A microstructural perspective of orogenesis in the Pioneer Mountains central Idaho

John Steven Davis

The University of Montana

A MICROSTRUCTURAL PERSPECTIVE OF OROGENESIS IN THE PIONEER MOUNTAINS, CENTRAL IDAHO

By

John Steven Davis

B.S., University of California, Santa Cruz, 1980

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1984

Approved by:

James W. Sears

Chairman, Board of Examiners

Dean, Graduate School

5/25/84

Date

John Steven Davis, M.S., June 1984 Geology

A Microstructural Perspective of Orogenesis in the Pioneer Mountains, Central Idaho.

Director: Dr. James W. Sears JWS

The Pioneer Mountains of central Idaho contain complexly deformed Proterozoic and Paleozoic metamorphic and sedimentary rocks. Microstructural relationships show that the Devonian Milligen Formation underwent three microstructural deformations. All other Paleozoic formations contain one or two generations of microstructures.

The first microstructural deformation of the Milligen Formation, during the Late Devonian Antler Orogeny, is represented by folded fractures and bedding and by a penetrative chlorite foliation. A layer-parallel chlorite foliation in the Ordovician to Silurian combined Phi Kappa-Trail Creek Formation and the unnamed Devonian-Silurian unit may be related to the Antler Orogeny.

Deposition of the Pennsylvanian to Permian Wood River Formation produced the two fracture sets and penetrative pressure-solution cleavage of the second microstructural deformation in the underlying Milligen Formation. Concurrently, the Wood River Formation developed a weak, layer-parallel pressure-solution cleavage.

Late Cretaceous contact metamorphic tremolite in the combined Phi Kappa-Trail Creek Formation is crosscut by a layer-parallel pressure-solution cleavage which also developed in the unnamed Devonian-Silurian unit.

The third microstructural deformation of the Milligen Formation formed several shear fabrics, crenulations, and fractures. This is coevally and structurally paralleled in the combined Phi Kappa-Trail Creek Formation, and relates to Paleocene movement on the Pioneer Thrust.

Microstructures in the Glide Mountain Plate and the Copper Basin Plate of the Mississippian Copper Basin Formation developed during the Paleocene and Late Cretaceous respectively. Microstructures in the Glide Mountain Plate include fractures and a penetrative, axial plane pressure-solution cleavage.

A palinspastic restoration of the Pioneer Mountains shows the structural equivalence of the Wood River Thrust and the Wildhorse Thrust that carries the Copper Basin Plate. The Pioneer Thrust, shown to be a late-stage splay off the Glide Mountain Thrust, has only 10 to 15 km of offset, far less than the previously estimated 100+ km.

TABLE OF CONTENTS

TABLES

FIGURES AND PLATES

ACKNOWLEDGEMENTS

Partial funding of this project was obtained through the Society of Sigma Xi Grants-in-aid of Research grant program. Special thanks go to Jim Sears who put up with my ever changing ideas, and who chaired the thesis committee. Thanks also go to Steve Sheriff and Thomas Margrave who also waded through this study as members of my thesis committee. Ian Watson and Rob Sengebush gave me the idea for this project, and then suffered the consequences (they had to listen to me!). Emily Deschamps and Cathy Hocanson helped me in innumerable ways.

To Camille who put aside her own interests to help me with mine.

INTRODUCTION

The Pioneer Mountains of central Idaho (Figure 1) consist of a complexly thrusted and deformed suite of rocks ranging from Proterozoic X crystalline basement to Paleozoic metasedimentary and sedimentary rocks. The complex geologic structures of the Pioneer Mountains have been attributed to deformations during the Late Devonian Antler Orogeny and the Mesozoic or Early Tertiary Sevier Orogeny (Roberts and Thomasson, 1964; Dover, 1969,1980,1981; Dover et al., 1980; Nilsen, 1977; Poole and Sandberg, 1977; Sandberg et al., 1975, Skipp and Hall, 1975; Skipp and Sandberg, 1975). Mississippian sediments in the Pioneer Mountains are widely interpreted as flysch deposited in the foreland trough of the Antler Highland (Roberts and Thomasson, 1964; Paull et al., 1972; Nilsen, 1977; Poole and Sandberg, 1977). Furthermore, Roberts and Thomasson (1964), Burchfiel and Davis (1972,1975), and Sandberg and Poole (1977) projected the classic Antler Orogenic Roberts Mountains Thrust of Nevada under the Snake River Plain and through the Pioneer Mountains in central Idaho (Figure 2).

Recent mapping and paleontologic evidence collected by Dover et al. (1980) shows that all thrust faults presently recognized in the Pioneer Mountains are younger than the Antler Orogeny , and most likely are the result of deformation during the Mesozoic or Early Tertiary Sevier Orogeny (Dover, 1980, 1981; Dover et al., 1980). In other parts of the Pioneer Mountains Nilsen (1977), Skipp and Hall (1975), and Skipp and Sandberg (1975) made the same interpretation based on similar evidence. The allochthonous nature of the Mississippian sediments in the Pioneer Mountains, and a lack of a well defined Mississippian overlap assemblage

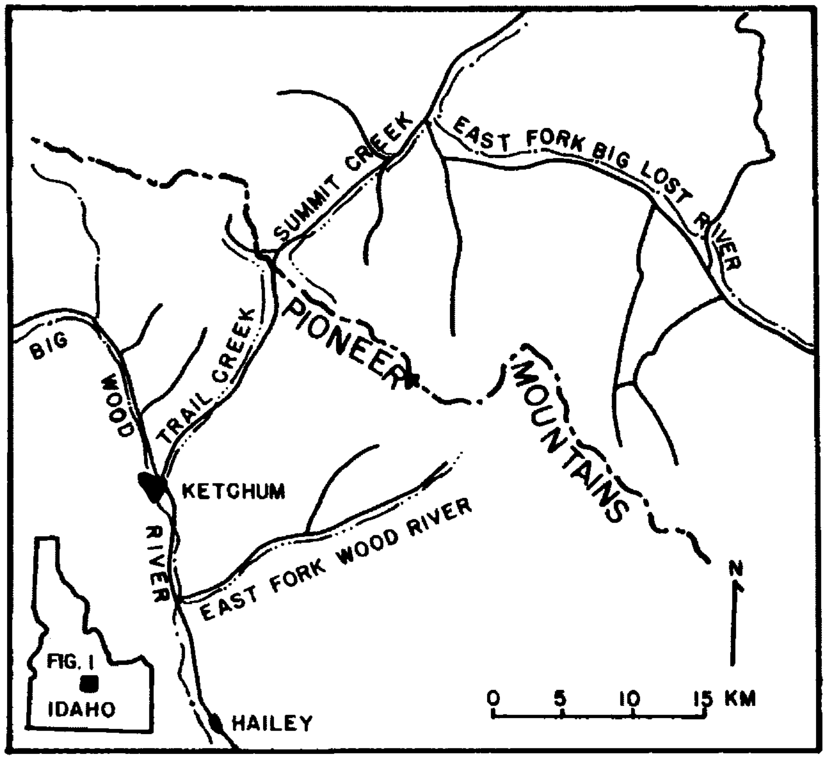


FIGURE I GEOGRAPHY OF THE PIONEER MOUNTAINS AFTER SIMONS ET AL, 1981

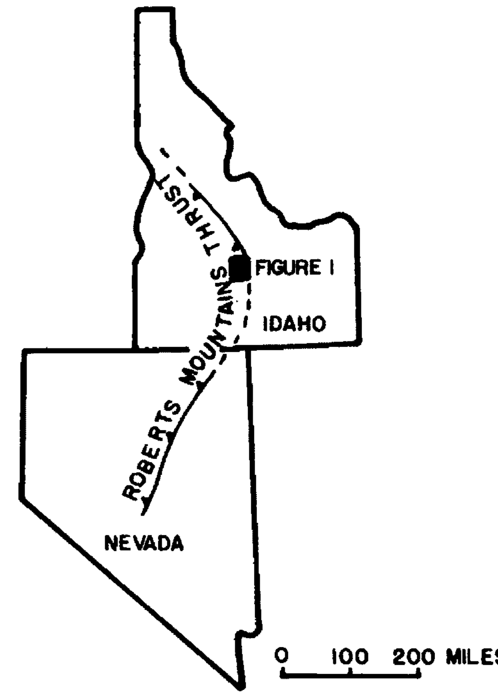


FIGURE 2

AFTER ROBERTS AND THOMASSON, 1964

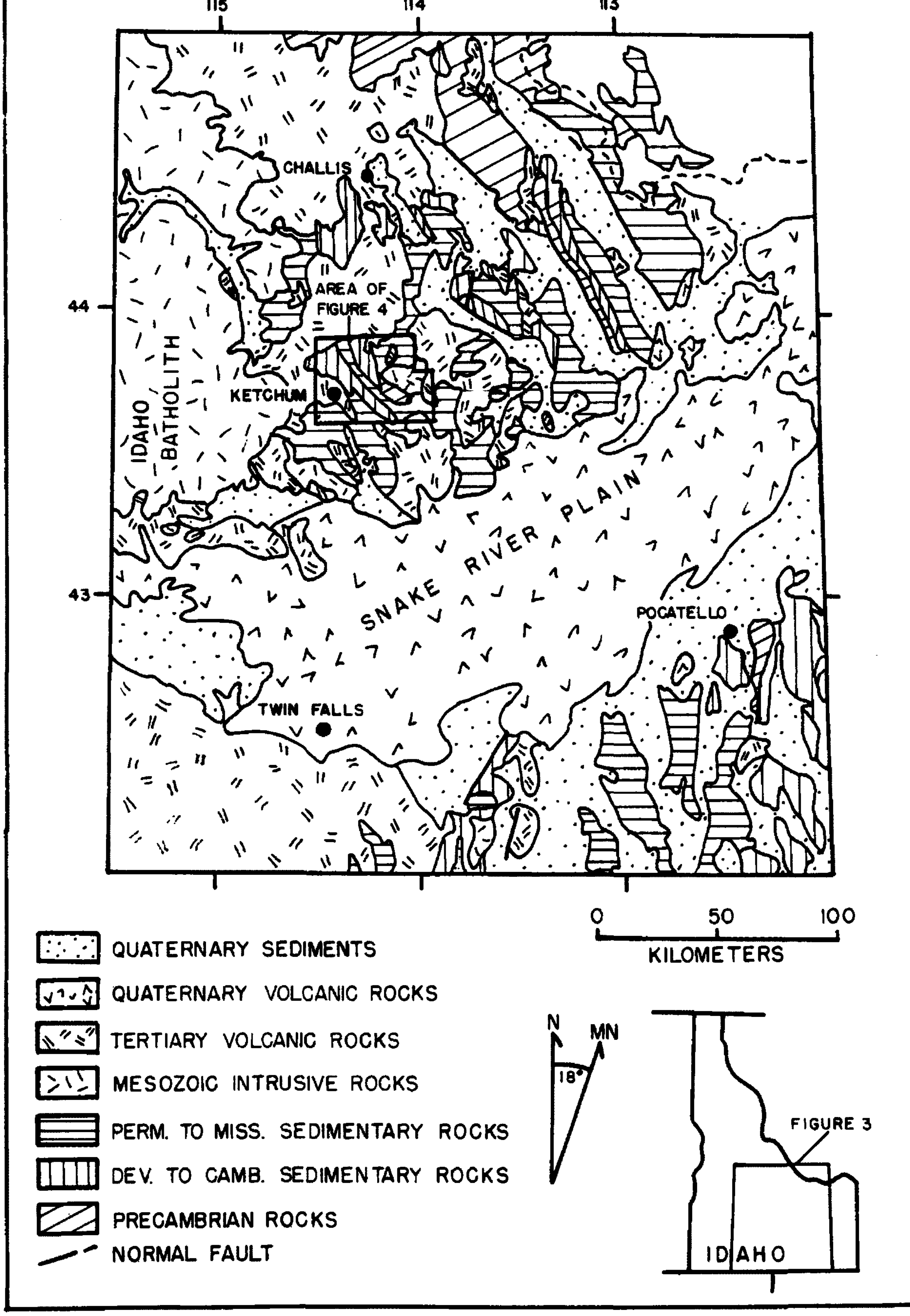
such as that which defines the Antler Orogeny in Nevada (Roberts, 1964; McKee, 1976; Smith and Ketner, 1975, 1977; Speed and Sleep, 1982) further argues against a classic Antler Orogenic genesis for the complicated structures in the Pioneer Mountains. To date, no previous geologic investigations in the Pioneer Mountains unequivocally prove the presence of structures related to the Antler Orogeny.

Previous workers concentrated on unravelling the large-scale structural relationships of the Paleozoic rocks in the Pioneer Mountains in an effort to gain a better understanding of the stratigraphy and sedimentology of those rocks. Only Dover (1969) focussed on smaller-scale, detailed structural analysis, although his study concentrated on the crystalline rocks in the Pioneer Window. In this study, I combine interpretations of microstructural relationships with inferred ages of metamorphism to show that the Antler Orogeny is microstructurally represented in at least one of the allochthonous formations in the Pioneer Mountains. I further show that most of the microstructures in the Paleozoic rocks in the Pioneer Mountains resulted from Latest Cretaceous to Paleocene deformation. Using the above interpretations together with a reinterpretation of Dover's 1981 geologic map of the Pioneer Mountains (Plate 1), I synthesize a new model of the structural evolution of the Pioneer Mountains. As a sidelight of the synthesis, I establish the equivalence of several of the major thrust faults currently mapped in the Pioneer Mountains.

REGIONAL GEOLOGY

The Pioneer Mountains lie just east of the Idaho Batholith within the Basin and Range extensional province (Figure 3). Autochthonous or parautochthonous Proterozoic and Paleozoic miogeoclinal sedimentary rocks are exposed in northwest-trending fault bounded mountain ranges north and south of the Snake River Plain (Figure 3). These rocks have been intruded by Cretaceous granitic rocks, and covered by Tertiary and Quaternary volcanic deposits (Figure 3). Extensive Quaternary sedimentation has covered all of the above rocks, but faulting during recent Basin and Range extension cuts the Quaternary deposits (Figure 3).

FIGURE 3 REGIONAL GEOLOGIC MAP AFTER NILSEN, 1977



GEOLOGY OF THE PIONEER MOUNTAINS

The geologic map of the Boulder-Pioneer Wilderness Study Area by Dover (1981) was the base map used in this study. Accordingly, the map units and their structural relationships as mapped by Dover (1981) are described herein. Table 1 presents the ages, thicknesses, lithologies, regional correlations, and structural statuses of the map units. Figures 4 and 5 show gross structural relationships, and Plate 1 shows the detailed geologic relationships and rock sample sites.

The Pioneer Mountains contain Paleozoic sedimentary rocks in four distinct allochthons. The Wood River Allochthon carries the shallow (?) marine facies Wood River Formation on the Wood River Thrust (Dover, 1981). The Sun Valley Allochthon carries the deep-water transitional facies Milligen Formation (Sandberg et al., 1975), the transitional facies unnamed Devonian-Silurian unit (Dover, 1981), the transitional facies combined Phi Kappa-Trail Creek Formation (Dover, 1981), flysch of the Glide Mountain Plate of the Copper Basin Formation (Dover, 1981), and the Wood River Allochthon, on the Pioneer Thrust (Dover, 1969, 1981). The Pioneer Thrust moved the Sun Valley Allochthon over crystalline rocks in the Pioneer Window, and over both structural plates of the Copper Basin Formation. The Glide Mountain Plate of the Copper Basin Formation (Dover, 1981) moved flysch facies (Nilsen, 1977) over cratonally-derived facies (Nilsen, 1977) of the Copper Basin Plate, on the Glide Mountain Thrust. The Wildhorse Thrust is by definition the thrust that seperates the structural plates of the Copper Basin Formation from the crystalline rocks in the Pioneer Window (Dover, 1981). This thrust carried the Glide Mountain Plate over the

TABLE 1

Information from Dover, 1981

FORMATION	AGE	THICKNESS	LITHOLOGY	REGIONAL CORRELATION	STRUCTURAL STATUS
Challis Volcanics	Eocene (42.0-49.2 MY)	---------	basalt, andesite, latite, rhyolite	-----------------------------------	----------------
Plutons and Stocks	Eocene (40.2-50.0)	---------	quartz monzonite	-----------------------------------	----------------
Intrusive sheet of the Pioneer Window	Latest Cretaceous (65.9 MY, reset ?)	---------	quartz diorite	-----------------------------------	allochthonous
Clastic Rocks	Latest Cretaceous (?) to Paleocene (?)	100+ M	pebble to boulder conglomerate	-----------------------------------	----------------
Wood River Formation	Middle Pennsylvanian to Early Permian	3000+ M	limestone, conglomerate, quartzite, cherty argillite	-----------------------------------	allochthonous
Copper Basin Formation: 1) Glide Mountain Plate	Mississippian	2000+ M	pebble to boulder conglomerate, quartzite, argillite	-----------------------------------	allochthonous
2) Copper Basin Plate a- Little Copper Member	Early Mississippian	975+ M	argillite, quartzite, granule conglomerate	-----------------------------------	allochthonous
b- Drummond Mine Limestone	Early Mississippian	810+ M	silty limestone to limy siltstone	-----------------------------------	allochthonous
c- Upper Clastic Member	Late Mississippian	1470+ M	argillite, gritty sandstone, granule conglomerate	-----------------------------------	allochthonous
Milligen Formation	Devonian	1200+ M	recrystallized chert, argillite, silty argillite, chloritic argillite and siltstone, phyllite, limestone, dolomite	Woodruff Formation (Nevada)	allochthonous
unnamed Devonian-Silurian unit	Late Silurian to Late Devonian	300+ M	carbonaceous argillite, limestone, limy to dolomitic siltstone, phyllitic siltston	-----------------------------------	allochthonous
combined Phi Kappa-Trail Creek Formation	Early Ordovician to Middle Silurian	300+ M	carbonaceous argillite and siltstone, fine grained quartzite, some contact metamorphic tremolite	-----------------------------------	allochthonous
undivided rocks in the Wildhorse and Dry Canyon Windows	Early Ordovician to Early Devonian	900+ M	dolomite, limestone, silty limestone, chert, and dolomitic siltstone	Devonian and Silurian correlates with Roberts Mountains Formation in Nevada and Idaho. Ordovician correlates with Saturday Mountain Formation in Idaho, and with Hansen Creek Formation in Nevada.	autochthonous
East Fork Formation	Middle to Late Ordovician	500+ M	quartzite, marble, calc-silicate schist and gneiss (amphibolite grade)	Saturday Mountain Formation, Ordovician rocksin Wildhorse Window, Kinnikinic Quartzite, Ella Dolomite (all units located in Idaho)	allochthonous
Hyndman Peak Formation	Ordovician or Late Proterozoic	1580+ M	two mica schist, quartzite, calc-silicate gneiss (amphibolite grade)	Clayton Mine Quartzite or Yellow Jacket Formation(both units located in Idaho)	allochthonous
Gneiss Complex	Proterozoic X (2 BY?)	2130+ M	migmatitic quartzo-feldspathic gneiss, calc-silicate marble	-----------------------------------	allochthonous

FIGURE 4 GENERALIZED GEOLOGY AND LOCATION OF FIELD AREA AFTER DOVER, 1980

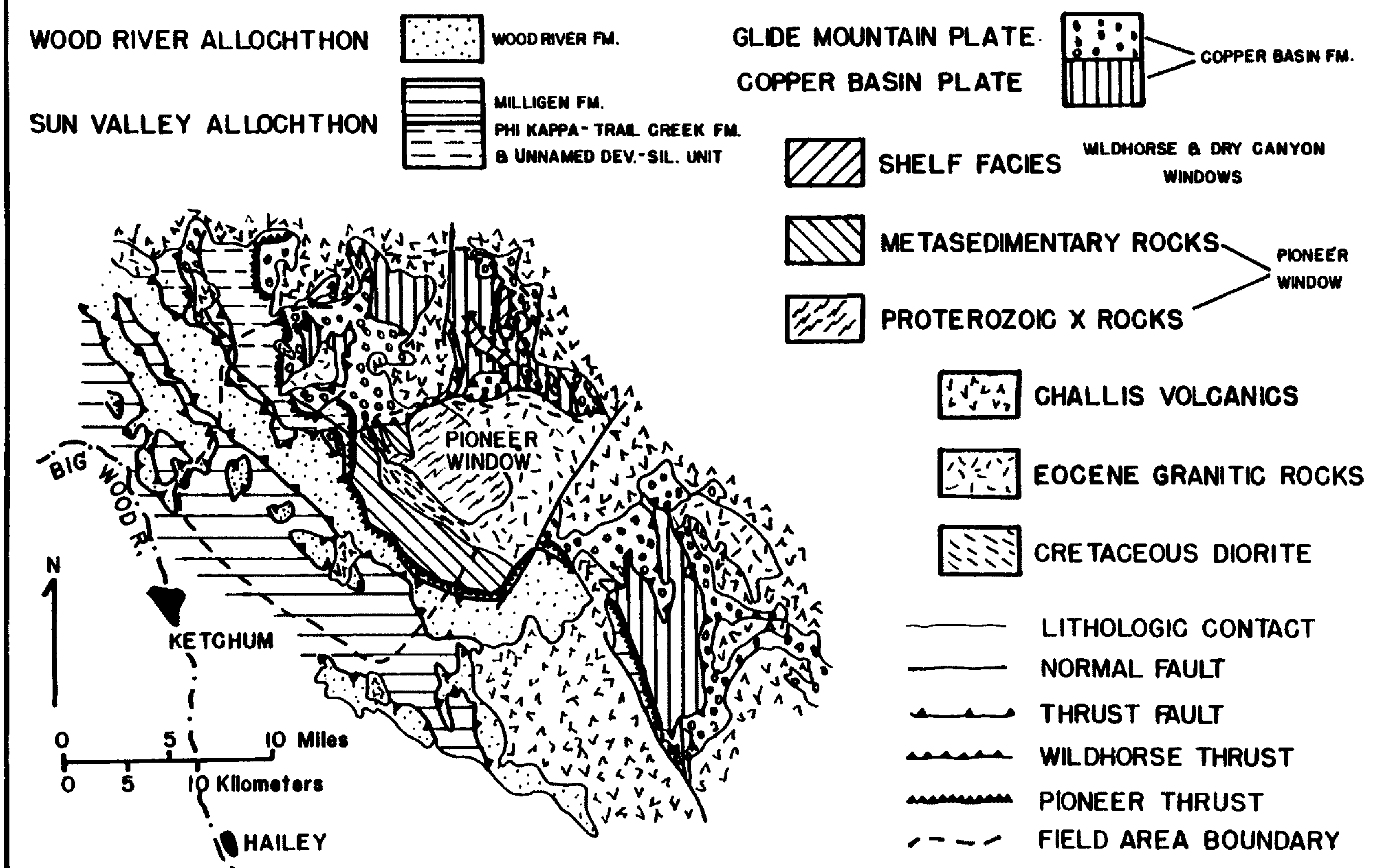
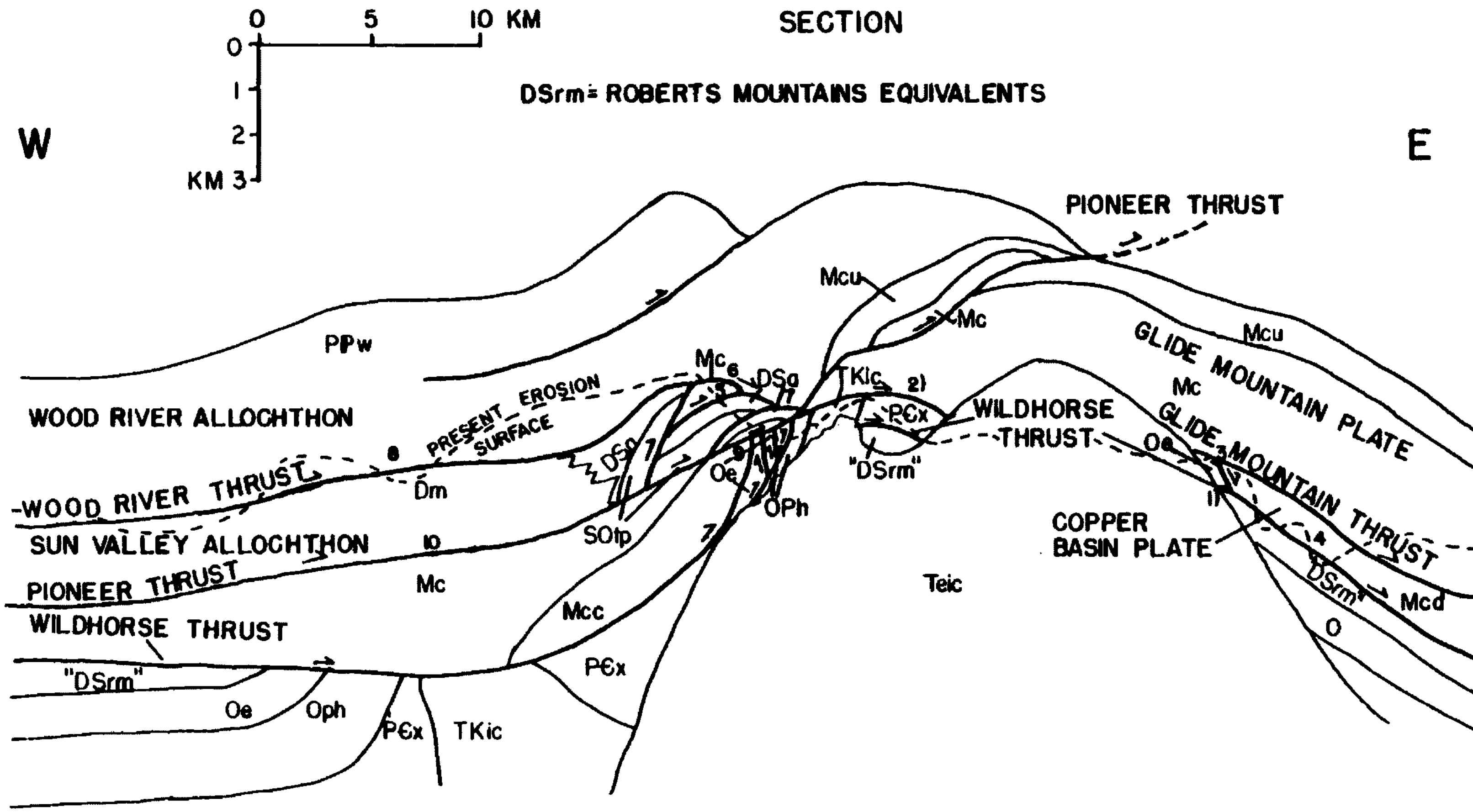


FIGURE 5 SCHEMATIC CROSS SECTION SHOWING DISTRIBUTION OF THRUST FAULTS, ALLOCHTHONS, AND FORMATIONS IN THE PIONEER MOUNTAINS

SYMBOLS EXPLAINED ON PLATE I

NUMBERS (e.g. 5) SHOW RELATIONS DISCUSSED IN STRUCTURAL EVOLUTION SECTION



crystalline rocks in in the Pioneer Window, and carried the Copper Basin Plate of the Copper Basin Formation over shelf facies rocks in the Wildhorse and Dry Canyon Windows, and over crystalline rocks in the Pioneer Window. Dover and Ross (1975) consider the shelf facies rocks in the Wildhorse and Dry Canyon Windows to be autochthonous, but Skipp and Haitt (1977) feel that they may be parautochthonous.

Dover (1969) interpreted the amphibolite facies metasedimentary East Fork Formation and Hyndman Peak Formation to be the result of synkinematic metamorphism. Likewise, Dover (1969) concluded that the quartz diorite intrusive sheet, in the Pioneer Window, was deformed coevally with the metasediments. Proterozoic X migmatitic gneiss (Dover, 1969), the East Fork Formation, the Hyndman Peak Formation, and the quartz diorite intrusive sheet make up an allochthonous or parautochthonous slice of crystalline basement (Dover, 1980, 1981) now exposed in the Pioneer Window.

Eocene granitic plutons and stocks intrude the crystalline rocks of the Pioneer Window, the Sun Valley Allochthon, and the Glide Mountain and Copper Basin Plates of the Copper Basin Formation. The Eocene Challis Volcanics overlie a Paleocene conglomerate (Dover, 1981) composed of rocks from various units described above. The Challis Volcanics cover extensive portions of the Pioneer Mountains.

High angle normal faults cut all of the above units. Quaternary sediments (glacial deposits, colluvium, and alluvium) cover every age of structure and all rock units in the Pioneer Mountains.

Vergence of folds, and sedimentary facies juxtapositions, yield eastward directed movement of all the allochthons in the Pioneer Mountains (Dover, 1969, 1980, 1981; Dover and Ross, 1975; Dover et al., 1980; Hall et al., 1974; Nilsen, 1977; Sandberg et al., 1975; Skipp and Hall, 1975; Skipp and Sandberg, 1975). The Wood River and Copper Basin Allochthons have moved a few tens of kilometers (Dover, 1981; Nilsen, 1977; Hall et al., 1974). The Glide Mountain Plate probably moved 50 to 80 km (Dover, 1980; Nilsen, 1977), and the Sun Valley Allochthon may have moved more than 100 km (Dover, 1980, 1981).

MICROSTRUCTURAL RELATIONSHIPS

The development of microstructures in the Paleozoic sedimentary rocks of the Pioneer Mountains varies widely. This section discusses the temporal relationships between the microstructures in each formation and unit examined. Table 2 summarizes the microstructures in each unit. Appendix A gives detailed lithologic descriptions of each thin section examined, and Appendix B describes the microstructures in each formation or unit.

WOOD RIVER ALLOCHTHON

Wood River Formation

The penetrative pressure-solution cleavage in the Wood River Formation was found only in the cores of large-scale folds, and it is important to note that it is layer-parallel, and not axial-planar. This suggests that the pressure-solution cleavage formed prior to folding, during diagenesis, and that the folds localized in the penetratively cleaved zones. The lack of extensive thrust imbrication of the Wood River Formation makes it unlikely that the pressure-solution resulted from tectonic loading. The pressure-solution cleavage of MTS-62 is completely irrotational, despite being from within 20 meters of the Wood River Thrust. This suggests that there is no genetic relationship between thrusting and formation of the cleavage.

The lack of penetrative strain features relatable to meso- and macroscopic structural geometries in the Wood River Allochthon suggests that deformation of the Wood River Formation always was brittle.

TABLE 2 : Summary of Microstructures in Paleozoic Sedimentary Rocks in the Pioneer Mountains

FORMATION	CHLORITE FOLIATION	PRESSURE SOLUTION CLEAVAGE	SHEAR FABRICS	CRENULATIONS	CRENULATION CLEAVAGE	SMALL-SCALE FOLDS IN BEDDING	DISCRETE SLIP SURFACES	FRACTURES/ FILLING
Wood River		XX;L.P						XX;Cc,Qtz; 2
Unnamed Devonian-Silurian Unit	XX;L.P.	XX;L.P.	XX;V.	XX		XX		XX;Qtz;2
Phi Kappa-Trail Creek	XX;L.P.	XX;L.P.				XX	XX	XX;Qtz;1
Milligen	XX;V.	XX;V.	XX;V.;2	XX;2	XX	XX	XX	XX;Cc,Qtz; 5
Copper Basin: Glide Mountain Plate		XX;A.P.	XX;V.					XX;Qtz;2
Copper Basin Plate: Little Copper		XX;A.P.						XX;Qtz;1
Drummond Mine Limestone		XX;A.P.				XX		XX;Cc;2+
Upper Clastic		XX;L.P.					XX	XX;FeO;1

L.P. = Layer-parallel; A.P. = Axial-planar; V. = Variable orientation; 1,2,...,n= number of generations of given feature; Qtz = Quartz filling; Cc = Calcite filling; FeO = Iron-oxide filling

Brittle fracture features mentioned above clearly postdate the penetrative pressure-solution features. These fractures may be the only manifestation of brittle large-scale deformation.

SUN VALLEY ALLOCHTHON

Unnamed Devonian-Silurian Unit

Both the chlorite foliation and the pressure-solution cleavage in the unnamed Devonian-Silurian unit formed parallel to primary layering. Despite intense meso- and macroscopic folding and thrusting, little of the penetrative strain relates to deformational geometries. A well-developed axial-planar cleavage transposes primary layering in MTS-39, but is restricted to the chloritic argillite layers. In general, the mesoscopic structures deform the penetrative fabrics at the outcrop scale. This suggests that both the chlorite foliation and pressure-solution cleavage formed by sedimentary or tectonic loading of flat-lying (undeformed) rocks prior to larger-scale deformation.

The lack of penetrative fabrics related to the intense macroscopic deformation of the unnamed Devonian-Silurian unit suggests that the large-scale deformation occurred when the rocks were cool and brittle. If this is the case, then there must have been sufficient time for the rocks to cool following greenschist facies metamorphism (chlorite foliation). A pre-chlorite fracture set indicates lithification of the unnamed Devonian-Silurian unit prior to metamorphism. This yields a brittle to ductile to brittle deformation history for the unnamed Devonian-Silurian unit.

Combined Phi Kappa-Trail Creek Formation

Contact metamorphism of the combined Phi Kappa-Trail Creek Formation preceded all deformation of this unit. Contact metamorphic tremolite occurs as disoriented single grains and polycrystalline aggregates. The chlorite in the chlorite foliation varies from moderately to very strongly oriented, but does not show a clear relationship with the tremolite. What is clear is that the pressure-solution cleavage cuts the tremolite, and the shear cleavage cuts the pressure-solution cleavage. The shear cleavage makes a small angle (less than 20 degrees) with the layer-parallel pressure-solution cleavage where the pressure-solution cleavage has been transposed with primary layering. In turn, the shear cleavage was crenulated, then cut by the thin section scale thrust in MTS-43. From the above relationships it may be seen that the combined Phi Kappa-Trail Creek Formation proceded from contact metamorphism to layer-parallel pressure-solution. Mesoscopic folding reoriented the pressure-solution cleavage and primary layering prior to, and during (?) shearing. The shear cleavage crosscut all penetrative fabrics, and developed according to the orientation between shear planes and previous fabrics. Locally this was followed by layer-parallel shortening, as manifested by crenulations, small folds, and thin section-scale thrusting.

Development of the layer-parallel chlorite foliation and pressure-solution cleavage appears to be a passive response to sediment or tectonic loading of flat-lying rocks. Subsequent folding was followed by a transition from ductile, penetrative shear to less ductile crenulation and small-scale thrusting. This suggests changing strain fabrics during one deformation event. If this is so, then perhaps the change in microstructural styles reflects a progressive shallowing of sructural level during deformation of the combined Phi Kappa-Trail Creek Formation.

Milligen Formation

Three completely unique periods of deformation can be delineated from the microstructures in the Milligen Formation. The first period of deformation initiated with pre-metamorphic fracturing. The fractures were then filled with quartz, and were folded along with primary layering. The folding was followed by greenschist facies metamorphism which recrystallized the matrix and vein quartz as well as produced the strong chlorite foliation. The highly variable orientation of the chlorite foliation to primary layering suggests mesoscopic and macroscopic deformation of the Milligen Formation prior to metamorphism.

The second stage of deformation initiated with the formation of the pressure-solution cleavage. Chlorite in the pressure-solution planes suggests that the pressure-solution occurred after metamorphism had ceased. This was followed by propagation of a closely-spaced fracture set, possibly during unloading of the load responsible for the pressure-solution cleavage.

Pervasive shearing and chlorite foliation-parallel flowage of the Milligen Formation signal the start of the third period of deformation. This penetrative movement of the rock disrupted preexisting planar features, and caused thin section-scale folding. Subsequent to this, shortening was accomodated by crenulation, and then by zonal shear. The last stage of dynamic strain occurred as slip on chlorite foliation-parallel fractures which offset all other strain fabrics in the Milligen Formation.

The sequence of deformation suggests several transitions between ductile and brittle strain regimes. The first period of deformation involved transition from brittle to ductile deformation. Ductile to brittle deformation characterizes both the second and third periods of deformation. The cause of the transitions is not obvious, but the relatively parallel orientations of the penetrative planar fabrics in the Milligen Formation suggests that the bulk orientation of the Milligen Formation did not change after the initial pre-metamorphic folding. This would suggest that the chlorite foliation and the pressure-solution cleavage formed under some form of loading without translation or other deformation of the Milligen Formation. Subsequent shear fabrics parallel to sub-parallel to the preexisting penetrative fabrics suggests a horizontal deviatoric stress which acted upon the Milligen Formation , and caused a transition from ductile to brittle shear fabrics as the Milligen Formation rose to shallower levels during movement on the Pioneer Thrust.

GLIDE MOUNTAIN PLATE

The development of penetrative strain fabrics in the Glide Mountain Plate is entirely dependent on position with respect to the Glide Mountain Thrust. MTS-15 and MTS-60, collected from very close to the Glide Mountain Thrust, have well developed penetrative fabrics. Other samples collected from higher structural levels with respect to the Glide Mountain Thrust, developed no penetrative fabrics despite proximity to the cores of meso- and macroscopic folds.

The strain history of the Glide Mountain Plate involves initial brittle fracturing followed by penetratlive strain only in proximity to the Glide Mountain Thrust. The pattern of strain development is a classic example of shallow level deformation where penetrative strain localizes near major surfaces of translation.

COPPER BASIN PLATE

Little Copper Member

The deformation history of the Little Copper Member easily relates to the large-scale structural development of the Copper Basin Plate. After an initial brittle fracturing, large-scale folding produced a weak axial-planar cleavage best observed in outcrop. The Little Copper Member never underwent ductile deformation, thereby suggesting a shallow level deformational history.

Drummond Mine Limestone

After brittle deformation of the Drummond Mine Limestone, mesoscopic and macroscopic folding produced the axial-planar, penetrative pressure-solution cleavage. The pressure-solution cleavage was followed by two stages fracturing, the last being parallel to the pressure-solution cleavage. As with the Little Copper Member, there is no evidence that the Drummond Mine Limestone deformed ductiley, thus indicating shallow structural levels of deformation.

Upper Clastic Member

Deformation of the Upper Clastic Member initiated with brittle fracturing. Following this, primary layer-parallel compression (sedimentary or tectonic loading) produced the pressure-solution cleavage. Since the pressure-solution cleavage is folded mesoscopically, it is likely that the offset observed in thin section resulted from flexural slippage during folding.

TIMING OF METAMORPHISM

The ages of metamorphism of the pre-Mississippian formations in the Pioneer Mountains provide crucial control on the ages of microstructural deformation for these units. The Milligen Formation and the unnamed Devonian-Silurian unit experienced one episode of metamorphism, while the combined Phi Kappa-Trail Creek Formation has experienced two metamorphic events.

Evidence for the age of metamorphism of the Milligen Formation comes from examination of lithic fragments in the Mississippian flysch of the Copper Basin Formation. Lithic fragments include recrystallized chert, quartz siltites, quartz argillites, phyllitic quartz siltites, phyllitic quartz argillites, silty quartzose chlorite-phyllites, and silty phyllites. The chlorite foliation of these lithic fragments is randomly oriented which indicates that the lithic fragments were metamorphosed prior to deposition. While all these rock types are common in the Milligen Formation, they are also found to some extent in the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation. However, two features unique to the Milligen Formation are: 1) distinct, medium- to fine-sand sized, ovoid polycrystalline quartz aggregates, found in all lithologies of the Milligen Formation (except the carbonates); and 2) a general lack of opaque, carbonaceous, organic matter compared with that contained in the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation. A large proportion (50% to 60%) of the lithic fragments in the flysch of the Copper Basin Formation contain polycrystalline quartz aggregates, and lack appreciable carbonaceous, organic matter. This suggests that the Milligen Formation was a major source for the Mississippian flysch, and that metamorphism of the Milligen Formation occurred prior to erosion. The only documented orogenic event which could regionally metamorphose the Devonian Milligen Formation in pre-Copper Basin time is the Late Devonian Antler Orogeny

The temporal relationship between contact metamorphic tremolite and regional (?) metamorphic chlorite in the combined Phi Kappa-Trail Creek Formation is ambiguous. Contact metamorphism of the combined Phi Kappa-Trail Creek Formation cannot be older than Jurassic (the oldest intrusive rocks to the west of the Pioneer Mountains are Jurassic). The allochthonous nature of the Jurassic intrusive rocks (Hamilton, 1977) indicates that the growth of tremolite resulted from contact metamorphism associated with intrusion of rocks related to the Idaho Batholith during the Late Cretaceous. The growth of layer- parallel chlorite in the combined Phi Kappa-Trail Creek Formation may be the result of the same regional metamorphic event which produced the chlorite foliation in the Milligen Formation during the Antler Orogeny.

Metamorphism of the unnamed Devonian-Silurian unit is difficult to date. The primary layer-parallel aspect of its chlorite foliation is similar to that of the combined Phi Kappa-Trail Creek Formation, and also may have resulted from regional metamorphism. No direct evidence of contact metamorphism such as the disoriented tremolite aggregates in the combined Phi Kappa-Trail Creek Formation, exists in the unnamed Devonian-Silurian unit. Presence of lithic fragments in the Mississippian flysch of the Copper Basin Formation similar to rock types in both the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation may indicate pre-Mississippian metamorphism for both units. However, these rock types are similar to those in the Milligen Formation which was a source for the Mississippian flysch. Therefore, evidence of the age of metamorphism of the unnamed Devonian-Silurian unit is inconclusive.

In summary, the Milligen Formation experienced greenschist facies metamorphism during Late Devonian time. This metamorphism probably occurred during the Antler Orogeny. The primary layer-parallel chlorite foliation of the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation suggests regional metamorphism similar to that in the Milligen Formation, indicating a possible relationship between the metamorphism and the Antler Orogeny. Contact metamorphism of the combined Phi Kappa-Trail Creek Formation most likely resulted from intrusion of rocks related to the Idaho Batholith during the Late Cretaceous.

AGES OF MICROSTRUCTURAL DEFORMATIONS

Absolute ages of microstructural development of the Paleozoic rocks in the Pioneer Mountains can be deduced from the timing of metamorphism, and from the map relationships between the major thrust faults and the Latest Cretaceous to Eocene intrusive rocks. Figures 4 and 5 and Plate 1 show the map and structural relationships.

Deformation of the Mississippian Copper Basin Formation occurred in two stages. Nilsen (1977) postulated that the first stage involved movement of the Glide Mountain Plate over the Copper Basin Plate during Middle to Late Mississippian time. His evidence comes from an unnamed Late Mississippian unit containing clasts which appear to be derived from the Glide Mountain Plate. However, the Wildhorse Thrust along the northern margin of the Pioneer Window carries the Glide Mountain Plate over the crystalline rocks of the Pioneer Window. Therefore, the Wildhorse Thrust along the northern margin of the Pioneer Window occupies the same structural position as the Glide Mountain Thrust, and must be equivalent to the Glide Mountain Thrust. Since the Glide Mountain Plate structurally overlies the Latest Cretaceous quartz diorite intrusive sheet in the Pioneer Window, and is intruded by the Eocene granitic stocks, the age of the Glide Mountain Thrust is constrained to Latest Cretaceous to Eocene.

The other phase of deformation of the Copper Basin Formation carried the Copper Basin Plate over crystalline rocks of the Pioneer Window during movement on the Wildhorse Thrust. Near the northeastern margin of the Pioneer Window, the Copper Basin Plate structurally overlies the East Fork Formation, which was synkinematically metamorphosed in Latest Cretaceous to Earliest Tertiary time (Dover, 1969). Eocene granitic stocks intrude the Copper Basin Plate, thus establishing a minimum age of deformation as Eocene, and a maximum age of Latest Cretaceous to Earliest Tertiary.

Penetrative structural deformation in both structural plates of the Copper Basin Formation easily relates to meso- and macroscopic deformation assocated with movement of the plates. Therefore, the ages of deformation range from Latest Cretaceous or Earliest Tertiary to Eocene.

Development of microstructures in the combined Phi Kappa-Trail Creek Formation probably involved two discrete phases. The first stage produced the regional (?) metamorphic primary layer-parallel chlorite foliation. However, as noted in the previous section, the age of the chlorite is unclear, and it is possible that the chlorite resulted from the same contact metamophism which produced the tremolite.

The other penetrative fabrics in the combined Phi Kappa-Trail Creek Formation clearly postdate the growth of the tremolite in the Late Cretaceous. The pressure-solution cleavage crosscuts the tremolite, thus establishing a maximum age of Late Cretaceous for the cleavage. The shear fabric of the combined Phi Kappa-Trail Creek Formation geometrically relates to movement on the Pioneer Thrust. The Pioneer Thrust moves the Sun Valley Allochthon over the Glide Mountain Plate, the Copper Basin Plate, and over the crystalline rocks of the Pioneer Window. This places a maximum age of Early Paleocene on the shear cleavage and subsequent microstructures in the combined Phi Kappa-Trail Creek Formation. The minimum age of the microstructures is established by Eocene granitic rocks which crosscut the penetrative fabrics and the

Pioneer Thrust.

The unnamed Devonian-Silurian unit lacks conclusive evidence which dates the penetrative microstructures in it. The similarity between the layer-parallel chlorite foliation in the unnamed Devonian-Silurian unit and the layer-parallel chlorite foliation in the combined Phi Kappa-Trail Creek Formation suggests that they formed coevally.

The unnamed Devonian-Silurian unit is in thrust contact with the combined Phi Kappa-Trail Creek Formation. This thrust parallels primary layering in both formations suggesting that the unnamed Devonian-Silurian unit moved along a stratigraphic horizon. The lack of shear fabrics related to movement on this thrust indicates two things. First, movement probably was not extensive. Second, if the layer-parallel pressure-solution cleavage had formed prior to movement on the thrust, the pressure-solution cleavage probably would have been activated as slip surfaces during the thrusting. No evidence for movement on the pressure-solution surfaces exists, suggesting that the pressure-solution cleavage formed after thrusting. Likewise, pressure-solution surfaces in the combined Phi Kappa-Trail Creek just beneath the thrust do not appear to have been activated as slip surfaces. Therefore, pressure-solution in both the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation probably developed after thrusting of the unnamed Devonian-Silurian unit over the combined Phi Kappa- Trail Creek Formation. The primary layer-parallel pressure-solution cleavage is inferred to be the result of the same Late Cretaceous loading event which produced the primary layer-parallel pressure- solution cleavage in the combined Phi Kappa-Trail Creek Formation. Movement on the Pioneer Thrust folded the penetrative fabrics of the unnamed Devonian-Silurian unit, thus placing a minimum age of the penetrative microstructures as Paleocene.

Microstructural deformation of the Milligen Formation involved three discrete phases as discussed earlier. The first stage evolved before and during metamorphism of the Milligen Formation to the lower greenschist facies. The metamorphic event produced a chlorite foliation which crosscut previously folded quartz filled fractures and primary layering. Since the greenschist facies metamorphism probably occurred during the Antler Orogeny, it follows that the microstructural deformation preceding the chlorite foliation most likely resulted from deformation during the Antler Orogeny.

The second stage of microstructural deformation of the Milligen Formation occurred subsequent to the Antler Orogeny. The complete absence of pressure- solution cleavage in lithic fragments of the Mississippian flysch of the Copper Basin Formation suggests development of the pressure-solution fabrics after the Mississippian. The parallel to subparallel orientation of the pressure-solution cleavage to the chlorite foliation indicates that the Milligen Formation behaved passively during the loading event which produced the pressure-solution cleavage. Two possible loading events may be responsible for the pressure-solution cleavage. First, deposition of over 3000 meters of the Wood River Formation unconformably on the Milligen Formation could have produced the pressure-solution cleavage during the Permian. This seems somewhat likely considering that, at least locally, the much coarser grained Wood River Formation contains a pressure-solution cleavage and sutured grain boundaries.

The second possible loading event is the movement of the Wood River Allochthon over the Milligen Formation. Since the Wood River Thrust is folded about axes parallel to those in the complexly thrust imbricated unnamed Devonian-Silurian unit and combined Phi Kappa-Trail Creek Formation, it is likely that the Wood River Thrust was folded during movement on the Pioneer Thrust. Therefore, the Wood River Thrust predates movement on the Pioneer Thrust. As seen later, the Wood River Thrust probably developed during the Late Cretaceous to Early Paleocene.

At this point no line of evidence convincingly argues for either loading hypothesis. However, there is no reason why movement of the Wood River Allochthon over the Milligen Formation should have produced a pressure-solution fabric. It is worth noting that before movement of the Wood River Allochthon, the Milligen Formation already had the full thickness of the Wood River Formation overlying it. Movement of the Wood River Allochthon would not have produced an additional loading since the overlying column of rock would have had the same thickness. Therefore, the sedimentary loading hypothesis seems to be the most reasonable explanation for the second stage of microstructural deformation of the Milligen Formation.

The third stage of microstructural deformation in the Milligen Formation produced penetrative fabrics geometrically reconcilable with Paleocene movement on the Pioneer Thrust. Eocene granitic rocks intrude and crosscut all penetrative fabrics in the Milligen Formation, thus establishing the minimum age of microscopic deformation of the Milligen Formation.

The weakly-developed primary layer-parallel pressure-solution cleavage in the Wood River Formation may have resulted from sedimentary or tectonic loading. Tectonic loading by thrust imbrication of the Wood River Allochthon cannot be responsible for the penetrative pressure-solution cleavage since it occurs on the upper and lower plates of the Wood River Allochthon. Therefore, the pressure-solution cleavage probably resulted from sedimentary diagenesis during the Permian.

Figure 6 summarizes the conclusions developed in this section. Many of the map relationships developed in this section will be used later to help produce a synthesis of the structural evolution of the Pioneer Mountains. The next section develops the pre-Antler Orogeny paleogeography of central Idaho in order to provide a base on which to construct the structural synthesis.

FIGURE 6 Summary of Ages of Microstructures

LATE DEVONIAN
First stage of microstructural deformation of the Milligen Formation during the Antler Orogeny. Chlorite foliation developed in the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation

↓

PERMIAN
Second stage of microstructural deformation of the Milligen Formation. Penetrative pressure solution cleavage developed in the Wood River Formation ? Both due to loading during deposition of the Wood River Formation.

↓

LATE CRETACEOUS
Growth of contact metamorphic tremolite in the combined Phi Kappa-Trail Creek Formation. Development of penetrative pressure solution cleavage in the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation ?

↓

LATEST CRETACEOUS to EOCENE
Development of penetrative, axial-planar, pressure solution cleavage in the Copper Basin Plate. Development of axial-planar pressure solution cleavage and shear cleavage in the Glide Mountain Plate.

↓

PALEOCENE to EOCENE
Third stage of microstructural deformation of the Milligen Formation. Development of shear fabrics, crenulations, and small scale folds in the combined Phi Kappa-Trail Creek Formation. Deformation in both formations due to movement on the Pioneer Thrust.

PRE-MISSISSIPPIAN PALEOGEOGRAPHY OF CENTRAL IDAHO

The Early Paleozoic sedimentary rocks currently exposed in the Pioneer Mountains represent continental shelf facies, transitional facies, and rise facies. Table 1 details proposed ages, regional correlations, and structural statuses for these Early Paleozoic units. Rocks exposed in the Wildhorse and Dry Canyon Windows include the westernmost exposures of autochthonous shelf and upper slope transitional facies rocks in central Idaho (Dover and Ross, 1975). The allochthonous metasedimentary sequence in the Pioneer Window correlates with shelf rocks in the Wildhorse Window, and probably with shelf rocks exposed north of the Pioneer Mountains (Dover, 1980, 1981).

The Early Paleozoic sedimentary rocks carried in the Sun Valley Allochthon represent deepwater to transitional facies eugeoclinal deposits (Roberts and Thomasson, 1964; Dover and Ross, 1975; Sandberg et al., 1975; Nilsen, 1977; Poole and Sandberg, 1977; Dover et al., 1980; Dover 1980,1981).

The Devonian paleogeography of central Idaho may be inferred by combining interpretations from the above studies. During Devonian and Late Silurian time, sediments equivalent to the Roberts Mountains Formation were deposited in a location in and near the present position of the Wildhorse and Dry Canyon Windows (Dover and Ross, 1975). These sediments were deposited between the miogeoclinal shelf and the eugeocline to the west. The relatively high carbonate content of the Roberts Mountains Formation equivalents in the Pioneer Mountains suggests deposition on the edge of the shelf and on the upper slope. This places the shelf-slope break at or slightly east of the Pioneer

Mountains.

Sandberg et al. (1975) interpret the allochthonous Milligen Formation as deepwater transitional facies sediments deposited on the continental rise. The more calcareous nature of the partially time-equivalent unnamed Devonian-Silurian unit suggests deposition in a slope environment closer to the shelf sediment source.

The upward increase in the carbonate content of the combined Phi Kappa-Trail Creek Formation, and the limited movement of the unnamed Devonian-Silurian unit over the combined Phi Kappa-Trail Creek Formation on a stratigraphic horizon, suggests that they were deposited in stratigraphic continuity. The allochthonous East Fork Formation correlates sedimentologically and temporally with quartzites in the Wildhorse Window (Dover, 1981), and temporally with the combined Phi Kappa-Trail Creek Formation.

The reconstructed Devonian paleogeography is shown graphically in Plate 2, part A.

STRUCTURAL EVOLUTION OF THE PIONEER MOUNTAINS

The object of this section is to provide a reasonable model which explains the macrostructural and microstructural relationships in the rocks of the Pioneer Mountains. The model is presented in Figure 7, with specific reference to Plate 2. Plate 2 graphically summarizes the large-scale structural evolution of the rocks exposed along A-A′ and B-B′ on plate 1 (A-A′ is projected onto B-B′).

Relationships in Figure 5 and Plate 1, which are important to the structural model presented in this section, include: 1) the Copper Basin Plate is in thrust contact with the East Fork Formation; 2) the Glide Mountain Plate is in thrust contact with the Proterozoic X gneiss complex and the quartz diorite intrusive sheet; 3) the Glide Mountain Thrust truncates structures in the Copper Basin Plate; 4) the Copper Basin Plate structurally overlies the shelf facies rocks in the Wildhorse and Dry Canyon Windows; 5) the Glide Mountain Plate structurally overlies the unnamed Devonian-Silurian unit; 6) the Wood River Allochthon structurally overlies the Glide Mountain Plate along the Wood River Thrust. 7) the Wood River Allochthon is in thrust contact with the complexly thrust imbricated unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation; 8) the Wood River Thrust truncates structures in the Milligen Formation; 9) the complexly thrust-imbricated unnamed Devonian-Silurian unit and combined Phi Kappa-Trail Creek Formation structurally overlie crystalline rocks in the Pioneer Window along the Pioneer Thrust; 10) the Milligen Formation structurally overlies the Copper Basin Plate. 11) the Eocene granitic pluton in the Pioneer Window intrudes all rocks it is in

DEVONIAN Plate 2, Part A

Paleogeography of central Idaho.

↓

LATE DEVONIAN - Antler Orogeny - Plate 2, Part B

First stage of deformation of the Milligen Formation in the Antler Highland. Chlorite foliation in unnamed Devonian-Silurian unit and combined Phi Kappa-Trail Creek Formation?

↓

MISSISSIPPIAN - Plate 2, Part C

Deposition of the Copper Basin Formation in subsiding foreland trough of the Antler Highland.

↓

PENNSYLAVANIAN-PERMIAN - Plate 2, Part D

Deposition of Wood River Formation on eroded Milligen Formation with 3000 meters of subsidence of the Milligen Formation. Second stage of deformation of the Milligen Formation. Development of weak layer-parallel pressure solution cleavage in the Wood River Formation. Early fracturing in Copper Basin Formation?

↓

LATE CRETACEOUS

Contact metamorphism of the combined Phi Kappa-Trail Creek Formation during intrusion of Idaho Batholith related rocks. Development of lyer-parallel pressure solution cleavage in the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation.

↓

LATEST CRETACEOUS - Plate 2, Part E

Intrusion of quartz diorite intrusive sheet near shelf-slope break domes and metamorphoses overlying sediments, and forms East Fork and Hyndman Peak Formations.

↓

LATEST CRETACEOUS TO PALEOCENE - Plate 2, Part F

Propagation of the Wildhorse Thrust along the base of the Wood River Formation and Copper Basin Formation. The Wildhorse Thrust cuts down section at the domed area near the shelf-sope break and forms a thrust duplex (c.f. Boyer and Elliot, 1982) involving the Roberts Mountains Formation equivalents, the East Fork Formation, the Hyndman Peak Formation, the Proterozoic X gneiss complex, and the quartz diorite intrusive sheet. The duplex is moved over the Roberts Mountains Formation equivalents. Shortening in the duplex is about 25 - 30 KM. Folding of the Upper Clastic Member, the Drummond Mine Limestone, and the Little Copper Member forms the axial plane cleavage of the Copper Basin Plate. Deformation associated with the thrust duplex forms a penetrative foliation in the East Fork Formation, the Hyndman Peak Formation, and the Quartz diorite intrusive sheet.

↓

PALEOCENE - Plate 2, Part G

Propagation of the Glide Mountain Thrust through the Milligen Formation, the unnamed Devonian-Silurian unit, the combined Phi Kappa-Trail Creek Formation, and upsection through the Copper Basin Formation (forms the Glide Mountain Plate), and through the basement thrust duplex. Movement on the Glide Mountain Thrust forms a thrust duplex in the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation. The duplex, the Milligen Formation and the Wood River Allochthon are transported toward the crystalline rocks in the Pioneer Window. Flysch facies in the Glide Mountain Plate are transported over distal facies in the Copper Basin Plate. The third stage of deformation of the Milligen Formation and the equivalent deformation in the combined Phi Kappa-Trail Creek Formation occur during movement along the Glide Mountain Thrust. Shear Fabrics in the Glide Mountain Plate develop in proximity to the Glide Mountain Thrust.

↓

LATE PALEOCENE - Plate 2, Part H

The Pioneer Thrust splays off the Glide Mountain Thrust, and juxtaposes the thrust duplex of the unnamed Devonian-Silurian unit and combined Phi Kappa-Trail Creek Formation over the crystalline rocks in the Pioneer Window. This is a continuation of the third stage of deformation of the Milligen Formation.

↓

EOCENE - Plate 2, Part I

The Eocene quartz monzonite intrudes and domes the rocks in the Pioneeer Mountains. Erosian results in the present topography of the Pioneer Mountains.

FIGURE 7 Model of Structural Evolution of the Pioneer Mountains contact with. This is in variance to Dover's 1981 interpretation in which he feels that the contact between the Eocene pluton and the structural plates of the Copper Basin Formation is a "minor" thrust fault.

The Late Devonian paleogeographic reconstruction is based on the preceding section, and on the following assumptions: 1) a passive continental margin with an average slope of 4 degrees and a width of 100 km; 2) the thicknesses of pre-Mississippian units are as presented in Table 1; 3) the rocks in the Wildhorse and Dry Canyon Windows are autochthonous or parautochthonous.

Other assumptions used to graphically represent the large scale structural evolution of the Pioneer Mountains include: 1) at least 3000 meters of subsidence of the Milligen Formation during deposition of the Wood River Formation; 2) flexural behavior of the Earth's crust (i.e. non-Airy subsidence; Watts et al., 1982); 3) upto 100 km of lateral translation of the Milligen Formation (Dover, 1980,1981), 50 to 80 km of movement of the Glide Mountain Plate (Nilsen, 1977), 20 to 35 km of movement of the Wood River Allochthon and the Copper Basin Plate (Hall et al., 1974; Nilsen, 1977; Dover, 1980, 1981).

Several interesting results come from the model in Figure 7 and the structural reconstruction developed in Plate 2. These include the following: 1) The Pioneer Thrust mapped by Dover (1981) is a late-stage splay off the Glide Mountain Thrust, and has 10 to 15 km of offset. Dover (1980, 1981) previously felt that the Pioneer Thrust was responsible for more than 100 km of movement of the Sun Valley Allochthon; 2) the Wood River Thrust and the Wildhorse Thrust which carries the Copper Basin Plate are equivalent to each other; 3) the

Wildhorse Thrust which carries the Copper Basin Plate, acted as a roof thrust for a basement thrust duplex (c.f. Boyer and Elliot, 1982) which is now exposed in the Pioneer Window; 4) the Wood River Thrust acted as a roof thrust for a duplex which resulted in the complex thrust imbrication of the unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation; 5) movement on the Wood River Thrust must be of Latest Cretaceous to Early Paleocene age since it is equivalent to the Copper Basin Thrust; 6) the Wood River Thrust was reactivated as the roof thrust mentioned in 4) above for a short duration; and 7) the downflexing of the Earth's crust during deposition of the Wood River Formation may be responsible for post-chlorite foliation, pre-pressure-solution fractures in the second stage of microstructural deformation of the Milligen Formation. The downflexing may also be responsible for some of the early fractures in the Copper Basin Formation.

SUMMARY OF CONCLUSIONS

This section summarizes the most important conclusions reached in the preceding sections. 1) Microstructures in the Milligen Formation represent three distinct stages of deformation. The first stage includes fracturing, folding, and the growth of a chlorite foliation. This stage probably occurred during the Antler Orogeny. The second stage of deformation of the Milligen Formation resulted in two stages of fracturing and a penetrative pressure-solution cleavage. The fracturing and pressure-solution cleavage most likely resulted from sedimentary loading and subsidence during deposition of the Wood River Formation in Pennsylvanian and Permian Time. The third stage of microstructural deformation of the Milligen Formation produced shear fabrics, crenulations, crenulation cleavage, and fractures. This stage resulted from movement on the Pioneer Thrust during Middle and Late Paleocene. 2) The unnamed Devonian-Silurian unit and the combined Phi Kappa-Trail Creek Formation underwent seemingly parallel microstructural deformation histories. The first penetrative fabric in these units is an undated, primary layer-parallel chlorite foliation. The combined Phi Kappa-Trail Creek Formation contains Late Cretaceous contact metamorphic tremolite. A primary layer-parallel pressure-solution cleavage cut the tremolite, and also formed in the unnamed Devonian-Silurian unit at the same time. Further penetrative small-scale deformation did not affect the unnamed Devonian-Silurian unit. The combined Phi Kappa-Trail Creek Formation contains shear fabrics which cut the pressure-solution cleavage, and also contains crenulations and small-scale folds. The shear fabrics, crenulations, and folds geometrically relate to movement on the Pioneer Thrust, and correlate with the third stage of micostructural deformation in the Milligen Formation. 3) The Wood River Formation contains only a weakly-developed, primary layer-parallel pressure-solution cleavage. This cleavage formed by sedimentary diagenesis during the Permian, and may correlate temporally with the pressure-solution cleavage in the Milligen Formation. 4) Microstructural deformation of the Glide Mountain Plate developed only in proximity to the Glide Mountain Thrust. The penetrative fabrics include a pressure-solution cleavage and a shear fabric. The pressure-solution cleavage is axial-planar to mesoscopic folds formed during movement of the Glide Mountain Plate. 5) The Copper Basin Plate of the Copper Basin Formation contains a penetrative, axial-planar pressure-solution cleavage. The axial plane cleavage formed in the cores of meso- and macroscopic folds during movement of the Copper Basin Plate. Extensive fracturing also characterizes the Copper Basin Plate. 6) The Pioneer Thrust of Dover (1980, 1981) is a late-stage splay off the Glide Mountain Thrust. Although Dover (1980,1981) estimates over 100 km of translation on the Pioneer Thrust, the reconstruction presented in Plate 2 indicates that only 10 to 15 km of movement occurred. 7) The Wood River Thrust and the Wildhorse Thrust which carries the Copper Basin Plate are structurally equivalent to each other.

The Antler Orogeny in Idaho, as represented in the Milligen Formation, differs in several aspects from the Antler Orogeny in Nevada. First, there is no evidence that the Antler Orogeny in Idaho included major thrusting. Evidence for this may be obscured by younger tectonic activity, and by later igneous activity in western Idaho. The lack of shear fabrics in clasts of the flysch facies of the Copper Basin Formation suggests that little or no thrusting occurred during the Antler Orogeny in Idaho. Second, The Antler Orogeny in Idaho produced a metamorphic fabric, a feature that did not develop in Nevada (Speed and Sleep, 1982). Third, the Antler Orogeny in Idaho occurred in Late Devonian time only, whereas in Nevada, the Antler Orogeny started in the Late Devonian and continued through the Mississippian (McKee, 1976; Smith and Ketner, 1975, 1977; Speed and Sleep, 1982)

APPENDIX A

Lithologic descriptions by allochthon and formation

Qtz - quartz
Cc - calcite
Ksp - potassium feldspar
Mi - mica
Bio - biotite
Mus - muscovite
Chl - chlorite
Ep - epidote

Hbl - hornblende
Tr - tremolite
Pl - plagioclase
Cd - chalcedony
Cl - clay
Op - opaque minerals
FeO - iron oxides
Org - carbonaceous organic matter

Li - lithic fragments
Ar - argillite
Phy - phyllite
Ss - siltstone
Ch - chert
Mc mudchips

Occurrences:
V - veins
D - detrital
M - matrix
Cm - cement
Met - metamorphic
Di - diagenetic

Textures:
Ws - well sorted
Ms - moderately sorted
Ps - poorly sorted
A - angular
Sa - subangular
Sr - subrounded
R - rounded
Wr - well rounded

ALLOCHTHON	FORMATION/MEMBER	SAMPLE	MINERALOGY (% TOT)	MINERAL OCCURRENCE	SEDIMENTARY FEATURES	ROCK TYPE
Wood River	Wood River	HTS-4a	Qtz(90-95%);Cc(5-10%);Ksp(<1%)	Qtz(D(F,Ms,Sr-R)), Cc(Cm(<VF)), Ksp(D(F))	Homogeneous	Quartzite
		HTS-6	Cc(75-80%);Qtz(20-25%);Ksp(<1%); Mi(<1%)	Cc(V(<VF,Tw),Cm,D(S-VF));Qtz(D(S-VF,Ms,A));Mi;Ksp(D(S))	Homogeneous	Silty Limestone
		HTS-35b	Qtz(90-95%);Mi(Chl,Bio,Mus,5%);Cc(5%);Ksp(<1%);FeO(<1%);Op(<1%)	Qtz(D(S-VF,Ms,Sr-A, St));Mi(D(S,St)); Cc(Cm);Ksp(D(S-VF))	Homogeneous	Quartzite
		HTS 36 A & 15	Qtz(55-60%);Cc(35-40%);Ksp(<2%); Bio(<1%);Hbl(<5%)	Qtz(D(S-VF,Ms,Sr-Sa, St));Cc(V,Cm);Ksp(D(S-VF));Bio(D(<5,St)); Chl(D(<5,St))	Slight compositional layering	Calcareous Quartz Siltstone
		HTS 62 A & 13	Cc(70%);Qtz(30%); Bio(<1%);Op(<1%)	Cc(D(VC,St)Cm(<50µ), V(<200µ,Tw));Qtz(D(S, Ms,R-A,St))	Homogeneous	Silty Fossiliferous Limestone
Sun Valley	Milligen	HTS-2	Qtz(50-70%);Chl(20-30%);Org(30-50%)	Qtz(M(≤15µ),Pc);Chl(Met(≤10µ,St));Org(D(≤5µ))	Compositional layering	Phyllitic Quartz Argillite
		HTS-3	Qtz(50-70%);Chl(30-50%);FeO(<1%); Cc(<1%)	Qtz(D(S,Ms,Sa),M(≤10µ));Cc(P,R,St));Chl(Met(≤5µ))	Size sorting and compositional layering	Silty Phyllitic Quartz Argillite
		HTS-8	Chl(70%);Qtz(30%);FeO(<1%)	Chl(Met(≤8));Qtz(D(S,Pa,A,St),Pc(St),V(St))	Homogeneous	Silty Quartzose Argillitic Phyllite
		HTS-10a	Qtz(70-75%);Chl(20-25%);Op(5%)	Qtz(D(S-VF,Pa,A-Sr,St), Pc(S-F,St),M(≤20µ),V(St));Chl(Met(≤10µ))	Size sorted layering	Silty Phyllitic Quartz Argillite
		HTS-10b	Qtz(99%);Chl(<1%);Op(<1%)	Qtz(M(5-20µ),V(St)); Chl(Met(20-40µ))	Homogeneous	Cherty Argillite
		HTS-12	Qtz(90-95%);Chl(5%);Mus(<2%);FeO(<4%)	Qtz(D(S-F,Pa,Sa-Sr,Mi)),Pc,M(2.5-25,St),V(St)); Chl(Met(≤20µ))	Size sorted layering	Chloritic Sandy Quartz Argillite
		HTS-11	Qtz(90-95%);Chl(5-10%);Op(<2%);FeO(<2%);Op(<1%)	Qtz(D(VF,Pa,St),M(5-30µ,St),V(S-F,St)); Chl(Met(5-40µ,St))	Compositional layering	Chloritic Sandy Quartz Argillite
		HTS-20	Qtz(50%);Chl(40-50%);Cc(5%);FeO(<1%)	Qtz(D(S-VF,Pa,Sa-Sr,St),M(5µ),V(S-VF,St)); Chl(Met(≤20µ,St)); Cc(D(≤5µ))	Size sorted and compositional layering	Silty Quartzose Argillitic Phyllite
		HTS-28	Qtz(80-90%);Chl(10%);Mus(10-15%); FeO(<1%)	Qtz(D(S)),M(≤10µ),Pc); Chl(Met(≤10µ));Mus(D(≤10µ))	Homogeneous	Silty Phyllitic Quartz Argillite
		HTS-29	Cc(75%);Qtz(25%); Op(<1%)	Cc(Cm(Tw),Cm(10-20µ, Tw),V(Tw));Qtz(D(S-Med,Pa,Sa-Sr),V(St))	Size sorted and compositional layering	Sandy Limestone
		HTS 63 A & 11	Chl(50-55%);Qtz(40%);FeO(5-10%); Op(<2%)	Chl(Met(≤20µ,St)); Qtz(D(<VF,Pa,R-Sr,St),M(≤10µ,St),FeO(Met))	Size grading	Silty Quartzose Argillitic Phyllite
	Unnamed Devonian-Silurian unit	HTS-39	Qtz(90%);Org(15%);Chl(<5%)	Qtz(D(S,Sa-Sr),M(≤10µ)); Chl(Met(≤10µ))	Homogeneous	Organic Silty Quartz Argillite
		HTS-41	Op(70-80%);Qtz(10%);[illegible](10%)	Qtz(D(S,St))	Homogeneous	Argillitic Chlorite Phyllite
		HTS-43a A & 11	Cc(99%);Qtz(<1%);FeO(<1%);Op(<1%)	Cc(D or Cm(Tw)); Qtz(D(S,A))	Size sorted layering	Limestone
		HTS-42b	Qtz(60%);Chl(20%); Op(15-20%);Cc(<1%);Ksp(<1%); Mus(<1%)	Qtz(D(S,Pa,Sa-R,St), M(2-10µ));Chl(Met(20µ))	Size sorted and compositional layering	Organic Silty Quartz Argillite
	[illegible] Kappa-Fall Creek	HTS-17	Qtz(60-70%);Tr(30-40%)	Qtz(D(S,Pa,Sa-R),M)); Tr(Met(≤150µ,St))	Compositional layering	Tremolitic Silty Quartz Argillite
		HTS-30a A & 11	Qtz(75-80%);Chl(20-25%);Cc(<5%)	Qtz(D(VF,Pa,Sa-R,St), M(≤15µ));Chl(Met(?))	Compositional layering	Silty Chloritic Quartz Argillite
		HTS-30b	Qtz(50-60%);Tr(40-50%)	Qtz(D(S,Pa,Sa-R),M (≤10µ));Tr(Met(≤200µ,St))	Homogeneous	Tremolitic Silty Quartz Argillite
		HTS-43	Chl(60-70%);Qtz(20-30%);Org(10%);Ksp(<1%)	Chl(Met(≤5µ)),Qtz(D(S,Ms,A-Sa),M)	Compositional and size layering	Argillitic Chloritic Phyllite
[illegible] Mountain Plate		HTS-15	Cc(60-80%);Qtz(30-40%);Mus(<5%); FeO(<1%);Ksp(<1%); Org(5%)	Cc(P(S,R),Mi); Qtz(D(F,S,Pa,A-R),V(≤250µ,St));Mus(D(S-30µ,St));Fe(D(<5));Ksp(D(<5))	Graded and size sorted layering	Quartzose Greywacke
		HTS-45	Qtz(60%);Li(Chy,Ar,30-40%);Op(<1%);Cd(<1%); FeO(<5%)	Qtz(D(Med,Pa,A-Sr, St));Li(D(F,R,Sq))	Homogeneous	Lithic Arenite
		HTS-46b	Qtz(70%);Li(Ch, Phy,Ar,Sa,30%)	Qtz(D(S-Med,Pa,Sr-R, St));Li(D(S-Med,Pa,R, Sq))	Homogeneous	Lithic Arenite
		HTS-51	Li(Ch,Ar,Sa,Phy,Ch, Phy,80-85%);Qtz(15-20%)	Li(D(S-P,R-Wr,Sq)); Qtz(D(VF-VC,Pa,R-Wr, St))	Homogeneous	Lithic Conglomerate
		HTS-58	Qtz(50-60%);Cl(25-30%);Mc(10%); Chl(<5%);Mus(<2%)	Qtz(D(F,Pa,Sa-R)); Mc(D(F,Ps));Cl(M); Chl(D(F,St));Mus(D(F,St))	Homogeneous	Quartzose Graywacke
		HTS-60	Li(Ch,Ar,Phy,Ar, Phy,Sa,70-80%);Qtz(20-30%);Mi(<1%),Op(<1%)	Li(D(S-VC,Pa,A-Wr, Sq));Qtz(D(VC,Pa,Sa-R,St),Pc,Mi)	Homogeneous	Lithic Arenite
Copper Basin Plate	Upper Clastic	HTS-54	Li(Ch,Phy,Ar,50-60%);Qtz(30%);Cl(10-20%);Op(<1%);FeO(<1%)	Li(D(VF,Pa,A-R,Sq)); Qtz(D(VF,Pa,A-R,St), Pc));Cl(M(≤30µ))	Size sorted layering	Quartzose Lithic Graywacke
	Drummond Mine Limestone	HTS-34	Cc(85-90%);Qtz(10-15%);Org(<1%);FeO(<1%);Mi(<1%)	Cc(Ff(St),Cm(St)); Qtz(D(VF,Ms,A-Sr, St))	Compositional layering	Silty Fossiliferous Limestone
		HTS-47a	Cc(90%);Qtz(<1%);FeO(<1%);Org(<1%)	Cc(Ff,Cm(≤20µ),V (Tw));Qtz(D(S,Ms,A))	Homogeneous	Fossiliferous Limestone
		HTS-47b	Cc(90-95%);Qtz(2.5-5%);Mi(2.5-5%);FeO(<1%);Op(<1%)	Cc(Cm(≤30µ,Tw,St),V(≤50µ,St));Qtz(D(S,Pa,Sa-Sr));Mi(D(≤15µ,St))	Homogeneous	Silty Fossiliferous Limestone
		HTS-49 A & 11	Cc(97%);Qtz(2.5-3%);FeO(<1%);Op(<1%)	Cc(Ff(Sim),Cm,V (≤50µ,Tw));Qtz(D (S))	Preferred orientation of fossil fragments	Fossiliferous Limestone
	Little Copper	HTS-50a	Qtz(60-70%);Mi(30-40%);Op(<2%)	Qtz(D(S,Ms,Sr-R), M(≤5µ));Mi(D(≤5,St)), M(≤10µ))	Homogeneous	Micaceous Quartz Siltstone
		HTS-50b	Li(Ch,Ar,Phy,50-60%);Qtz(40-50%);Mi(<3%);FeO(<2%)	Li(D(Med,Pa,Sa-R, Sq));Qtz(D(Med,Pa, Sa-R,St));Mi(D(St))	Homogeneous	Lithic Arenite
		HTS-55	Qtz(80%);Chl(10%); FeO(5%);Op(5%)	Qtz(D(S,Ms,Sa-Sr, St),Cm);Chl(Pc (10-40µ))	Homogeneous	Micaceous Quartz Siltstone

Textures: continued
VC - very coarse sand sized
C - coarse sand sized
Med - medium sand sized
F - fine sand sized
VF - very fine sand sized
S - silt sized
P - pebble sized
- micrometer

Tw - twinned
St - strained
Sq - squished
Pc - polycrystalline aggregates
Ff - fossil fragments

APPENDIX B: MICROSTRUCTURAL DESCRIPTIONS

Forty-five thin sections of the Early to Late Paleozoic sedimentary rocks in the Pioneer Mountains provide data necessary for interpretation of the structural evolution of the Pioneer Mountains. Thin sections from the Sun Valley Allochthon include twelve from the Milligen Formation, five from the unnamed Devonian-Silurian unit, and five from the combined Phi Kappa-Trail Creek Formation. Seven thin sections from the Wood River Allochthon are comprised of two thin sections of the lower unit of the Wood River Formation and five from the upper unit of the Wood River Formation. Seven thin sections from the Glide Mountain Plate and nine from the Copper Basin Plate (one from the Upper Clastic Member, five from the Drummond Mine Limestone, and three from the Little Copper Formation) make up the thin sections of the Copper Basin Formation (see Plate 1 for sample locations; note that samples are labled MTS-n and correlate with field stations labled MT-n).

The thin sections are oriented approximately perpendicular to penetrative fabrics in each sample. Generally this includes at least one thin section about normal to primary layering. Where several orientations of penetrative structures exist, thin sections normal to all penetrative structures are used. The thin sections were ground to 0.030 millimeters thickness, and were examined with a polarizing light microscope using both plane light and crossed nicols.

Observations from each thin section include lithology, primary depositional features, and microstructures. Observations of lithology and primary depositional features are summarized in Appendix A. Observations of microstructures aim at describing both penetrative and spaced features and the angular and temporal relationships between them. From the observations, interpretations of the structural and ductility histories of the rock were made for each thin section. All of this information is synthesized for each formation and presented in this appendix.

WOOD RIVER ALLOCHTHON

Wood River Formation

Samples of the Wood River Formation, from the Wood River Allochthon, were collected from within 20 meters of the Wood River Thrust to over 500 meters above the thrust.

Penetrative deformation in the Wood River Allochthon is weakly developed, and is expressed as a primary layer-parallel, penetrative, pressure-solution cleavage. The cleavage is defined by flattened and sutured quartz and calcite grains, and by insoluble residues (micas, opaque minerals, and organics) in the cleavage planes. Development of pressure-solution features is controlled by proximity to the cores of map-scale folds in the Wood River Allochthon. Only samples MTS-35b, MTS-36, and MTS-62 have penetrative pressure-solution features and these were collected in the cores of folds. Lithologic control was exhibited on the microscopic scale in MTS-36 where penetrative pressure solution was best developed in calcite rich layers.

Other indications of internal strain in the Wood River Allochthon include strained quartz grains and twinned, recrystallized, calcareous fossil fragments.

Widely-spaced (greater than 2 cm), calcite-filled fractures cut the penetrative pressure-solution cleavage of MTS-36 and MTS-62 at an angle of about 70 degrees. A second set of calcite-filled fractures developed parallel to the pressure-solution cleavage in MTS-62, and crosscuts the steeply inclined fractures. The calcite in both fractures exhibits twinning and suturing.

SUN VALLEY ALLOCHTHON

Unnamed Devonian-Silurian Unit

Samples of the unnamed Devonian-Silurian unit were collected from a narrow range of structural levels with respect to thrust faults within the Sun Valley Allochthon. Because of the intense thrust imbrication of the unnamed Devonian-Silurian unit, samples were collected from within 10 meters to less than 150 meters above a thrust surface.

Penetrative strain was developed in most samples of the unnamed Devonian-Silurian unit. Penetrative strain formed a weakly- to moderately- developed chlorite foliation (MTS-39, MTS-41,MTS-42b) and a well-developed pressure-solution cleavage (MTS-41, MTS-42a, MTS-42b).

The chlorite foliation parallels small-scale primary layering. It is defined by an extremely strong preferred orientation of very fine-grained chlorite. The chlorite grew most strongly in quartz-poor layers indicating strong lithologic control on its development. The chlorite foliation parallels layering everywhere, and occurred at all levels sampled.

The penetrative pressure-solution cleavage developed parallel to both the primary layering and the chlorite foliation. In general it is defined by flattened and aligned quartz and calcite grains, and by insoluble residues (opaque minerals and organics) in the cleavage planes. The penetrative pressure-solution cleavage formed in all lithologies sampled, and at all structural levels.

The unnamed Devonian-Silurian unit contains several sets of quartz-filled fractures at the thin section scale. One set predating development of the chlorite foliation and pressure-solution cleavage is cut and wrinkled by the pressure-solution cleavage. All other sets crosscut the penetrative fabrics, and vary from 25 to 80 degrees to the penetrative fabrics. No movement has occurred on any of the post-foliation fracture sets.

Combined Phi Kappa-Trail Creek Formation

Samples of the combined Phi Kappa-Trail Creek Formation were collected from various structural levels within the Sun Valley Allochthon. Intense thrust imbrication restricted samples to structural levels ranging from within 20 meters to less than 100 meters above a thrust.

Penetrative strain developed in all samples of the combined Phi Kappa-Trail Creek Formation. Penetrative fabrics include a moderately-developed chlorite foliation (MTS-38a, MTS-43), a moderately-developed pressure-solution cleavage (MTS-17, MTS-38a, MTS-38b), a well-developed shear fabric (MTS-17, MTS-38a, MTS-38b, MTS-43), and crenulations (MTS-43).

The chlorite foliation is defined by a very strong preferred orientation of fine-grained chlorite parallel to primary layering. The foliation formed only in pelitic samples , and within these samples it formed in the pelitic layers. The chlorite foliation was found at all structural levels sampled.

Penetrative pressure-solution cleavage developed parallel to primary layering. It is defined by flattened and aligned quartz grains, by flattened and crosscut tremolite, and by insoluble residues (opaque minerals and organics) in the cleavage planes. Penetrative pressure-solution occurred in all samples examined, but developed best in the more siliceous layers. Structural level and geometry do not affect the presence of the pressure- solution cleavage in the combined Phi Kappa-Trail Creek Formation.

The shear fabric developed at varying orientations to primary layering. Where it developed parallel to primary layering, shear is pervasive. Where the shear developed at an angle to primary layering , it became zonal, and transposed layering into the shear cleavage. The shear cleavage is defined by faulted and rotated detrital quartz grains with pressure shadows, faulted tremolite, and transposed primary layering. Lithologic variation had little affect on the degree to which the shear cleavage developed. While structural level does not affect the presence of the shear cleavage, preexisting deformation does show a strong control.

Small crenulations with axial planes about normal to the chlorite foliation (and primary layering) and direction of shear, occur in domains in the most chloritic sample examined (MTS-43). The relationship between development of crenulations and level with respect to thrust faults is unclear since only one sample contained crenulations.

Thin section-scale thrusting, found only in MTS-43, offsets all penetrative fabrics. A small-scale fold overturned and broke parallel to its axial plane. This yielded a small-scale thrust slightly inclined to the chloritic foliation , with about 2 mm of offset.

Other microscopic strain features include undulose quartz grains, and sutured quartz-quartz, quartz-tremolite, and tremolite-tremolite grain boundaries. One set of quartz filled fractures offsets the thin section scale thrust in MTS-43, but no other manifestations of brittle deformation developed at the thin section scale in the combined Phi Kappa-Trail Creek Formation.

Milligen Formation

Samples of the Milligen Formation, in the Sun Valley Allochthon, were collected from structural levels ranging from within 30 meters of the Pioneer Thrust to over 900 meters above the thrust.

The Milligen Formation is extremely deformed on the thin-section scale. Three stages of microstructural deformation were recorded in the Milligen Formation, two of which formed several penetrative structural fabrics. Juxtaposed with the penetratilve fabrics are several generations of quartz-filled fractures (veins). Each fracture set filled with quartz before the next deformation, thereby establishing a clear record of crosscutting relationships.

Penetrative strain fabrics were found in all samples (except MTS-29), and include a well-developed chlorite foliation (MTS-2, MTS-3, MTS-8, MTS-10a, MTS-20, MTS-28, MTS-63), moderately-developed pressure-solution cleavage (MTS-10b, MTS-12, MTS-13, MTS-63), strongly-expressed shear cleavage (MTS-2, MTS-8, MTS-20, MTS-63), well-developed flow foliation (MTS-8, MTS-10a, MTS-20), strongly-developed shear zones (MTS-3, MTS-10b, MTS-13, MTS-20, MTS-63), weakly- to strongly-developed crenulations (two generations; MTS-10a, MTS-20, MTS-63), and moderately-developed crenulation cleavage (MTS-20, MTS-63).

The chlorite foliation responsible for the phyllitic nature of the Milligen Formation formed at angles ranging from 10 to 90 degrees to primary layering. It is defined by a very strong preferred orientation of chlorite. The degree to which the chlorite foliation developed relates strongly to lithologic variation. It is best developed in the pelitic layers, and is nearly absent in the very quartzose recrystallized cherts. Structural level had no effect on the presence of the chlorite foliation.

The pressure-solution cleavage developed at angles ranging from 0 to 66 degrees to primary layering, but is parallel to sub-parallel to the chlorite foliation. Pressure-solution features include flattened and sutured quartz grains, aligned chlorite in the cleavage, and insoluble residues (opaque minerals, and organics) in the cleavage planes. Pressure-solution preferentially developed in the most quartzose samples examined. It is either overprinted by other fabrics, or never formed in all other samples. In some cases the pressure-solution cleavage is axial-planar to micro- and mesoscopic folds, and therefore, seems also to be controlled by structural geometry. However, the pressure-solution cleavage only appeared in samples from higher structural levels with respect to the Pioneer

Thrust.

Flow foliation parallel to the chlorite foliation is expressed as gentle folding of primary layering, and as an anastamosing network of slip surfaces. The flow foliation developed only in the most phyllitic rocks, but occurs at all structural levels sampled.

The shear cleavage in the Milligen Formation developed at angles ranging from 25 to 60 degrees to primary layering. The shear cleavage is expressed as an anastamosing network of slip surfaces which frequently bound augen of transposed primary layering and quartz grains. Other manifestations of movement on the shear cleavage include rotated quartz grains, floating microscopic folds, and offset primary layering, quartz veins, and quartz grains. While the bulk lithology of the Milligen Formation did not control the development of the shear cleavage, preexisting fabric anisotropies did. Where the chlorite foliation was strongly-developed, the shear cleavage developed parallel to sub-parallel to it. Structural level did not control the formation of the shear cleavage.

Of a more domainal nature are penetrative shear zones within 15 degrees of the shear cleavage or the chlorite foliation. They are defined by narrow (less than 0.5 mm) zones of anastamosing slip surfaces which truncate primary layering , quartz veins, flow folds, crenulations, and detrital quartz grains. The shear zones developed in diverse lithologies, and over a wide range of structural levels with respect to the Pioneer Thrust.

Crenulations in the Milligen Formation have axial planes varying from normal to parallel to primary layering. Two sets of orthogonally oriented crenulations developed in samples MTS-20 and MTS-63, and one set of ´flexural´ crenulations was found in MTS-10a. The crenulations are defined by bent chlorite grains, folded chlorite foliation, and folded primary layering. Lithologic variation limited crenulations to the most phyllitic samples, but the ´flexural´ crenulations formed in a silty argillite layer. In the field, crenulations were found at all structural levels.

The crenulation cleavage is axial-planar to the first generation of crenulations, and is about perpendicular to the chlorite foliation. The crenulation cleavage cuts and offsets primary layering and the chlorite foliation by as much as 1mm. Crenulation cleavage formed only in the most phyllitic rocks, but developed throughout the Sun Valley Allochthon.

Several generations of quartz-filled fractures (now veins) evolved in the Milligen Formation. The fractures formed at all angles to primary layering, in all rock types, and at all structural levels with respect to the Pioneer Thrust. Fractures formed and filled before metamorphism of the Milligen Formation are recystallized, and have gradational boundaries with the argillitic matrix. Fractures postdating metamorphism have distinct boundaries with the surrounding rock.

Pre-metamorphic quartz-filled fractures were found in several samples. They are tightly folded , truncated, and cut by all penetrative fabrics, and in places have been transposed into the shear cleavage.

Four other fracture sets developed during various post-metamorphic deformation stages of the Milligen Formation. These range from a closely-spaced (less than 2mm) fracture cleavage to fractures more than 1cm apart. Preexisting fabric anisotropy influenced the orientation of two fracture sets which developed parallel to the chlorite foliation. Movement on one of the chlorite foliation-parallel fracture sets offsets primary layering, veins, zonal shear cleavage, and crenulations.

GLIDE MOUNTAIN PLATE

Samples of the Copper Basin Formation from the Glide Mountain Plate were collected from within 15 meters to over 700 meters above the Glide Mountain Thrust.

Penetrative strain was developed in only two samples. Penetrative fabrics of MTS-15 include a pressure-solution cleavage and a shear cleavage. MTS-60 only developed a shear cleavage.

The pressure-solution cleavage of MTS-15 is axial-planar to mesoscopic folds. It is defined by flattened quartz grains and insoluble residues (e.g. opaque minerals) in the cleavage planes. The pressure-solution cleavage, accentuated by a strong preferred orientation of detrital micas, developed most strongly in highly quartzose layers. Evidence for slip or flowage parallel to the pressure-solution cleavage includes flow-folded primary layering and offset quartz-filled fractures.

Shear in MTS-60 is defined by through-going, narrow zones of very closely spaced (less than 10 microns) fractures which cut and offset non-matrix detrital grain boundaries.

Other non-penetrative pressure-solution features in the Glide Mountain Plate include flattened quartz and lithic grains, abundant long or concavo-convex grain boundaries, rare sutured grain boundaries, and insoluble residues. Compression-related features assocated with the pressure-solution structures include micaceous lithic fragments squeezed into the matrix, bent detrital micas and lithic grains, and weak to moderate preferred orientation of detrital micas. The non-directionality of the non-penetrative pressure-solution features suggests pressure solution from lithostatic stress.

Two generations of widely-spaced quartz-filled fractures formed in the Glide Mountain Plate. The first is cut by the penetrative fabrics, and the quartz filling is highly strained. Other samples containing similar fractures with highly strained quartz fillings, suggest that the fractures predate the penetrative fabrics. The second set of fractures clearly crosscuts the shear cleavage of MTS-60.

COPPER BASIN PLATE

Little Copper Member

Two samples of the Little Copper Member were collected from within 60 meters of the Wildhorse Thrust. The third sample (MTS-50) was collected from an unknown structural level with respect to the Wildhorse Thrust.

Weak penetrative strain in the form of a pressure-solution cleavage evolved in all three samples of the Little Copper Member. The pressure solution cleavage developed parallel to the axial planes of macroscopic folds, and is oriented at varying angles to primary layering. It is defined by slightly flattened detrital quartz grains, squeezed or smeared out micaceous lithic fragments, and by insoluble residues (micas, opaque minerals, and iron oxides) in the cleavage planes. Variation of lithology and structural level did not control development of the pressure solution cleavage.

One set of fractures formed at the thin section scale. The fractures are widely spaced (greater than 6mm) and quartz filled. The penetrative pressure solution cleavage crosscuts the fractures.

Drummond Mine Limestone

Samples of the Drummond Mine Limestone came from within 100 meters of the Glide Mountain Thrust, an unknown distance above the Wildhorse Thrust.

A well-developed axial-planar, pressure-solution cleavage formed in all samples of the Drummond Mine Limestone except MTS-49. The pressure-solution cleavage is defined by flattened and truncated calcite grains and calcareous fossil fragments, slightly aligned quartz grains, and insoluble residues (micas, opaque minerals, iron oxides, and organics) in the cleavage planes. Variations in lithology and structural level had no affect on the development of the penetrative pressure-solution cleavage.

Several generations of calcite-filled fractures formed in the Drummond Mine Limestone. Fractures predating the pressure-solution cleavage are cut and folded to varying degrees by the cleavage. Fractures postdating the pressure- solution cleavage crosscut both the cleavage and the earlier fractures. These in turn are crosscut by unfilled fractures parallel to the pressure- solution cleavage.

Upper Clastic Member

The sample from the Upper Clastic Member was collected from an unknown structural level above the Wildhorse Thrust.

Penetrative strain in the Upper Clastic Member is expressed as a primary layer-parallel, zonal pressure-solution cleavage. The cleavage is defined by flattened quartz and lithic grains, squeezed out micaceous lithic fragments, and insouble residues (opaque minerals and iron oxides) in the cleavage surfaces. The cleavage, best-developed in the more siliceous layers, occurs as narrow zones (less than 1 mm wide) about 1 mm apart. Minor slip in a few of the the pressure-solution zones offset some of the lithic fragments.

A closely-spaced, iron-oxide-filled fracture cleavage is oriented approximately normal to the pressure-solution cleavage. The pressure-solution cleavage cuts, but does not offset or fold the fractures.

BIBLIOGRAPHY

Boyer, Steven E., and Elliot, David, 1982, Thrust Systems; Am. Assoc. Pet. Geologists Bull., V.66, N.9, pp 1196-1230;

Burchfiel, B.C., and Davis, G.A., 1972, Structural Framework and Evolution of the Southern Part of the Cordilleran Orogen, Western United States; Am. Jour. Sci., V.272, N.2, pp 97-118;

Burchfiel, B.C., and Davis, G.A., 1975, Nature and Controls of Cordilleran Orogenesis, Western United States: Extensions of an Earlier Synthesis; Am. Jour. Sci., V. 275-A, pp 363-396;

Dover, J.H., 1969, Bedrock Geology of the Pioneer Mountains, Blaine and Custer Counties, Central Idaho; Idaho Bureau of Mines and Geology Pamphlet 142, 66 pages

Dover, J.H., 1980, Status of the Antler Orogeny in Central Idaho - Clarifications and Constraints from the Pioneer Mountains, Central Idaho; in, Fouch, T.D., and Magathan, Ester, eds., Paleozoic Paleogeography of the West-central United States; Rocky Mountain Section of the Soc. Econ. Paleontologists and Mineralogists Paleogeography Symposium 1, pp 371-385;

Dover, J.H., 1981, Geology of the Boulder-Pioneer Wilderness Study Area, Blaine and Custer Counties, Idaho; in, Simons, F.S., Dover, J.H., Hobbs, S.W., Tuchek, E.T., Ridenour, J., Mabey, D.R., 1981, Mineral Resources of the Boulder-Pioneer Wilderness Study Area, Blaine and Custer Counties, Idaho; U.S. Geol.Survey Bull. 1497, pp 15-75;

Dover, J.H., Berry, W.B.N., and Ross, R.J., Jr., 1980, Ordovician and Silurian Phi Kappa and Trail Creek Formations, Pioneer Mountains, Central Idaho - Stratigraphic and Structural Revisions and New Data on Graptolite Faunas; U.S. Geol. Survey Prof. Paper 1090, 54 pages;

Dover, J.H., and Ross, R.J., Jr., 1975, Ordovician and Middle Silurian Rocks of the Wildhorse Window, Northeastern Pioneer Mountains, Central Idaho; U.S. Geol. Survey Jour. Res., V.3, n.1, pp 89-95;

Hamilton, W., 1978, Mesozoic Tectonics of the Western United States; in, Howell, D.G., and McDougall, K.A., eds., Soc. Econ. Paleontologists and Mineralogists, Mesozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium 2, pp 33-70;

McKee, E.H., 1976, Geology of the Northern Part of the Toquima Range, Lander, Eureka, and Nye Counties, Nevada; U.S. Geol. Survey Prof. Paper 931, 49 pages;

Nilsen, Tor H., 1977, Paleogeography of Mississippian Turbidites in South-central Idaho; in, Stewart, J.H., Stevens, C.H., and Fritsche, A., eds., Paleozoic Paleogeography of the Western United States, Soc. Econ. Paleontologists and Mineralogists, Pacific Coast Paleogeography Symposium 1, pp 257-297;

Paull, R.A., Wolbrink, M.A., Volkman,R.G., and Grover, R.L., 1972, Stratigraphy of the Copper Basin Group, Pioneer Mountains, South-central Idaho; Am. Assoc. Pet. Geologists Bull., V.56, N.8, pp 1370-1401;

Poole, F.G., and Sandberg, C.A., 1977, Mississippian Paleogeography and Tectonics of the Western United States; in, Stewart, J.H., Stevens, C.H., and Fritsche, A., eds., Paleozoic Paleogeography of the Western United States, Soc. Econ. Paleontologists and Mineralogists, Pacific Coast Section, Pacific Coast Paleogeography Symposium 1, pp 181-215;

Roberts, R.J., 1964, Stratigraphy and Structure of the Antler Peak Quadrangle, Humbolt and Lander Counties, Nevada; U.S. Geol. Survey Prof. Paper 459 A, 91 pages;

Roberts, R.J., and Thomasson, M.R., 1964, Comparison of Late Paleozoic Depositional History of Northern Nevada and Central Idaho; U.S. Geol. Survey Prof. Paper 475-D, pp D1-D6;

Sandberg, C.A., Hall, W.E., Batchelder, J.N., and Axelson, Claus, 1975, Stratigraphy, Conodont Dating, and Paleotectonic Interprretation of the Type Milligen Formation (Devonian), Wood River Area, Idaho; U.S. Geol. Survey Jour. Res., V.3, N.6, pp 707-720;

Simons, F.S., Dover, J.H., Hobbs, S.W., Tuchek, E.T., Ridenour, J, and Mabey, D.R, 1981, Mineral Resources of the Boulder-Pioneer Wilderness Area, Blaine and Custer Counties; U.S. Geol. Survey Bull. 1497, 303 pages;

Skipp, Betty, and Haitt, M.H., 1977, Allochthons Along the North-east Margin of the Snake River Plain, Idaho; Twenty-ninth Annual Field Conference Guidebook, Wyoming Geological Association;

Skipp, Betty, and Hall, W.E., 1975, Structure and Paleozoic Stratigraphy of a Complex of Thrust Plates in the Fish Creek Resevoir Window Area, South-central Idaho; U.S. Geol. Survey Jour. Res., V.3, N.6, pp 671-689;

Skipp, Betty, and Sandberg, C.A., 1975, Silurian and Devonian Miogeosynclinal and Transitional Rocks of The Fish Creek Resevoir Units, Central Idaho; U.S. Geol. Survey Jour. Res., V.3, N.6, pp 691-706;

Smith, J.F., and Ketner, K.B., 1975, Stratigraphy of Paleozoic Rocks in the Carlin-Pinon Range Area, Nevada; U.S. Geol. Survey Prof. Paper, 867-A, 87 pages;

Smith, J.F., and Ketner, K.B., 1977, Tectonic Events Since Early Paleozoic in the Carlin-Pinon Range Area, Nevada; U.S. Geol. Survey Prof. Paper 867-C, 18 pages;

Speed, R.C., and Sleep, N.H., 1982, Antler Orogeny and Foreland Basin: A Model; Geol. Soc. Am. Bull., V.93, pp 815-828;

Watts, A.B., Karner,G.D., and Steckler, M.R., 1982, Lithospheric Flexure and the Evolution of Sedimentary Basins; Phil. Trans. R. Soc. London; V.305, N.1489, pp 249-281.