 1972) and the Flathead Quartzite in Montana (Lochman-Balk, 1972). There are no cratonal equivalents of the Three Sisters Formation.

Structural Geology

The study areas lie at the southern end of the Kootenay arc (Fig. 5), an arcuate, convex-eastward belt of deformed Precambrian and Paleozoic rocks that probably evolved during the early to middle Mesozoic (Yates, 1976; Snook and others, 1982). The arc extends from Revelstoke, British Columbia, south to the Fort Spokane, Washington, area (Fig. 5) (Yates, 1976). Rocks in the arc are divided into two sequences, a lower, Ordovician and older

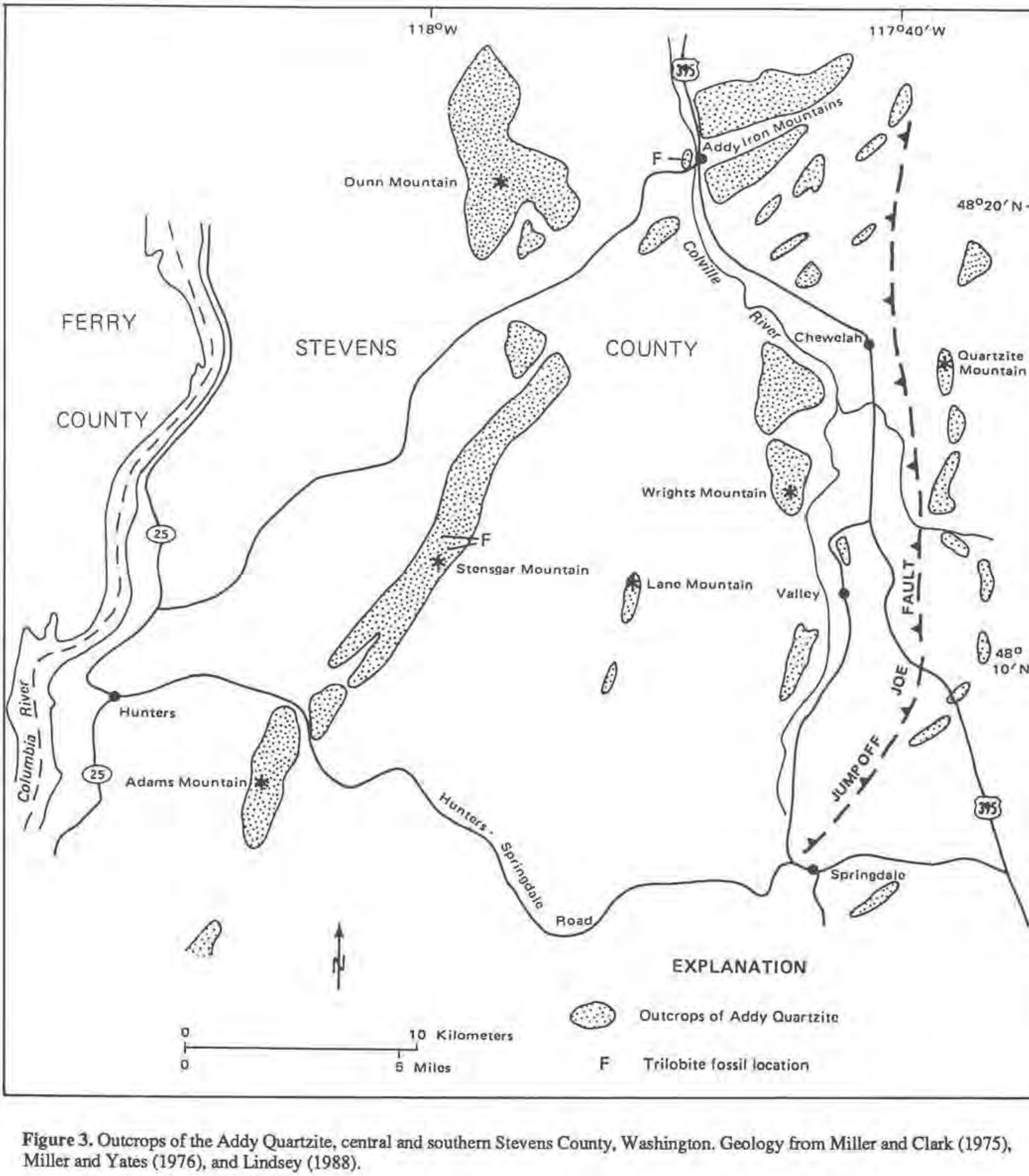


Figure 3. Outcrops of the Addy Quartzite, central and southern Stevens County, Washington. Geology from Miller and Clark (1975), Miller and Yates (1976), and Lindsey (1988).

miogeoclinal assemblage (to which the Addy, Gypsy, and Three Sisters belong) and an upper, post-Cambrian eugeoclinal assemblage (Yates, 1976).

Many of the rocks in the arc have undergone at least three phases of folding, faulting, and associated metamorphism, which probably was produced by east-directed compression along the convergent western margin

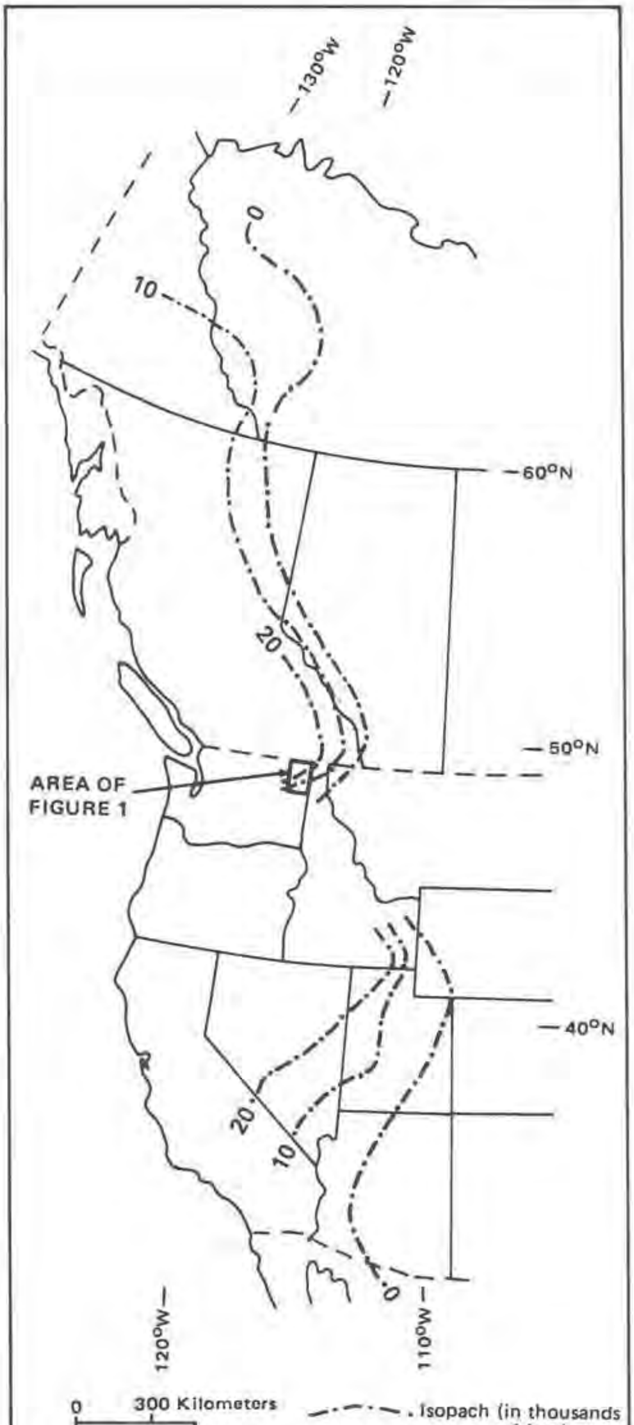


Figure 4. Isopach map of the Cordilleran miogeocline. Redrawn and adapted from Stewart (1972).

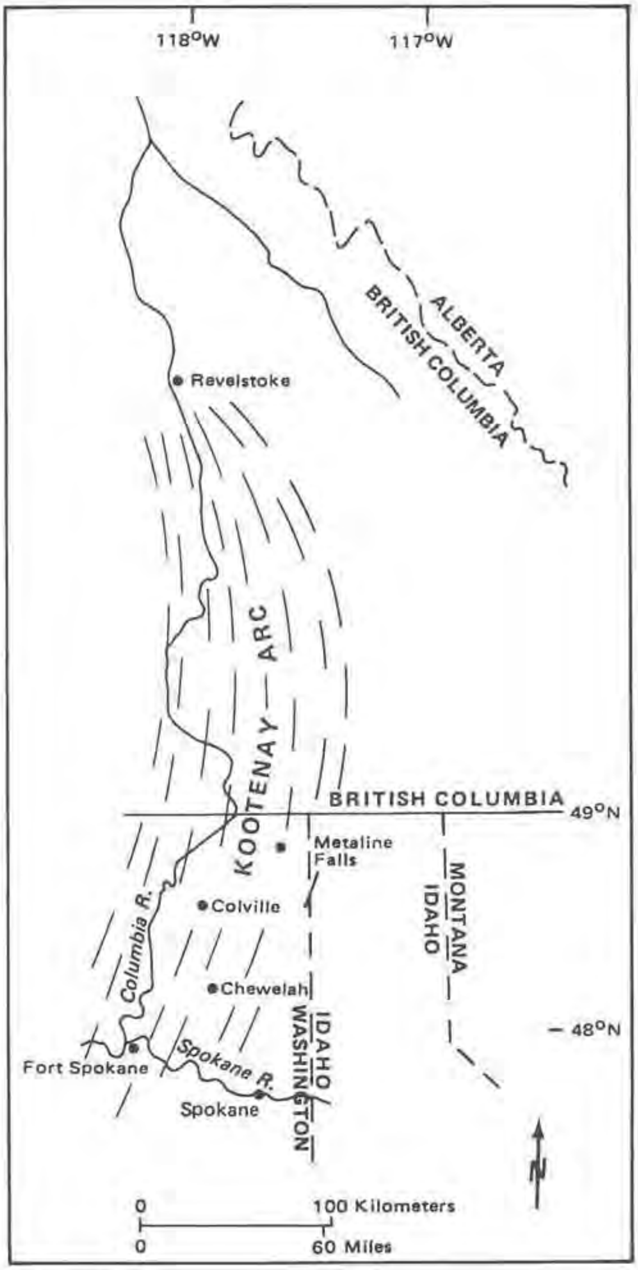


Figure 5. Location of the Kootenay arc. Redrawn and adapted from Yates (1976).

of North America during Late Triassic to Early Cretaceous time (Mills and Nordstrom, 1973; Yates, 1976; Snook and others, 1982). The first two phases of folding produced axial planes generally parallel to the trend of the arc, and the third phase produced axial planes transverse to the arc (Miller and Clark, 1975; Snook and others, 1982). Thrust faults were formed by the same stresses that produced folding (Snook and others, 1982) and probably record east-directed movement (Miller and Clark, 1975; Yates, 1976). However, Miller and Clark (1975) note that several of these faults truncate and thus post-date Kootenay arc folds. Of these faults, Miller and

Clark (1975) note that at least one, the Jumpoff Joe thrust, also cross-cuts Cretaceous intrusions.

The Addy and Gypsy Quartzites and the Three Sisters Formation within the areas studied do not display the high degree of deformation and metamorphism that commonly is associated with rocks in the Kootenay arc. The Addy, Gypsy, and Three Sisters dominantly are metamorphosed to lower greenschist facies, and as a result primary sedimentary structures and depositional fabrics in these units are preserved. The lack of strong deformation may be due to: (1) the location of the study areas near the less deformed eastern and southern fringe of the arc, and (2) the fact that quartzitic rocks such as the Addy and Gypsy Quartzites and Three Sisters Formation are relatively competent and therefore less easily deformed.

Northeastern Washington also is the site of Jurassic to Cretaceous quartz monzonites and granodiorites, the bulk of which post-date Kootenay arc structures (Miller and Clark, 1975; Yates, 1976; Snook and others, 1982). These intrusions are part of the late Mesozoic igneous arc that stretches the length of the western North American Cordillera. In the areas studied, intrusive rocks are in direct contact with the Addy Quartzite at only two locations, the Iron Mountains and on Adams Mountain. At those places, local contact metamorphism is present.

The most recent structural elements in the region are high-angle faults. These faults, referred to as "block or extensional faults" by Yates (1976, p. 382) are thought to have a Late Cretaceous to Eocene age. They may have formed as a result of early Tertiary extension related to oblique subduction in western Washington and British Columbia. Regionally, these faults probably bound many of the ridges, hills, and mountains on which the Addy and Gypsy Quartzites and Three Sisters Formation are exposed. Locally, high-angle faults cut the Addy Quartzite on Stensgar Mountain, Dunn Mountain, and in the Iron Mountains; they also offset the Gypsy Quartzite and Three Sisters Formation between Gypsy Peak and Salmo Mountain and on Sullivan Mountain.

Precambrian structures, some of which may have influenced deposition of the Three Sisters Formation, also are present in the area. High-angle faults and broad folds restricted to the Middle Proterozoic Belt Supergroup and correlative (?) Deer Trail Group (Miller and Clark, 1975; Miller and Whipple, 1989) may have formed at some time between 1,250 and 950 Ma (Reid and others, 1973; McMechan and Price, 1982; Evenchick and others, 1984). These structures and younger Precambrian faults may have played a role in deposition of the Three Sisters Formation between 760 and 570 Ma during Late Proterozoic continental rifting (Lindsey, 1987; Devlin and Bond, 1988).

STRATIGRAPHY OF THE ADDY QUARTZITE, THREE SISTERS FORMATION, AND GYPSY QUARTZITE

History

Addy Quartzite

The Addy Quartzite was the first of the three units to be named, and it has been accepted by geologic investigators in northeastern Washington as a formal unit. However, a type section for the Addy Quartzite has never been designated. The name Addy Quartzite first appeared in Weaver's (1920) report on the mineral resources of Stevens County. Weaver applied the name Addy Quartzite to rocks described as massive, hard, crystalline, light-colored quartzites, minor quartz-mica schists, banded slates, and mica-banded quartzites of probable Early Cambrian age. Weaver named the Addy Quartzite from outcrops in the Iron Mountains less than 1 km east of Addy, Washington (Fig. 3). Weaver's (1920) Addy Quartzite was 1,000 to 2,000 m thick, underlain by Precambrian argillites, siltites, quartzites, and carbonates that he designated the Deer Trail Argillite, and overlain by schists, phyllites, argillites, quartzites, and limestones he designated the Chewelah argillite. A second Lower Cambrian quartzite unit also was described by Weaver (1920) in central Stevens County. This unit, the Eagle Mountain quartzite, was mapped on Eagle Mountain east of Chewelah, Washington, and described as gray to brown, crystalline to vitreous, commonly micaceous quartzite.

Bennett (1941) modified Weaver's (1920) definition of the Addy Quartzite during his study of the magnesite belt of Stevens County (Fig. 6). Bennett noted that the Addy Quartzite as mapped by Weaver contained greenstone and conglomerate in its lower parts which were not included in Weaver's descriptions. Bennett assigned these greenstones and conglomerates to a new unit underlying the Addy Quartzite: the Huckleberry Formation (Fig. 7). An Early Cambrian age for the Huckleberry was inferred by Bennett (1941) on the basis of its stratigraphic position above strata thought to be Precambrian. The Precambrian rocks, which had been designated the Deer Trail argillite by Weaver (1920), were redesignated the Deer Trail Group by Bennett (1941). Bennett (1941) also redefined the upper contact of the Addy Quartzite by remapping the Chewelah argillite of Weaver as undifferentiated, unnamed, Lower Cambrian limestones.

The next study involving the Addy Quartzite was that of Okulitch (1951). This was the first study in which fossils from the Addy Quartzite were described. From exposures near Addy, Early Cambrian trilobites (*Nevadia addyensis* Okulitch, later renamed *Nevadella addyensis* (Miller and Clark)[1]), brachiopods (*Kutorgina cingulata* Billings), and mollusks (?) *Hyolithus* sp. were collected. This fossil assemblage confirmed an Early Cambrian age

[1] According to Miller and Clark, 1975, p. 28, *Nevadia* = *Nevadella*

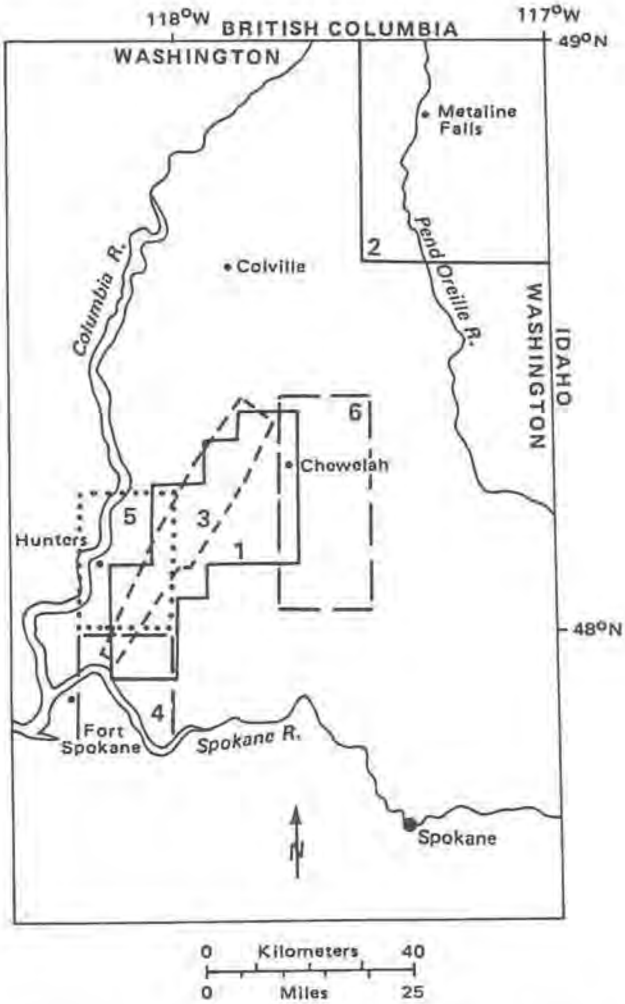


Figure 6. Locations of selected previous studies in the Addy and Gypsy Quartzite, northeastern Washington. 1, Bennett, 1941; 2, Park and Cannon, 1943; 3, Campbell and Loofbourow, 1962, and location of magnesite belt; 4, Becraft and Weis, 1963; 5, Campbell and Raup, 1964; 6, Miller and Clark, 1975.

for at least part of the Addy Quartzite. However, Okulitch's fossil localities were situated in fault-bounded exposures of unclear straigraphic position.

Subsequent to Okulitch's and prior to our study, several investigators re-examined the stratigraphy of the Addy Quartzite and adjacent units. The unnamed limestones that Bennett (1941) described above the Addy Quartzite were redesignated the Old Dominion limestone (Fig. 7) by Becraft and Weis (1963), Campbell and Raup (1964), and Evans (1982) in the southern and central magnesite belt. The Metaline Limestone (Fig. 7), another Lower Cambrian limestone, was mapped above the Addy in the Colville River valley (Miller and Clark, 1975). A third unit, the Maitlen Phyllite (Fig. 7), also was found to overlie the Addy on and north of Dunn Mountain (Lucas, 1980; Snook, 1981). These three units are thought to conformably overlie the Addy.

Interpretations of the stratigraphic relations of the Addy Quartzite with underlying units also have been modified. The Huckleberry Formation is now thought to be Late Proterozoic in age (Miller and others, 1973; Devlin and others, 1985) and the Deer Trail Group, Middle Proterozoic in age (Miller and Clark, 1975; Miller and Yates, 1976; Miller and Whipple, 1989). Mapping by Miller and Clark (1975) and Miller and Yates (1976) has shown that the Addy also overlies the Monk Formation and Belt Supergroup (Fig. 7). The Monk Formation is of Late Proterozoic age and overlies the Huckleberry Formation (Miller and others, 1973; Miller and Clark, 1975). The Belt Supergroup is Middle Proterozoic in age and probably correlative with the Deer Trail Group (Miller and Clark, 1975; Miller and Whipple, 1989).

Weaver's (1920) and Bennett's (1941) studies did not describe the internal stratigraphy of the Addy in any detail, indicating only that it consisted predominantly of quartzite. However, local studies by Becraft and Weis (1963), Reynolds (1968), Vacher (1969), and Lucas (1980) showed that the Addy displayed a distinct vertical lithostratigraphic succession. In addition, Becraft and Weis (1963) and Vacher (1969) showed that argillite and siltite made up a significant portion of the upper Addy on and south of Stensgar Mountain. Regional mapping by Miller and Yates (1976) showed the presence of a persistent purple quartzite marker bed in the middle of the Addy Quartzite.

Gypsy Quartzite and Three Sisters Formation

The name Gypsy Quartzite was first applied to quartzite cropping out northeast of Metaline Falls by Park and Cannon (1943). They described the Gypsy Quartzite as 1,700 to 2,750 m of quartzite, "grit", and conglomerate, with conglomerate most abundant in the lower half. Park and Cannon placed the base of the Gypsy at the bottom of the lowest thick "grit" bed overlying phyllites and carbonates that they assigned to the Precambrian Monk Formation. They placed the contact between the Gypsy Quartzite and overlying Maitlen Phyllite at the base of "fucoidal" argillites that occurred 20 to 40 m below the lowest gray-white limestone found in the Maitlen Phyllite. Park and Cannon assigned an Early Cambrian age to the Gypsy on the basis of: (1) rare trilobite fragments in its upper parts; (2) its position above the upper Precambrian Monk Formation; and (3) its position below Lower Cambrian archeocyathid-bearing limestones in the Maitlen Phyllite.

From 1943 until 1982 all published geologic maps of northern Pend Oreille and Stevens Counties used the Gypsy Quartzite as defined by Park and Cannon (1943). This changed in 1982 when Miller (1982) noted that rocks in Canada correlative to Park and Cannon's Gypsy Quartzite were divided into two units: a lower conglom-

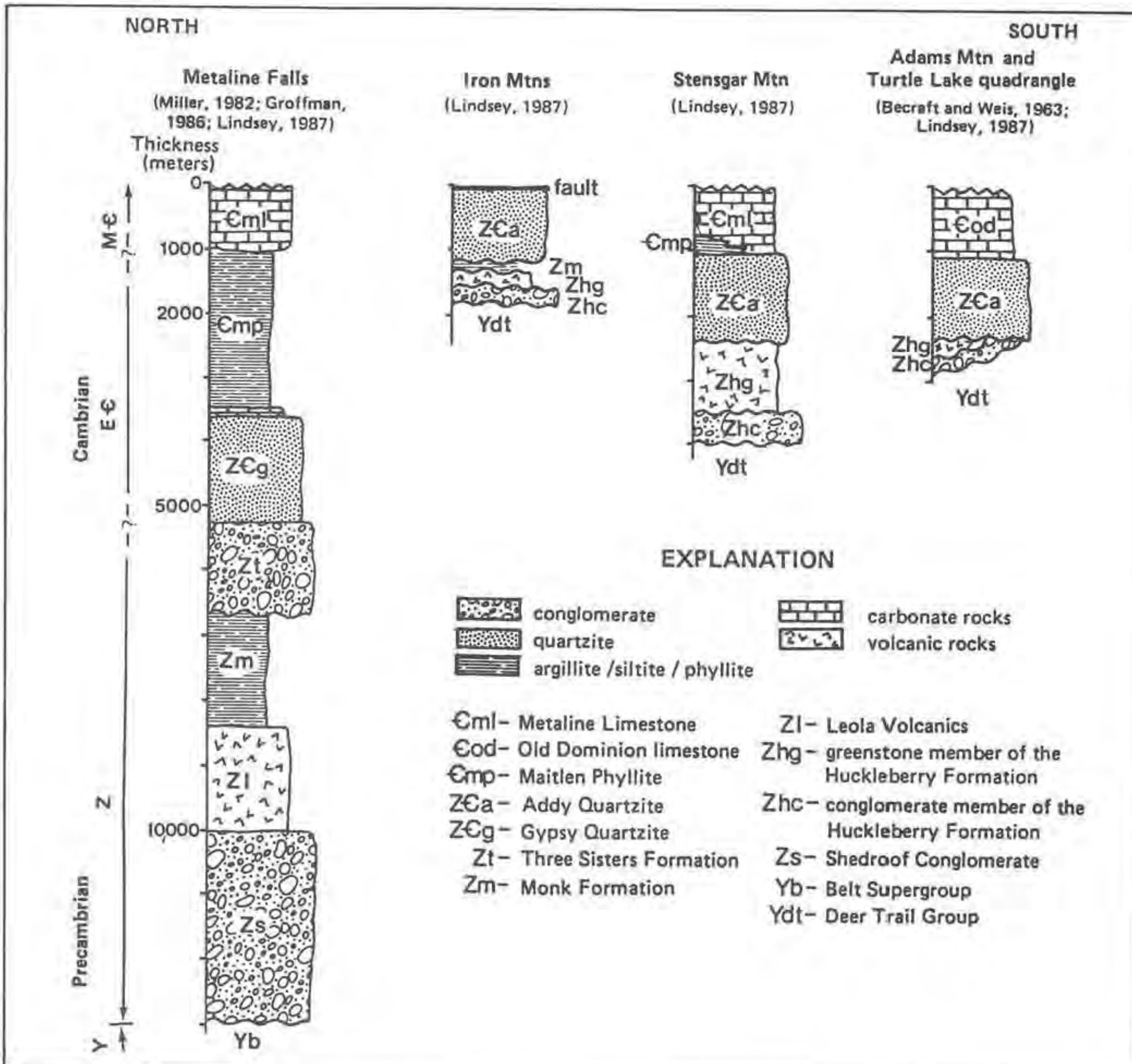


Figure 7. Late Proterozoic to Cambrian stratigraphy in northeastern Washington.

eratic unit, the Three Sisters Formation; and an upper quartzitic unit, the Quartzite Range Formation. This stratigraphy was first defined by Walker (1934). Miller recognized that the Gypsy Quartzite, as originally defined by Park and Cannon (1943), consisted of a lower conglomeratic interval and an upper quartzitic interval. Consequently, Miller proposed that Park and Cannon's Gypsy Quartzite be divided into two units, a conglomeratic lower unit designated the Three Sisters Formation and a quartzitic upper unit that retained the name Gypsy Quartzite (Fig. 7). In addition, Miller assigned argillites with thinly interbedded quartzites, which were formerly included in the upper Monk Formation, to the lower part of the Three Sisters Formation.

Miller (1982) also redefined the upper boundary of the Gypsy Quartzite as the base of the Reeves Limestone Member of the Maitlen Phyllite. This lithostratigraphic boundary is much sharper and more easily recognized than one at the base of the "fucoidal" quartzites due to the scarcity of limestone in the Gypsy Quartzite (Miller, 1982). Where the Reeves Limestone Member is absent, the top of the Gypsy is at the top of the highest thick quartzite bed underlying the black and green phyllites of the Maitlen Phyllite. However, Miller did not designate a type section for his redefined Gypsy Quartzite.

The Three Sisters Formation and Gypsy Quartzite as described by Miller (1982) display a distinct lithostratigraphic succession. The Three Sisters Formation was described as having a lower argillaceous interval and an upper quartzite and conglomerate interval. From bottom to top the Gypsy Quartzite was divided into a basal quartzite, an argillaceous interval, purple-banded quartzites, and interbedded quartzites and argillites (Miller, 1982; Burmester and Miller, 1983). This stratigraphy accounts for most of the major lithostratigraphic trends displayed by the Three Sisters Formation and Gypsy Quartzite, and it will be generally followed in this report.

Stratigraphy

Three Sisters Formation

The Three Sisters Formation as described by Miller (1982) in northeastern Washington consists of a lower argillaceous interval overlain by a succession of quartzite- and conglomerate-dominated intervals. This stratigraphic succession formed the basis of our descriptions of the Three Sisters Formation in earlier reports (Groffman, 1986; Groffman and Lindsey, 1986; Lindsey, 1988). However, recently we have come to reconsider this stratigraphy.

Because of lithologic similarities between the argillite-dominated lower Three Sisters Formation and the underlying Monk Formation and the lack of thick (>2 m) quartzite and conglomerate beds in the Monk Formation, we assign the argillaceous strata formerly mapped as the lowest unit of the Three Sisters Formation (Miller, 1982; Burmester and Miller, 1983; Groffman, 1986; Groffman and Lindsey, 1986) to the Monk Formation. Argillite-dominated strata formerly assigned to the lower Three Sisters consist of thin-bedded, black and gray argillite and siltite containing lenticular interbeds of limestone, dolomite, and fine-grained quartzite less than 1 m thick. Assigning these rocks to the Monk Formation places all the argillaceous strata overlying Late Proterozoic greenstones (Leola Volcanics or Huckleberry greenstone member) and lying beneath Upper Proterozoic to Lower Cambrian quartzitic strata (Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite) into one formation (Fig. 7). This is essentially a return to Park and Cannon's (1943) original definition of the Monk Formation. A contact between argillaceous (Monk Formation) and quartzitic (Three Sisters Formation) units is more easily recognized and mapped and more logical than one within the argillites. The redefined Monk Formation is Late Proterozoic in age and consists dominantly of thin-bedded, black and gray argillite and phyllite containing thin, lenticular interbeds of limestone, dolomite, and quartzite.

The Three Sisters Formation as redefined here unconformably overlies the Monk Formation, consists dominantly of quartzite and conglomerate, and is divided into three units: (1) the lower quartzite unit; (2) the conglomerate unit; and (3) the upper quartzite unit (Fig. 8). These units comprise the upper unit of the Three Sisters Formation as used in Lindsey (1988). Many of the criteria used in defining these units are the same as those Miller (1982) used in describing the Three Sisters Formation. The Three Sisters Formation is known to crop out only north of Metaline Falls.

Lower quartzite unit

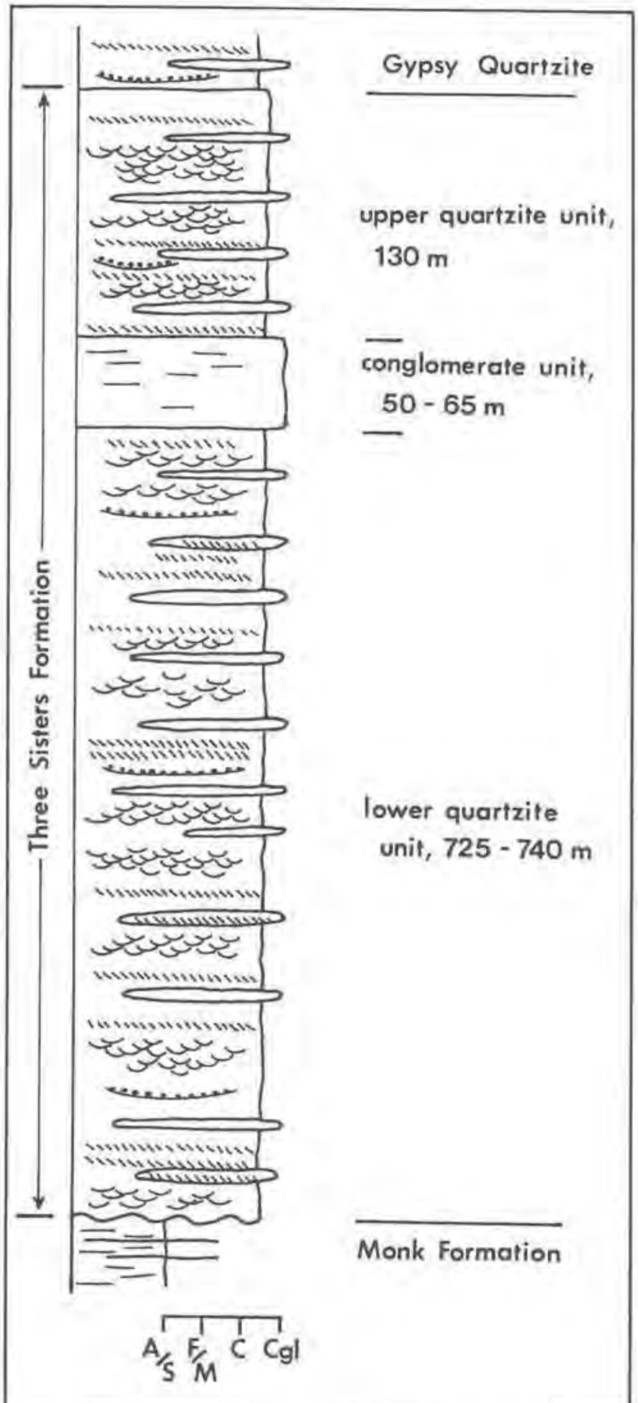
The lower quartzite unit consists of 725 to 740 m of gray, blue, tan, and green quartzite and pebble conglomerate with minor thin interbeds of argillite and cobble conglomerate (Figs. 8 and 9). The quartzite is dominantly coarse-grained to granular, texturally immature quartz arenite. Minor arkosic quartzite also is present. Conglomerate clasts consist most commonly of polycrystalline quartzite, quartz mica tectonite, chert, and monocrystalline quartz.

Trough and planar cross-bedded quartzite and pebble conglomerate dominate the lower quartzite unit. Plane bedding also is present but less abundant than cross-bedding. Local cobble conglomerate beds generally are massive to crudely graded. These cross-bedded to massive conglomerates and quartzites commonly overlie broad (>10 m wide), shallow (<2 m deep), flat-bottomed channels. High-angle scour surfaces, possibly associated with deeper channels, also are present. The quartzite and conglomerate filling the channels commonly display poorly defined coarsening- and fining-upward sequences. Strata comprising the lower quartzite unit generally are laterally discontinuous, displaying wedge and lenticular geometries. Paleocurrent indicators in these strata are unidirectional and indicate flow to the northwest.

The lower quartzite unit abruptly overlies the Monk Formation. The contact is placed at the base of the lowest bed of coarse-grained to granular quartzite or pebble conglomerate typical of the lower quartzite unit. Coarse quartzite and conglomerate are rare in the Monk Formation. In addition, an angular discordance of less than 10 degrees between the Three Sisters Formation and the Monk Formation is displayed locally. These characteristics suggest the lower quartzite unit unconformably overlies the Monk Formation.

Conglomerate unit

The 50- to 65-m-thick conglomerate unit is composed of green cobble and boulder conglomerate (Figs. 8 and 10). Beds in the lower 40 m of the unit average 0.5 to 0.8 m thick and are massive to crudely plane bedded. In the upper 15 to 20 m of the unit, beds are thinner and less massive. Clasts consist most commonly of phyllite and white, pink, and blue quartzite. The phyllite clasts decrease in abundance up-section. Other less common clasts are fine-grained or porphyritic volcanic rock, greenstone, and red chert. Matrix in these conglomerates consists of medium-grained to granular quartzite.



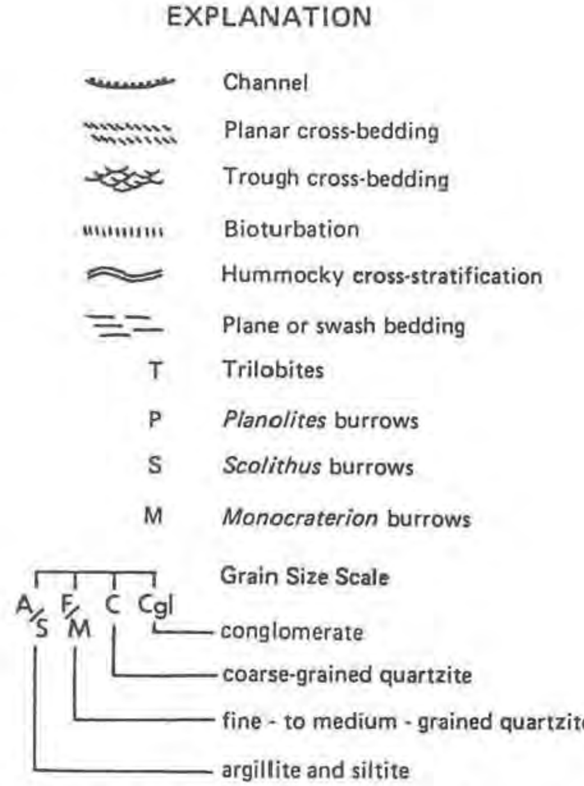


Figure 8. Idealized stratigraphic column of the Late Proterozoic Three Sisters Formation. Based on Groffman (1986) and Lindsey (1987) and not to scale.

The base of the unit is sharp and easily recognized. It is placed at the bottom of the lowest thick (>0.5 m) cobble conglomerate bed overlying cross-bedded granular and thin pebble conglomerates. The contact does not appear to be scoured, but because it is so abrupt, it may be disconformable.

Upper quartzite unit

The upper quartzite unit is a 130-m-thick sequence of white, gray, tan, blue, and green, cross-bedded, fine-grained to granular quartzite and pebble conglomerate. The quartzite is dominantly coarse grained to granular and similar to the quartzite comprising the lower quartzite unit. Conglomerate clast types are the same as in underlying strata. However, cobble conglomerate largely is absent from the unit. Argillite and siltite are restricted to rare, thin (<20 cm), lenticular interbeds.

Sedimentary structures in the upper quartzite unit are similar to those seen in the lower quartzite unit. Planar cross-bedding is the most abundant sedimentary structure. Trough cross-bedding and plane bedding also are common but less abundant. Beds greater than 1.5 m thick commonly are massive. Channels consisting of broad (>10 m), shallow (<1 m) scour surfaces also are present. Beds in the unit are generally laterally discontinuous.

The upper quartzite unit gradationally overlies the conglomerate unit. The contact is placed at the top of the highest cobble conglomerate bed greater than 30 cm thick. The upper quartzite unit of the Three Sisters Formation is overlain by the Gypsy Quartzite.

The nature of the contact between the Gypsy Quartzite and the Three Sisters Formation is open to question. In

Figure 9. Cross-bedded quartzite and pebble conglomerate of the lower quartzite unit of the Three Sisters Formation 3 km south of Gypsy Peak.

southern British Columbia, within 50 km of the international border, the contact between the Quartzite Range Formation (Gypsy correlative) and the Three Sisters Formation is thought to be conformable (Walker, 1934; Mansy and Gabrielse, 1978; Devlin and Bond, 1988). By contrast, Miller (1982) and Burmester and Miller (1983) believe the contact is an unconformity in northeastern Washington and place it at the top of the uppermost granular to conglomeratic quartzite that they assign to the Three Sisters Formation. However, the lowermost Gypsy Quartzite as mapped by Miller (1982) and Groffman (1986) contains thin pebble conglomerates that are very similar to those seen in the uppermost Three Sisters Formation. This suggests the Three Sisters/Gypsy contact is gradational and therefore conformable. Consequently, we place the top of the Three Sisters Formation at the top

Figure 10. Massive cobble and boulder conglomerate of the conglomerate unit of the Three Sisters Formation 2 km north of Sullivan Mountain.

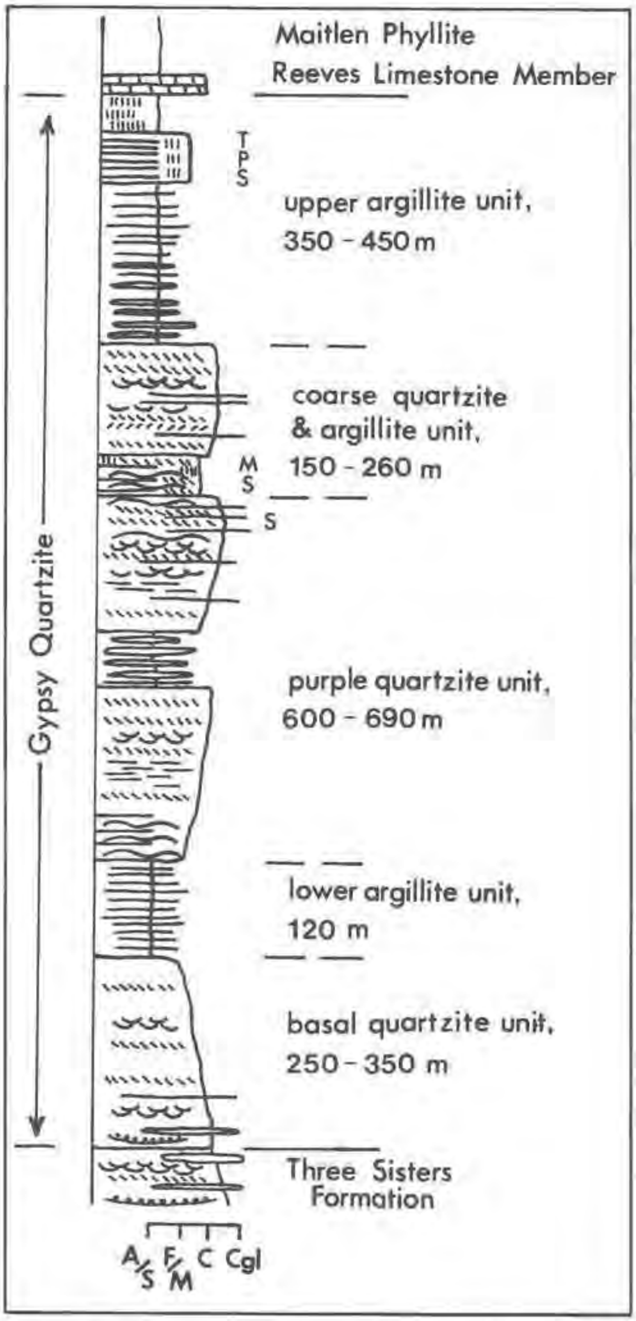


Figure 11. Idealized stratigraphic column of the Late Proterozoic to Early Cambrian Gypsy Quartzite in northern Pend Oreille County, Washington. Redrawn and adapted from Groffman (1986) and Lindsey (1987) and not to scale. See Figure 8 for explanation of other symbols.

of the stratigraphically highest thick (>1 m) pebble conglomerate bed that generally lies in a transitional interval as much as 50 m thick where pebble conglomerates thin up-section.

Gypsy Quartzite

Quartzite, siltite, and argillite make up the 1,470- to 1,800-m-thick Gypsy Quartzite in the study area northeast of Metaline Falls. The lower 1,000 to 1,300 m of the Gypsy are dominated by quartzite containing minor interbedded argillite and siltite; the upper 350 to 450 m comprise an interbedded sequence of quartzite, siltite, and argillite (Fig. 11). The Gypsy Quartzite is divided into five distinct lithostratigraphic units. In ascending order these are: (1) the basal quartzite unit; (2) the lower argillite unit; (3) the purple quartzite unit; (4) the coarse quartzite and argillite unit; and (5) the upper argillite unit.

Basal quartzite unit

The basal quartzite unit is a 250- to 350-m-thick sequence of white, well sorted, cross-bedded quartzite. Medium- to thick-bedded, medium-grained to granular quartzite with lenticular interbeds of pebble conglomerate filling shallow channels is common in the lowermost 10 to 30 m of the unit. The balance of the unit consists of fine- to coarse-grained, well sorted, medium- to thick-bedded, white quartzite. Siltite and argillite interbeds less than 1 m thick are present but rare.

Planar cross-bedding occurs throughout the unit and is the most common sedimentary structure preserved. Trough cross-bedding is common in the pebbly interbeds at the base of the unit and occurs locally throughout the rest of the unit. Swash cross-lamination, bedding-top pebble lags and mud partings, hummocky and swaley bedding surfaces, plane bedding, and herringbone cross-stratification occur sporadically throughout the unit.

The basal quartzite unit conformably overlies the Three Sisters Formation. Where the Three Sisters Formation is absent, the basal unit unconformably overlies the phyllite and argillite of the Monk Formation (Miller and Yates, 1976). At these localities the contact is placed at the base of the lowest thick (>1 m) quartzite bed above which thick (>0.5 m) argillite and phyllite beds are absent. This contact is abrupt due to the absence of thick (>1 m) quartzite beds in the Monk Formation and the absence of thick (>0.5 m) argillite beds in the basal quartzite unit.

Lower argillite unit

The 120-m-thick lower argillite unit consists of lenticular to wavy bedded, olive and brown argillite interbedded with brown, tan, and white, fine-grained quartzite (Fig. 12). Beds range from less than 1 cm to more than 70 cm thick. Quartzite and siltite beds more than 30 cm thick form laterally continuous bodies; beds less than 30 cm thick are continuous or lenticular. Primary sedimentary structures are rare in the unit, but ripple cross-lamination can be observed locally. In addition, bedding is disrupted in places by what appear to be compressed, sand-filled, vertical burrows. Many of the beds display low relief (<10 cm high) hummocky and swaley bounding surfaces.

Figure 12. Interbedded argillite and quartzite of the lower argillite unit of the Gypsy Quartzite on the ridge 100 to 200 m west of the crest of Gypsy Peak.

The base of the lower argillite unit is sharp and easily recognized. It is at the bottom of the lowest interval of interbedded quartzite, siltite, and argillite overlying the distinct white quartzites of the basal quartzite unit. Due to the sharpness of this contact, we infer that it is disconformable.

Purple quartzite unit

The purple quartzite unit is 600 to 690 m thick and consists dominantly of medium- to coarse-grained, thin- to thick-bedded, purple, blue, gray, and white quartzite. The quartzite commonly displays red to purple banding which is parallel, subparallel, and transverse to bedding. Liesegang bands, hematitic cements, and detrital heavy mineral layers form the banding. The unit is divided into an upper and lower interval on the basis of the banding, sedimentary structures, and lithology.

The lower 400 to 450 m of the unit consists dominantly of fine- to coarse-grained quartzite (Fig. 11) in which purple banding is abundant. Granule and pebble beds, isolated sand-supported pebbles, and purple argillite and siltite interbeds are present but rare. Hummocky cross-lamination is common locally. Ripple cross-lamination, planar cross-beds, and trough cross-beds are common.

The upper 200 to 300 m of the unit consist of medium- to thick-bedded, blue and purple, medium-grained to granular quartzite (Fig. 11). Granules and, less commonly, pebbles are concentrated in thin (<3 cm) layers on bedding tops. These bedding tops commonly display a hummocky and swaley topography and are capped by argillite partings. Planar cross-bedding is common throughout the interval; trough cross-bedding is less abundant; plane beds are rare. Broad channels defined by shallow (<1 m deep) scours and channel lags are present locally. The vertical burrow *Scolithus linearis* Haldeman (Fig. 13) occurs locally in the uppermost 50 m of the unit.

The base of the purple quartzite unit is placed at the base of the lowest blue, purple, or lavender, fine- to coarse-grained quartzite greater than 0.5 m thick overlying the interbedded quartzite, siltite, and argillite of the lower argillite unit. This contact lies within a gradational interval less than 3 m thick.

Coarse quartzite and argillite unit

The coarse quartzite and argillite unit is 150 to 260 m thick and consists of a lower argillaceous interval 30 to 60 m thick and an upper quartzitic interval 120 to 200 m thick (Fig. 11). The lower interval consists of sequences of white and brown, fine- to coarse-grained, thin- to medium-bedded quartzite alternating with sequences of interbedded quartzite and argillite. Quartzite beds in the interbedded sequences are hummocky and swaley bedded and commonly display vertical *Scolithus* burrows. The quartzitic sequences are planar cross-bedded and herringbone cross-bedded, and they contain the vertical burrow *Monocraterion* (Fig. 14).

The upper quartzitic interval consists predominantly of white to tan, thin- to thick-bedded, medium-grained to granular quartzite that displays abundant planar and trough cross-bedding. Argillites and siltites are present but restricted to thin, lenticular interbeds and interlaminations. Thin (<20 cm), lenticular pebble conglomerate beds and channel cut-and-fill structures occur locally.

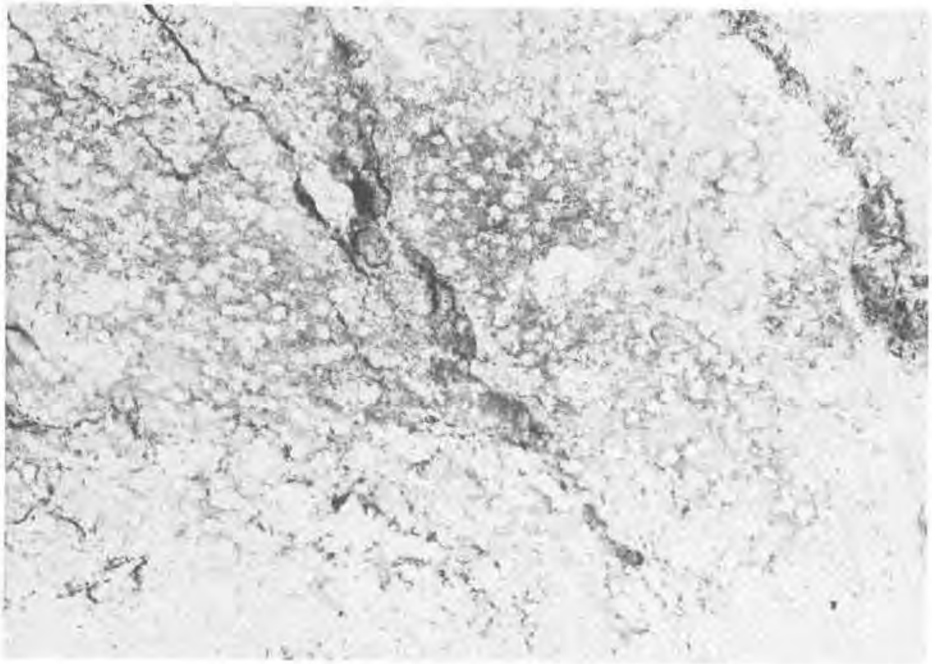


Figure 13. Bedding-top view of the vertical burrow *Scolithus linearis* in the purple quartzite unit of the Gypsy Quartzite at a locality 0.5 km north of Sullivan Mountain. Burrows are from 3 to 4 mm in diameter.

The contact between the coarse quartzite and argillite unit and the underlying purple quartzite unit is in a gradational interval 10 to 15 m thick. Gray, blue, and purple, medium-grained to granular quartzites at the base of the transition interval are gradually replaced up-section by argillite, siltite, and white and tan, medium- to coarse-grained quartzite. We place the contact at the base of the lowest thick (>1 m), light colored, cross-bedded quartzite with interbedded argillite.

Upper argillite unit

The upper argillite unit consists of 350 to 480 m of interbedded quartzite, siltite, and argillite (Fig. 11). Most of the unit consists of 1- to 4-m-thick beds of black, gray, and brown argillite that alternate with 0.5- to 4-m-thick fine- to medium-grained, brown, tan, and white, commonly argillaceous quartzite beds. Quartzite beds generally are thinner and less abundant up-section. Lenticular, wavy, and sheet-like bedding geometries are common in

Figure 14. The vertical burrow *Monocraterion* in the coarse quartzite and argillite unit of the Gypsy Quartzite on Sullivan Mountain. Ruler is 6 in. (15.24 cm) long.

the unit. Rare thin calcareous quartzite beds are present in the upper half of the unit.

Primary sedimentary structures are rare in the upper argillite unit. Planar cross-bedding is present in quartzites in the lower half of the unit. Small (<2 cm) ball and pillow structures and soft sediment deformed starved ripples occur in thin (<10 cm) quartzite interlaminations throughout the unit. Hummocky and swaley bedding and ripple cross-lamination are present locally.

Non-trilobite trace fossils are abundant in the unit, especially the upper half. Fossiliferous beds in the upper 50 to 100 m of the unit contain the vertical burrow *Scolithus bulbus* Alpert in quartzite beds and the horizontal burrow *Planolites beverlyensis* Nicholson in argillite and siltite beds. Several unidentified burrows and trails also are found in the unit. The fossilifereous beds lying near the top of the unit probably correspond to Park and Cannon's (1943) "fucoidal" beds.

Trilobite body and trace fossils are rare in the upper argillite unit. A few disarticulated trilobite spines have been found in the upper 100 m of the unit (Park and Cannon, 1943; Miller, 1982; Groffman, 1986). The trilobite resting trace *Rusophycus* occurs locally in association with these spines (Groffman, 1986).

The basal contact of the unit is is placed at the bottom of the lowest interval of interbedded argillite, siltite, and quartzite overlying the white and tan, cross-bedded, coarse-grained quartzite of the coarse quartzite and argillite unit. The contact lies in a transitional interval 1 to 3 m thick.

The upper contact of the Gypsy Quartzite is at the base of the gray, crystalline, archeocyathid-bearing Reeves Limestone Member of the Maitlen Phyllite. This contact is very abrupt because no gray limestones resembling those in the Reeves are found in the upper argillite unit of the Gypsy Quartzite. Where the Reeves is absent, the contact is placed where interbedded brown quartzite, siltite, and argillite typical of the upper argillite unit are replaced by black and green phyllite typical of the Maitlen Phyllite. This transition is gradational and tends to occur in an interval as much as 30 m thick.

Addy Quartzite

The Addy Quartzite consists of interbedded quartzite, siltite, and argillite in the magnesite belt west of the Jumpoff Joe fault (Fig. 3). In this area the Addy Quartzite attains maximum thicknesses of 1,100 to 1,400 m and is divided into four units: (1) the basal unit; (2) the purple-banded unit; (3) the coarse unit; and (4) the upper unit (Fig. 15). A complete section of the Addy Quartzite is not found east of the Jumpoff Joe fault because the basal unit is absent and the top of the Addy Quartzite has been removed in most places by faulting or erosion.

Basal unit

The basal unit consists dominantly of fine- to medium-grained, very mature and well sorted, white quartzite. It is present west of the Jumpoff Joe fault but is absent east of the fault. The basal unit is 150 to 200 m thick on Dunn and Adams Mountains and 90 to 200 m thick elsewhere.

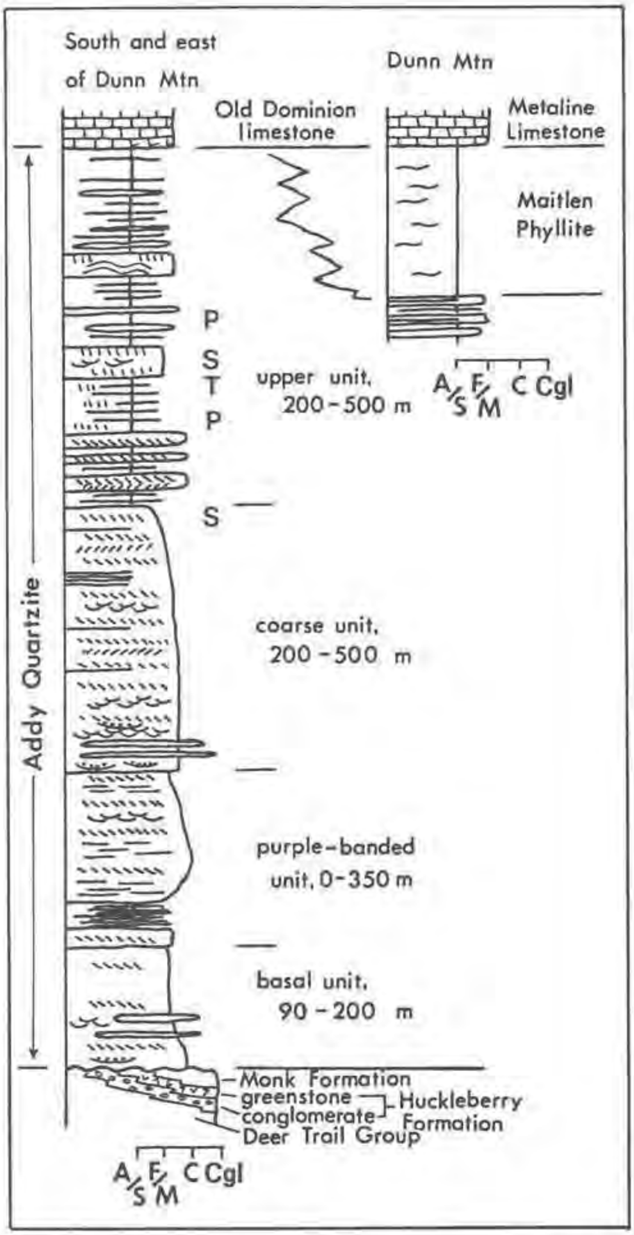


Figure 15. Idealized stratigraphic column of the Late Proterozoic to Early Cambrian Addy Quartzite west of the Jumpoff Joe fault. Based on Lindsey (1987) and not to scale. See Figure 8 for explanation of other symbols.

Exposures of the basal unit are typically poor because it crops out along slope bases where it is covered by talus or thick vegetation. Where exposed, the quartzite in the unit is commonly white, fine to medium grained, medium to thick bedded, and massive. Rare coarse-grained to granular quartzite also is present. Purple and brown, thin

(<10 cm), lenticular interbeds and partings of argillite and siltite occur throughout the unit. Planar cross-bedding is the most abundant sedimentary structure in the unit; trough cross-beds and channels are present but less abundant.

The quartzite of the basal unit is well lithified in most places. However, at two localities the unit was found to be very friable. The smaller of these consists of a highly cleaved and fractured exposure in a logging roadcut approximately 1 km south of the crest of Stensgar Mountain (Fig. 3). The second location is a 2- to 3-km^2 area on the southeast side of Adams Mountain (Fig. 3) where grain cements apparently have been removed. Friable quartzite also crops out at the Lane Mountain quarry, approximately 10 km east of Stensgar Mountain; this locality was not investigated. On the basis of examination of hand samples from the quarry, strata exposed on Lane Mountain are tentatively assigned to the basal unit. These friable quartzites are discussed in more detail under the heading "Economic Geology".

The contact between the Addy Quartzite and underlying strata is a low-angle unconformity that locally appears to be a disconformity. The bottom of the basal unit is placed at the base of the lowest quartzite bed that overlies thick Upper to Middle Proterozoic pelitic and metavolcanic units. These older strata increase in age from north to south within the magnesite belt. At the northern end of the magnesite belt in the northeastern Iron Mountains, the Addy Quartzite overlies the Monk Formation (Fig. 7). The Monk Formation pinches out in the southwestern Iron Mountains, where the Addy Quartzite overlies the greenstone member of the Huckleberry Formation. Throughout central Stevens County the Addy Quartzite overlies the Huckleberry greenstone. On Adams Mountain, the Addy Quartzite overlies the next older unit, the conglomerate member of the Huckleberry Formation (Fig. 7). Near Fort Spokane, the Addy Quartzite overlies the Middle Proterozoic Deer Trail Group.

Purple-banded unit

Previous investigators recognized that purple-banded quartzite occurred in the Addy Quartzite and formed a distinctive horizon (Vacher, 1969; Miller and Clark, 1975; Miller and Yates, 1976; Lucas, 1980). This horizon is here designated the purple-banded unit of the Addy Quartzite. North of the Hunters-Springdale road (Fig. 3) the unit is 200 to 350 m thick. South of the road the unit pinches out on Adams Mountain.

West of the Jumpoff Joe fault medium- to coarse-grained, cliff-forming quartzite dominates the unit. Fine-grained quartzite also is present but is less abundant. Lenticular interbeds and partings of purple siltite and argillite less than 10 cm thick in most places are present locally in the unit. However, in the lower 50 to 100 m of the unit, argillite beds as much as 1 m thick are common, forming a useful marker interval for the lower part of the unit. Granular quartzites forming thin (<10 cm), lenticular interbeds are rare except near the top of the unit. Pebble conglomerate also is rare in the purple-banded unit.

The purple banding consists of liesegang bands, hematitic cements, and detrital heavy mineral layers. Most of the bands are 1- to 4-mm-wide stripes that parallel bedding and accentuate sedimentary structures (Fig. 16). Less commonly, banding cross-cuts bedding or forms diffuse zones as much as 10 cm thick.

The quartzites of the purple-banded unit are most commonly plane bedded and plane laminated. Low-angle (<10 degrees) planar truncation surfaces and broad arcuate scours, ripple cross-lamination, and planar cross-bedding also are common in the unit. Ripple cross-lamination occurs in fine- to medium-grained quartzite, whereas planar cross-bedding is most common in medium-grained to granular quartzite. Symmetrical ripple formsets and trough cross-beds are scattered throughout the unit.

West of the Jumpoff Joe fault the base of the purple-banded unit is placed at the base of the lowest purple-banded quartzite greater than 2 m thick. Purple argillite and siltite partings and interbeds are common in the lower part of the purple-banded unit and aid in the recognition of its base. The contact between the purple-banded unit and the underlying basal unit is conformable and occurs in a 5- to 10-m-thick transitional zone in which basal unit lithologies are replaced up-section by those of the purple-banded unit.

East of the Jumpoff Joe fault strata assigned to the purple-banded unit form the base of the Addy Quartzite. Here the unit consists of 150 m of poorly exposed pink, red, and purple, medium- to coarse-grained, locally purple-banded quartzite. Near Quartzite Mountain lenticular pebble conglomerate interbeds are common. Sedimentary structures are rare, but planar cross-bedding is present. The purple-banded unit east of the fault unconformably overlies different units of the Middle Proterozoic Belt Supergroup.

Coarse unit

The coarse unit consists predominantly of cross-stratified, coarse-grained to granular, thin- to thick-bedded, white and gray quartzite (Fig. 17). Subordinate medium-grained, thin- to thick-bedded quartzite is present throughout the unit. Lenticular interbeds of pebbly quartzite and pebble conglomerate are common in the lower 100 m of the unit, and lenticular partings and thin interbeds of brown and purple argillite and siltite increase in abundance up-section. The coarse unit is 200 to 500 m thick in the Iron Mountains, 350 m thick on Dunn Mountain, 250 m thick on northern Huckleberry Mountain, and 400 m thick on Adams and Stensgar Mountains. Faulting appears to have controlled the thickness of the unit only in the Iron Mountains, where the top of the unit has been removed and the section duplicated. Elsewhere, variations in thickness probably are due to facies changes.

Figure 16. Purple-banded quartzite typical of the purple-banded unit of the Addy Quartzite and the purple quartzite unit of the Gypsy Quartzite. Outcrop located on the east side of Stensgar Mountain below the No Huck triangulation station. Ruler is 6 in. (15.24 cm) long.

The coarse unit is divided into an upper and lower sequence. The lower sequence consists of approximately 100 m of coarse-grained to granular, medium- to thick-bedded quartzite and pebble conglomerate. Pebble conglomerate is present as thin (<25 cm), lenticular interbeds. Thin (<10 cm), lenticular interbeds of argillite and siltite are present locally. Planar and trough cross-bedding are common throughout this sequence. Less common sedimentary structures in the lower sequence are plane bedding, ripple cross-lamination, and channels that consist of broad, shallow scours as much as 5 m across and 50 cm deep.

The upper sequence of the coarse unit consists of 150 to 300 m of medium-grained to granular quartzite. In most places, granules are restricted to thin layers (1 to 5 grains thick) on the tops of beds. These granule layers are commonly overlain by thin (<1 cm) argillite partings. Argillite and siltite interbeds are common throughout the sequence. Planar cross-bedding, ripple cross-lamination, and herringbone cross-bedding also are common, but trough cross-bedding is rare. Deformed *Scolithus* burrows are present locally in the upper sequence.

West of the Jumpoff Joe fault, except on Adams Mountain, the coarse unit overlies the purple-banded unit. The contact between the two units is at the base of the lowest interval of white to tan, cross-bedded, granular quartzite greater than 2 m thick. On Adams Mountain, where the purple-banded unit pinches out, the coarse unit overlies the basal unit. Here, the contact is placed at the base of the lowest coarse-grained to granular, cross-bedded quartzite more than 2 m thick that overlies finer grained, generally massive, friable quartzite. The contact between the coarse unit and underlying rocks is gradational and lies in a 10- to 20-m-thick transition zone.

East of the Jumpoff Joe fault, rocks assigned to the purple-banded unit grade upward into a sequence of fine- to coarse-grained, locally granular, white, tan, brown, and pink quartzite. Planar cross-bedding and asymmetrical ripples are present locally in this quartzite. Argillite partings are common, and argillite interbeds as much as 3 m thick occur locally. These strata are assigned to the coarse unit because they overlie purple-banded quartzites and display gross lithologic similarities to the coarse unit west of the Jumpoff Joe fault. Faulting and erosion have removed the top of the unit east of the Jumpoff Joe fault; consequently, the unit is nowhere more than 150 m thick.

Upper unit

The upper unit consists of 200 to 500 m of interbedded quartzite, siltite, and argillite. On Stensgar, Huckleberry, and Dunn Mountains the upper unit is divided into an upper and a lower sequence. Elsewhere, the upper unit is not subdivided.

The lower sequence of the upper unit on Stensgar, Huckleberry, and Dunn Mountains consists of interbedded quartzite, siltite, and argillite that fines up-section. Quartzite beds at the base of the lower sequence form intervals as much as 5 m thick and are white, coarse grained to granular, medium to thick bedded, planar and herringbone cross-bedded. At the top of the lower sequence quartzite beds are brown, silty, fine to medium grained, thin to medium bedded, and less than 2 m thick. The tops of quartzite beds in the lower interval are commonly wavy and capped by granule or pebble lags and argillite partings. Argillite and siltite beds generally are

Figure 17. Cross-bedded, coarse-grained to granular quartzite of the coarse unit of the Addy Quartzite 2 to 3 km north of Stensgar Mountain. Ruler is 6 in. (15.24 cm) long.

1 to 5 m thick in the lower half of the lower sequence and 2 to 10 m thick in the upper half. The argillites and siltites are brown, tan, and gray and contain thin (<20 cm) lenticular quartzite interbeds. A black to purple, weakly magnetic, silty argillite is present locally near the top of the lower sequence of the upper unit on Stensgar Mountain. On Stensgar and Huckleberry Mountains the lower sequence is 150 to 200 m thick; on Dunn Mountain it is 125 to 150 m thick and more argillaceous.

Body and trace fossils are abundant in the lower sequence of the upper unit. Vertical burrows belonging to the ichnogenus *Scolithus* (*S. bulbus* and *S. linearis*) and horizontal burrows of the ichnogenus *Planolites* (*P. beverlyensis*) are most common. Unnamed, randomly

Figure 18. The trace fossil *Rusophycus* from the upper unit of the Addy Quartzite 2 km north of Stensgar Mountain. Both specimens are about 3 cm long.

Figure 19. A fragmented cephalon of the Early Cambrian trilobite *Nevadella addyensis* Okulitch in the upper unit of the Addy Quartzite 2 km north of Stensgar Mountain. This specimen would be about 4 cm wide if unbroken.

oriented meandering trails and the trilobite trace fossils *Rusophycus* (Fig. 18) and *Cruziana* also are present. The most abundant body fossil is the Early Cambrian trilobite *Nevadella addyensis* (Fig. 19). The Early Cambrian brachiopod *Kutorgina* (Fig. 20) and the mollusk-like trace fossil *Hyolithus* also are present in the lower sequence.

The top of the lower sequence of the upper unit is commonly marked by a discontinuous 5- to 20-m-thick interval of mottled, medium-grained, green quartzite that contains abundant *S. bulbus*. Trough cross-bedding and thin (<10 cm) argillite interbeds are scattered throughout this quartzite interval. The mottled quartzite has been mapped locally as a marker bed in the upper unit. (See Lindsey, 1988.)

On Huckleberry and Stensgar Mountains, the upper sequence of the upper unit is approximately 300 m thick and composed of 40- to 60-m-thick intervals of thinly to thickly interbedded, brown, green, and gray argillite, siltite, and fine-grained quartzite. These interbedded lithologies alternate with 5- to 30-m-thick intervals of white and tan, mature, fine- to medium-grained, thin-bedded to massive, planar cross-bedded and ripple cross-laminated quartzite. Quartzite intervals in the upper sequence decrease in abundance and thickness up-section, while argillite and siltite intervals increase. Quartzite beds in the upper 100 to 150 m of the upper sequence are less than 5 m thick. Brown and tan, silty limestones less than 1 m thick are present locally in the upper 50 m of the unit. The interbedded argillite, siltite, and quartzite intervals are wavy to lenticular bedded, locally mottled, and display hummocky and swaley bedding surfaces (Fig. 21) and hummocky cross-stratification. *Planolites* burrows and *Cruziana* also are present.

The upper sequence of the upper unit on Dunn Mountain is 80 m thick and consists of fine-grained, massive to thin-bedded, mottled, silty, brown quartzite with thin (<3 m) interbeds of brown and green siltite and argillite. *Planolites* burrows and wavy beds are the only well preserved structures in this silty quartzite. Siltite and argillite interbeds are plane laminated to massive and contain lenticular quartzite interlaminations.

In the Iron Mountains the upper unit is not subdivided and consists of 300 m of interbedded quartzite, siltite, and argillite. Quartzite beds are less than 3 m thick and dominantly fine grained and, in places, display symmetric ripples. Thin (<2 m) beds of coarse-grained to granular, trough cross-bedded quartzite are present locally. Argillite and siltite beds are dominantly thick laminated to thin bedded, contain lenticular interbeds of quartzite,

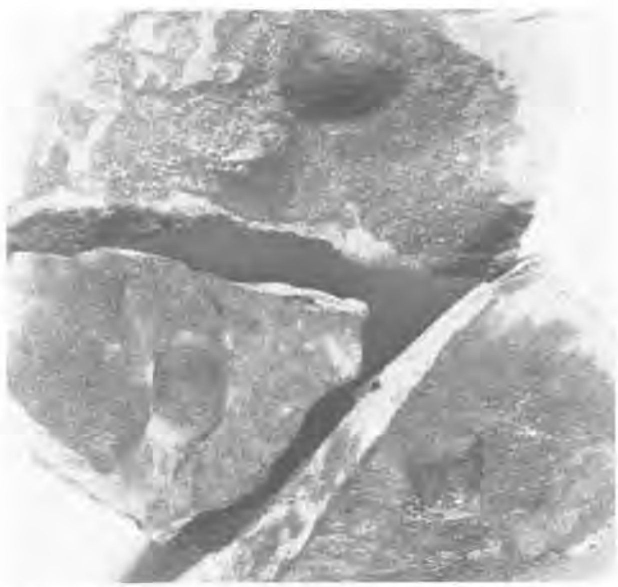


Figure 20. The Early Cambrian brachiopod *Kutorgina* from the upper unit of the Addy Quartzite just west of Addy, Washington. The specimens are slightly less than 1 cm wide.

and commonly have scoured tops. Thin beds of "fossil hash" in a silty dolomitic matrix are fairly common in the unit near the town of Addy.

The southernmost exposures of the upper unit studied are on Adams Mountain, where it is strongly metamorphosed and deformed. Here, the unit consists dominantly of vitreous, recrystallized, white and tan quartzite interbedded with strongly cleaved and foliated, brown and green phyllite. The few undeformed exposures of the unit on Adams Mountain are very similar to those of the upper sequence on Stensgar Mountain (10 km to the north). South of Adams Mountain, in the Turtle Lake quadrangle, Becraft and Weis (1963) described and mapped interbedded quartzite, siltite, and argillite in the upper one-third of the Addy that appears to be similar to strata comprising the upper unit of the Addy Quartzite on Stensgar Mountain.

The bottom of the upper unit is placed at the base of the lowest thick (>1 m) argillite or siltite that contains lenticular to wavy bedded quartzites. The contact between the upper unit and the underlying coarse unit is easily recognized because of the lack of thick (>1 m) argillite and siltite in the coarse unit.

The upper unit is not present east of the Jumpoff Joe fault except possibly near Springdale, Washington. On the mountain approximately 3 km southeast of Springdale, Miller and Clark (1975) described a swale containing argillite float that separates the Metaline Limestone from the Addy Quartzite. They suggested the swale may be the site of very poorly outcropping argillaceous strata. If the upper unit is present here, it is no more than 100 m thick.

Three units appear to conformably overlie the upper unit of the Addy Quartzite. They are: (1) the Lower Cambrian Maitlen Phyllite on Dunn Mountain; (2) the Lower to Middle Cambrian Old Dominion limestone on and south of Huckleberry Mountain; and (3) the Lower to Middle Cambrian Metaline Limestone adjacent to the Colville valley. In central and southern Stevens County these three units appear to be laterally equivalent. However, on a regional scale the Maitlen Phyllite underlies both the Metaline Limestone and the Old Dominion limestone, which are correlative. The nature of the upper boundary of the Addy Quartzite will be described further in the sections on correlation and geologic history.

The lithologic break separating the Addy Quartzite from overlying units is sharp but rarely well exposed. The contact between the Addy Quartzite and the Old Dominion limestone and Metaline Limestone is placed at the base of the lowest thin-bedded, dark-gray, platy limestone. Where exposed, this horizon is easily recognized because gray limestone is not present in the Addy. The contact between the Addy Quartzite and Maitlen Phyllite is placed at the top of the highest brown, fine- to medium-grained, silty quartzite. This horizon also is easily recognized because of the absence of quartzite in the mottled, brown, micaceous argillite of the Maitlen Phyllite (Park and Cannon, 1943; Lucas, 1980).

Age

Three Sisters Formation and Gypsy Quartzite

An Early Cambrian age was first assigned to the Gypsy Quartzite by Park and Cannon (1943). This age was based on rare trilobite fragments in the uppermost Gypsy, the Gypsy's position below archeocyathid-bearing limestone, and its position above the Monk Formation, to which Park and Cannon (1943) assigned a late Precambrian age. When Miller (1982) divided Park and Cannon's Gypsy Quartzite into two units, the upper unit, the redefined Gypsy Quartzite, was assigned an Early Cambrian age, while the lower unit, the Three Sisters Formation, was assigned a Late Proterozoic (Precambrian Z) age.

Figure 21. Hummocky and swaley bedding developed in the upper unit of the Addy Quartzite at the north end of the Huckleberry Mountains.

A Late Proterozoic age for the Three Sisters Formation has been inferred on the basis of its position above rocks whose correlatives throughout the Cordilleran miogeocline are thought to be Late Proterozoic in age (Stewart and Suczek, 1977) and assignment of a late Precambrian age to the Three Sisters Formation in British Columbia (Walker, 1934; Mansy and Gabrielse, 1978). In addition, the position of the Three Sisters 1,300 to 1,600 m below the lowest known occurrence of Early Cambrian trilobites also suggests a Late Proterozoic age.

Recent work on subsidence rates (Bond and Kominz, 1984; Devlin and others, 1985) also supports a Late Proterozoic age. Strata regionally correlative to the Three Sisters Formation lie near the base of the Cordilleran miogeocline and are thought to have been deposited soon after subsidence of the miogeocline began (Stewart, 1972; Stewart and Suczek, 1977; Devlin and others, 1985; Devlin and Bond, 1988). Subsidence curves and radiometric dates suggest that subsidence in the miogeocline began between 650 and 550 Ma (Armin and Mayer, 1983; Bond and Kominz, 1984; Evenchick and others, 1984; Devlin and others, 1985; Devlin and Bond, 1988). Consequently, terrigenous clastic strata lying near the base of the miogeocline—including the Three Sisters Formation—are no older than 650 Ma or quite possibly Late Proterozoic in age.

When Miller (1982) redefined the Gypsy Quartzite the Cambrian/Precambrian boundary was placed at the contact between the Gypsy Quartzite and the Three Sisters Formation. Our investigations (Groffman, 1986; Lindsey, 1987; this report) suggest the boundary could lie higher in the section. Disarticulated and broken trilobite spines found in the Gypsy Quartzite (Park and Cannon, 1943; Miller, 1982; Groffman, 1986) come from the uppermost 100 m of the upper argillite unit (Groffman, 1986). These fossils are too fragmentary to allow species identification, but they display gross similarities with trilobite fossils found in the upper unit of the Addy Quartzite that belong to the species *Nevadella addyensis* (Okulitch, 1951; Miller and Clark, 1975; Lindsey, 1987). *N. addyensis* belongs to the middle Early Cambrian *Nevadella* Zone, the second oldest trilobite zone in western North America (Fritz, 1972). Fossils belonging to the older *Fallotaspis* Zone were not found. Trilobite trace fossils (*Rusophycus*) also have been found within the upper 200 m of the unit (Groffman, 1986). The lowest occurrences of trilobite body and trace fossils in the upper argillite unit of the Gypsy Quartzite are within the upper half of the unit. Similar lithologies in the lower half of the unit are devoid of fossils. If distribution of trilobite remains in the upper half of the upper argillite unit was facies controlled, they should occur throughout the unit. Since they do not, their first appearence is inferred to be have biostratigraphic significance.

Using body and trace fossil criteria outlined by Alpert (1977), the stratigraphic position of the Precambrian/Cambrian boundary can be approximated. Alpert (1977) places that boundary just below the lowest occurrence of trilobite body or trace fossils that are not facies restricted. In the Gypsy Quartzite this occurs in the upper half of the upper argillite unit, 1,200 to 1,400 m above the base of the formation. However, because fossils belonging to the *Fallotaspis* Zone are absent, the position of the Precambrian/Cambrian boundary cannot be determined with certainty, even using Alpert's criteria. On the other hand, there is no justification for arbitrary placement of the boundary at the base of the Gypsy Quartzite, 1,200 to 1,400 m below strata that are clearly middle Early Cambrian in age. For this reason we infer that the Precambrian/Cambrian boundary probably is best situated in the lower part of the Gypsy Quartzite, at least 500 m below the lowest occurrence of trilobite trace fossils and the base of the *Nevadella* Zone as seen in the Gypsy.

Addy Quartzite

The Addy Quartzite has been traditionally assigned an Early Cambrian age on the basis of its Early Cambrian fossils and its position unconformably overlying Precambrian rocks. The distribution of body and trace fossils in the Addy Quartzite is essentially the same as seen in the Gypsy Quartzite. All body and trace fossils found in the Addy, except *Scolithus*, are found only in the upper unit. *Scolithus*, which is not useful for age determinations (Alpert, 1977), is present locally in the coarse unit. The lowest appearance of trilobite fossils, consisting of the traces *Rusophycus* and *Cruziana* and the body fossil *N. addyensis*, in the argillites and siltites of the upper unit is at least 50 m above the base of the upper unit. Similar lithologies down-section are devoid of fossils. As is the case in the Gypsy Quartzite, this first appearence is inferred to have biostratigraphic significance.

For the same reasons discussed for the Gypsy Quartzite, the Addy Quartzite also may be in part Late Proterozoic in age. Trilobite body and trace fossils first occur in interbedded quartzite, siltite, and argillite 50 m above the base of the upper unit. Similar strata down-section do not contain such fossils. In addition, justification for arbitrary placement of the boundary at the base of the Addy, at least 1,000 m below the first trilobite fossils, appears to be lacking. The presence of *N. addyensis* near the top of the Addy Quartzite also indicates it is no younger than middle Early Cambrian (555 Ma). Consequently, the Addy Quartzite quite possibly has a Late Proterozoic to Early Cambrian age, and the boundary is inferred to be situated in the lower part of the Addy, at least 500 m below the base of the *Nevadella* Zone.

Correlation

Becraft and Weis (1963) were the first to propose that the Addy and Gypsy Quartzites were correlative. This correlation was based on: (1) the stratigraphic position of these units below archeocyathid-bearing Early Cambrian limestones; (2) their position above rocks thought to be Precambrian in age; and (3) the presence of trilobite

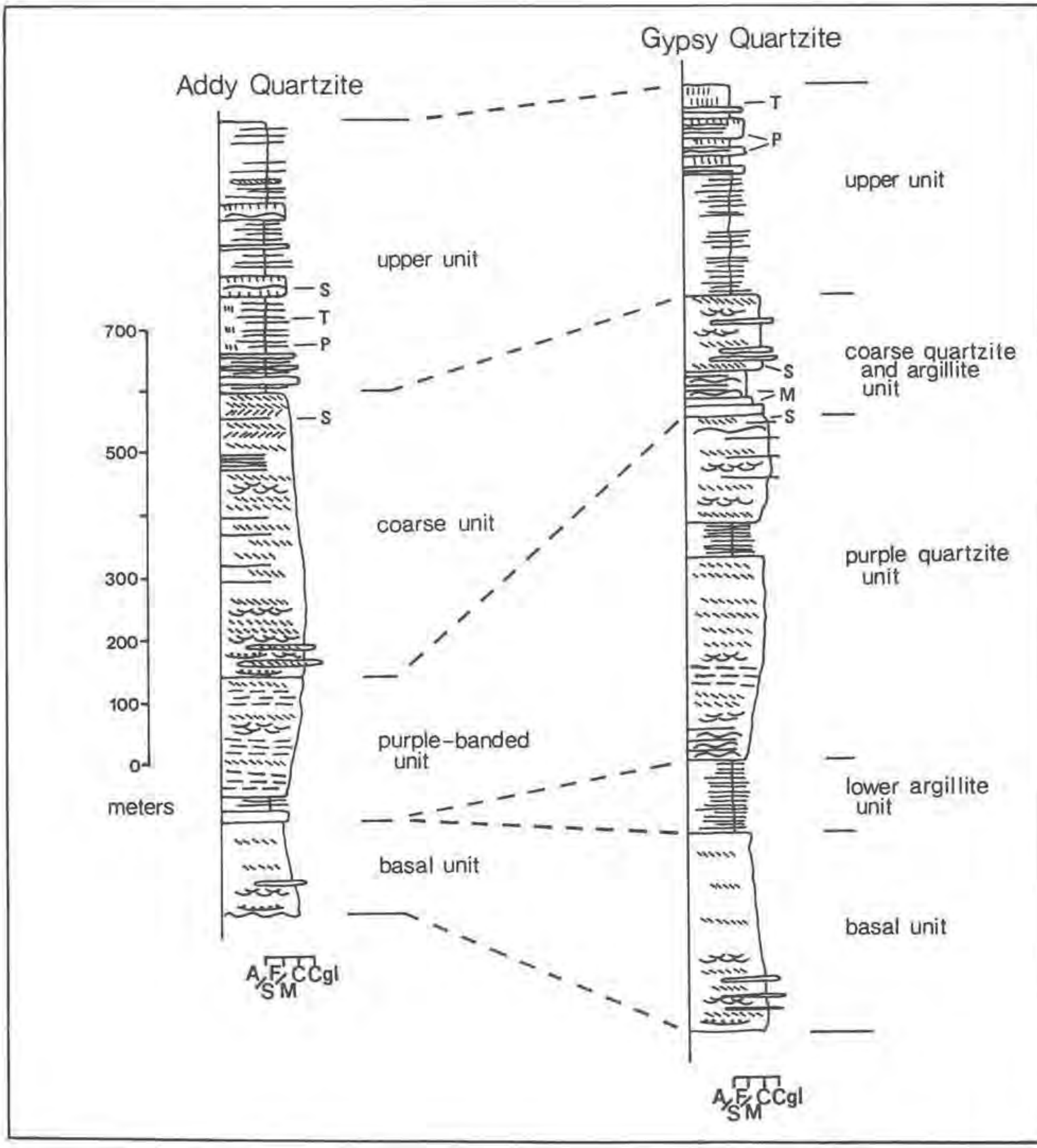


Figure 22. Comparison and correlation of the Addy and Gypsy Quartzites. See Figure 8 for explanation of symbols.

fragments in both units. The results of our investigation support and refine Becraft and Weis' (1963) conclusion.

A number of direct lithostratigraphic correlatives are present in the Addy and Gypsy Quartzites. The basal units of the Addy and Gypsy Quartzites are both composed of white, mature, cross-bedded quartzite and are thus inferred to be correlative. The basal quartzite unit of the Gypsy Quartzite is overlain by the thin (110 to 125 m) lower argillite unit. This argillaceous unit has no correlative in the Addy Quartzite 55 km to the southwest. However, the thinly interbedded sequence of argillite, siltite, and quartzite at the base of the purple-banded unit of the Addy Quartzite may in part be correlative to the lower argillite unit of the Gypsy.

The next units up-section in the Addy and Gypsy Quartzites are the purple-banded and purple quartzite units, respectively. Both units are dominantly medium- to coarse-grained, blue, purple, and lavender, cross-bedded and plane bedded, purple-banded quartzites. In addition, argillites are relatively rare in both units, and both purple units occur stratigraphically above the white, cross-bedded quartzites of the basal units. We consider the purple quartzite and purple-banded units to be correlative (Fig. 22).

Coarse-grained to granular, commonly pebbly, cross-bedded quartzites with locally interbedded argillites dominate the coarse quartzite unit of the Gypsy Quartzite and the coarse unit of the Addy Quartzite. In addition, coarse lithologies are common in the upper part of the purple quartzite unit of the Gypsy Quartzite. These coarse units are overlain by the interbedded quartzites, siltites, and argillites that comprise the upper units of the Addy and Gypsy Quartzites. The upper units also contain abundant trace fossils and trilobites of the middle Early Cambrian *Nevadella* Zone. The coarse quartzite unit of the Gypsy Quartzite and coarse unit of the Addy Quartzite are inferred to be correlative, as are the upper units of both formations (Fig. 23). In addition, the abundance of the coarse strata in the upper part of the purple quartzite unit suggests that it may be in part correlative with the lower part of the coarse unit of the Addy Quartzite.

Regional correlatives of the Addy and Gypsy Quartzites are present both in the miogeocline and on the craton. Broadly coeval units include the miogeoclinal Quartzite Range Formation (Late Proterozoic (?) through Early Cambrian) in south-central British Columbia (Becraft and Weis, 1963) and the Hamill Group (Late Proterozoic through Early Cambrian) in central British Columbia (Mansy and Gabrielse, 1978; Devlin and Bond, 1988). The miogeoclinal Brigham Group (Late Proterozoic through Early Cambrian) in southeastern Idaho and northern Utah also is a correlative (Lochman-Balk, 1972; Stewart and Suczek, 1977). To the east on the craton, the Addy and Gypsy Quartzites are homotaxial with the Gold Creek Quartzite (Middle Cambrian) in northern Idaho (Vacher, 1969; Lochman-Balk, 1972) and the Flathead Quartzite (Middle Cambrian) in Montana and Wyoming (Lochman-Balk, 1972).

The final correlation to be discussed involves the stratigraphic relation between the upper unit of the Addy Quartzite and the Maitlen Phyllite. In northern Stevens and Pend Oreille Counties the Maitlen Phyllite is at least 500 m thick and conformably overlies both the Addy and Gypsy Quartzites (Miller and Yates, 1976; Yates, 1976; Miller, 1982; Burmester and Miller, 1983). However, in central Stevens County stratigraphic trends suggest the Maitlen Phyllite is correlative with the upper unit of the Addy Quartzite (Fig. 23). On Dunn Mountain the Maitlen Phyllite thins to 200 m and consists of gray, green, and tan, mottled, micaceous argillite conformably overlying the 200-m-thick upper unit of the Addy Quartzite and underlying the Metaline Limestone (Figs. 15 and 23) (Lucas, 1980; Lindsey, 1987). On Stensgar Mountain, 10 km south of Dunn Mountain, argillaceous strata such as those comprising the Maitlen Phyllite on Dunn Mountain are absent, and the upper unit of the Addy is conformably overlain by the Old Dominion limestone (correlative with the Metaline Limestone) (Figs. 15 and 23) (Lindsey, 1987). At this locale the upper unit of the Addy Quartzite is twice as thick as on Dunn Mountain, and the upper 150 to 200 m are dominantly argillite and siltite with minor interbedded quartzite (Figs. 15 and 23). These stratigraphic trends suggest the Maitlen Phyllite on Dunn Mountain interfingers with the upper part of the upper unit of the Addy Quartzite 10 km to the south on Stensgar Mountain.

STRATIGRAPHIC SUMMARY AND PROPOSED TYPE LOCALITIES AND SECTIONS

Introduction

As defined in this report, the Gypsy Quartzite is composed of 1,400 to 1,800 m of quartzite, siltite, and argillite that crop out generally north of latitude 48°30′. The Gypsy Quartzite is divided into five lithostratigraphic units in the study area. These units are: (1) the basal quartzite unit; (2) the lower argillite unit; (3) the purple quartzite unit; (4) the coarse quartzite and argillite unit; and (5) the upper argillite unit (Fig. 11).

In northern Pend Oreille County the Gypsy Quartzite conformably overlies the Late Proterozoic Three Sisters Formation (Fig. 11). Just to the north, in southern British Columbia, the Gypsy's correlative, the Quartzite Range Formation, also conformably overlies the Three Sisters Formation (Walker, 1934). In the Deep Creek and Colville areas, 16 to 40 km west of Metaline Falls, the Three Sisters Formation is apparently absent, and the Gypsy Quartzite unconformably overlies the Late Proterozoic Monk Formation. In and outside the study area the Gypsy Quartzite is conformably overlain by the middle to late Early Cambrian Maitlen Phyllite (Miller and Yates, 1976). The Gypsy Quartzite is inferred to be Late Proterozoic to Early Cambrian in age. This definition preserves the spirit of Park and Cannon's (1943) original definition of the Gypsy Quartzite as quartzitic rocks above Precambrian strata and below Cambrian limestone and argillite. In addition, it incorporates the more recent suggestions of Miller (1982) and Burmester and Miller (1983) that the Gyspy Quartzite not include conglomeratic strata assigned to the Three Sisters Formation in southern British Columbia.

The Addy Quartzite, as defined in this report, is a 1,100- to 1,450-m-thick sequence of quartzite, siltite, and argillite. It is divided into four lithostratigraphic units: (1) the basal unit; (2) the purple-banded unit; (3) the coarse unit; and (4) the upper unit (Fig. 18). The Addy Quartzite unconformably overlies a series of Middle to

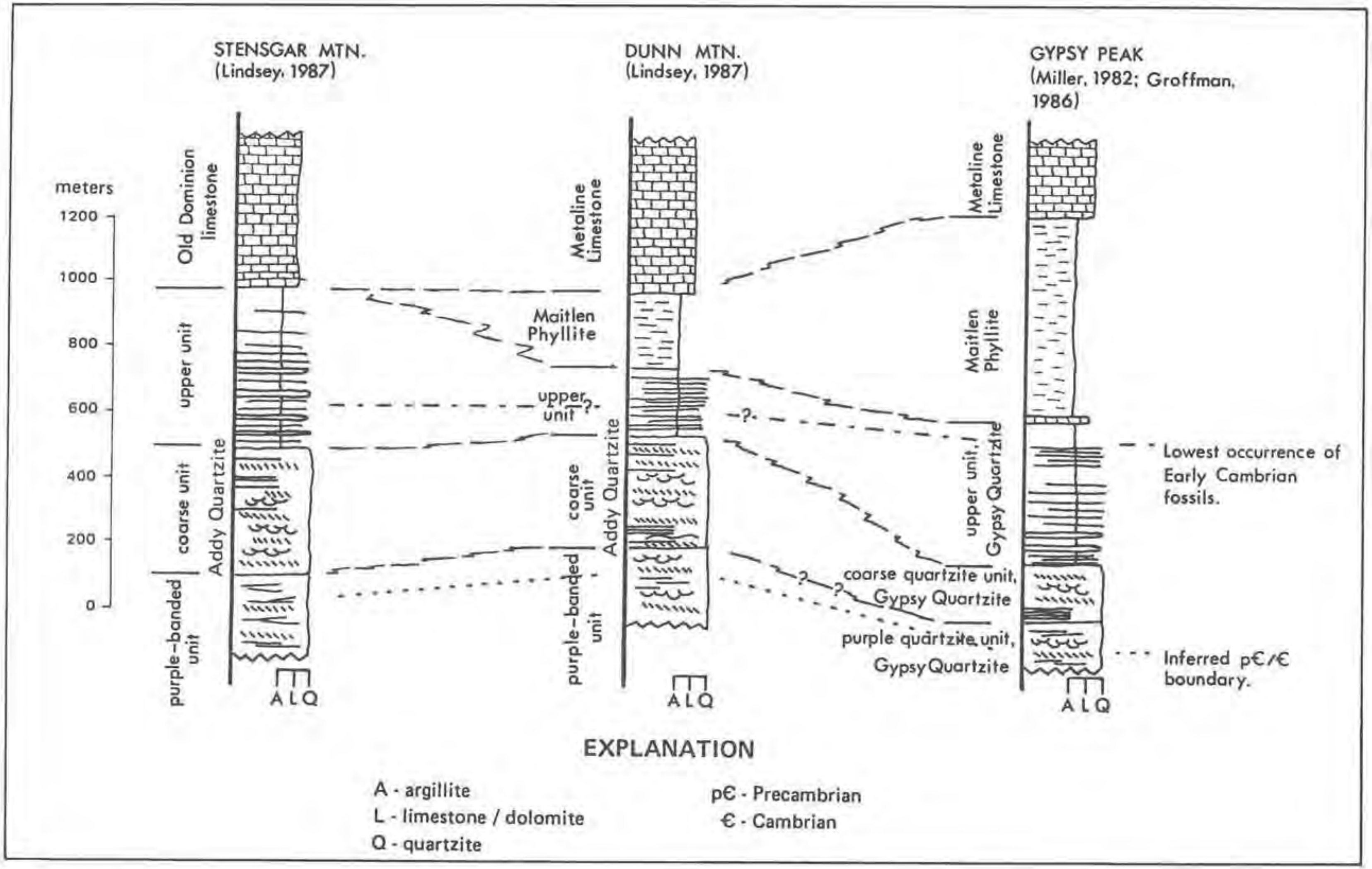


Figure 23. Stratigraphy and correlation of the upper halves of the Addy and Gypsy Quartzites and inferred position of the Precambrian/Cambrian boundary. See Figure 8 for explanation of symbols.

Late Proterozoic units and conformably underlies the Early Cambrian Maitlen Phyllite and the Early to Middle Cambrian Old Dominion limestone and Metaline Limestone. The Addy Quartzite is assigned a late Late Proterozoic through middle Early Cambrian age. This definition preserves the spirit of Weaver's (1920) and Bennett's (1941) original definitions of the formation and incorporates the results of more recent stratigraphic investigations of the Addy Quartzite.

Type Sections

On the basis of the history of use of the terms Addy Quartzite and Gypsy Quartzite and their geographic distribution and stratigraphic trends, type sections are defined for each. The Addy and Gypsy Quartzites have been used separately on maps and in written reports since each was first defined. We feel combining them into one unit would needlessly confuse prior usage because they are established in the literature as separate units. Geographically, the name Gypsy Quartzite has always been applied to strata in northern Stevens and northern Pend Oreille Counties and the name Addy Quartzite to rocks in central and southern Stevens County, southern Pend Oreille County, and northern Lincoln County. We found no report in which this rule was broken. Finally, while the Addy and Gypsy Quartzites display a very similar stratigraphy, they also display differences in thickness and composition.

Gypsy Quartzite

We propose that the type section for the Gypsy Quartzite be placed on and around Gypsy Peak in northern Pend Oreille County, Washington (Figs. 1 and 2). Gypsy Peak lies in the Salmo-Priest Wilderness Area of the Colville National Forest approximately 4.5 km north of the Bear Pasture road terminus. The base of the proposed type section lies on the east side of Gypsy Peak approximately 900 m north-northeast of Watch Lake in the northeast quarter of sec. 30, T. 40 N., R. 45 E. (Fig. 24). The section proceeds up the ridge to the crest of Gypsy Peak and from there along the north-northwest trending ridge. The top of the section lies in the saddle northwest of the crest of Gypsy Peak in the southwest quarter of sec. 18, T. 40 N., R. 45 E. This saddle lies due west of the 7,152-ft summit shown as the South Fork triangulation station.

Addy Quartzite

The area where Weaver (1920) orginally mapped the Addy Quartzite, the Iron Mountains adjacent to Addy, is not appropriate for definition of a type section because faulting has everywhere removed the top of the section and good exposures of all the lithostratigraphic units are not present. The best and most complete exposures of the Addy Quartzite lie on and adjacent to Stensgar Mountain, 25 km southwest of Addy. However, even on Stensgar Mountain a single, complete, well exposed section is not present due to the heavy forest cover across much of the mountain. Nevertheless, the principal type section and two supplemental type sections we define will provide a complete picture of the Addy Quartzite.

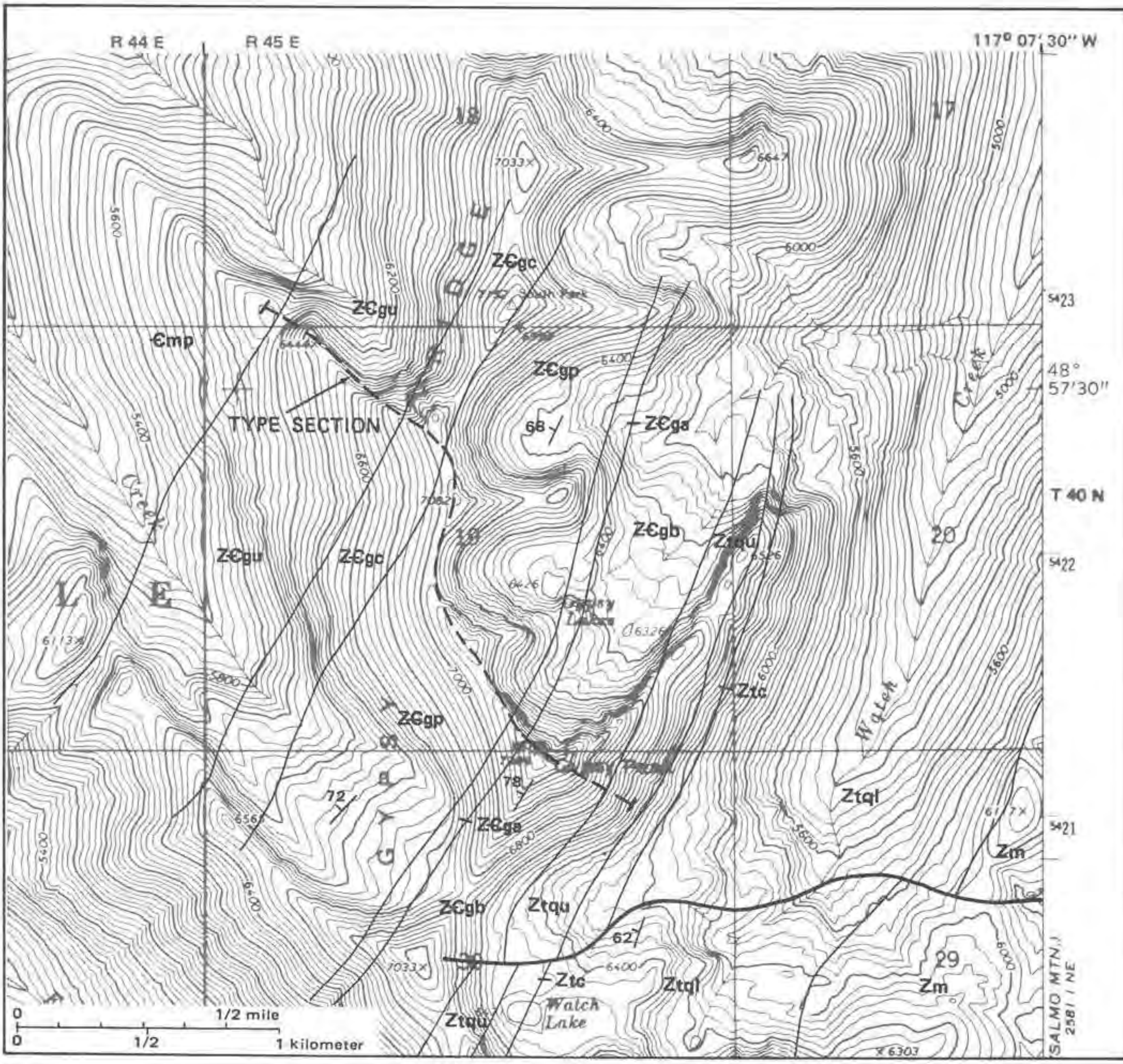
The principal type section for the Addy Quartzite starts in the southeast quarter of sec. 14, T. 31 N., R. 38 E. in the saddle due west of the fire tower on the crest of Stensgar Mountain (elev. 5,819 ft) (Fig. 25). This saddle separates a prominent knob 5,790 ft high composed of Huckleberry greenstone from the Addy Quartzite, which makes up the ridge and crest of Stensgar Mountain. The principal section continues west along the ridge to the crest of Stensgar Mountain. Along this ridge are poor exposures of the basal unit and good exposures of the lower purple-banded unit. From the crest of Stensgar Mountain the section proceeds to the west roughly parallel with a road that winds down the west side of the mountain. Exposures of the coarse unit begin just below and west of the crest of the mountain, at 5,640 ft, and continue to an elevation of 5,200 ft. Continuing down the west slope of the mountain, poor exposures of the upper unit are present between elevations of 5,200 ft and 3,640 ft. The contact between the Addy Quartzite and the Old Dominion limestone is at the base of the mountain in the southwest quarter of sec. 15, T. 31 N., R. 38 E.

The two supplemental type sections for the Addy Quartzite, one for the lower half and one for the upper half of the unit, are located a few kilometers north of the principal section. The section for the lower half is 3.5 km north of Stensgar Mountain on the crest of the ridge at the No Huck triangulation station. This section begins in the west half of sec. 1, T. 31 N., R. 38 E., in the swale at 4,990 ft (Fig. 26). From here the section extends west, up the ridge to the crest 250 m north of the triangulation station. The basal contact of the Addy Quartzite, the basal unit, purple-banded unit, and lower coarse unit are well exposed at this locality. The second supplemental section is 1.5 km north of Stensgar Mountain on a west-trending ridge (Fig. 25). The base of the section lies in the southeast quarter of sec. 11, T. 31 N., R. 38 E., at an elevation of 5,000 ft (Fig. 25). It extends west along the ridge and ends in the southeast quarter of sec. 10, T. 31 N, R. 38 E., at 3,800 ft elevation. The upper coarse unit, upper unit, and the contact between the Addy Quartzite and Old Dominion limestone are exposed in this locality.

GEOLOGIC HISTORY

Introduction

The Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite lie near the base of the Cordilleran miogeocline in northeastern Washington (Stewart and Suczek, 1977). This miogeocline extends from the Yukon to northern Mexico and consists of Late Proterozoic through early Paleozoic volcanic and sedimentary rocks (Stewart, 1972; Stewart and Suczek, 1977; Devlin and others, 1985). From bottom to top the miogeocline is divided into a lower diamictite and volcanic sequence, a middle terrigenous detrital sequence, and an upper car-



EXPLANATION

Qau	undifferentiated alluvium and colluvium	ZЄac	coarse unit, Addy Quartzite
Єmp	Maitlen Phyllite	ZЄap	purple-banded unit, Addy Quartzite
Єod	Old Dominion limestone	ZЄab	basal unit, Addy Quartzite
ZЄgu	upper argillite unit, Gypsy Quartzite	Ztqu	upper quartzite unit, Three Sisters Formation
ZЄgc	coarse quartzite and argillite unit, Gypsy Quartzite	Ztc	conglomerate unit, Three Sisters Formation
ZЄgp	purple quartzite unit, Gypsy Quartzite	Ztql	lower quartzite unit, Three Sisters Formation
ZЄga	lower argillite unit, Gypsy Quartzite	Zm	Monk Formation
ZЄgb	basal quartzite unit, Gypsy Quartzite	Zhg	greenstone member, Huckleberry Formation
ZЄau	upper unit, Addy Quartzite		

Contact — Fault — 72 Strike and dip of bedding

Figure 24. Geologic map of the proposed type locality for the Gypsy Quartzite. Base from the U.S. Geological Survey Gypsy Peak 7.5 minute quadrangle.

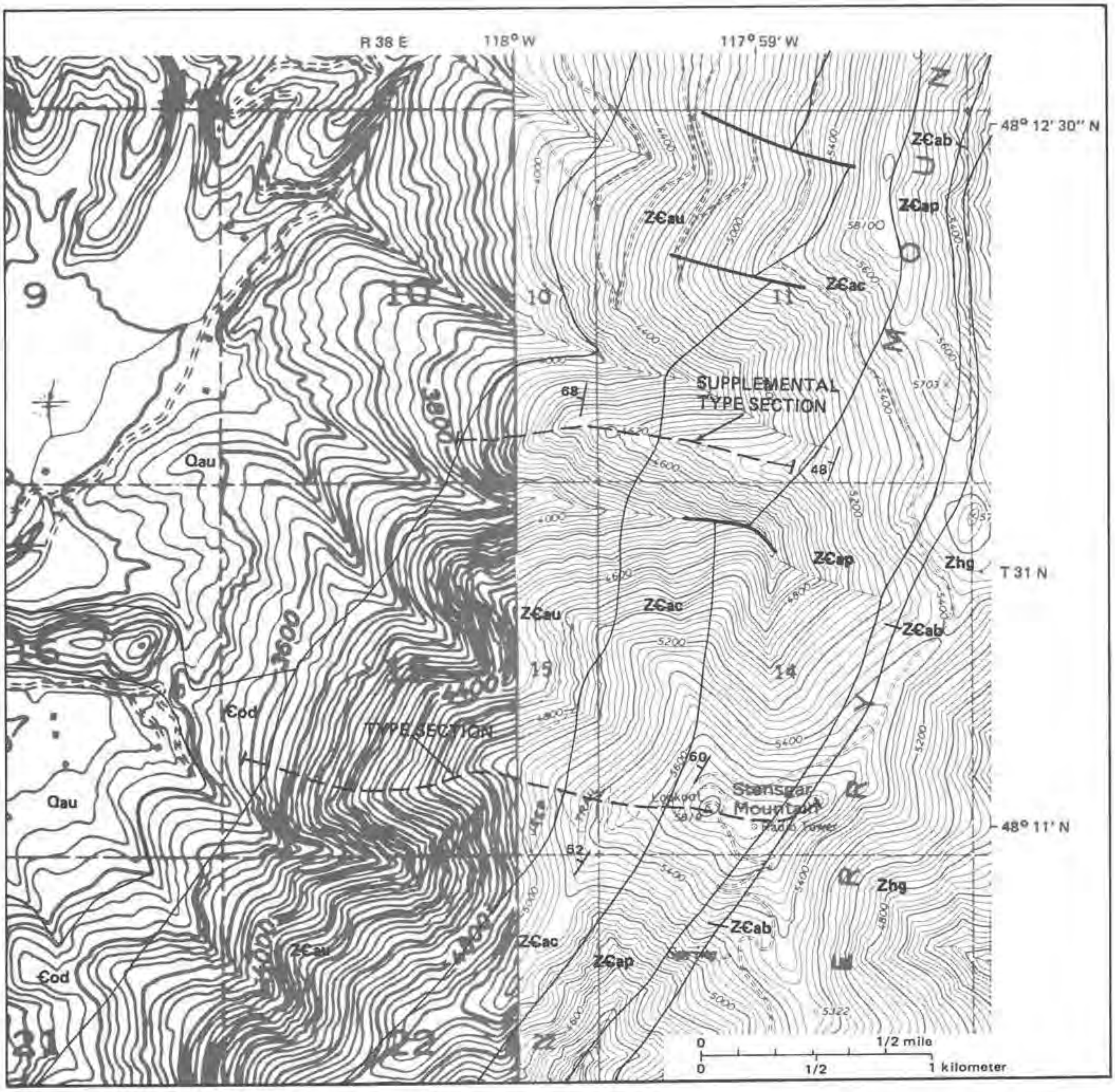


Figure 25. Geologic map of the proposed type locality and the second supplemental type locality for the Addy Quartzite. Base from U.S. Geological Survey Stensgar Mountain 7.5 minute and Hunters 15 minute quadrangles. See Figure 24 for explanation.

bonate sequence (Stewart and Suczek, 1977). The Three Sisters Formation and Addy and Gypsy Quartzites are part of the middle sequence.

Deposition in the Cordilleran miogeocline is thought to have begun during Late Proterozoic rifting that formed or modified the western edge of the North American craton (Stewart, 1972; Stewart and Suczek, 1977; Armin and Mayer, 1983; Devlin and others, 1985; Devlin and Bond, 1988). It is unclear whether a large continent (such as Asia or Australia) or microcontinents were separated from North America during rifting (Burchfiel and Davis, 1975; Stewart and Suczek, 1977; Sears and Price, 1978; Harper and Link, 1986) or if no continental separation occurred (Struik, 1987). Following rifting, the newly formed cratonal margin began to subside, sea level began to rise, and passive margin sedimentation was initiated

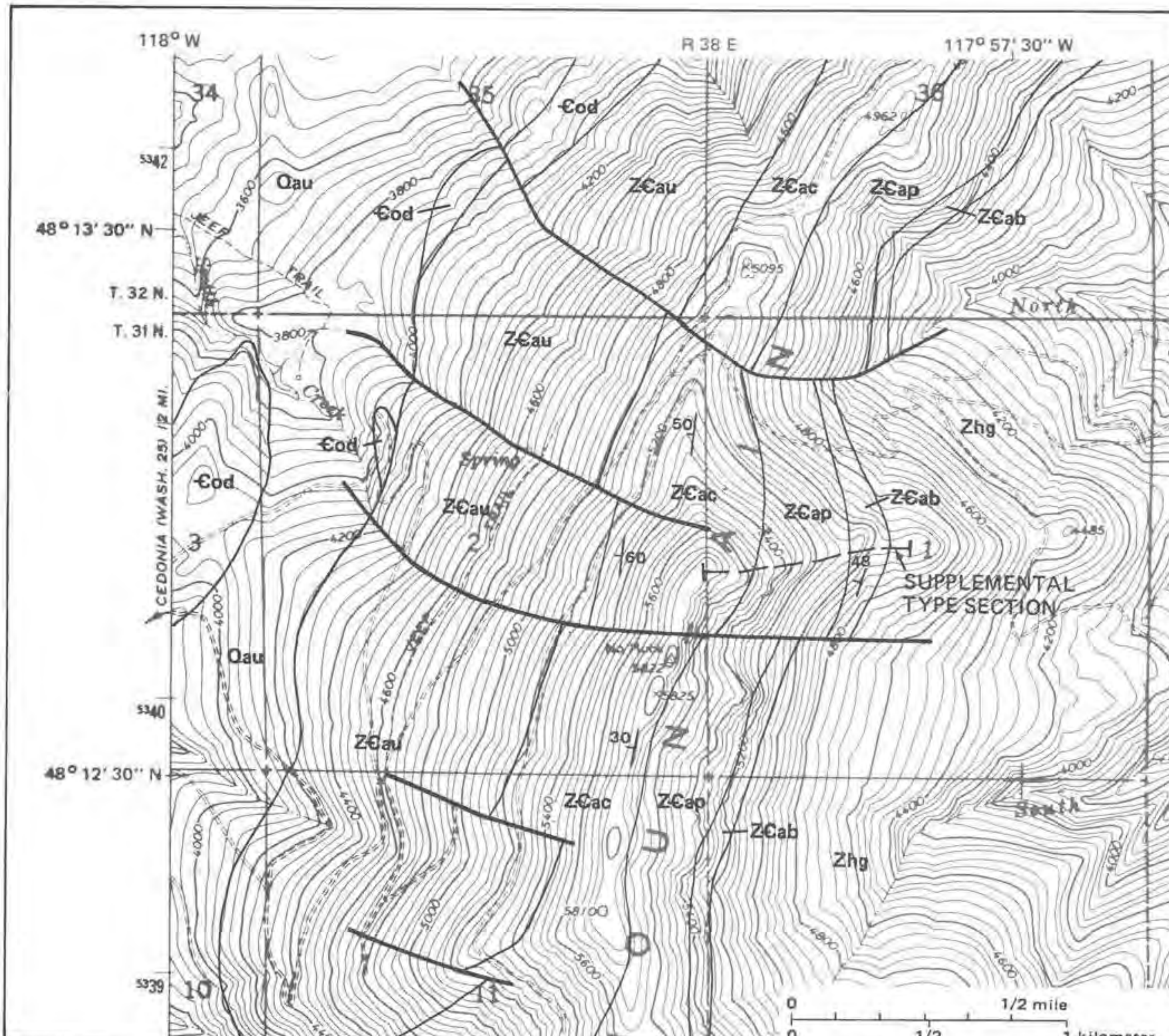


Figure 26. Geologic map of the proposed first supplemental type locality for the Addy Quartzite. Base from U.S. Geological Survey Stensgar Mountain 7.5 minute quadrangle. See Figure 24 for explanation.

(Stewart and Suczek, 1977; Armin and Mayer, 1983; Bond and Kominz, 1984). Stewart and Suczek (1977) interpret the strata of the lower diamictite and volcanic sequence as having been deposited during the initial stages of rifting. The middle terrigenous detrital sequence was deposited as rifting waned and during the early stages of passive continental margin development; the upper carbonate sequence formed on a mature passive margin following rifting.

The age of rifting and initiation of the miogeocline is unclear. The only radiometric dates known for the miogeoclinal succession anywhere in North America are from the rift-related volcanic rocks of the lower sequence in northeastern Washington. Miller and others (1973) obtained K-Ar ages of 918 to 827 Ma for the Huckleberry greenstone. However, Devlin and others (1985) feel these ages have been disturbed by Mesozoic deformation and therefore "the preferred ages of 827-918 Ma derived from the K-Ar analysis of Miller et al. (1973) are not indicative of the extrusion age of the Huckleberry greenstone" (p. 834). Preliminary dating of relatively unaltered greenstone by W. J. Devlin (Exxon Production Research

Co., written commun., 1988) yields a Sm-Nd age of 762 ± 44 Ma for the Huckleberry greenstone.

Several indirect lines of evidence also yield ages for rifting and the initiation of the miogeocline. Strata at the base of the miogeocline in northern British Columbia unconformably overlie granitic rocks dated at 800 to 720 Ma (Evenchick and others, 1984); consequently, mio-geoclinal sedimentation and rifting in northern British Columbia must be younger than 720 Ma. Subsidence curves for the Cordilleran miogeocline suggest post-rift miogeoclinal sedimentation began approximately 600 to 550 Ma (Armin and Mayer, 1983; Bond and Kominz, 1984; Devlin and others, 1985; Devlin and Bond, 1988). Early Cambrian fossils occurring in the upper half of the terrigenous clastic sequence in northeastern Washington (Miller and Clark, 1975; Groffman, 1986; Lindsey, 1987), southeastern Idaho (Crittenden and others, 1972; Oriel and Armstrong, 1971; Link and others, 1987), and the Great Basin (Stewart, 1970; Mount and others, 1983) indicate passive margin shelf sedimentation was occurring in the miogeocline by 550 Ma.

Recent stratigraphic investigations in British Columbia by Devlin and Bond (1988) suggest that two episodes of rifting, rather than one, took place. This conclusion is based on the presence of the 100- to 150-m.y. gap between radiometric and subsidence curve ages, the unconformity between the lower and middle sequences, and changes in stratigraphic trends. Strata belonging to the lower volcanic and diamictite sequence yield radiometric ages of 762 ± 44 Ma, while subsidence curves indicate the unconformably overlying terrigenous detrital sequence began to accumulate approximately 600 Ma (Armin and Mayer, 1983; Bond and Kominz, 1984; Devlin and others, 1985; Devlin and Bond, 1988). In addition, strata belonging to the lower sequence appear to have been deposited in laterally restricted rift basins, whereas the majority of the overlying middle sequence is laterally extensive.

The Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite accumulated during and following these Late Proterozoic rifting events. Stratigraphic and sedimentologic trends outlined in the following discussion indicate that the Three Sisters Formation was deposited during the final stages of intracratonic rifting and that the Addy and Gypsy Quartzites were deposited after rifting on the newly formed passive margin. This interpretation is similar to that proposed by Devlin and Bond (1988) for correlative strata in British Columbia.

Three Sisters Formation: Rift Deposition

The Three Sisters Formation unconformably overlies the Late Proterozoic Windermere Group (U.S. usage; Devlin and Bond, 1988, have elevated the Windermere to supergroup status in British Columbia). The Windermere Supergroup in British Columbia is thought to have been deposited during the initial stages of continental rifting

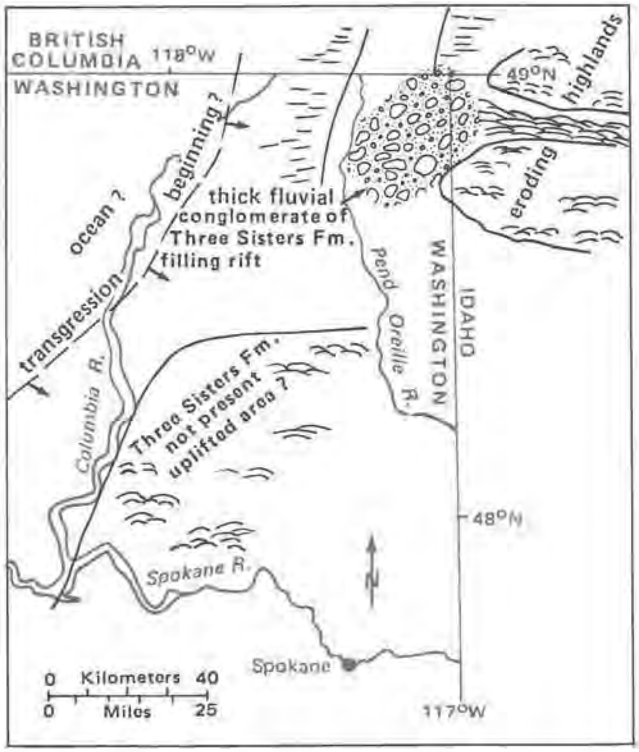


Figure 27. Paleogeographic and tectonic reconstruction of northeastern Washington during the second phase of rifting and deposition of the Three Sisters Formation approximately 580 Ma.

(Devlin and others, 1985; Devlin and Bond, 1988). Sedimentary structures and bedding geometries in the Three Sisters Formation are interpreted to indicate deposition in braided fluvial environments. Paleocurrents indicate that sediment transport was from east to west, off the craton (Groffman, 1986). Cross-bedded, coarse-grained to granular quartzites and pebble conglomerates displaying tabular to lenticular bedding geometries dominate the three units of the Three Sisters Formation. Evidence of channelization consists of broad, shallow, channel-like scour surfaces. Crudely defined fining-upward sequences interpreted as channel cut-and-fill sequences also are present but rare. The abundance of shallow channels interstratified with cross-bedded quartzite and conglomerate is suggestive of a braidplain setting (Vos and Eriksson, 1977; Cotter, 1978; Long, 1978; Rust and Koster, 1984). Debris flow deposits are common in the conglomerates, suggesting at least local fan development.

Evidence of syndepositional uplift during Three Sisters time is present. Locally derived matrix-supported conglomerate interpreted as debris flow deposits is common in the conglomerate unit of this formation. Poorly exposed, highly altered greenstone, possibly formed as a result of extensional volcanism, also occurs in the conglomerate unit. Where the Three Sisters Formation is

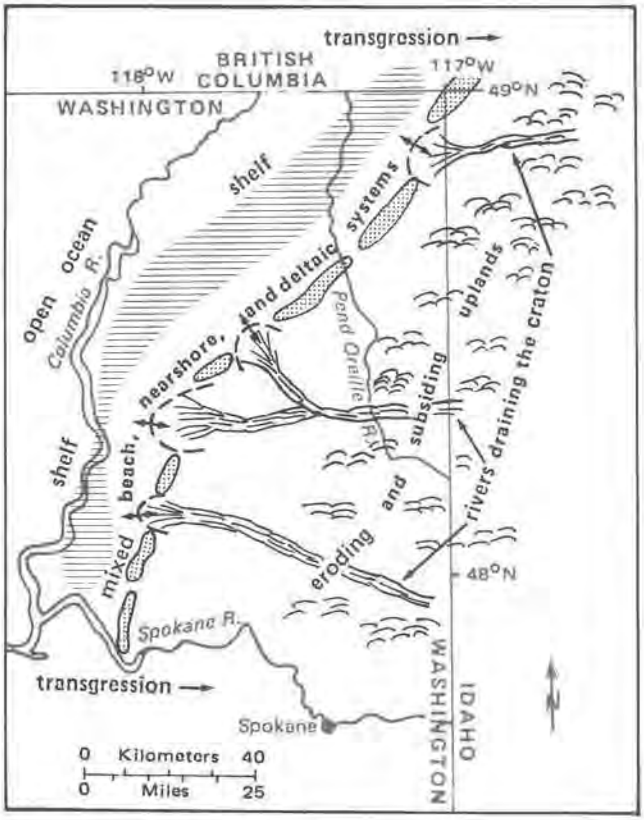


Figure 28. Paleogeographic and tectonic reconstruction of northeastern Washington during the early stages of post-rift transgression and deposition of the Addy and Gypsy Quartzites between approximately 580 and 555 Ma. During Addy/Gypsy deposition, transgression displaced coastal environments to the east so that by the end of Addy/Gypsy time all of northeastern Washington and adjacent Idaho was the site of shelf to slope deposition.

absent, a low-angle unconformity separates the Windermere Group/Supergroup from the overlying Addy and Gypsy Quartzites. Where the Three Sisters Formation is present, a low-angle unconformity separates the Three Sisters from the underlying Monk Formation (Windermere Group/Supergroup). The supra-Windermere unconformity may have formed during a period of gentle uplift that terminated deposition of the Windermere sequence.

The Three Sisters Formation is inferred to have been deposited in a localized rift basin. The Three Sisters is restricted to a fairly small area and displays evidence of syndepositional uplift. The present distribution of Late Proterozoic strata suggests this basin extended from Metaline Falls into southern British Columbia (Fig. 27). Areas south of this basin are inferred to have been uplifted and exposed during deposition of the Three Sisters (Fig. 27) on the basis of the unconformity between the Addy Quartzite and the Windermere Group. Deposition of the Three Sisters Formation must have been completed by 580 to 570 Ma because subsidence curves suggest rifting had largely ceased by that time (Bond and Kominz, 1984; Devlin and Bond, 1988) and because the Three Sisters Formation is overlain by regionally extensive shelf deposits whose upper parts contain Early Cambrian fossils.

Addy and Gypsy Quartzites: Passive Margin Sedimentation

The Addy and Gypsy Quartzites were deposited across northeastern Washington in the Late Proterozoic and Early Cambrian and form the base of Sloss' (1963) Sauk transgressive sequence. Paleogeographic reconstructions for the early Cambrian (Scotese and others, 1979) show the present north-south outcrop belt of the Addy and Gypsy Quartzites parallel to the early Cambrian paleoshoreline, which was situated at 5° to 10° N latitude. Deposition of the Addy and Gypsy Quartzites began as the continental margin began to subside and passed from the rift stage into the passive margin stage.

Deposition of the Addy and Gypsy Quartzites is inferred to have begun because post-rift cooling, erosion, and sediment loading of the continental margin, possibly coupled with eustatic sea-level rises, had progressed to the point where the margin subsided and was drowned in northeastern Washington. Removal of rift-generated uplifts bounding the continental margin by subsidence and erosion is inferred to have allowed fluvial systems (not preserved) draining the craton to deliver large volumes of terrigenous clastic sediment to the margin. These drainage systems are thought to have been the source for the more than 1,000 m of quartz sands that comprise the Addy and Gypsy Quartzites. The quartzites were deposited in a mix of fluvial, nearshore, and inner shelf environments on the newly drowned margin (Groffman, 1986; Lindsey, 1987) (Fig. 28).

The lowermost part of the basal quartzite unit of the Gypsy displays many of the same characteristics as the underlying Three Sisters Formation and also is interpreted as having been deposited in a braided fluvial setting. The balance of the basal quartzite unit was deposited in a nearshore to coastal setting (Fig. 29). Sedimentary structures and sequences present in the basal unit include mature herringbone cross-stratified beds and low-angle beach swash deposits interbedded with fining-upward sequences interpreted as tidal channel-fill deposits. Hummocky cross-stratified quartzite is present locally in the basal quartzite unit. Associations similar to those in the basal quartzite unit are commonly interpreted as nearshore to coastal deposits (Elliott, 1978, 1986; Hayes, 1980; Dott and Bourgeois, 1982; Reinson, 1984).

The basal unit of the Addy Quartzite unconformably overlies rocks older than the Three Sisters Formation. The extreme textural and compositional maturity of the basal unit suggests it was deposited in a high-energy coastal environment (Fig. 29). This interpretation is supported by the presence of rare fining-upward channel-fill sequences interpreted to be tidal in origin and the position

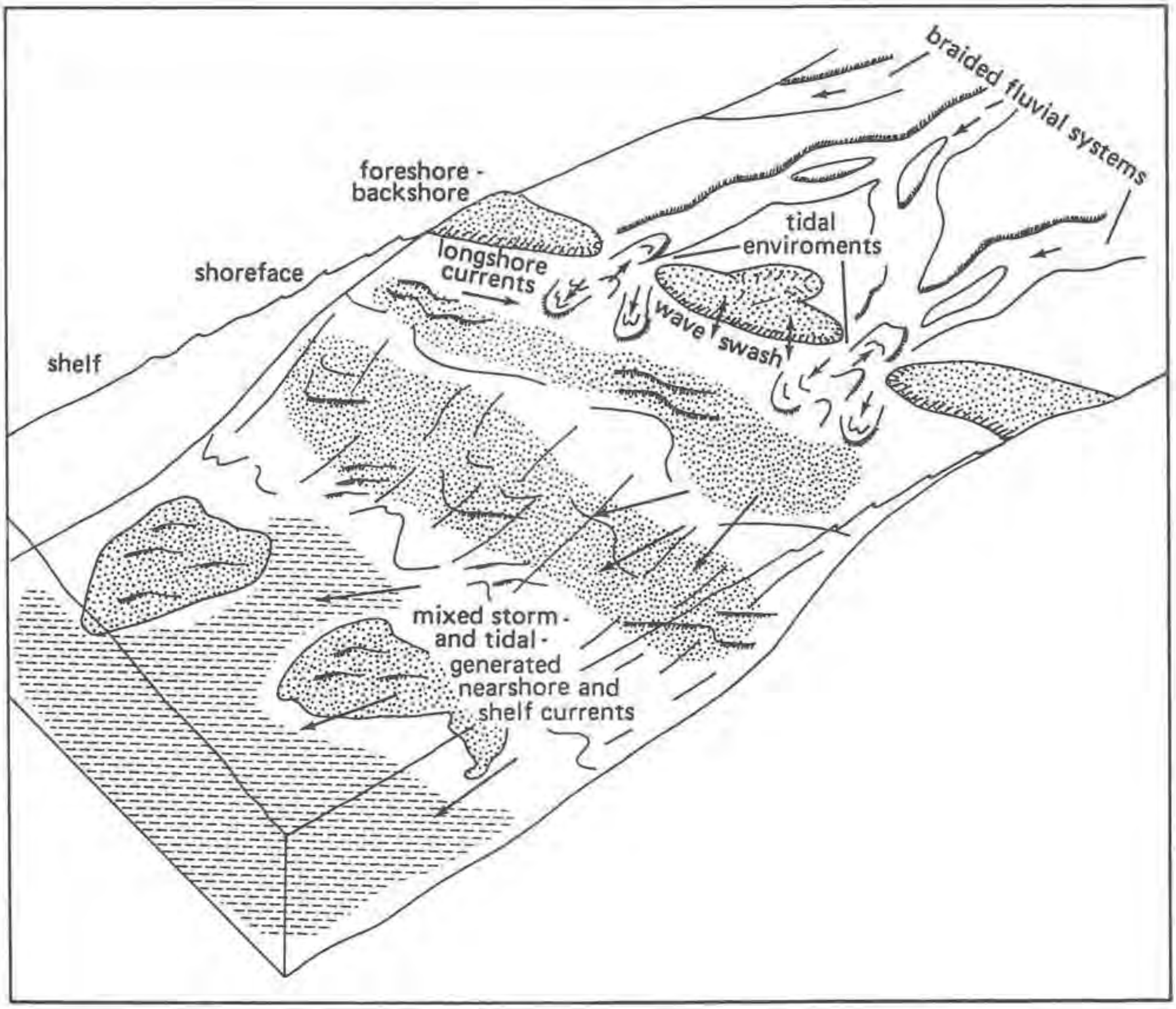


Figure 29. Idealized depositional model for the Addy and Gypsy Quartzites. Diagram not to scale.

of this basal unit at the base of a transgressive sequence above an unconformity.

Near Metaline Falls, where the Gypsy Quartzite conformably overlies the Three Sisters Formation, subsidence and sedimentation is inferred to have been essentially continuous from the latest Proterozoic into the Early Cambrian. Here, the basal quartzite unit of the Gypsy Quartzite records the change from the fluvial depositional systems typical of the Three Sisters Formation to nearshore marine depositional systems as sea level rose (Groffman, 1986; Groffman and Lindsey, 1986; Lindsey, 1987). Where the Three Sisters Formation is absent, south and west of Metaline Falls, the basal quartzite unit of the Gypsy Quartzite and the basal unit of the Addy Quartzite were deposited along the leading edge of the rising sea as the prexisting Precambrian erosion surface was drowned.

Continued sea-level rise terminated deposition of the basal units of the Addy and Gypsy Quartzites. However, relative sea-level rise appears to have been greater near Metaline Falls than in areas to the south. At Metaline Falls the basal quartzite unit of the Gypsy Quartzite is overlain by interbedded argillites, siltites, and quartzites assigned to the lower argillite unit. The presence of oscillation ripples, normally graded beds, possible trace fossils, and rare storm deposits suggests these strata were deposited on the inner shelf (Fig. 29) (Groffman, 1986; Groffman and Lindsey, 1986; Lindsey, 1987). To the south, the basal unit of the Addy Quartzite (correlative to the basal quartzite unit of the Gypsy) is overlain by the purple-banded unit of the Addy Quartzite. The lower

50 m of the purple-banded unit contains locally abundant argillite interbeds in plane bedded, swash bedded, and multidirectional cross-bedded quartzites. This sequence is interpreted as a lower shoreface to inner shelf deposit (Lindsey, 1987). This was a shallower water setting than that in which the lower argillite unit was deposited.

Following deposition of these lower shoreface to inner shelf sands, silts, and muds, shallower water environments prograded basinward. The purple quartzite unit of the Gypsy Quartzite and the majority of the purple-banded unit of the Addy Quartzite record this progradation.

The purple quartzite unit of the Gypsy Quartzite was deposited on the inner shelf, shoreface, foreshore, and in places the beachface (Fig. 29). The majority of the unit consists of planar and trough cross-bedded quartzites displaying bidirectional paleocurrents (Groffman, 1986; Groffman and Lindsey, 1986; Lindsey, 1987). Such deposits are known in foreshore to shoreface sand bodies, ridge and runnel systems, and ebb tidal deltas (Elliott, 1978, 1986; Reinson, 1984; Davis, 1985; Niedoroda and others, 1985). The cross-bedded quartzites are capped in many places by bedding-top pebble lags and argillite partings that are similar to strata interpreted as nearshore shallow-water storm or storm-modified tidal lag deposits by Anderton (1976), Levell (1980), and Soegaard and Eriksson (1985). Hummocky cross-stratification is present locally in the unit, suggesting deposition on the inner shelf to shoreface by storms (Dott and Bourgeois, 1982; Walker and others, 1983; Walker, 1984). Other indicators of marine deposition consist of local *Scolithus* burrows, part of the marine Scolithus ichnofacies (Frey and Pemberton, 1984), and evidence of beachface, nearshore, and tidal channel progradation consisting of coarsening-up sequences composed of planar, trough, and herringbone cross-bedded and ripple cross-laminated shoreface sands overlain by plane bedded beachface and storm lag deposits (Groffman, 1986; Lindsey, 1987).

The purple-banded unit of the Addy Quartzite was deposited in an environment similar to that of the purple quartzite unit of the Gypsy Quartzite: on the inner shelf, shoreface, foreshore, and beachface (Fig. 35). Swash lamination and plane bedding associated with heavy mineral lamination and texturally and compositionally mature quartzite is common throughout the purple-banded unit. The association of these types of sedimentary structures commonly indicates beachface deposition (Elliott, 1978, 1986; Reinson, 1984; Davis, 1985). These inferred beachface deposits are interbedded with planar and trough cross-bedded quartzites that are very similar to those seen in the purple quartzite unit of the Gypsy Quartzite and display bidirectional paleocurrents. The cross-bedded quartzites of the purple-banded unit are interpreted as ridge and runnel, nearshore bar, and ebb-tidal delta deposits. Oscillation ripples, hummocky cross-stratification, and tidal channel deposits occur locally in the purple-banded unit and also suggest a shallow marine depositional setting (Elliott, 1978, 1986; Boothroyd, 1985; Davis, 1985; Niedoroda and others, 1985).

Deposition of the purple-banded unit of the Addy Quartzite ceased when a fluvial system prograded basinward, burying the shoreface, foreshore, and beach deposits of the purple-banded unit (Lindsey, 1987). The cross-bedded quartzites and pebble conglomerates of the lower part of the coarse unit of the Addy Quartzite are grouped into laterally extensive, crudely defined, 2- to 5-m-thick, channel-fill sequences (Lindsey, 1987). These sequences commonly display a gradation from trough and planar cross-bedding to plane bedding up-section, overlie flat, shallow scours, and display west-directed, unidirectional paleocurrents (Lindsey, 1987). The types of evidence indicative of marine processes in underlying and overlying strata are not present in the lower coarse unit. Associations similar to those seen here have been described from deposits interpreted as gravelly braidplain, alluvial plain, and sandy braided deposits (Vos and Eriksson, 1977; Cotter, 1978, 1983; Long, 1978; Rust and Koster, 1984; Walker and Cant, 1984).

This same period of progradation also may be recorded by the uppermost parts of the purple quartzite unit of the Gypsy Quartzite. These strata suggest repeated progradation of beach, nearshore, and tidal inlet systems (Fig. 28) (Groffman and Lindsey, 1986; Lindsey, 1987). The lack of fluvial deposits in the Gypsy Quartzite near Metaline Falls during this period of inferred progradation suggests that, here, relative sea-level rise outpaced fluvial deposition and progradation.

Renewed sea-level rise terminated nearshore and fluvial progradation and initiated deposition of the upper part of the coarse unit of the Addy Quartzite and coarse quartzite and argillite unit of the Gypsy Quartzite. The coarse quartzite and argillite unit consists of medium-grained to granular quartzite with interbedded pebble conglomerate, argillite, and siltite. These strata display herringbone cross-bedding, hummocky cross-stratification, and *Scolithus* and *Monocraterion* burrows, structures suggestive of shallow-water nearshore deposition (Leeder, 1982; Frey and Pemberton, 1984; Boothroyd, 1985). Channels and channel-fill sequences also are present locally. The coarse quartzite and argillite unit is inferred to have been deposited in a complex of fluvial, tidal channel, nearshore tidal, and storm-modified inner shelf environments (Groffman, 1986; Groffman and Lindsey, 1986; Lindsey, 1987).

Medium- to coarse-grained quartzites with abundant, thin (<20 cm), lenticular interbeds of argillite and siltite are common in the upper coarse unit of the Addy Quartzite (Lindsey, 1987). The quartzites are herringbone cross-bedded and capped in many places by storm-generated bedding-top gravel lags and mud partings. Paleocurrents are bidirectional with west-directed (basinward) flow dominating. These currents are inferred to have been produced by ebb tides or storm relaxation currents.

Scolithus is present locally in the upper coarse unit. These characteristics are similar to those displayed by storm-enhanced nearshore to shelf tidal deposits described worldwide (Anderton, 1976; Levell, 1980; Soegaard and Eriksson, 1985). We interpret the upper coarse unit as having been deposited in a nearshore to inner shelf, storm-modified tidal system.

The upper units of both the Addy and Gypsy Quartzites are fining-upward sequences that record continued sea-level rise. Herringbone cross-bedded and hummocky cross-stratified quartzite interbeds are most common in the lower parts of the upper units. They indicate deposition on the innermost shelf (Fig. 35) by both storm and tidal currents alternating with periods of quiet water (Dott and Bourgeois, 1982; Leeder, 1982; Walker, 1984; Johnson and Baldwin, 1986). Argillite and siltite beds in the upper units commonly contain the trace fossils *Cruziana*, *Rusophycus*, and *Planolites*, which belong to the Cruziana ichnofacies, a marine shelf indicator (Frey and Pemberton, 1984). The argillites and siltites with thin interbedded silty quartzites that make up the uppermost parts of the upper units were deposited under progressively more distal shelf conditions where the impact of storm and tidal currents was lessened. Deposits similar to those comprising the upper units have been interpreted as having been deposited largely below storm wave base on the inner to middle shelf (Brenchley and others, 1979; Nelson, 1982; Walker, 1984; Johnson and Baldwin, 1986).

Deposition of the upper units of the Addy and Gypsy Quartzites ceased as sandy depositional systems were displaced cratonward (eastward) by a rising sea, cutting off the supply of sand to the shelf in northeastern Washington. However, because the first occurrence of trilobites is much closer to the top of the Gypsy Quartzite than to the top of the Addy Quartzite, we infer that deposition of the Gypsy Quartzite ended before that of the Addy Quartzite. Following the end of Gypsy deposition but before the end of Addy deposition, the fine sediments of the Maitlen Phyllite began to accumulate. The Maitlen sediments were probably deposited in quiet water in a middle to outer shelf environment that, in the United States, extended from the Canadian border as far south as Dunn Mountain (approximately 90 km). South of Dunn Mountain the Maitlen Phyllite pinches out and is inferred to interfinger with the upper unit of the Addy Quartzite. Southward thinning and eventual pinch out of the Maitlen Phyllite suggests the shelf environment became shallower and more agitated in the south. Shallowing to the south may reflect that the Metaline Falls area was the site of greater subsidence and hence deeper water than areas to the south. Greater subsidence may have led to the termination of Gypsy deposition earlier than Addy deposition.

By late Early Cambrian time carbonate deposition became dominant across the entire study area. Deposition of carbonate (Old Dominion limestone and Metaline Limestone) seems to have begun at approximately the same time across northeastern Washington, marking the end of Maitlen deposition in the north and Maitlen/Addy deposition in the south. The Old Dominion limestone and Metaline Limestone were deposited as shelf rim buildups and on the slope (John Bush, Univ. of Idaho, oral commun., 1986).

ECONOMIC GEOLOGY

The Addy and Gypsy Quartzites and Three Sisters Formation are not commonly thought of in terms of economic geology. However, one of the largest silica operations in the United States exploits the Addy Quartzite (Reed, 1974; Joseph, 1987).

Quartzite is one source of silica for glass, foundry and blasting sand, and silicon. Manufacture of these products requires a source whose silica content exceeds 95 percent. Silica sands and quartzite are also used in the production of portland cement. This industry can use sand (or crushed products in this size range) in which iron and alumina contents are about 6 percent each. Further, manufacturers prefer sources in which the chemical composition is consistent. The desirability of a silica source is also enhanced by the potential for low-cost production of the required grain size. Therefore, easily disaggregated quartzites may be an economical source of silica (Reed, 1974; Knutson, 1979; Joseph, 1986).

Examination of 60 thin sections of Addy and Gypsy Quartzites shows that their quartz content averages more than 95 percent. XRF analysis of six samples reveals that silica content is well over 95 percent. In addition, thin sections and XRF analysis indicate that impurities such as clays, micas, feldpsars, and ferromagnesian minerals constitute less than 2 percent of most samples (Groffman, 1986; Lindsey, 1987). No quartzites from the Three Sisters Formations were examined by XRF, but thin section point count analysis showed that typical quartz contents are in excess of 90 percent in 15 samples.

The Addy and Gypsy Quartzites and Three Sisters Formation are well lithified throughout the vast majority of their outcrop belt. In fact, they are so well lithified that it is not economic to mine or mill these units for silica (Reed, 1974). Friable, easily disaggregated quartzites occur at only a few localities.

Silica Mines

Lane Mountain Quarry

Lane Mountain, west of Valley (Fig. 3), is the site of the area's largest and best known silica quarry. There, the Addy Quartzite occurs as a fault-bounded block that crops out on and west of the crest of the mountain (Miller and Yates, 1976; Knutson, 1979). On the basis of Knutson's (1979) descriptions, Miller and Yates' (1976) map, and three hand samples, we tentatively assign the strata on Lane Mountain to the basal unit of the Addy Quartzite. Knutson (1979) attributes the friability of the

Addy Quartzite on Lane Mountain to the removal of grain cements by vadose water and to fracturing by freezing and thawing. The impact of the vadose waters is enhanced by the presence of a shear zone cross-cutting the Addy, which facilitated the movement of water through the normally hard, impermeable quartzite (Knutson, 1979).

Inactive Silica Operations

Northwest Alloys, Inc., has intermittently operated the Blue Creek silica quarry on the southwest side of the Iron Mountains southeast of Addy (Fig. 3) (Joseph, 1987). This silica was used in the production of ferrosilicon. The basal unit of the Addy Quartzite is the source of silica at the Blue Creek quarry.

Lyons Hill, southwest of Springdale (Fig. 3), is the site of another inactive quarry, also in the Addy Quartzite. This quarry was used for silica production, but high iron content forced its closure (Knutson, 1979). The poor quality and small size of outcrops at Lyons Hill prevent assignment of the exposed strata to a specific unit in the Addy Quartzite. However, the high iron content and Knutson's (1979) lithologic descriptions suggest these strata have affinities to the purple-banded unit.

A third inactive quarry is near Metaline Falls. Here, the Lehigh Portland Cement Co. obtained silica from the Three Sisters Formation for use in cement production (Joseph, 1987). Production from this mine ceased in 1986. We do not know the stratigraphic position of the mined strata.

Other Friable Quartzite Localities

Two previously undescribed localities where silica content is high and the rock is very friable were located during this study. Both localities are in the basal unit of the Addy Quartzite.

The smaller of the two sites lies approximately 1 km south of the crest of Stensgar Mountain (Fig. 3) in a logging roadcut. This outcrop appears to be fairly small as friable quartzite is found only in and near the roadcut, which is 80 m long and 3 to 8 m high. Overlying quartzite and quartzite less than 0.5 km away along strike are not friable. The friable quartzite in the roadcut is highly fractured, white, fine to medium grained, and recrystallized. XRF analysis of a single sample revealed a silica content of 99 percent and a total iron oxide content of less than 1 percent. The cause of friability in this outcrop is not known.

The white to tan, fine- to medium-grained quartzites of the basal unit also are friable over a 2- to 3-km^2 area on the southeast side of Adams Mountain (Fig. 3). Strata in the overlying coarse unit are slightly friable as well. This friability appears to be due to the absence of grain cements. Fluids from or related to a large Cretaceous granitic pluton situated 1 to 2 km away on the west side of Adams Mountain might have removed these cements.

SUMMARY

In the areas studied, the Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite are easily divisible into a series of distinct lithostratigraphic units. Reconnaissance suggests this stratigraphy persists throughout northeastern Washington.

The 1,500-m-thick Upper Proterozoic Three Sisters Formation is divided into three lithostratigraphic units. The lowest unit, the lower quartzite unit, consists of white, gray, and blue, coarse-grained to granular, cross-bedded quartzite and pebble conglomerate. Cobble and boulder conglomerate comprises the overlying conglomerate unit. The uppermost unit, the upper quartzite unit, is very similar to the lower quartzite unit. We assign argillaceous strata formerly mapped as lower Three Sisters Formation to the Monk Formation. In northeastern Washington the Three Sisters Formation unconformably overlies the Monk Formation and is known to occur only near Metaline Falls.

Conformably overlying the Three Sisters Formation is the 1,400- to 1,750-m-thick late Late Proterozoic to middle Early Cambrian Gypsy Quartzite. Where the Three Sisters Formation is absent, the Gypsy Quartzite unconformably overlies the Monk Formation. The Gypsy Quartzite is divided into five units. The lowest unit, the basal quartzite unit, consists of white, medium-grained, cross-bedded quartzite. Interbedded argillite, siltite, and quartzite compose the overlying lower argillite unit. The next unit up-section, the purple quartzite unit, consists of purple, blue, and lavender, banded, cross-bedded to plane bedded, coarse-grained quartzites. White, coarse-grained, cross-bedded quartzite with interbedded argillite assigned to the coarse quartzite unit overlies the purple quartzite unit. Interbedded argillite, siltite, and quartzite comprise the fossiliferous upper argillite, the youngest unit of the Gypsy Quartzite. The Gypsy Quartzite conformably underlies the Maitlen Phyllite. The type section we propose is located on Gypsy Peak.

The upper Upper Proterozoic to middle Lower Cambrian Addy Quartzite is correlative with the Gypsy Quartzite. The 1,100- to 1,450-m-thick Addy Quartzite is divided into four units. White, medium-grained quartzites comprise the basal unit. Purple-banded, coarse-grained, cross-bedded to plane bedded, gray, blue, and purple quartzites assigned to the purple-banded unit overlie the basal unit. The next unit up-section, the coarse unit, consists of coarse-grained to granular, cross-bedded quartzite and minor pebble conglomerate. Fossiliferous interbedded quartzite, siltite, and argillite make up the upper unit. From north to south in the magnesite belt the Addy Quartzite unconformably overlies the progressively older Monk Formation, Huckleberry Formation, and Deer Trail Group. East of the magnesite belt the Addy Quartzite unconformably overlies the Belt Supergroup. The Addy is conformably overlain by the Maitlen Phyllite, Old Dominion limestone, or Metaline Limestone.

The type section and supplemental sections we propose for the Addy Quartzite are on and near Stensgar Mountain.

The Addy and Gypsy Quartzites are easily correlated. The basal, purple-banded, coarse, and upper units of the Addy Quartzite correlate with the basal quartzite, purple quartzite, coarse quartzite, and upper argillite units of the Gypsy Quartzite, respectively. Only the lower argillite unit of the Gypsy Quartzite does not have a correlative in the Addy Quartzite. However, because of previous mapping, usage, and lithostratigraphic differences, we do not combine the Addy and Gypsy Quartzites as one formation.

The Three Sisters Formation, Gypsy Quartzite, and Addy Quartzite were deposited in a rifted continental margin setting. Rifting began in the Late Proterozoic. The Three Sisters Formation was deposited near the end of that rifting. The formation is inferred to have been deposited dominantly in fluvial environments in an intracratonic rift.

As rifting waned, the newly formed continental margin subsided, and the Sauk transgression began. The Addy and Gypsy Quartzites were deposited in mixed fluvial/deltaic, nearshore, and inner shelf environments during the early stages of post-rift sea-level rise. The basal and purple-banded units of the Addy Quartzite and basal quartzite, lower argillite, and lower purple quartzite units of the Gypsy Quartzite were deposited in beach, tidal channel, and nearshore environments and in minor fluvial and inner shelf environments along the leading edge of the transgressing sea. Fluvial/deltaic and beach/nearshore progradation is recorded in the coarse unit of the Addy Quartzite and upper purple quartzite and coarse quartzite units of the Gypsy Quartzite. Renewed sea-level rise led to deposition of the upper units of the Addy and Gypsy Quartzites in nearshore to inner shelf settings by mixed tidal and storm processes. Deposition of the Addy and Gypsy Quartzites terminated in the middle Early Cambrian as transgression continued and clastic depositional systems were displaced onto the craton. Following the end of coarse terrigenous clastic deposition, the miogeocline in northeastern Washington became the site of middle to outer shelf and shelf edge mud and carbonate deposition.

The basal unit of the Addy Quartzite has a high silica content and hosts a large silica quarry on Lane Mountain. Several inactive silica operations also are present in this formation, two in its basal unit and one in the purple-banded unit. One inactive quarry worked the Three Sisters Formation. Two previously undescribed exposures of friable silica-rich quartzite were found in the basal unit of the Addy on Stensgar and Adams Mountains during our study.

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