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Bedrock Geology of the Pioneer Mountains, Blaine and Custer Counties, Central Idaho

James H. Dover

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IDAHO BUREAU OF MINES AND GEOLOGY

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BEDROCK GEOLOGY OF THE PIONEER MOUNTAINS BLAINE AND CUSTER COUNTIES, CENTRAL IDAHO

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ABSTRACT

Three major units of crystalline rocks form the autochthonous core of the Pioneer Mountains:

(1) The lowest structural unit, containing the oldest rocks in the area, is designated the Wildhorse Canyon Migmatitic Gneiss Complex. The heterogeneous migmatites are predominantly of sedimentary derivation. The migmatites form two gneiss domes. Most minor structures appear to have formed at the time of doming. The history of the migmatites prior to doming is uncertain.

(2) About 7000 feet of metasedimentary rocks overlying the migmatites have undergone regional, synkinematic, isochemical metamorphism in the upper almandine-amphibolite facies. Mineral assemblages indicate that metamorphism occurred at relatively low pressure. Only one metamorphic event is recognized in the metasedimentary succession.

Pelitic schist, gneissose quartzite, and banded calc-silicate members comprising the lower part of the metasedimentary sequence (Hyndman Formation) are lithologically similar to uppermost Precambrian rocks such as concordantly underlie the Prospect Mountain Quartzite in northeastern Nevada (Misch and Hazzard, 1962), but may be metamorphosed Beltian equivalents. Relatively pure dolomitic marble and quartzite members of the concordant upper part of the succession (East Fork Formation) may be metamorphosed lower Paleozoic rocks.

Recrystallized pre- or synmetamorphic thrust faults imbricate the metasedimentary succession.

(3) An intrusive sheet ranging from gneissose quartz diorite and granodiorite to directionless, porphyritic quartz monzonite separates the two metamorphic units. Field and petrographic evidence indicates that the pluton was intruded during a waning stage of the same episode of intense regional orogenic metamorphism that affected the metasedimentary wallrocks. The late-synorogenic pluton is petrologically identical to marginal facies of the Idaho Batholith which yield Pb-alpha and K/Ar dates averaging 110 million years. Thus the middle Cretaceous may mark a time of diminishing Mesozoic orogeny that culminated in emplacement of this satellite of the Idaho Batholith.

The crystalline core of the range is exposed in a window, modified by high-angle faults, through only weakly metamorphosed Paleozoic rocks. This weak metamorphism is probably a shallow crustal manifestation of the intense Mesozoic regional metamorphism that affected the adjacent metasediments. Four allochthonous formations are recognized southwest of the range crest in the Wood River region. Upper Paleozoic rocks northeast of the range crest are undifferentiated

owing to major stratigraphic and structural problems involved in that area. However, at least locally in the northeastern Pioneer Mountains, intensely contorted coarsely clastic rocks overlie dominantly carbonate rocks along a major thrust fault.

Thrusting of the Paleozoic rocks post-dates regional metamorphism. The magnitude of the thrusting was sufficient to produce a major metamorphic break between the allochthonous Paleozoic rocks and the autochthonous crystalline core, and to at least partially account for abrupt east-west facies changes in the Paleozoic rocks across central Idaho.

Small post-orogenic quartz monzonite plutons, one of which cuts both plates of a major post-metamorphic thrust fault, probably were emplaced during the Tertiary. Unconformable deposition of Tertiary Challis volcanic rocks also post-dates thrusting. The present relief of the range can be attributed to uplift associated with late Tertiary and/or Quaternary high-angle faulting.

Stratigraphic and tectonic considerations suggest that the northern extension of the late Paleozoic Antler Orogenic Belt may lie west of the Pioneer Mountains in the area now occupied by the southern end of the Idaho Batholith.

The presence of several units of igneous rocks datable by standard radiometric methods affords an excellent opportunity for precise dating of major metamorphic, deformational and intrusive events in the Pioneer Mountains.

INTRODUCTION

LOCATION

The Pioneer Mountains occupy the area of central Idaho north of the Snake River Plain and between the valleys of the Big Wood River and Big Lost River (Fig. 1).

REGIONAL SETTING

The first geological discussion of the Pioneer Mountains was published in a reconnaissance study of the geology and ore deposits of the Wood River region by Umpleby, Westgate and Ross in 1930. In that report, high-grade metasedimentary rocks (Hyndman and East Fork Formation), heterogeneous gneisses, and granitic rocks in the core of the range were briefly described; the stratigraphy of the "non-metamorphosed" Paleozoic rocks of the area was outlined; and the structural complexity of the region was recognized. The metasediments were tentatively assigned to the "Algonkian (?)" on the basis of their high metamorphic grade; the heterogeneous gneisses and granitic rocks were considered to be related parts of an intrusive outlier of the Cretaceous Idaho Batholith. Both rock units are still so designated on the current Geologic Map of Idaho (1947). More recently, Cook (1956) and Holm (1962) regard the heterogeneous gneisses as sedimentary derived.

The Pioneer Mountains area has generated special interest in recent years because of its critical and perhaps unique position with respect to a variety of major geologic elements in the Cordilleran region (Fig. 2). For instance, the area lies near the projected intersection of three distinct belts of Precambrian rocks yielding average radiometric ages of 2.5 b.y., 1.6 b. y. and 1.0 b. y. (Beltian), any of which might represent the age of gneisses and metasedimentary rocks in the range (see Engel, 1963; Giletti, 1966, and others). On the other hand, uppermost Precambrian rocks such as concordantly underlie the Prospect Mountain Quartzite in the northeastern Great Basin (Misch and Hazzard, 1962) could be present here. The Antler Orogenic Belt of the western Great Basin (Roberts, 1964; Roberts and Thomasson, 1964) and the belt of Mesozoic metamorphism and orogeny in the eastern Great Basin (Misch, 1960) have also been suspected by some, but never proved, to extend north across the Snake River Plain into this part of central Idaho. In addition, the area lies near the southeastern margin of the Idaho Batholith where the effects of Cretaceous plutonism might be expected to be superimposed on all pre-existing elements.

PURPOSE

This study was undertaken to answer specific questions raised by the earlier reconnaissance concerning:

(1) the nature and origin of heterogeneous gneisses inthe core of the range previously interpreted as Cretaceous intrusive rocks but more recently regarded as of sedimentary origin;

(2) the age of the metamorphism that affected the high-grade metasedimentary succession, and the stratigraphic age of the rocks involved in that metamorphism;

(3) the stratigraphic and structural relations between the metamorphic rocks and the "non-metamorphosed" Paleozoic strata;

(4) the type of tectonic deformation characterizing the Paleozoic sedimentary units; and

(5) the relation of the intrusive granitic rocks to all foregoing stratigraphic, tectonic and metamorphic features.

METHOD

Three summers of detailed geologic mapping and sampling were conducted in an area of about 250 square miles along the crest of the Pioneer Mountains. The map area includes the crystalline core of the range and its contacts with surrounding weakly-metamorphosed Paleozoic rocks. The geology was plotted on U. S. Forest Service aerial photographs at scales of 1:20,000 and 1:11,880, and transferred to U. S. Forest Service planimetric base maps at appropriate scales. The U. S. Geological Survey's 30-minute Hailey quadrangle (1895) contains the only published topography of the map area.

Rock sampling was selective at most places. Collections of representative rock samples and fossils are deposited in the University of Washington museum as Lot No. 1966-70.

Petrographic study of nearly 200 thin sections of crystalline rocks supports field observations. Mineral determinations were made optically; refractive indices of a few minerals were determined by standard immersion techniques in index oils using white light. Plagioclase composition was determined primarily by the a-normal method and occasionally by the Michel-Levy method. Identification of K-feldspar was facilitated by staining both slabs and thin sections with sodium cobaltinitrite solution using the method of Williams (1960). Modal analyses were made by counting 500-1000 points on a grid placed on stained slabs.

The stratigraphy of weakly-metamorphosed Paleozoic rocks was studied only insofar as it bears on the problems of tectonic, metamorphic and plutonic history. More detailed stratigraphic and paleontological studies of Paleozoic rocks in limited parts of the range have been conducted by Bostwick (1955), Thomasson (1959), Ross (1960), Skipp (1961a,b), Churkin (1963), and Ross and Berry (1963). Workers who have included rocks of the Pioneer Mountains in regional studies of the Paleozoic history of central Idaho are Ross (1934a, 1962b , c), Thomasson (1959a), Shannon (1961), Churkin (1962), and Scholten and Hait (1962).

GEOGRAPHY

Ketchum and Hailey, in the Wood River region, are the closest towns to the map area. The best road across the Pioneer Mountains connects Ketchum and the well-known resort of Sun Valley with Mackay in the Big Lost River valley, This road is unpaved where it crosses the northern part of the map area. Unpaved Forest Service roads ascending major tributary valleys afford fair access to other parts of the area. Local inquiry on road conditions is recommended; annual damage from snowslides and from runoff of the winter snowpack controls the extent to which roads are passable.

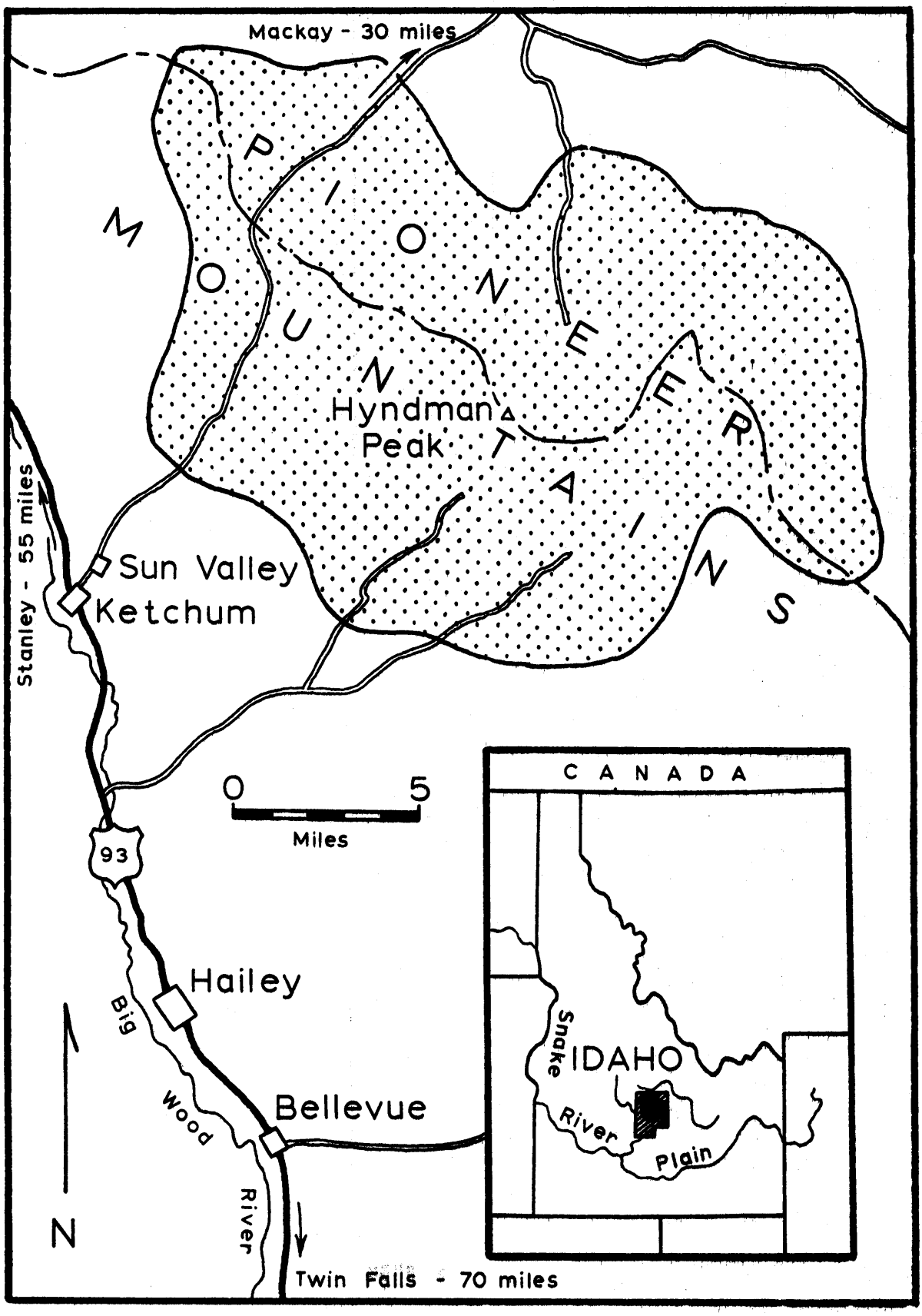


Figure 1. Location map.

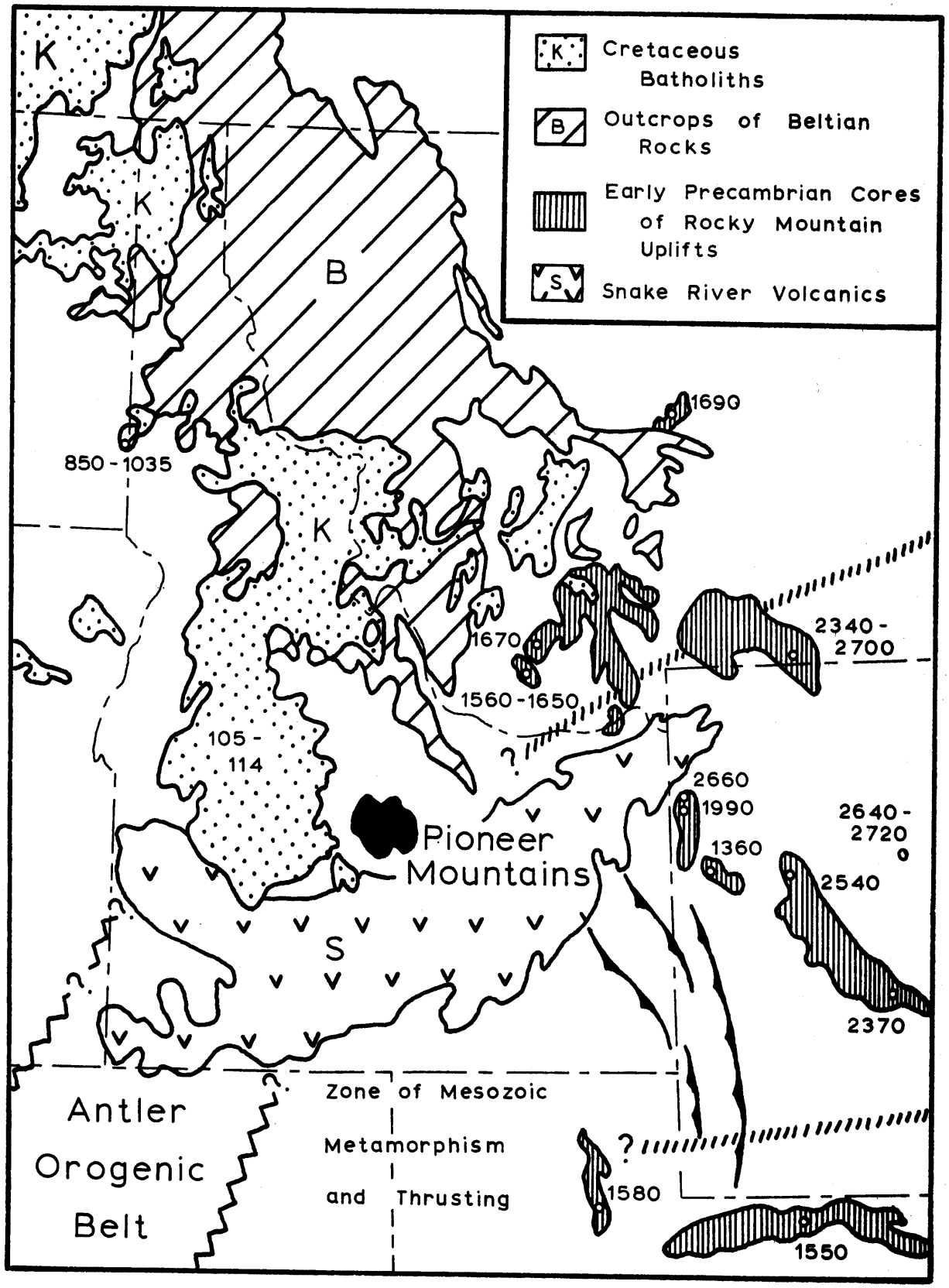


Figure 2. Regional geologic setting. (Radiometric dates in millions of years, compiled from various sources)

The altitude of Ketchum is 5823 feet; Hyndman Peak, 12,078 feet, is the highest point in the range. The topography of the Pioneer Mountains was modified significantly by Pleistocene glaciation. Extensive networks of cirques with up to 4500 feet of local relief afford excellent exposures in the crystalline core. Only a few small patches of permanent ice are present now. Exposures of Paleozoic sedimentary rocks in the unglaciated foothills are less satisfactory.

Summers are ordinarily warm and dry in this part of Idaho, but nights are cool at high altitudes even in summer. Winters are rigorous, though conditions vary considerably from year to year. In 1964, the high country was open for field work in early June. In 1965, however, persistence of the snowpack delayed work in cirques above 9000 feet until mid-July. Snowfed creeks and streams provide excellent water throughout the summer and fall. The map area lies within the Sawtooth and Challis National Forests; their boundary follows the crest of the range. Vegetation and wildlife are diverse.

ACKNOWLEDGMENTS

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The cooperation of the U. S. Forest Service personnel of the Ketchum and Hailey Ranger Districts of Sawtooth National Forest facilitated the field work. John Combs was especially helpful in providing information and maps.

Finally, I am deeply indebted to my wife, Sue. Her assistance, encouragement and patience throughout the study made its successful completion possible.

WILDHORSE CANYON MIGMATITIC* GNEISS COMPLEX

INTRODUCTORY STATEMENT

Heterogeneous gneisses occupy about 20 square miles in the upper Wildhorse Creek and Kane Creek areas (Fig. 3). They constitute the lowest structural unit in the Pioneer Mountains and are presumably the oldest rocks in the range (Fig. 4). The gneisses are cut off on the north by the Summit Creek Fault and are surrounded on all other sides by granitic rocks of the Pioneer Mountains Pluton.

These gneisses were regarded by Umpleby, et al. (1930) as intrusive rocks related to the Cretaceous Idaho Batholith. Their gneissose structure and pronounced layering were attributed to flow prior to consolidation, and layers of unquestionable sedimentary origin such as marble and quartzite were considered to be inclusions.

Field and petrographic examination during the present study support the suggestion of Cook (1956) and Holm (1962) that the gniesses are predominantly of sedimentary derivation. Thick quartzitic gneiss units are much more quartzose in bulk composition than any known magmatic rocks, and marble, quartzite and schist layers are far too continuous and regularly interbedded to be zenoliths. Where sedimentary-derived rocks can be distinguished from meta-igneous rocks on the basis of field relations, mineral composition and texture, those of sedimentary parentage predominate. However, the origin of about 25 per cent of the rocks is uncertain.

LITHOLOGIC CHARACTER

Five distinct stratigraphic units aggregating a minimum thickness of 7000 feet are recognized within the complex (Plate I). All are roughly concordant but they vary considerably in thickness from place to place, probably owing to tectonic squeezing and intrusion.

Basal Quartzitic Gneiss Unit

Highly quartzitic, locally garnetiferous biotite gneiss with granoblastic texture predominates in the basal unit. It is best exposed along Wildhorse Creek below the junction of its two main forks.

The quartz content ranges from 50 per cent to 85 per cent; typical samples contain 50 per cent to 60 per cent. Some samples contain 1 per cent or less of garnet. Biotite occurs in amounts of less than 20 per cent. The plagioclase content varies inversely with quartz. Where intermediate plagioclase (An20-An56) is abundant, the rock approaches leuco-trondhjemite in composition. Late poikiloblasts of perthitic microcline constitute 30 per cent of some micro-layers, but K-feldspar typically occurs only in accessory amounts.

In some places, the contact between quartzitic and feldspathic phases of the

*The term "Migmatitic" as used here refers to a "mixed rock" containing darker metamorphic layers and lighter layers of granitic composition, regardless of their origin (Sederholm, 1913; Turner and Verhoogen, 1960, p. 359).

gneiss is irregular but gradational. The writer favors Cook's suggestion (1956, p. 13) that granitic phases of this lower unit were produced by metasomatism of quartzitic sedimentary rocks.

Subordinate calc-silicate-bearing layers and thin marble beds, some containing scheelite (Cook, 1956), occur locally.

Marble Marker Horizon

A prominent impure dolomitic marble bed averaging 100 feet in thickness overlies the basal gneiss unit. The marble forms distinctive outcrops in tributary cirques along the west side of upper Wildhorse Canyon and at the junction of the two main forks of Wildhorse Creek. The map pattern of the marble of Plate I is complicated by the cirque topography. In some places, the marble may occur in two or more layers separated by quartzitic gneiss.

The assemblage: calcite-diopside-forsterite-phlogopite-calcic scapolite in marble exposures along Wildhorse Creek establishes the high metamorphic grade in the core of the migmatite complex.

Middle Quartzitic to Granitic Gneiss Unit

Quartzitic biotite gneiss and leuco-trondhjemitic to quartz monzonitic gneiss overlying the marble unit is well-exposed throughout the Wildhorse Canyon area. Locally, irregular masses of the feldspathic varieties are nearly structureless. Where the dominant gneiss lacks a quartzose sedimentary composition and displays no cross-cutting field relations or relict igneous texture, its parentage is uncertain. This middle gneiss unit differs from the basal quartzitic gneiss chiefly in having a greater percentage of feldspathic rocks of questionable origin, and in its generaly higher K-feldspar content. However, individual outcrops or samples may not be diagnostic.

Mafic Gneiss Unit

Dark, quartzitic to mafic gneiss overlying the middle gneiss unit crops out in a prominent band in both the Wildhorse Creek and Kane Creek areas.

Both the higher color index and typically more contorted aspect of this unit result from its higher mafic and lower feldspar content. Subordinate thin calc-silicate, marble and quartzite beds are intercalated in the lower part (Fig. 5). One thin, discontinuous layer of sillimanite-biotite schist near the top of the unit at the head of Boulder Creek establishes the high metamorphic grade in the upper part of the migmatitic gneiss complex.

Upper Quartzite and Granitic Gneiss Unit

The uppermost unit consists of gneissose quartzite that grades upward through quartzitic gneiss into more feldspathic material. This unit is exposed in discontinuous layers and isolated blocks on the northeast side of upper Wildhorse Canyon, at the head of Box Canyon, and in the Kane Creek area. Quartzite in the lower

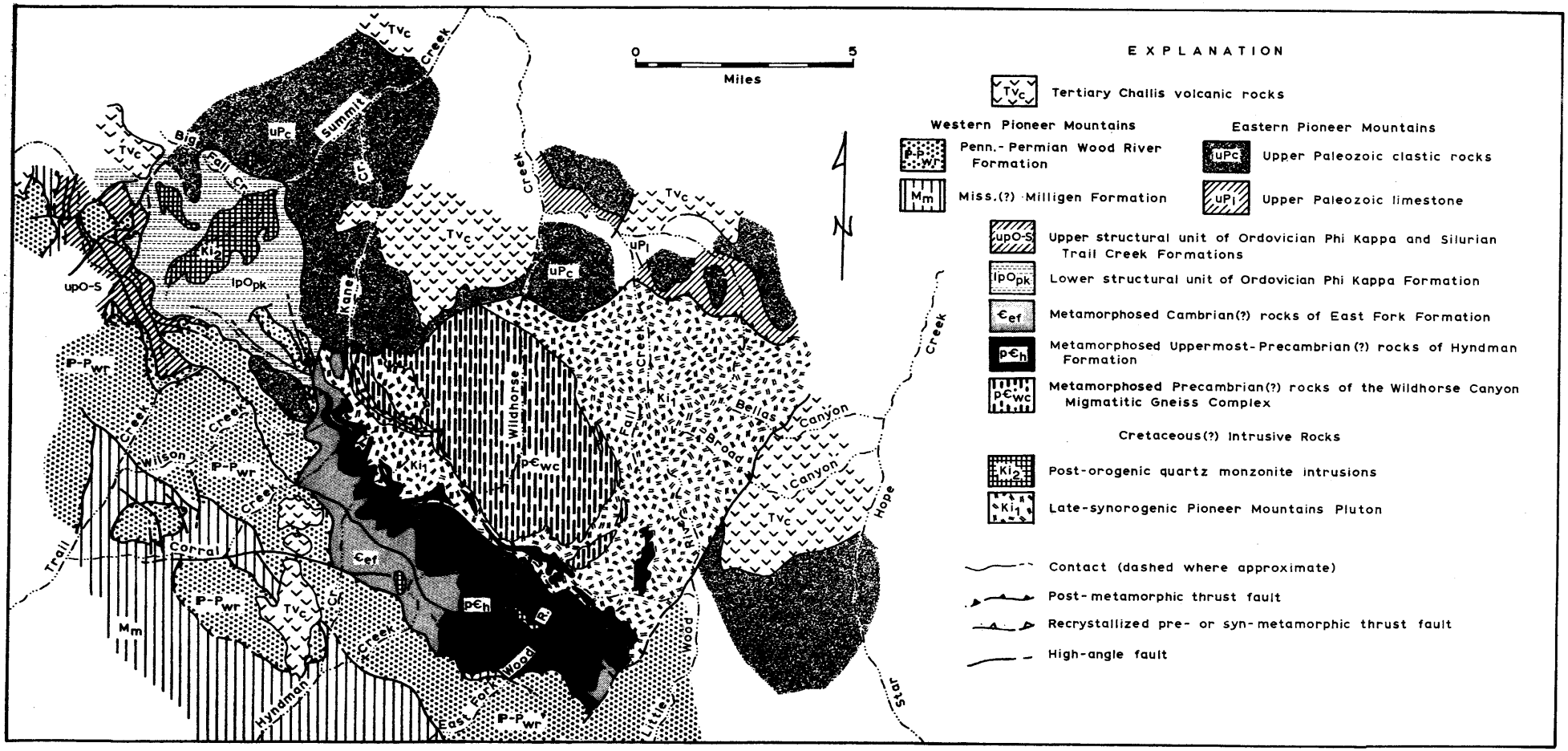


Figure 3. Generalized geologic map showing distribution of major rock and structural units in the Pioneer Mountains

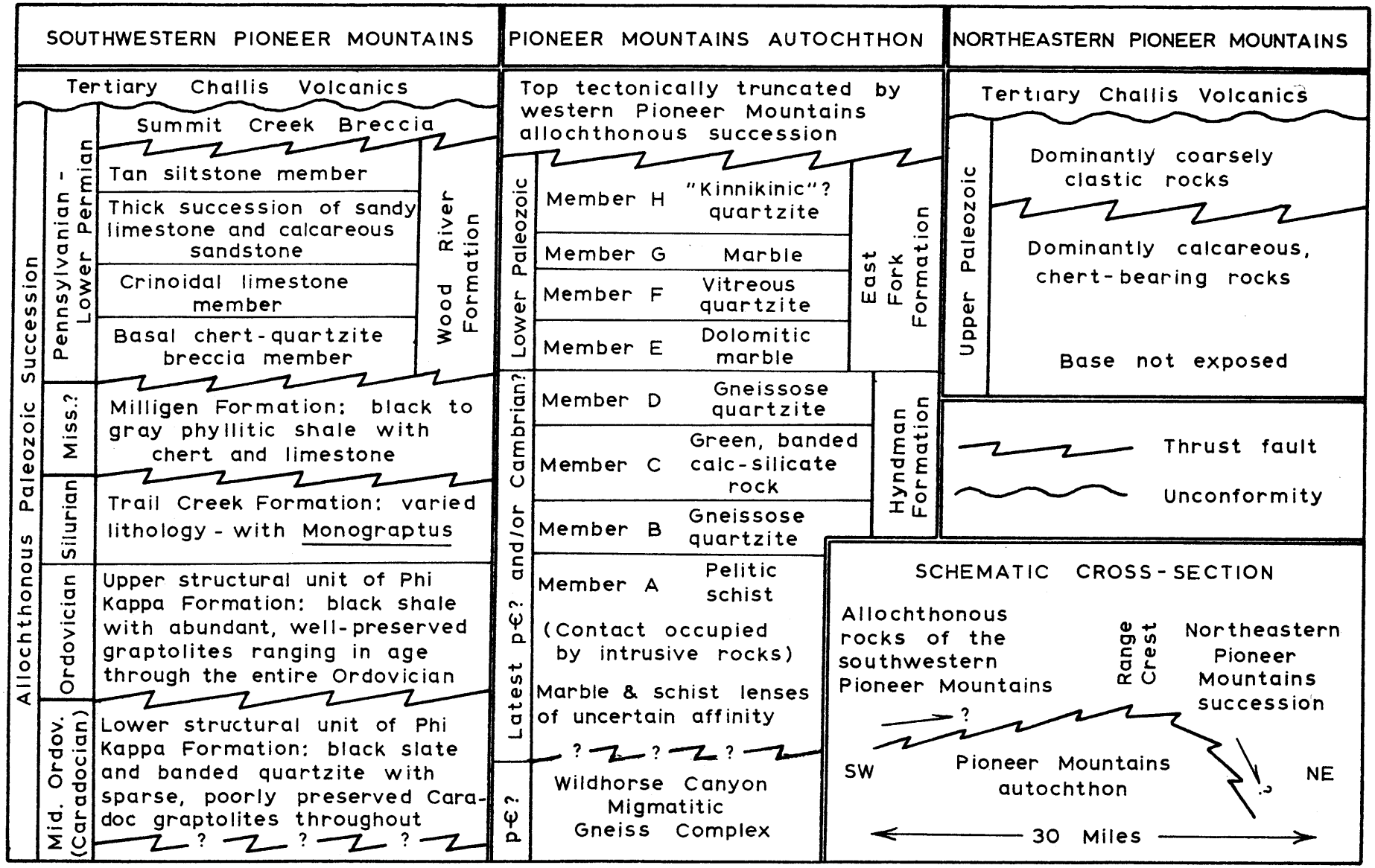
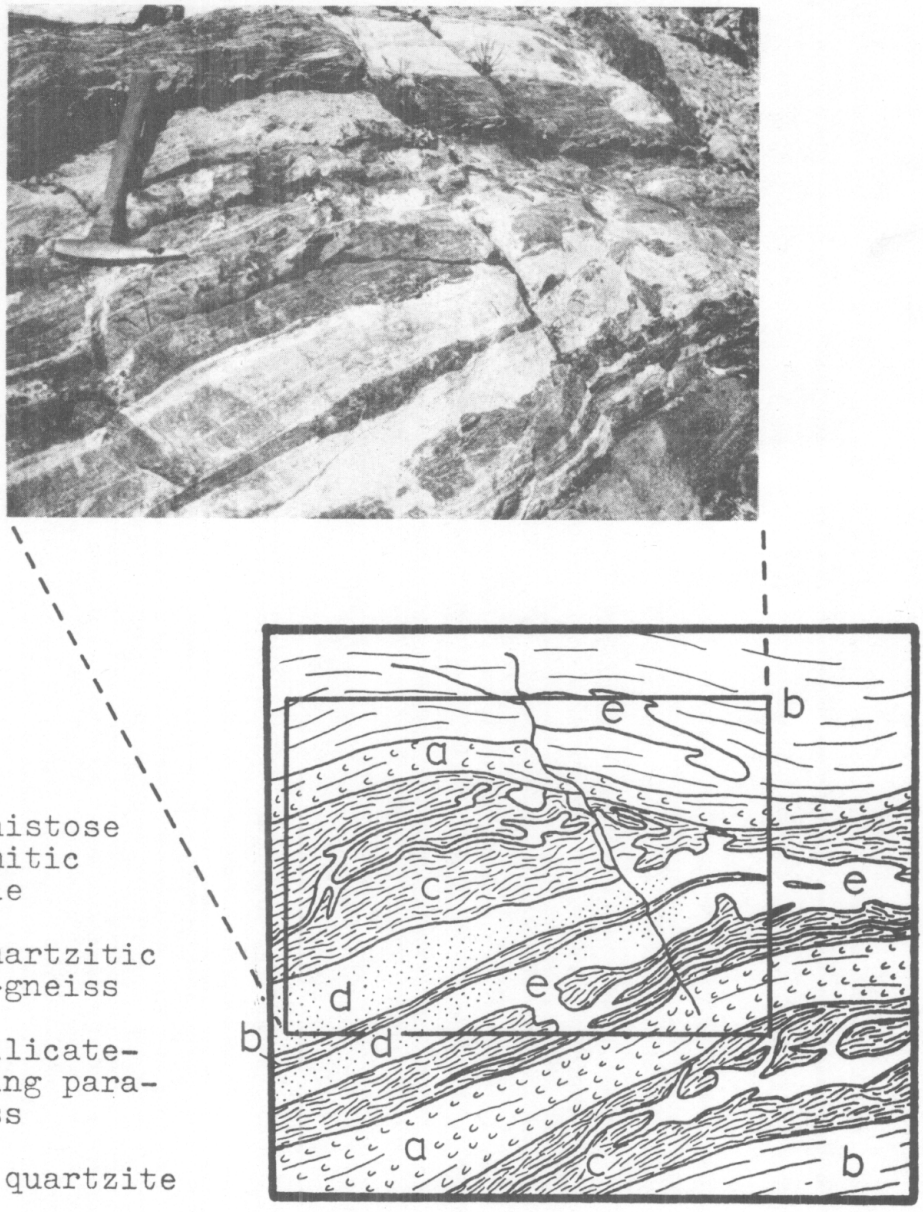


Figure 4. Schematic diagram showing generalized stratigraphic and structural framework of the Pioneer Mountains (thicknesses not to scale).



(a) Tan schistose dolomitic marble

(b) Dark quartzitic para-gneiss

(c) Calc-silicate-bearing para-gneiss

(d) Banded quartzite

(e) Late-metamorphic intrusive granitic material

Note: Sedimentary layers are somewhat discordant owing to metamorphic shearing. Also, intrusive granitic material (e) grades into banded quartzite (d), illustrating small-scale granitization.

Figure 5. Photograph and field sketch of marble, quartzite and calc-silicate layers in quartzitic para-gneiss, with intercalated intrusive granitic material, in cirque west of upper Wildhorse Creek

part of this unit can be distinguished by its purity and thickness from all other gneiss units, but upper feldspathic parts of this unit can be distinguished from the lower and middle gneiss units only by stratigraphic position.

Biotized amphibolite of both igneous and sedimentary derivation, and granitic intrusive rocks impart the heterogeneous character to the migmatites (Fig. 6).

Amphibolitic Rocks

Thin, concordant but discontinuous amphibolite layers of probable sedimentary origin are distributed widely throughout the migmatite complex.

Para-amphibolite samples are typically heterogeneous and contain sodic andesine (An32-An43), up to 15 per cent quartz, and locally as much as 15 per cent of accessory carbonate, zircon, apatite, sphene and opaques. In one sample, plagioclase is reversely zoned from An36 to An64. Schistosity is marked by aligned hornblende and biotite formed from hornblende. Biotite has undergone incipient alteration to penninite.

Locally, the contacts of para-amphibolite interbeds in quartzitic gneiss units are gradational.

Metamorphosed intermediate to basic dikes and sills are represented by schistose biotized leuco-amphibolite and amphibolite. Most are three feet or less in thickness and have sharp contacts.

The ortho-amphibolite contains 30 per cent to 60 per cent hornblende or ferrohastingsitic hornblende, 30 per cent to 50 per cent intermediate plagioclase ranging from An40 to An60, less than 10 per cent quartz and up to 20 per cent of biotite after hornblende. The hornblende has patchy zoning and actinolitic rims. The texture is medium-grained and granoblastic; hornblende and biotite are aligned.

One strongly foliated sample contains 70 per cent hornblende, minor cummingtonite, 25 per cent labradorite, and no quartz. Another, containing 15 per cent ferrohastingsitic hornblende, 20 per cent biotite, 30 per cent andesine with relict igneous textures, 35 per cent quartz, and minor pistacite and penninite, is from a nearly directionless dike that underwent incomplete recrystallization under somewhat lower epidote-amphibolite facies conditions. The occurrence of ortho-amphibolite in all stages between these two extremes suggests that dike injection may have been essentially syn-metamorphic (see Gates, 1967).

Amphibolites that lack cross-cutting field relations or diagnostic mineral compositions and textures are of uncertain derivation.

Syn- to Post-Metamorphic Granitic Intrusive Rocks

Partially metamorphosed granitic intrusive rocks ranging in composition from granodiorite to quartz monzonite constitute an estimated 25 per cent of the volume of the migmatite complex. The intrusive rocks occur as irregular, cross-cutting masses, pods, sills, dikes and smaller veinlets, intimately mixed with the other

rock types of the gneiss complex.

One prominent sill of quartz monzonite orthogneiss about 100 feet thick was traced from the head of Kane Creek to the cirque north of Hyndman Peak. The sill lies between the two upper gneiss units for much of its length. Between the two forks of Wildhorse Creek, a complex and irregular zone of quartz monzonite injection occurs at the sill horizon. The sill has undergone stronger deformation and more complete recrystallization than most of the other granitic rocks.

Quartz in the granitic rocks occurs as elongated sutured grains recrystallized from smeared out mortar. Essentially undeformed brown biotite post-dates cataclasis. Plagioclase ranges from An20 to An40, and exhibits typical igneous textures such as euhedral oscillatory zoning, subhedral crystal form, synneusis, and blocky growth twinning. Plagioclase, and locally, microcline occur as broken crystals with granulated margins. At most places, however, poikiloblastic microcline associated with myrmekite post-dates cataclasis.

Irregular networks of thin, directionless aplitic dikes are present throughout the gneiss complex. Similar dikes occur in the other crystalline rocks of the Pioneer Mountains.

ORIGIN

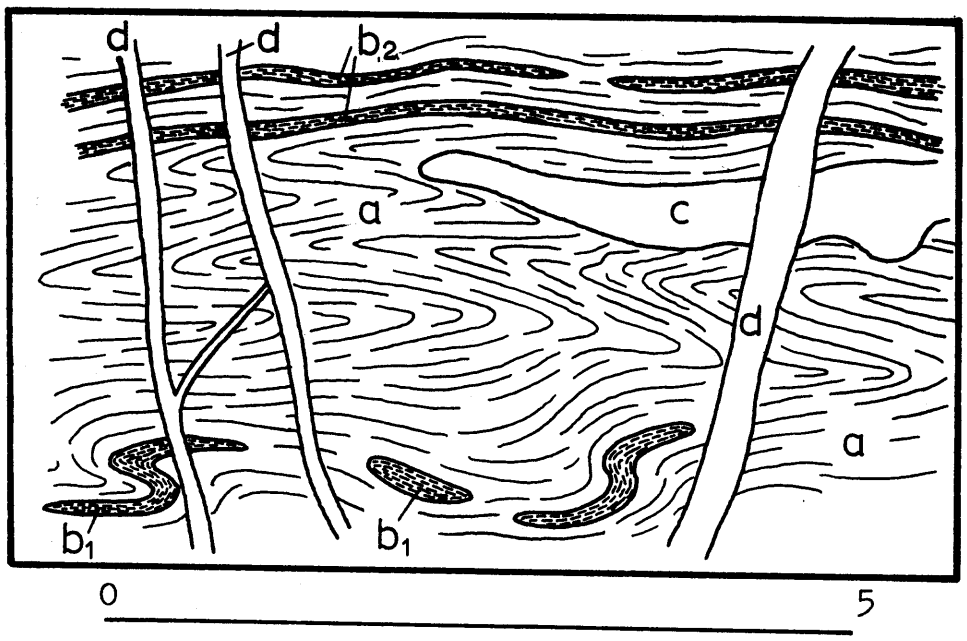
The various gneiss units are considered to have been produced by high-grade regional metamorphism in the upper almandine-amphibolite facies of a thick succession of quartzitic (to arkosic?) sedimentary rocks containing a dolomitic limestone bed in the lower part and an argillaceous horizon in the upper part. Thin argillaceous, limey and tuffaceous interbeds occur at various horizons in the section. Locally, some feldspathic varieties of gneiss may have been produced by metasomatic granitization from more quartzose rocks.

Mafic dikes and sills intruded during metamorphism are converted to orthoamphibolite.

Partially metamorphosed granitic rocks were probably injected in a late state of metamorphism. These granitic rocks are similar in range of composition and texture to the rocks of the surrounding Pioneer Mountains pluton (see Chap. V). The stronger deformation and more complete recrystallization of the prominent sill between the two upper gneiss units suggests a somewhat earlier emplacement. Aplite represents post-metamorphic injection silicic fluids. Partial melting during metamorphism may have generated the late-synorogenic granitic rocks within the migmatite complex and in the surrounding Pioneer Mountains Pluton.

Conclusive petrographic evidence has been found for only one metamorphic episode.

Figures 7 through 10 illustrate some inter-relations of rock types at selected localities.



(a) Quartzitic para-gneiss

(b) Leuco-ortho-amphibolite

(c) Granite pegmatite

(d) Partially-metamorphosed granodiorite dikes

The partial history includes:

(1) Deposition of quartzose sedimentary rocks.

(2) Injection of basic sill (now b_1).

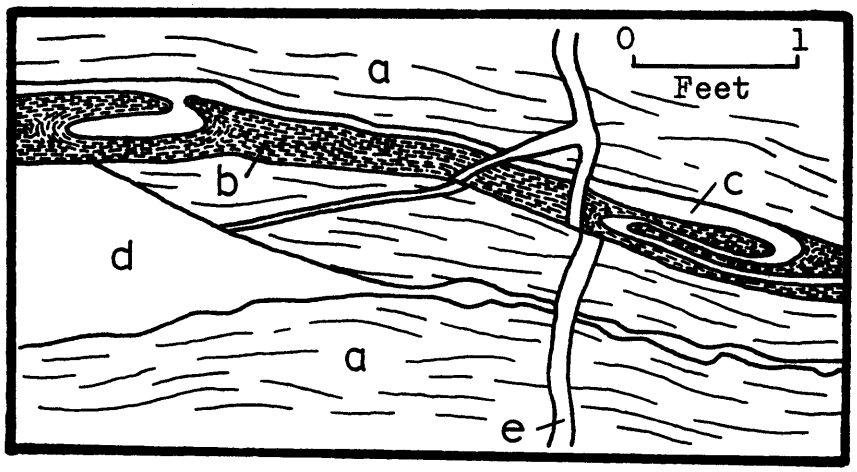
(3) Metamorphism, with production of recumbent folds in quartzitic gneiss (a) and conversion of folded sill to amphibolite (b_1).

(4) Injection of basic sills and dikes (now amphibolite b_2) parallel to axial planes of paragneiss folds, either in a late orogenic phase of metamorphism (3) so that they did not participate in folding, or after metamorphism (3) which would require a second, later metamorphic episode to account for their re-crystallization.

(5) Injection of granitic pegmatite (c) along axial zone of paragneiss recumbent fold, probably late in metamorphism (3).

(6) Late-metamorphic injection of granodiorite dikes (d).

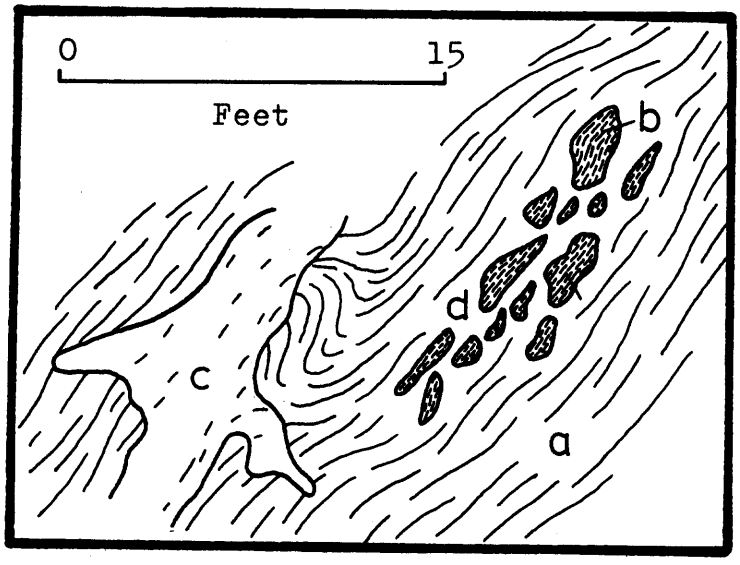
Figure 7. Field sketch of outcrop (plan view) near head of East Fork of Wildhorse Creek, showing tightly folded paragneiss and several stages of intrusion



(a) Quartzitic gneiss (b) Biotitized amphibolite

(c) Quartz veinlet (d) Granitic pegmatite (e) Aplite

Figure 8. Field sketch of outcrop (cross-section) at head of Boulder Creek, showing folded amphibolite (b) and quartz veinlet (c) and post-aplite fault



(a) Granitic gneiss (c) Quartz monzonite

(b) Biotitized ortho-amphibolite (d) Directionless granitic material

Figure 9. Field sketch of outcrop (cross-section) at head of Box Canyon showing fragmented blocks of ortho-amphibolite and cross-cutting quartz monzonite with weak gneissose structure reflecting folded structure of the dominant gneiss

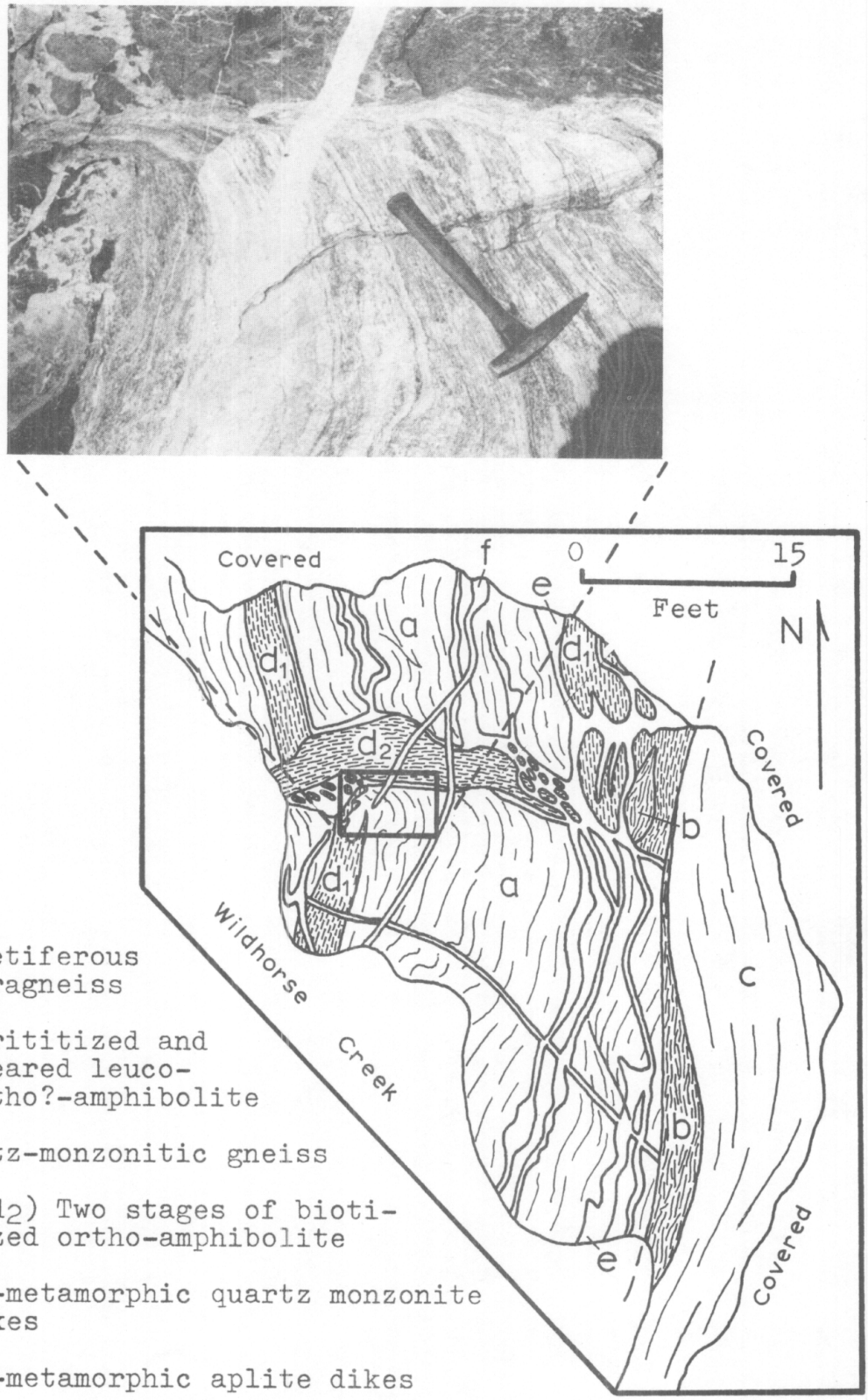
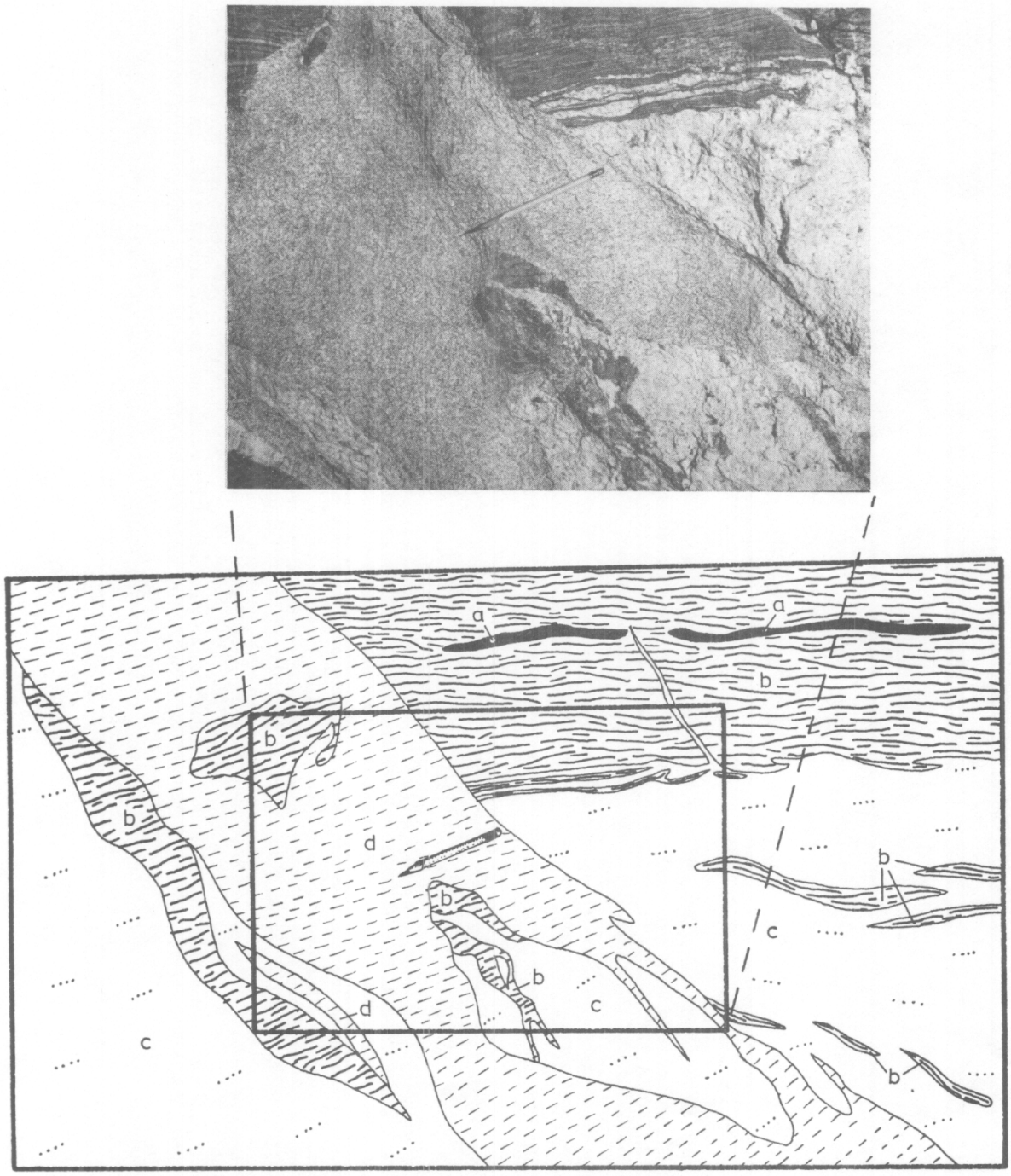


Figure 6. Photograph and field sketch of outcrop (plan view) at the junction of the two main forks of Wildhorse Creek, showing migmatite heterogeneity



(a) Concordant amphibolite

(b) Dark mafic gneiss

(c) Granitic, locally pegmatic, material with very faint foliation, due in part to the scarcity of mafic minerals

(d) Moderately strongly foliated, late-synorogenic granodiorite dike

Figure 10. Photograph and field sketch of outcrop (plan view) at the head of the southeast fork of Wildhorse Creek showing relation of late metamorphic intrusive granitic rocks to the heterogeneous gneisses.

PRELIMINARY STRUCTURAL ANALYSIS

The structural methods used in this study are described by Turner and Weiss (1963). Field data were analyzed on a Wulff stereonet and summarized for presentation on Schmidt equal-area diagrams. In all cases, projections are on the lower hemisphere. Separate analyses are presented for each of four arbitrarily defined sub-areas (Fig. 11). Structures recorded are foliation, mineral lineations, joints, minor fold axes and axial planes, slickensides, and boudin lines. Poles to foliation are plotted as β-diagrams*.

Description of Structural Elements

Foliation is marked by parallel arrangement of micaceous minerals. The foliation is essentially parallel to original bedding as marked by marble marker beds, gross lithologic layering and smaller scale compositional banding. Axial plane schistosity may occur locally, but it has not been distinguished because the axial planes of most minor folds are nearly parallel to bedding foliation. Mineral lineations represent parallel arrangement of tabular hornblende and, less commonly, streaking of micas. Chlorite and mica streaks may be related in some cases to slickensides. Minor folds range from structures with an amplitude of several feet to crenulations a fraction of an inch across. Boudin lines mark breaks in competent quartzitic layers surrounded by less rigid micaceous material.

The orientation of bedding foliation and the outcrop pattern of the five stratigraphic units define two northwest-trending domes, the larger in the upper Wildhorse Creek area and the smaller along Kane Creek.

Wildhorse Canyon Dome

Two hundred ninety-one measurements of bedding foliation indicate that the Wildhorse Canyon dome is asymmetrical with a gently dipping southwest flank and a steep to locally overturned northeast flank. The foliation forms well-defined β-girdles in each of the three sub-areas covering the dome, and a statistical b-axis is plotted for each (Fig. 11A, B, E). In sub-areas I, II, and III, the b-axes plunge 35° N30W, 15° S20E, and 28° S3E, respectively. An average of the three b-axes defines the N25W trend of the major domal axis. Maxima within the β-girdles are a result of uneven sampling. The marble marker bed in the core defines a few subsidiary folds of moderate size with axes that parallel the domal axis.

Most of the 94 mineral lineations measured throughout the Wildhorse Canyon dome nearly parallels the b-direction (Fig. 11A, B, E). In each of the three sub-areas, however, statistical lineation maxima diverge by up to 10° and 15° in plunge from the statistical b-axes defined by foliation girdles. Moreover, about 25 per cent of the lineations scatter widely and a few deviate by as much as 90° from the average. The generally close association of mineral lineations and

* "β-diagram" is used in this report in preference to Sander's term "π-diagram" (1942), following the usage of Turner and Weiss (1963, p. 155).

b-axes suggests that most lineations are genetically related to (and contemporaneous with) doming. Additional data are needed to prove that divergent lineations represent statistical maxima recording earlier deformations as suggested by Holm (1962).

Minor fold axes scatter widely around the statistically-derived b-axes in sub-area II (Fig. 11D). Poles to axial planes of minor folds show similar scatter along the foliation girdle of sub-area II (Fig. 11D). Thus most of the minor folds recorded appear to be genetically related to doming. Insufficient data are available to speculate on the significance of scatter and deviations among the minor folds (Fig. 11D, F, I).

Five boudin lines in sub-area II (Fig. 11C) and three in sub-area III (Fig. 11F) scatter along the main domal axis.

Kane Canyon Dome

Poles to 36 foliations in the Kane Canyon dome define an elongated maxima representing an incomplete N30E-trending girdle (Fig. 11I). Uneven sampling accounts for the poor definition of the girdle. The N60W strike of the approximate b-axis suggests that the Kane Canyon dome trends 35° more westerly than the Wildhorse Canyon dome. Seven of eight mineral lineations cluster around the b-axis. The Kane Canyon dome is much smaller than that in Wildhorse Canyon and has been examined in less detail. However, it appears to be notable in its greater divergence of foliation and lithologic layering (Plate I). The reason for the more westerly trend of the Kane Canyon dome is not clear, but possible explanations include: (1) rotation of the Kane Canyon dome along undetected faults or in surrounding intrusive rocks, (2) effects on doming of inhomogeneities in the rocks or concealed buttresses, or (3) occurrence of the N60W doming in a later stage of deformation than that which produced the Wildhorse Canyon dome. The latter could be related to a slightly later phase of the main orogenic metamorphism in which re-oriented stresses affected still mobile rocks in the Kane Canyon area, or to an entirely later episode of tectogenesis, perhaps related to emplacement of overlying allochthonous Paleozoic rocks (see Chapter IX).

Joints

Poles to 379 joints measured in both the Wildhorse Canyon and Kane Canyon domes define two prominent steeply-dipping sets bearing N20E and N65W, and two much weaker sets trending N-S and N80E (Fig. 11H). The absence of a large central maxima marking the strong sheeting present in both domes results from sampling bias caused by masking of sheeting by gently-dipping bedding and foliation.

Ten slickensides in sub-area II (Fig. 11C) and three in sub-area IV (Fig. 11I) define a distinct N60W-trending girdle, indicating that some displacement has occurred on the N65W joint set.

Facilitation of erosion along joints controls the strong northeast and southwest drainage pattern characterizing the entire Pioneer Mountains region (see Umpleby, et al., 1930, p. 72).

Joints in the migmatite complex appear to be related to joints with similar

disposition in all of the other major rock units of the Pioneer Mountains (compare Fig. 11H and Fig. 30, for example). All are related to an integrated and pervasive joint system that post-dates doming in the migmatitic gneiss complex.

CONCLUSION

The majority of structural elements examined in the migmatitic gneiss complex are genetically related and are tentatively attributed to the episode of orogenic metamorphism that produced doming. However, the significance of anomalous structural trends observed locally is uncertain. Additional data are required to determine if these are statistically valid relicts of earlier orogenic cycles, the effects of which have been almost completely destroyed. Joints represent a distinctly later phase of deformation.

MEDIUM-GRADE TO HIGH-GRADE METASEDIMENTARY ROCKS

GENERAL STATEMENT

Overlying the migmatites is a succession of metasedimentary rocks (Fig. 4) originally divided by Umpleby, et al. (1930) into the Hyndman and East Fork Formations. The Hyndman Formation was reported to contain gneissose quartzite, schist and "green hornfels" units; "limestone" and quartzite were described in the East Fork Formation.

In the discussion to follow, the names Hyndman Formation and East Fork Formation are retained despite changes in internal stratigraphy because of their establishment in the literature and in view of lithologic distinctions between the two parts of the metasedimentary succession they represent. Eight lithologically distinct members of the two formations are given letter designations. No formal stratigraphic names are proposed because of the restriction of the units to a small area in the Pioneer Mountains.

The metasedimentary succession crops out in a northwest-trending belt about 10 miles long and one to three miles wide near the crest of the Pioneer Mountains (Fig. 3). The rocks are well-exposed in the cirques on the southwest side of the range and along the top of the steep, east-facing cirque wall at the head of Wildhorse Creek. Several of the members can be recognized from several miles distance or on aerial photographs from their distinctive colors.

The metasediments are exposed in three or possibly four thrust slices. Tectonic truncation and repetition locally complicate stratigraphic relations and account for the wide variations in thickness observed by Umpleby. Bedding, thrust faults and regional schistosity maintain a moderate to high degree of parallelism throughout the metasedimentary belt.

Regional, synkinematic to nearly static, isochemical metamorphism in the upper almandine-amphibolite facies characterizes the metasedimentary rocks. The lower part of the succession is truncated on the northeast by an intrusive sheet of granitic rocks; overlying weakly metamorphosed Paleozoic rocks are separated by thrust faults.

The Hyndman and East Fork Formations were tentatively assigned to the "Algonkian(?)" by Umpleby, et al. (1930). The Precambrian assignment was based on the high-grade of their metamorphism relative to the weak metamorphism of adjacent Paleozoic rocks as old as Ordovician. However, the allochthonous origin of most, if not all, of the weakly metamorphosed Paleozoic rocks casts considerable doubt on the validity of this evidence. Moreover, the earlier workers failed to distinguish between the age of metamorphism and the stratigraphic age of the rocks involved in the metamorphism. The present study suggests that the Hyndman and East Fork Formations are latest Precambiran and Early Paleozoic quartzitic, pelitic and calcareous sedimentary rocks that were subjected to post-Ordovician metamorphism.

MARBLE AND SCHIST OF UNCERTAIN AFFINITY

Prominent but discontinuous forsterite marble and garnetiferous biotite-quartz schist layers can be traced from Box Canyon to the cirque northeast of Hyndman Peak. The marble band overlies the migmatite dome at the latter locality, but at all other places, these units are separated by intrusive granitic rocks from the underlying migmatites and the overlying metasedimentary rocks. The marble and schist are complexly broken and intruded in a giant breccia zone at the head of East Fork Canyon (Fig. 12).

The marble contains 40 per cent forsterite, 60 per cent calcite and traces of colorless phlogopite.

The schist contains 65 per cent to 70 per cent quartz, 5 per cent to 10 per cent calcic oligoclase, 15 per cent to 20 per cent red-brown biotite, up to 2 per cent garnet, 3 per cent to 4 per cent magnetite, and accessory epidote, rounded zircon, apatite, phengite and tourmaline. A micro-layer in one section contains late K-feldspar.

The marble resembles member E of the metasedimentary succession. The schist is most similar to metasedimentary member A, but is somewhat more quartzitic and less pelitic. These two units are tentatively grouped with the metasediments (Fig. 4), but their relation to the sequence established is uncertain. They may be remnants of tectonic slivers engulfed by the surrounding granitic rocks.

HYNDMAN FORMATION

The Hyndman Formation constitutes the lower part of the metasedimentary succession and the northeastern two-thirds of its outcrop belt. The formation consists of four lithologically distinct units here designated members A through D, from oldest to youngest. The four members aggregate a minimum thickness of 5200 feet. Umpleby, et al. (1930) described quartzite in a position below member A at the head of East Fork Canyon as the basal unit of the Hyndman Formation. This quartzite is clearly a stratigraphically higher quartzite thrust into its present position.

Member A (Pelitic Schist)

The pelitic schist of member A is best exposed in the cirque at the head of the East Fork of the Big Wood River and in the cirques southwest of Hyndman Peak. Schist also caps the spectacular headwall east of Hyndman Peak in Wildhorse Canyon.

About 2000 feet of schist is exposed on the west side of upper East Fork Canyon. This estimated thickness may be slightly high because of injection of granitic sills near the base of the unit. However, this is a minimum stratigraphic thickness owing to tectonic truncation of the base at this locality.

In the East Fork Canyon area, the rock is an andalusite-muscovite-biotite-quartz schist (Fig. 13). Locally, small clusters of penninite appear to be pseudomorphs after cordierite.

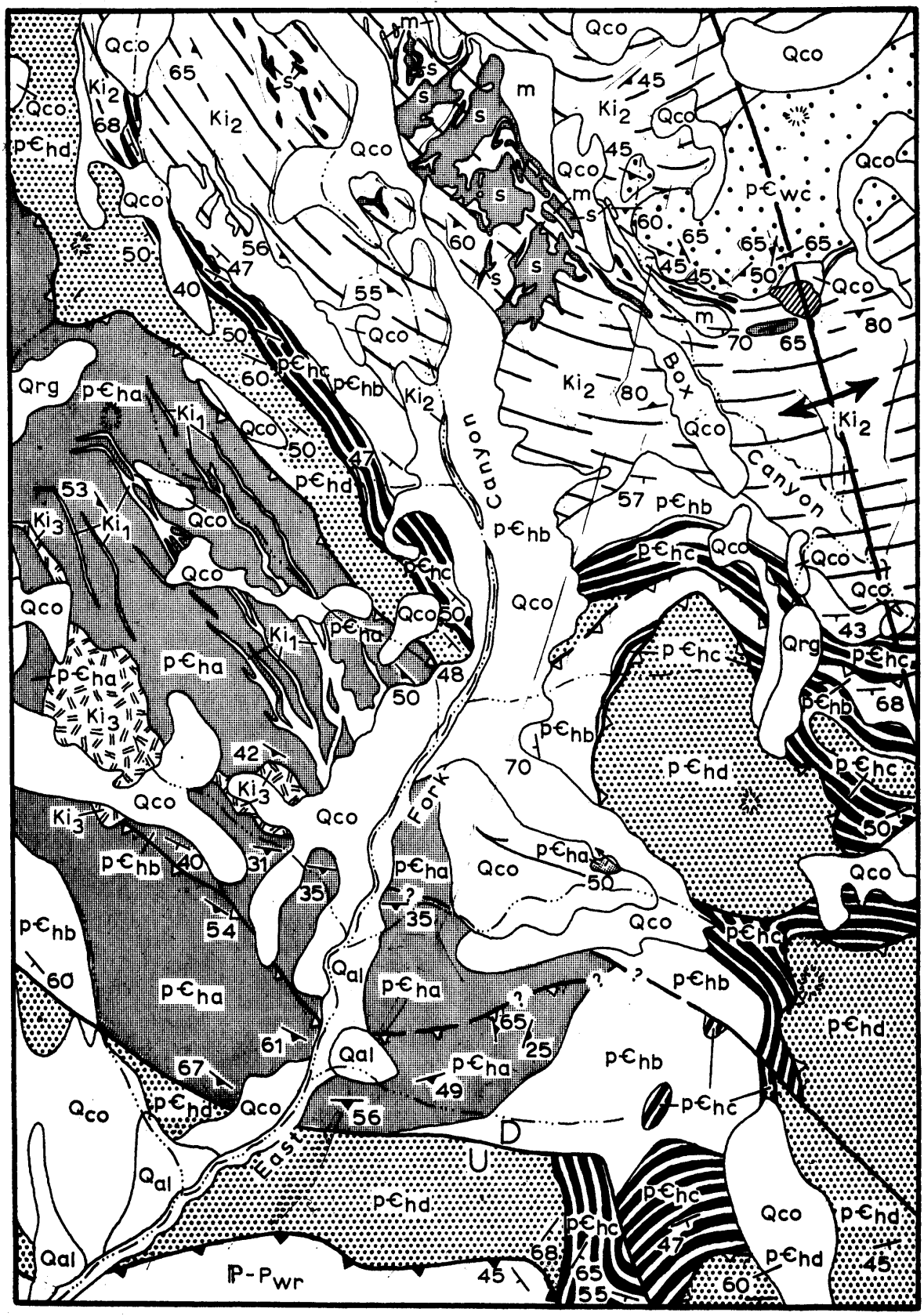


Figure 12. Enlarged geologic map (3" per mile; north at top) of the East Fork Canyon and Box Canyon areas showing "giant breccia zone" (top center), assimilation zone (left center), and East Fork Canyon Arch. (Qco - colluvium; see Plate I for legend)

Subhedral andalusite porphyroblasts up to one inch long constitute as much as 40 per cent of some samples. Retrogressive sericite envelopes have replaced 50 per cent to 90 per cent of the volume of most porphyroblasts. The andalusite is late-kinematic. Some porphyroblasts have weak helicitic structure; others are broken and cut by an incipient s_2. Local migration and recrystallization of coarse-grained quartz occurred in strain shadows next to andalusite porphyroblasts. Coarse-grained quartz also recrystallized in the axial areas of s_1 microfolds, whereas synkinematic muscovite is concentrated in the higher pressure environment along microfold limbs.

Some sections contain two distinct sizes of quartz grains which appear to represent sand-size and silt-size fractions of the original sediment. Locally, a directional trend from finer to coarser clast size suggests graded bedding. Layers containing an intimate mixture of the two fractions were probably poorly sorted.

Zircon, magnetite and euhedral zoned tourmaline are common accessories. The tourmaline has blue cores and olivine-green rims.

The metamorphic history of the andalusite schist is as follows: (1) development of s_1, marked by weak compositional layering, mica alignment, elongated quartz grains and trains of opaque inclusions; (2) essentially simultaneous development of incipient s_2 along the axes of s_1 microfolds and late-kinematic crystallization of andalusite (and probably cordierite) porphyroblasts; and (3) retrogressive sericitization of andalusite and breakdown of cordierite to penninite.

Northwest of East Fork Canyon, the schist contains sillimanite instead of andalusite. The sillimanite forms late-kinematic euhedral poikiloblasts and glomeroblasts in many thin sections (see Fig. 14), whereas others contain only fibrolite. In addition to sillimanite, some samples contain late-kinematic garnet and main-assemblage cordierite (Fig. 15). Typical samples also contain dark red-brown, aligned biotite; quartz; calcic andesine and minor muscovite. Less than one per cent of staurolite occurs in one section containing abnormally abundant (12 per cent) cordierite.

One sample of schist at the gneissose granodiorite contact at the head of Wilson Creek contains 35 per cent of main-assemblage orthoclase in addition to 20 per cent sillimanite, a trace of muscovite and only 6 per cent quartz. This assemblage was produced by the reaction: muscovite + quartz ⇌ sillimanite + orthoclase. The completeness of the reaction accounts for the low quartz content and near absence of muscovite.

Sillimanite constitutes as much as 25 per cent of some samples. Some porphyroblasts attain a length of one cm. The porphyroblasts lie in the plane of schistosity (s_1) with no apparent lineation; the schistosity is bowed out by porphyroblast growth. Slightly bent and broken porphyroblasts indicate that deformation outlasted latest-kinematic crystallization of the sillimanite. The sillimanite has undergone no appreciable retrogression. Most rocks with abundant sillimanite are

poor in muscovite. About half of the thin sections examined contain a fibrous variety of sillimanite. The fibrolite occurs in knots and stringers associated with biotite, which appears to have been a favorable host because of its sheet structure. Fibrolite alone is not considered a reliable index of metamorphic grade.

Synkinematic biotite constitutes 10 per cent to 30 per cent of the schist. The biotite marks strong crystallization foliation (s_1) and polygonal arcs. In some sections, bent biotite indicates that deformation outlasted crystallization; in others, crystallization of undeformed biotite outlasted deformation. Aligned biotite commonly occurs in a mosaic of elongated quartz grains. Incipient s_2 is developed in a few sections. The dark red-brown color of the biotite reflects its high Fe^{++}/Fe^{+++} ratio and/or its high Ti content

Phengitic muscovite ($2V_x = 20^o$ to 30^o) ranges from 0 to 42 per cent but commonly constitutes less than 15 per cent of the schist. It is stably intergrown with biotite. The two micas appear to have crystallized essentially simultaneously at most places. Locally, however, muscovite is retrogressive.

Less than 5 per cent of garnet is present in most sections; a few contain as much as 10 per cent. The garnet is free of internal structure except along its margins where incorporated s_1 marked by aligned biotite muscovite, quartz and trains of opaque inclusions has remained undisplaced.

Cordierite was found in only three sections in amounts of 12 per cent, 3 per cent and less than 1 per cent. It occurs as rounded grains with unusually high relief and it has yellow alteration(?) product along irregular fractures. The high relief and alteration (?) may be due to high iron content. The cordierite is a main-assemblage mineral chiefly associated with quartz. Its exact position in the paragenetic sequence could not be established by mineral textures. However, it appears to postdate at least some of the biotite.

Plagioclase typically constitutes 15 per cent to 30 per cent of the schist. Some quartzitic samples contain no plagioclase; one rock with 57 per cent plagioclase contains less than 5 per cent quartz. Normal zoning from calcic andesine (An43) to sodic andesine is common; calcic oligoclase occurs locally. Some plagioclase is euhedral and exhibits oscillatory zoning. Plagioclase locally contains wormy intergrowths of quartz.

Quartz occurs as elongate grains with undulatory extinction and as stringers. Faserkiesel is common in some sections. Local migration and recrystallization of coarse-grained undeformed quartz (and some non-aligned mica) occurred in strain shadow areas next to late-kinematic garnet and sillimanite porphyroblasts.

Very minor retrogression of biotite to penninite and of sillimanite and plagioclase to sericite occurred in some samples.

Accessory allanite, zircon, apatite, magnetite and tourmaline are present in varying proportions.

The schist contains evidence for only one metamorphic event. All of the major constituents, including cordierite and andalusite, constitute a high-grade, regional, synkinematic equilibrium assemblage.

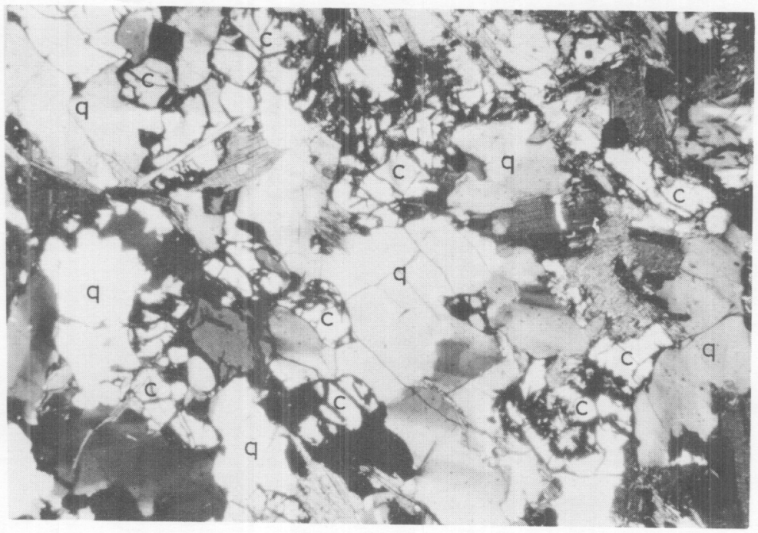


Figure 15. Photomicrograph of cordierite (c, with dark, iron-stained fractures) associated with quartz (q) in pelitic schist of member A. (Crossed nicols, X 25)

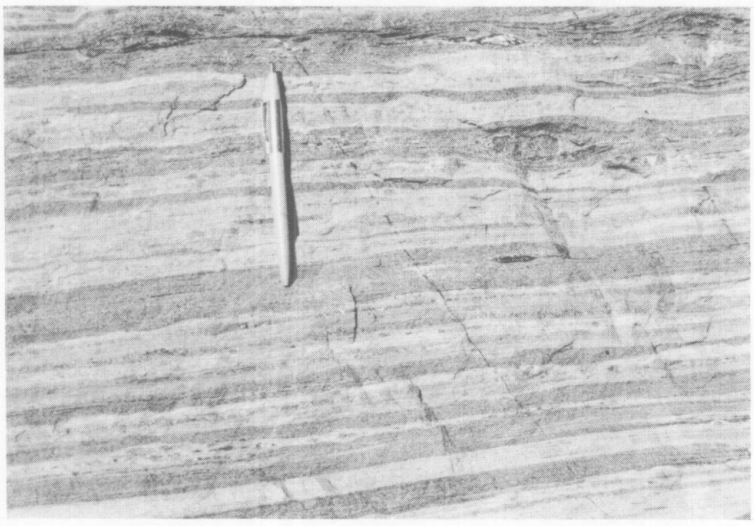


Figure 16. Mineralogic banding in calc-silicate rock of member C reflects primary compositional layering in the original sediment with only minor modification by shearing and metamorphic differentiation.



Figure 13. Photomicrograph of late-kinematic andalusite poikiloblasts (a) in pelitic schist of member A. Note enrichment of quartz in strain shadow area between the two poikiloblasts. (Crossed nicols, X 25)

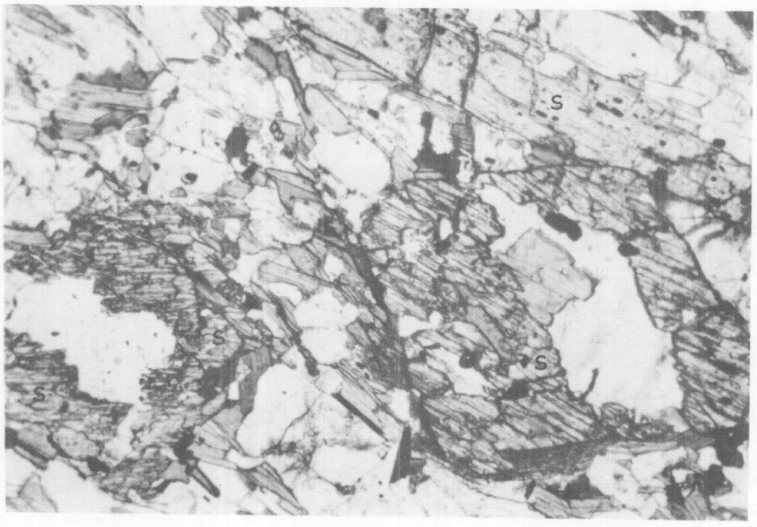


Figure 14. Photomicrograph of subhedral to euhedral post-kinematic sillimanite porphyroblasts (s) in pelitic schist of member A. (Plane light, X 25)

The schist is truncated at the base by intrusive granitic rocks; a wide zone of injection and assimilation locally marks the contact.

Member B (Gneissose Quartzite)

Member A grades into overlying gneissose quartzite of member B. The quartzite crops out discontinuously in thrust slices from Box Canyon to the Devil's Bedstead, and forms the summit of Hyndman Peak. About 1200 feet of quartzite is exposed in the cirque at the head of the southeast fork of Hyndman Creek. The thickness of 2400 feet reported for this quartzite member of Umpleby, et al. (1930, p. 12 - his member C) appears to have been measured across a fault that repeats the full section.

The quartzite is white to mottled green and has thick, even-bedding. Thin biotite partings, locally arranged in a pattern resembling coarse-cross-bedding, impart the gneissose aspect to the quartzite. The rock tends to split along these partings into slabs six inches to three feet thick.

Typical thin sections contain 80 per cent to 90 per cent of coarsely recrystallized quartz, which occurs as sutured, strained grains averaging 1.0 mm. in size. The rest of the rock consists of variable proportions of microcline, plagioclase, well-aligned biotite altered to minor penninite, hornblende, salite and sericite.

Member C (Green Banded Calc-Silicate Rock)

Member B is overlain with a sharp and apparently concordant contact by green, banded calc-silicate rock of member C. The calc-silicate rocks crop out in narrow, discontinuous belts in thrust slices from Box Canyon to the Devil's Bedstead. Member C is about 600 feet thick in the cirque at the head of the southeastern fork of Hyndman Creek.

The banding of the rock is remarkably uniform and consistent (Fig. 16). It typically splits into large flat slabs a few feet thick; some slabs have dozens of square feet to surface area. Thickness of individual bands varies from a dozen or more bands per inch to several inches per band. The banding represents distinct mineralogical layering. Light-colored layers rich in quartz, calcite, microline, plagioclase, Ca-scapolite and Ca-garnet alternate with layers of various shades of green and purple containing abundant salite, ferrohastingsitic hornblende, highly-ferric pistacite and biotite. The proportion of these constituents varies considerably from band to band. The detailed mineralogy of individual layers in two typical samples is illustrated in Figures 17 and 18. Light-colored calcareous bands are commonly etched by weathering to a depth of one-half inch. Thin sections show that little or no reaction has occurred between bands; individual layers behaved essentially as closed systems. There can be no doubt that the banding reflects primary compositional layering. The sharpness of the bands may be locally intensified by minor metamorphic differentiation and shearing.

Highly-ferric pistacite, salite, ferrohastingsitic hornblende, Ca-scapolite and Ca-garnet are stably intergrown throughout the calc-silicate member.

The pistacite is strongly pleochroic (X - yellow). It occurs as overgrowths on allanite and as subhedral, poikiloblastic grains. Pistacite "balls" locally are thinly-rimmed by salite.

Salite has moderately strong absorption and weak pleochrism (X - green, Y and Z - pale green). Salite occurs mostly as disseminated grains.

Ca-scapolite locally is altered to very fine-grained indeterminable material. Some feathery scapolite is retrogressive.

Refractive indices indicate that Ca-garnet is a mixture of grossularite and andradite components. The andradite admixture imparts a distinctive rusty color to the garnet. Ferrohastingsitic hornblende ($2V_x = 25^o$ to 45^o; Z = dark blue-green, Y = dark olive green, X = light yellow brown) commonly is concentrated in narrow zones between argillaceous and carbonate-rich layers, where it occurs instead of salite and biotite. These hornblende concentrations probably formed in zones of intermediate composition. The absence of hornblende between many argillaceous and carbonate-rich layers suggests that the intermediate zone was absent. The hornblende is therefore a mineralogical expression of primary compositional layering and not a product of reaction between adjacent layers.

Strongly-aligned green-brown to brown biotite is associated with quartz and feldspar in argillaceous layers.

Gash fractures are filled with coarse-grained quartz, calcite and non-aligned muscovite in one section. Thin veinlets of pistacite and scapolite occur in other samples.

The recurring sequence of layers in one sample (see Fig. 17) suggests rhythmic alternation of argillaceous layers, now containing abundant biotite, quartz and feldspar, with carbonate-rich layers, now marked by salite, pistacite, calcite, Ca-scapolite and Ca-garnet. A systematic study of this relationship in the field might prove useful in determining top and bottom of beds in the metasedimentary succession.

Member D (Gneissose Quartzite)

Member C is overlain concordantly at most places by gneissose quartzite of member D. On the northwest side of upper East Fork Canyon, however, a basal meta-quartz-pebble conglomerate six feet thick occurs above the slightly discordant contact with the calc-silicate rocks. At this place, the contact appears to be a metamorphosed unconformity.

This upper quartzite member of the Hyndman Formation is well exposed in the cirques at the heads of several branches of Hyndman Creek. About 1400 feet of member D crops out on the ridge between the two southeast forks of Hyndman Creek.

The gneissose quartzite is white to gray or mottled green and has thick, even bedding along which the rock breaks in large flat slabs. Biotite partings mark bedding surfaces and commonly are arranged in a pattern resembling coarse cross-bedding (Fig. 19). Typical samples contain 70 per cent to 90 per cent of strained quartz in elongate grains averaging 0.5 mm. in length. Other locally abundant minerals are: microcline (5 per cent to 10 per cent), highly sericitized calcic andesine (5 per cent to 20 per cent), salite (10 per cent to 20 per cent), zoisite (3 per cent) and aligned

I. Argillaceous-feldspathic layers

25%	aligned brown biotite
6%	ferrohastingsitic hornblende
2%	salite
58%	microcline
5%	quartz and untwinned plagioclase
4%	magnetite
100%	

II. Intermediate layers

14%	ferrohastingsitic hornblende
10%	salite
1%	pistacite
63%	microcline
10%	quartz and untwinned plagioclase
2%	magnetite
100%	

III. Impure siliceous dolomite

36%	salite
4%	pistacite
13%	microcline
28%	quartz
18%	plagioclase
0.5%	magnetite
99.5%	

IV. Slightly impure dolomite

43%	garnet (grossularite with andradite admixture)
38%	salite
11%	Ca-scapolite
4%	quartz
4%	untwinned plagioclase
100%	

Note: No reaction has occurred between adjacent layers of types I and III, indicating that intermediate layers of type II reflect primary compositional layering.

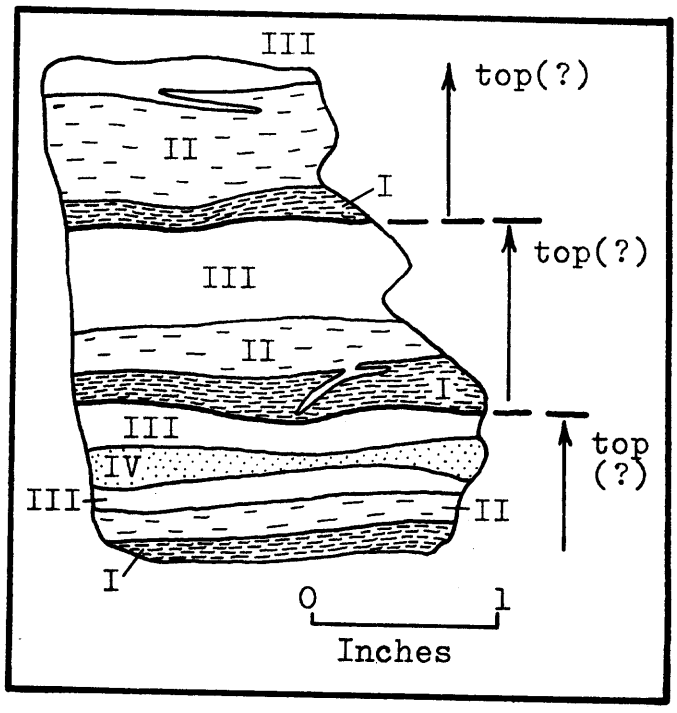


Figure 17.

Mineral composition of layers in rhythmically-banded sample of member C calc-silicate rock

I. Argillaceous-feldspathic layers

31% aligned brown biotite
3% pistacite
2% ferrohastingsitic hornblende
39% K-feldspar
15% plagioclase
10% sphene
100%

II. Intermediate layers

45% ferrohastingsitic hornblende
4% pistacite
19% K-feldspar
24% plagioclase
8% sphene
100%

III. Impure dolomitic layers

35% salite
16% pistacite
12% Ca-scapolite
23% plagioclase
9% sphene
5% quartz, calcite and other accessories
100%

IV. Impure siliceous dolomite layers

26% salite
27% pistacite
24% Ca-scapolite
20% labradorite
3% sphene, calcite and other accessories
100%

V. Slightly impure siliceous dolomite layers

90% Fe-poor pistacite
10% Ca-scapolite, salite and plagioclase
100%

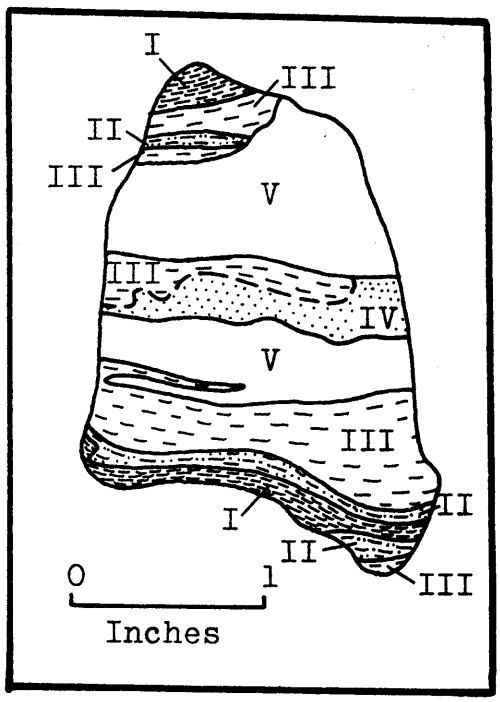


Figure 18.

Mineral composition of layers in typical sample of member C banded calc-silicate rock

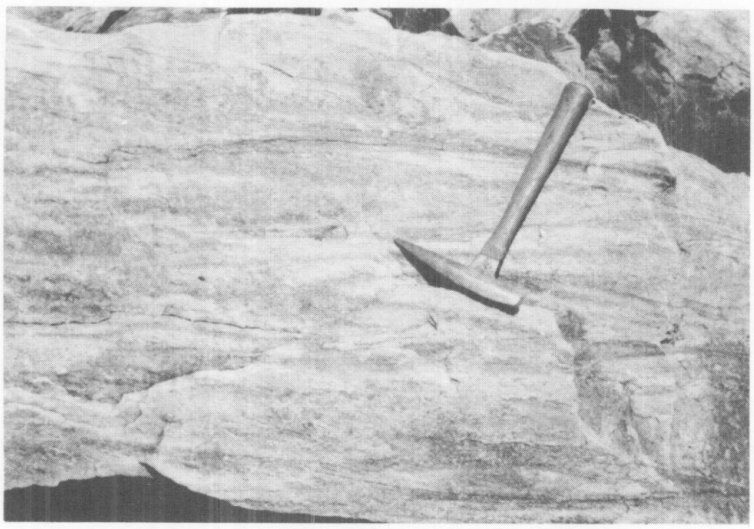


Figure 19. Coarse cross-bedding in gneissose quartzite of member D.

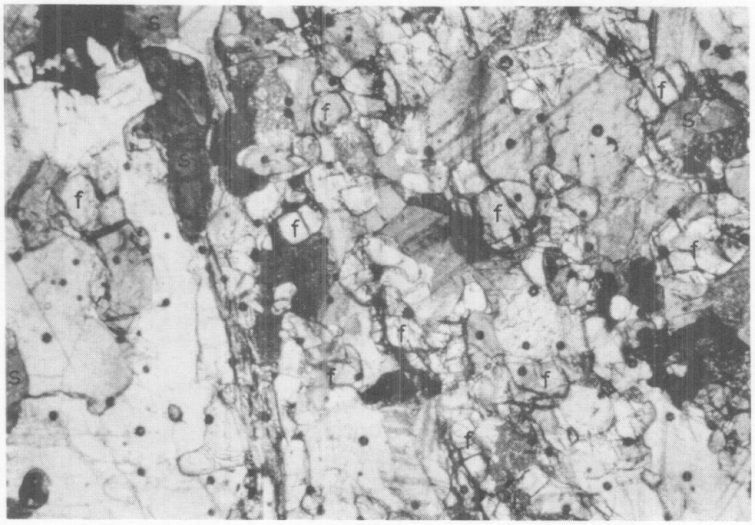


Figure 20. Photomicrograph of forsterite (f) and spinel (s) in dolomitic marble of member E. (Crossed nicols, X 25)

brown biotite (up to 50 per cent in thin partings) with minor alteration to penninite. Hornblende, phengite, calcite, zircon, magnetite and pistacite occur mostly in accessory amounts. The composition of the rock approaches quartzitic gneiss where feldspar and biotite are abundant. At some places, particularly southeast of East Fork Canyon, the rock contains abundant meta-quartz-pebble conglomerate beds. The quartz pebbles are recrystallized to a mozaic of smaller elongated grains with undulatory extinction.

The gneissose quartzite of member D is similar to that of member B except for its (1) lesser purity, (2) conglomeratic character and (3) more prominent cross-bedding. The two quartzite units can be distinguished with confidence only by stratigraphic position.

EAST FORK FORMATION

The East Fork Formation constitutes the upper part of the metasedimentary succession and the southwestern one-third of its outcrop belt. The four distinctive lithologic units comprising the formation are designated members E through H, from oldest to youngest. The three members aggregate about 4000 feet. This is a minimum figure owing to tectonic truncation at the top.

Member E (Dolomitic Marble)

Member D of the Hyndman Formation is concordantly overlain by dolomitic marble of member E. The marble is well exposed on the divide between upper Corral and Hyndman Creeks, in imbricate slices on the ridge between upper Wilson and Kane Creeks, and in the lower parts of the cirques west of Hyndman Peak. It forms prominent dip slopes on the southwest ends of ridges between major southwest-facing cirques. About 700 feet of the marble crops out on the ridge between the two northwest forks of Hyndman Creek.

The unit consists predominantly of white to cream-colored, tan-weathering, massive to slabby, coarsely-crystalline dolomitic marble that typically weathers to coarse calcite sand. The marble is weakly schistose in places. Subordinate white siliceous marble interbeds, including one about 50 feet thick, occur near the middle of the member. In addition to calcite, typical samples contain variable proportions of tremolite, diopside and magnetite. One schistose sample carries the assemblage: green spinel-forsterite-phlogopite-diopside-magnesian chlorite-calcite (Fig. 20). The phlogopite is aligned.

Member F (Vitreous Quartzite)

Member E grades into the overlying quartzite of member F. The quartzite crops out in a narrow, discontinuous band from the head of the Little Wood River to the Devil's Bedstead. It is well exposed in imbricate slices on the ridge between upper Wilson and Kane Creeks. The unit is very resistant to erosion and forms conspicuous dip slopes on the ridge between upper Wilson and Corral Creeks and on the ridge separating the two forks of Kane Creek. About 300 feet of quartzite is exposed in the lower parts of the cirques along the northwestern branches of Hyndman Creek.

The quartzite is white to pink on fresh surfaces, vitreous and quite pure. Reddish weathering is characteristic, especially at the top of the unit where oxidized pyrite is abundant. Thin muscovite partings are rare. The quartzite breaks along flat bedding fractures six inches to three feet thick. Locally, it contains brown-colored rings about one-half inch in diameter, which may have been organic. The rock carries 99 per cent quartz in interlocking recrystallized grains averaging 1.0 mm. in diameter. Some zones, with grains averaging 0.5 mm. across and containing 2 per cent to 3 percent disseminated pyrite, may not be fully recrystallized.

Member G (Marble)

The contact between member F and the overlying marble of member G is sharp and concordant. The best exposure of the marble is on the divide between upper Corral and Hyndman Creeks, where 800 feet of section was described by Umpleby, et al. (1930, p. 16). Smaller isolated outcrops occur along the southwestern edge of the metasedimentary units and by weakly-metamorphosed allochthonous Paleozoic rocks.

The lower part of this member consists of massive dark-gray marble and subordinate vitreous quartzite. The upper part of the marble has alternating light- and dark-colored bands. Light-colored layers contain calcite, diopside, quartz and minor K-feldspar, whereas dark layers are mostly calcite. Small pyrite cubes are locally abundant in dark layers. Individual bands are typically less than one inch thick. Numerous aplitic sills and dikes several inches to a few feet wide cut the banded marble on the divide between upper Corral and Hyndman Creeks. Most of the marble is somewhat schistose.

Member H (Kinnikinic? Quartzite)

Member G is overridden by at least 2000 feet of massive quartzite of member H in the Hyndman and Corral Creek areas. The contact is clearly tectonic in some places, and obscure elsewhere.

White to dull gray, tan-weathering feldspathic quartzite predominates in lower structural portions of member H; subordinate gray marble interbeds may also occur, but poor exposures obscure stratigraphic relations. Relatively pure, varicolored, vitreous quartzite constituting the upper part of member H resembles that of member F. Member H is regarded as a distinct unit on the basis of its much greater thickness and more feldspathic composition toward the base. The quartzite is highly fractured throughout; bedding is indistinguishable in most places.

Member H is truncated at the top by weakly metamorphosed allochthonous Paleozoic rocks.

NATURE OF METAMORPHISM

The mineralogy and textures of Hyndman and East Fork Formations indicate that the entire metasedimentary succession has undergone regional, synkinematic, isochemical metamorphism in the upper almandine-amphibolite facies. Not every member contains critical assemblages for determining grade. The following are most diagnostic:

(1) The assemblage sillimanite (or fibrolite)-almandine-biotite-muscovite, which characterizes the pelitic schist of member A in most places, corresponds to the sillimanite-almandine-muscovite subfacies of the upper almandine-amphibolite facies (Turner and Verhoogen, 1960). At one locality, the assemblage sillimanite-orthoclase-(biotite-minor quartz-trace of muscovite) places the metamorphism in the sillimanite-almandine-orthoclase subfacies. The location of this sample next to the granitic pluton is probably coincidental.

(2) The assemblages calcite-salite, pistacite-ferrohastingsitic hornblende-calcic scapolite-calcium garnet and calcite-diopside-tremolite place the metamorphism in calc-silicate rocks of member C near the highest-medium-grade to high-grade boundary. In some samples, pistacite has persisted above its normal stability range owing to armoring by salite.

(3) The occurrence of forsterite establishes the high metamorphic grade in silica deficient dolomitic rocks.

(4) Plagioclase from different metasedimentary members scattered throughout the outcrop belt has a maximum An content of 45 per cent to 55 per cent. The plagioclase composition indicates a minimum grade near the medium- to high-grade boundary.

The following evidence indicates that the metamorphism occurred at lower pressure than that characterizing the standard Barrovian sequence.

(1) Schistose rocks containing sillimanite grade into schist in which andalusite occurs instead of sillimanite in the regional synkinematic assemblage.

(2) Cordierite occurs as a stable phase in the regional synkinematic assemblage near the sillimanite-andalusite transition zone and in the andalusite schist.

(3) Kyanite, which has a high P/T stability field relative to sillimanite and andalusite, is absent.

(4) Except for traces in one sample of cordierite-sillimanite schist, staurolite is absent from the regional assemblage despite the favorable bulk composition of the schist.

The mineral assemblages present and physical conditions envisioned here are similar to those described by Read (1947) as the Buchan-type sequence.

The pelitic schist member of the Hyndman Formation is the only metasedimentary unit that underwent strong penetrative deformation throughout. Other members are only locally schistose and retain primary sedimentary features such as rythmic layering and cross bedding. The mechanically weak schist appears to have selectively absorbed most of the orogenic stresses associated with regional metamorphism.

There is no evidence in any part of the succession for more than one metamorphic

event. The only earlier features recognized are primary sedimentary relicts. Moreover, no significant transfer of materials is recognized or required to explain the existing mineral assemblages. This simple history of isochemical metamorphism contrasts with the more complex character of the underlying migmatites.

TENTATIVE STRATIGRAPHIC CORRELATION

No fossils are known in the metasedimentary rocks. Therefore, attemtps at regional correlation of their parent rocks are necessarily based on highly tenuous comparisons of lithology and stratigraphic sequence.

The Hyndman and East Fork Formations differ in their gross lithologic character. The Hyndman Formation was derived from impure argillaceous, quartzitic, dolomitic and locally feldspathic rocks generally high in iron. The parent materials of the East Fork Formation were comparatively pure siliceous dolomite, dolomitic limestone and quartz sandstone. Lithologically, the gneissose quartzite of member D belongs with the impure Hyndman Formation. However, the local disconformity below the quartzite and the apparent concordance of the overlying East Fork Formation suggest that member D should be grouped with the East Fork rocks. The quartzite is arbitrarily included in the Hyndman Formation following Umpleby's precedent.

Correlation with lower Precambrian rocks need not be considered because these are invariably migmatites with complex histories of deformation, metasomatism and intrusion. Possible stratigraphic equivalents of the metasedimentary rocks are: (1) the Belt Series, as originally suggested by Umpleby, et al. (1930); (2) uppermost Precambrian rocks such as lie disconformably below the Prospect Mountain quartzite and its correlatives in the northeastern Great Basin (Misch and Hazzard, 1962; and (3) Paleozoic rocks.

Beltian rocks are exposed as far south in Idaho as the Lemhi Range, about 50 miles northeast of the Pioneer Mountains. To establish some basis for comparison, typical Beltian rocks were briefly examined and sampled in the Little Belt Mountains, Glacier National Park, Flathead, Superior and Missoula regions of western Montana, and in the St. Regis and Orofino areas of Idaho. No specific section examined or described in the literature (esp. Ross, 1963d) quite fits the lithologic succession of the Hyndman or East Fork Formations. Beltian rocks generally contain a much higher proportion of argillaceous material concentrated in thick shale beds. Quartzite and carbonate units tend to be purer than quartzitic and carbonate-rich members of the Hyndman Formation and thicker than members of the East Fork Formation. However, lithologies from which the metasedimentary could have been produced are represented in the overall Belt sequence. Unfortunately, facies changes are poorly understood and correlations are dubious even between adjacent unmetamorphosed Belt localities. This makes attempts to correlate metamorphosed equivalents over large distances speculative, at best. Although it is the writer's feeling that these metasedimentary rocks are not metamorphosed Beltian, the possibility cannot be eliminated on the basis of the evidence available.

Uppermost-Precambrian rocks such as disconformably underlie the Prospect Mountain quartzite in Nevada (McCoy Creek Group of Misch and Hazzard, 1962) are considered the most likely correlatives of the Hyndman Formation. The McCoy Creek

Group was briefly examined and sampled at its type locality in the Schell Creek Mountains and in the Northern and Southern Snake Ranges of eastern Nevada. Suitable lithologic equivalents occur in the weakly metamorphosed argillaceous quartzites, argillites and minor calcareous rocks of the type-McCoy Creek Group, but there, as in the Belt Series, the details of the successions differ. Increased carbonate content in some members of a McCoy Creek equivalent section in the Pilot Range, northeastern Nevada (Woodward, 1967), may indicate a transitional facies from carbonate-poor rocks of the type-McCoy Creek to the carbonate-rich members of the Hyndman Formation.

Medium- to high-grade pelitic schist and gneissose quartzite, briefly examined and sampled in the Albion and Raft River Ranges of southern Idaho, bear striking resemblance to respective parts of the Hyndman Formation. The resemblance may simply reflect the similarity of the metamorphic grade in these two regions. The rocks of the Albion and Raft River Ranges are metamorphosed Paleozoic rocks (Misch and Hazzard, 1962; Armstrong, oral communication).

The rocks from which the East Fork Formation was derived are most similar in lithology and stratigraphic sequence to the lower Paleozoic succession in southeastern Idaho. The most likely correlation is with carbonate and quartzite beds of the Cambro-Ordovician St. Charles-Nounan-Garden City-Swan Peak succession (Mansfield, 1927). If the gneissose quartzite of member D can be considered the basal unit of the East Fork Formation, this quartzite probably correlates with the Brigham quartzite (Prospect Mountain in eastern Nevada). Possibly equivalent unmetamorphosed beds of the Bayhorse Dolomite and Kinnikinic Quartzite are exposed in the Bayhorse region less than 30 miles north of the Pioneer Mountains. Detailed re-examination of the critical East Fork units for fossils might shed light on problems of correlation.

Regardless of their exact stratigraphic equivalents, the metasedimentary rocks of the Pioneer Mountains are considered to be essentially autochthonous (or parautochthonous) uppermost-Precambrian and/or lower Paleozoic rocks that underwent post-Ordovician regional, orogenic metamorphism.

WEAKLY METAMORPHOSED PALEOZOIC ROCKS

GENERAL STATEMENT

The weakly metamorphosed Paleozoic rocks of the Pioneer Mountains (Fig. 4) were divided into four formations by Umpleby, et al. (1930): (1) the Ordovician Phi Kappa Formation, (2) the Silurian Trail Creek Formation, (3) the Mississippian(?) Milligen Formation, and (4) the Pennsylvanian through lower Permian Wood River Formation (Fig. 4).

These rocks surround the crystalline core of the Pioneer Mountains (see Fig. 3). Most, if not all, of the Paleozoic rocks are allochthonous. Tectonic emplacement postdates metamorphism.

Argillaceous parts of the Paleozoic succession have been converted to slate and phyllite at most places; calcareous rocks are somewhat recrystallized. Structural and petrologic data suggest that the low-grade metamorphism is a shallow crustal manifestation of the same metamorphic episode that produced high-grade metamorphism in the crystalline core.

The purposes of the discussion to follow are: (1) to describe the Paleozoic stratigraphic framework of the map area, (2) to review some of the stratigraphic problems already recognized in the Pioneer Mountains region, and (3) to discuss some additional problems and implications raised by the current study that are either unrecognized or not widely appreciated.

PHI KAPPA FORMATION

Rocks of the Phi Kappa Formation crop out in a northwest-trending belt five miles wide along the crest of the Pioneer Mountains in the northwestern part of the map area (Fig. 3). The name was originally proposed by Umpleby, et al. (1930) for exposures of black, locally graptolitic argillaceous rocks along Phi Kappa Creek near the middle of the outcrop belt.

In a more detailed study of the Phi Kappa Formation Churkin (1963) described two partly contemporaneous sections in thrust contact. The present mapping of the formation is based partly on the work of Churkin. Local extension of his units appears compatible with the lithologic and structural framework of the area.

Lower-plate rocks of the Phi Kappa Formation are well exposed in steep ridges and glaciated valleys in the northeastern two-thirds of the Phi Kappa outcrop belt, including the type area long Phi Kappa Creek. The rocks consist of black, blocky slate with two prominent light-colored banded quartzite interbeds 200 to 300 feet thick in the upper part. Churkin reports 3000 feet of argillite and quartzite in the lower plate succession. The slate contains sparse and poorly preserved graptolites of middle Ordovician (Caradocian) age throughout. Spotted slate and hornfels occur locally along the margins of a quartz monzonite intrusion near the center of the outcrop belt.

A much thinner upper-plate Phi Kappa succession consists of gray to black shale and slate with locally abundant and well-preserved graptolites ranging in age through the entire Ordovician (Arengian through Ashgillian). About 700 feet of upper-plate argillite is exposed on the ridge between Park Creek and Trail Creek and on the ridge to the north. A small exposure containing upper-plate graptolites near the head of Kane Creek suggests that these rocks extend beneath

overriding Wood River rocks all the way to the southeastern limit of Phi Kappa outcrop.

Fossil lists and more detailed lithologic descriptions have been given by Churkin (1963) and by Ross and Berry (1963).

Nowhere is the base of the Phi Kappa Formation exposed. It is separated from high-grade metamorphic rocks and intrusive rocks along the range crest to the southeast by a high-angle fault. Where the Ketchum-Mackay road passes the ridge north of Big Fall Creek, the lower-plate Phi Kappa rocks grade upward into black, gray-weathering limestone that may correlate with the middle Ordovician Saturday Mountain Formation described by Ross (1937) in the Bayhorse region to the north. Less than 250 feet of carbonate is present owing to tectonic truncation by contorted clastic Upper Paleozoic rocks of the eastern Pioneer Mountains.

Rocks of the upper-plate are considered by Churkin to have been deposited west of the lower-plate rocks. He regards the restriction of quartzite to the lower-plate as an indication of an eastern source area; the quartzite interbeds are considered possible tongues of the thick Kinnikinic Quartzite present to the east.

TRAIL CREEK FORMATION

About 500 feet of rocks which are lithologically similar to the Phi Kappa Formation but contain the Silurian index fossil Monograptus, were named the Trail Creek Formation by Umpleby, et al. (1930). The formation was first described along the southwest side of upper Trail Creek. Additional exposures on the ridges northeast of upper Trail Creek have been recognized by Churkin (1963) (Fig. 3).

The Trail Creek Formation constitutes the upper part of the allochthanous block containing the upper-plate Phi Kappa Formation. Churkin describes a section 300 feet thick on the southwest slope of the ridge between Trail Creek and Park Creek as physically conformable and paleontologically continuous with the underlying upper-plate Phi Kappa shale. At this locality, the graptolites are restricted to the lower 47 feet of the formation, and the uppermost graptolites are Wenlockian in age (see Churkin, 1963, for detailed faunal list). The graptolitic lower portion of the Trail Creek Formation is overlain by 250 feet of unfossiliferous gray calcareous shale and siltstone. Elsewhere, the Monograptus-bearing shale is reported to be associated with quartizitc sandstone, calcareous shale and siltstone, limestone and minor chert interbeds. Possibly some of the diverse lithologies may be unfossiliferous rocks of the adjacent Milligen and Wood River Formations erroneously included in the Trail Creek Formation.

MILLIGEN FORMATION

General Statement

The Milligen Formation, as defined by Umpleby, et al. (1930), consists of carbonaceous siltstone and associated chert beds that predominate in the lower part of Lindgren's original "Wood River Formation". The thickness, age and stratigraphic relations of the Milligen Formation are virtually unknown in the Wood River region owing to extremely poor exposures, extensive deformation, and the near absence of fossils.

Recently the name "Milligen" has been applied to rocks as far east as southwestern Montana (Scholten, et al., 1955). In view of the problems inherent in the type-Milligen, it seems stratigraphically unsound to use the name for rocks in distant or even adjacent areas where continuity of outcrop with the type area cannot be established. The regional stratigraphic relations of the Milligen Formation are a persistent problem of critical significance to any regional integration of the Late Paleozoic history of central Idaho. But until definitive work solves the problems of the type area, attempts at regional integration will be subject to doubt, at best, and may produce misleading mis-correlation and confusion. For this reason, use of the name "Milligen" should be restricted to the Big Wood River and Bayhorse regions of central Idaho where it originally was defined, and where exposures of the Milligen Formation (restricted) are uniform in lithology and essentially continuous over a large area.

Milligen Formation (Restricted)

Rocks of the Milligen Formation (restricted) crop out in a broad northwest-trending belt along the southwestern margin of the map area (Fig. 3). No type area was designated for the formation when it was introduced by Umpleby, et al. (1930). It takes its name from Milligen Creek, just south of the map area, because that locality is ". . . near the center of the largest exposure of the formation . . . ." The very poor exposures of the easily eroded unit along Milligen Creek are typical of the formation throughout its outcrop belt. The rocks form steep, sagebrush-covered ridges that commonly support less forest growth than adjacent slopes carved from calcareous rocks of the Wood River Formation (restricted).

Complexly contorted black, gray-weathering, phyllitic argillaceous rocks predominate. Blocky, gray to black chert interbeds one to several inches thick are common. Subordinate thin, gray limestone, quartzite, and conglomerate interbeds are reported to occur locally in the succession, but only very minor limestone interbeds were observed in the map area. None of the extensive coal beds reported from the formation was encountered during the present mapping. The Milligen Formation (restricted) is distinct lithologically from the Wood River Formation (restricted); it is locally difficult to distinguish black, non-phyllitic Milligen rocks from unfossiliferous black shale and slate of the Ordovician Phi Kappa Formation.

No section of the Milligen Formation (restricted) was measured owing to its complex deformation, extremely poor exposures, and the limited time available for its study. However, a thickness of several thousand feet seems required by the great areal extent and high relief of the outcrop area. The 3000 feet assigned to the Milligen Formation by Umpleby, et al., (1930), was a completely arbitrary figure ". . . for use in tables and columnar sections . . ." (p. 25), and should under no circumstances be regarded as an estimate or approximation of the true stratigraphic thickness.

The age of the Milligen Formation (restricted) is uncertain. Badly broken fragments of possible Devonian fossils were found by Umpleby, et al., (1930), in a brecciated limestone interbed. These remnants are of doubtful stratigraphic value because they may have been derived from pre-Milligen rocks. No fossils were encountered during the present mapping. The Milligen succession was assigned

to the Mississippian by Umpleby, et al., (1930), because (1) the rocks were thought to grade conformably upward into the Pennsylvanian Wood River Formation (restricted), and (2) coal beds as extensive as those reported in the Milligen Formation have not been found in pre-Mississippian rocks. How much of the Mississippian might be represented has never been established. The section where Milligen rocks were reported to grade conformably into the overlying Wood River Formation (Umpleby, et al., 1930) occurs near the head of Lake Creek just west of the map area. This locality was reexamined briefly by the writer and relationships were found to be structurally complex and inconclusive. Thomasson (1963) considers the Milligen-Wood River contact to be an unconformity; he suggests (on the basis of unpublished data) that the Milligen succession may be restricted to Lower Mississippian.

The base of the Milligen Formation (restricted) appears to be a low angle fault in the few places where it can be observed in the map area. A thrust fault mapped by Umpleby, et al. (1930), between the Milligen and underlying Trail Creek Formations on the southwest side of upper Trail Creek was not examined during the present study.

Ross (1937) considers these carbonaceous and argillaceous rocks to have been deposited in shallow restrected basins marginal to a land mass. But the presence of radiolarian chert in the Milligen succession (Thomasson, 1963) suggests that it was at least partially deposited in a deep water environment.

Clastic and calcareous rocks of the eastern Pioneer Mountains may be related in whole or in part to the Milligen Formation (restricted).

WOOD RIVER FORMATION

General Statement

The "Wood River Formation" as originally defined by Lindgren (1900, p. 193) included all argillaceous and calcareous rocks of probable Carboniferous age in the drainage basin of the Big Wood River. Umpleby, et al. (1930, p. 25) restricted the name Wood River to the calcareous quartzitic beds that predominate in the upper part of the succession. The lower, argillitic portion of the succession was designated Milligen. Umpleby, et al. (1930) also applied the name Wood River to coarsely clastic and calcareous rocks in the eastern Pioneer Mountains. This geographic extension of the name appears to have been premature, if not unwarranted, for the following reasons:

(1) The interbedded conglomerate, gritty sandstone, shale and limestone of the eastern Pioneer Mountains constitute a more clastic, continental or nearer-shore marine assemblage distinct from the shallow marine calcareous-quartzose rocks in the Wood River region to the west.

(2) The stratigraphic relations between the eastern Pioneer Mountains rocks and those of the Wood River region are unknown, but the distinction between them occurs near the crest of the range.

(3) The present mapping suggests that major structural complications may obscure stratigraphic relations over the entire area.

(4) The age of the rocks in the eastern Pioneer Mountains, at least within the area mapped by Umpleby, et al. (1930), has not been established.

In view of these uncertainties, it seems desirable to discontinue use of the name Wood River in the eastern Pioneer Mountains. These rocks will be referred to and treated separately below as "Coarsely-Clastic and Calcareous Rocks of the Eastern Pioneer Mountains". The Wood River Formation as so restricted refers only to rocks of the Big Wood River drainage basin where the formation was first described, and where its lithology is essentially uniform over a large area.

Wood River Formation (Restricted)

Rocks of the Wood River Formation (restricted) crop out in the upper plate of an extensive northwest-trending thrust belt that transects all older rock units on the west side of the Pioneer Mountains (Fig. 3). The rocks typically form steep slopes on which outcrops are extensively covered by sliderock, surface rubble, and vegetation. Particularly resistant beds locally are exposed as bold ledges. At such places, the section appears to dip homoclinally southwest at a moderate angle. However, small isoclinal folds observed in favorable exposures suggest that such structures are more common in the unit than may appear. The best exposures within the map area are in the steep canyon of Trail Creek and along the high cirque divide between the Lake Creek-Eagle Creek drainage and upper Trail Creek.

The Wood River Formation (restricted) is primarily composed of a monotonous succession of gray to tan, tan-weathering, thick- to medium-bedded sandy limestone or calcareous sandstone that through most of its considerable thickness contains no obvious marker beds. Poorly preserved fusilinids were found locally, but in insufficient quality and frequency to be a stratigraphic aid. Prominent chert-quartzite breccia and gray crinoidal limestone beds of variable thickness mark the base of the formation. Distinctive orange- to maroon-weathering siltstone with worm trails on irregular, slabby partings characterizes the formation near the crest of the range. The siltstone may correspond to Thomasson's (1959) Wolfcampian member of the Wood River Formation. On the ridge between Hyndman and Corral Creeks (Pioneer Cabin area), rocks referred to the Wood River Formation include massive quartzite similar to the structurally underlying quartzite of metasedimentary member H. The quartzite appears to be concordant with and lie stratigraphic above the crinoidal limestone beds. If it is Wood River, the quartzite is an unusual phase that has undergone extensive recrystallization, possibly representing an extension of a prominent contact metamorphic zone found to the east. However, it is possible that some rocks of member H are erroneously included with the Wood River at this place.

No section of the Wood River Formation (restricted) was measured owing to: (1) the absence of a recognizably complete and continuous section, (2) the absence of suitable marker beds, (3) the probability of unrecognized isoclinal folding throughout the unit, and (4) complications by faulting. However, from map patterns and relief at the Trail Creek and upper Lake Creek sections, several thousand feed were estimated to be present. The composite thickness of 7700 feet reported by Umpleby, et al. (1930, p. 29) is disregarded because of their inability to exclude structural effects from the measurements, and because a section of coarsely clastic and calcareous rocks measured in the eastern Pioneer Mountains (and not a proper part of

the Wood River Formation as here restricted) is included in their composite section.

The age of the Wood River Formation (restricted) has been established near Bellevue, 10 miles south of the map area, by Bostwick (1955) as Pennsylvanian (Desmoinesian) through lower Permian (Wolfcampian) on the basis of fusilinids.

At most places, a low-angle thrust fault can be demonstrated to separate upper-plate Wood River rocks from lower-plate rocks ranging from probable Upper Precambrian metasedimentary strata to the Silurian Trail Creek and Ordovician Phi Kappa Formations. The relation with the Mississippian (?) Milligen Formation is more obscure. The "gradational and conformable contact reported by Umpleby, et al. (1930, p. 28) in the Lake Creek area has already been questioned as inconclusive. In all other places, contorted Milligen rocks are separated from less deformed Wood River rocks by a low-angle thrust fault. Additional detailed work will be required to determine if this fault is an unconformity along which movement occurred as the Milligen and Wood River Formations (restricted) moved together as an allochthonous block, or a zone of major displacement of Wood River rocks over Milligen.

The Wood River Formation (restricted) is unconformably overlain by Tertiary Challis volcanic rocks.

The depositional environment of the Wood River rocks has been the object of considerable speculation. By analogy with north-central Nevada, Roberts and Thomasson (1963) suggest that they were formed from an apron of detritus spreading west into a shallow marine environment from a positive area near the present position of the Pioneer Mountains. These rocks constitute the upper, allochthonous part of their "Ketchum Sequence" which they regard as having been thrust eastward onto the source area from a depositional basin to the west. This conflicts with an earlier study of facies and sedimentary structures by Thomasson (1959a) indicating a western source for the Wood River Formation (restricted). In this writer's opinion, these quartzose-calcareous rocks could only have been derived from the stable continental platform to the east, precluding an intervening positive area in the position of the Pioneer Mountains, at least during Wood River time. The basal chert-quartzite breccia, on the other hand, was probably a clastic tongue from a positive area further to the west.

COARSELY-CLASTIC AND CALCAREOUS UPPER PALEOZOIC ROCKS OF THE NORTHEASTERN PIONEER MOUNTAINS

General Statement

Coarsely-clastic and calcareous rocks crop out northeast of the range crest (Figs. 3 and 4). They typically form steep ridges mangled with dark-brown, tan-weathering sliderock. Good exposures occur along both sides of lower Summit Creek north of the confluence of Phi Kappa and Big Falls Creeks. Descriptions of similar lithologies in the Copper Basin Area (Ross, 1960) and the White Knob Mountains (Skipp, 1961a and 1961b), both northeast of the map area, and in Star Hope Canyon (Thomasson, 1959b) near the eastern edge of the map, suggest that related rocks may be distributed over several hundred square miles in the eastern Pioneer Mountains region.

These rocks are known only in reconnaissance. Four lithologies are distinguished: (1) chert-quartzite pebble (locally coarser) conglomerate and breccia, (2) gritty quartzose to greywacke sandstone, (3) dark shale and (4) limestone. The relative proportions of the lithic components and their mutual relations have not been established. Limestone and coarse conglomerate and breccia horizons resemble portions of the Wood River Formation (restricted), but in gross character, the rocks of the eastern Pioneer Mountains contain a greater proportion of coarsely-clastic and argillaceous rocks, and the distribution of these lithologies is more irregular.

No sections were measured, nor estimates of thickness attempted. Umpleby, et al. (1930, p. 29) describe 6700 feet of section on the ridge northeast of the junction of the Big Lost River and its east fork, just north of the map area. The reliability of this figure is doubtful as no detailed measured section was included by the authors, and cursory examination shows some beds to be isoclinally folded.

The exact age of the coarsely-clastic and calcareous rocks is undetermined in the map area because no fossils were found. The succession is designated "Late Paleozoic" entirely on the basis of its lithologic similarity and continuity with adjacent rocks considered (in different places by different investigators) to represent all or part of Late Paleozoic time from Early Mississippian to Early Permian (see below).

The base of the succession is not exposed in the map area. It is separated from the Wildhorse Canyon migmatite complex and Cretaceous intrusive rocks by a fault. The coarsely-clastic rocks truncate northeasterly-dipping Ordovician rocks on the ridges northeast of Phi Kappa and Big Falls Creeks. A critical section that warrants further study occurs on the ridge northeast of the junction of Fall Creek and Wildhorse Creek. At this place, complexly folded gritty sandstone forms the upper plate of a low-angle thrust fault that truncates an eastward-dipping carbonate section several thousand feet thick. The carbonates contain chert nodules and interbeds similar to those of the "Brazer" Limestone to the east; no fossils were found. Thus, at least locally, major thrust faults complicate stratigraphic relations in the eastern Pioneer Mountains. No contact with the Milligen and Wood River Formations (restricted) occurs in the map area. The eastern Pioneer Mountains succession is overlain unconformably by Tertiary Challis volcanic rocks.

Regional Considerations

The rocks in the lower Summit Creek and upper Big Lost River regions of the northeastern Pioneer Mountains originally were referred to the Wood River Formation by Umpleby, et al. (1930). Examination of the succession in adjacent parts of the eastern Pioneer Mountains has resulted in conflicting correlations and recognition of stratigraphic complications.

In the northern part of the map area and in Star Hope Canyon to the east, Thomasson (1959a, available only in abstract) subdivides 10,000 feet of limestone, mudstone and graded greywacke (turbidites) into "four lithologically distinct, accurately dated members" representing "continuous deposition" from Early Mississipian through Early Permian time. He considers them to have been deposited in a

rapidly-subsiding northwest-trending trough receiving coarsely-clastic debris from a Late Paleozoic positive area to the west, and clastic carbonate material from the cratonic shelf to the east. Especially coarse horizons within the succession are considered to record at least three pulses of uplift in the western source area: the first in the Early Mississippian, a second stronger pulse in Late Chester time, and the third in Morrowan-Derryian time. However, from his abstract, Thomasson does not appear to have considered the structural complications recognized by this writer.

Ross (1960) and Skipp (1961a and 1961b) describe complex interfingering and lensing relations of clastic and carbonate rocks in the Copper Basin and White Knob Mountains regions, both northeast of the map area. The Copper Basin Formation is considered by Ross to range in age from Early Mississippian "through" Early Permian. In the White Knob Mountains, an interbedded quartzose clastic and carbonate succession 7365 feet thick is dated by Skipp as Early Mississippian (Osagian) through Late Mississippian (Merrimecian) on the basis of megafossila, endothyrid foraminifera and ostracodes. However, in that locality, an additional 4000 feet of unfossiliferous siliceous shale underlies the known Mississippian rocks.

Lithologic heterogeneity and scarcity of fossils in the rocks of the eastern Pioneer Mountains make determining their exact nature, age and stratigraphic relations one of the most difficult stratigraphic problems of central Idaho. Because these rocks occur between and contain lithic elements of both the Milligen-Wood River assemblage of the western Pioneer Mountains and the shelf carbonate facies of the Lost River Range to the east, the recent trend has been to consider them a Late Paleozoic interfingering facies that is time equivalent to both (Ross, 1960). The true relationship may not be so simple:

(1) A regional study of Late Paleozoic unconformity-bounded sequences by Schleh (1963) presents evidence for a hitherto unrecognized post-Merrimecian to pre-Desmoinesian sequence (designated Crow sequence) that persists across the Cordilleran region from western Colorado at least as far as eastern Nevada and southeastern Idaho. The possibility that such a sequence extends into this part of central Idaho makes it essential that age ranges and correlations based on any but the most convincing paleontological and stratigraphic evidence be avoided in this critical part of the Late Paleozoic column. Such evidence has been published only by Skipp (1961a and 1961b), in the White Knob Mountains.

(2) The present mapping indicates that stratigraphic relations throughout the Pioneer Mountains are complicated by thrust faults of uncertain, but possibly great, magnitude. The resulting stratigraphic telescoping is at least partially responsible for abrupt east-west Upper Paleozoic facies changes across this part of central Idaho. Most, if not all, of the Paleozoic rock units of the western Pioneer Mountains are allochthonous. Displacement of intensely folded clastic rocks of the eastern Pioneer Mountains may have been at least as great. In any case, the eastern Pioneer Mountains succession cannot be <u>assumed</u> to be autochthonous.

(3) The eastern Pioneer Mountains assemblage should not be correlated with the Milligen-Wood River succession in the Wood River region until the mutual stratigraphic and structural relations of these two formations can be determined with confidence.

(4) Possibly one or more of the foregoing relationships applies in different parts of the eastern Pioneer Mountains.

The purpose of this discussion has been to emphasize the potential stratigraphic and structural complexity of the eastern Pioneer Mountains. Future stratigraphic studies in the area must be supported by accurate paleontological data and sound structural analysis, if the results are to be meaningful. Moreover, until the exact stratigraphic and structural framework of the eastern Pioneer Mountains is established, attempts to reconstruct the Late Paleozoic history of central Idaho will be premature.

SUMMIT CREEK BRECCIA

Massive chert-quartzite breccia and laminated quartzite, about 800 feet thick and one square mile in area, cap the ridge between upper Summit and Wilson Creeks in the west-central part of the map area (Fig. 3). The breccia warrants separate treatment in view of the significance attached to it by Roberts and Thomasson (1964) following a reconnaissance study.

Dark- to light-colored chert and white quartzite fragments predominate in the breccia; argillaceous and calcareous fragments are less common. Lithologies of the fragments resemble elements of the Milligen Formation (restricted). The fragments commonly are six inches to a foot across; blocks three to four feet in diameter occur locally. White, vitreous "sparkling" quartzite with laminations that dip 15° to 30° SW forms the matrix in places. Except for its greater coarseness and thickness and its association with laminated quartzite, the breccia resembles chert-quartzite conglomerate and breccia horizons in both the Wood River Formation (restricted) and the coarsely-clastic rocks of the eastern Pioneer Mountains.

The breccia is fractured, shattered and locally brecciated at its base. The breccia extends slightly further down the southwest side of the ridge than it does on the northeast, suggesting that its brecciated base has a gentle southwest dip parallel to the laminations of its quartzite matrix. On the northeast side of the ridge, the breccia is separated from the underlying Phi Kappa Formation by a poorly exposed disturbed zone about 200 feet thick. This zone contains mostly dark, but locally tan-weathering shale which is pulverized and silicified in places, and associated with black gouge such as characterizes many fault zones in the map area. The tan siltstone member of the Wood River Formation (restricted) crops out below the massive breccia on the southwest side of the ridge.

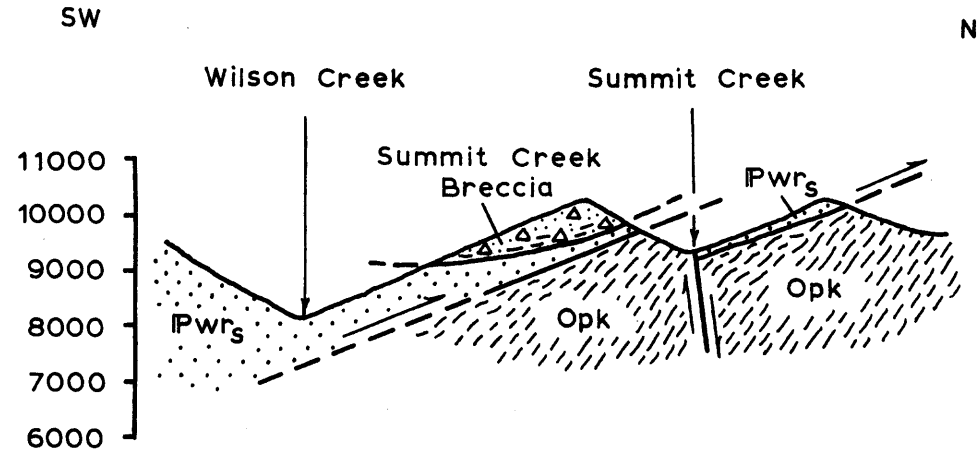
Field relations indicate that the Summit Creek Breccia nearly truncates a thrust fault between the Wood River siltstone and underlying Phi Kappa rocks that comes to the surface on the northeast side of the ridge just below the base of the breccia. Deformation at its base supports the idea that the breccia is a klippe (Fig. 21, A). Moreover, the steep southwest slope of the ridge and the relatively gentle southwest dip of the rocks make it geometrically difficult, if not impossible, to interpret the Wood River siltstone as being thrust over the breccia as first reported by Umpleby, et al. (1930) and adopted by Roberts and Thomasson (1964) (Fig. 21, B). The breccia is tentatively regarded as a klippe of unusually coarsely-clastic rocks of the northeastern Pioneer Mountains succession, but it might be a remnant of a higher structural level of the Wood River Formation (restricted).

The implications of this structural re-interpretation are significant in that:

(1) The breccia is not an autochthonous block of orogenic sediment deposited essentially in place and consequently cannot be considered to mark the position of a late Paleozoic positive area as suggested by Roberts and Thomasson (1964).

(2) Structural relations in the Summit Pass area do not support the idea that Wood River rocks of a "Western Facies Ketchum Sequence" have been thrust eastward over coarse breccia of a "Transition Facies" that marks an orogenic belt.

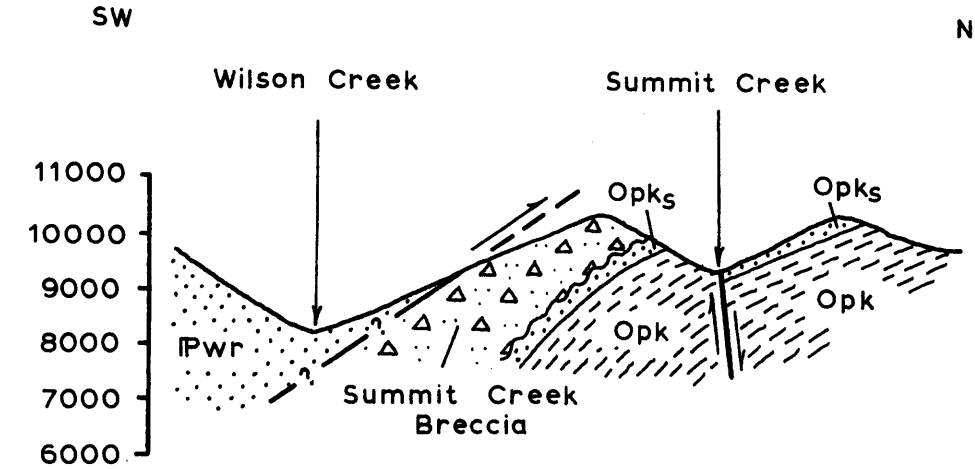
(3) The breccia is an allochthonous block or klippe that could be part of either the Wood River Formation (restricted) or the coarsely-clastic succession of the eastern Pioneer Mountains. If the latter, it would strongly indicate that at least part of the rocks of the eastern Pioneer Mountains tectonically overlie the allochthonous rocks of the western Pioneer Mountains.



PPwrs Tan siltstone member of the Wood River Formation

Opk Shale and slate of the Phi Kappa Formation

A. Allochthonous relations of the Summit Creek Breccia as interpreted in this report.



PPwr Wood River Formation

Opk Phi Kappa Formation

Opks Tan siltstone member of the Phi Kappa Formation

B. Interpretation originally proposed by Umpleby, et al. (1930) and adopted by Roberts and Thomasson (1964).

Figure 21. Stratigraphic and structural relations of the Summit Creek Breccia.

SYNOROGENIC CRETACEOUS INTRUSIVE ROCKS OF THE PIONEER MOUNTAINS PLUTON

INTRODUCTORY STATEMENT

Gneissose and granitic rocks occupy 75 square miles in the heart of the Pioneer Mountains. The predominantly metasedimentary origin of the layered migmatites in the core of the crystalline complex has already been discussed in Chapter II. The partly gneissose plutonic rocks that nearly surround the migmatites are to be considered here.

AREAL DISTRIBUTION

The plutonic rocks form an intrusive sheet that separates the Wildhorse Canyon migmatite complex from overlying metasedimentary rocks. The pluton has an arcuate outcrop belt that occupies about 50 square miles. The belt widens from one mile at the apex of the arc near the head of the East Fork of the Big Wood River to six miles on the northeast flank of the arc in the Broad Canyon area (Fig. 3). The pluton is well exposed along the crest of the Pioneer Mountains and in the rugged interior of the northeastern part of the range.

GENERAL DESCRIPTION

The granitic rocks range in composition from clinopyroxene-hornblende-biotite quartz diorite and mafic granodiorite to leucocratic hornblende-biotite quartz monzonite (Figs. 22, 23 and 24). The mineral constituents and paragenetic sequence of these various rocks are identical except for the restriction of minor clinopyroxene to the quartz dioritic and mafic granodioritic rocks. Small bodies approaching pyroxenite in composition are locally associated with the quartz diorite.

The rocks are coarse-grained and range from even-grained and moderately strongly gneissose to directionless and coarsely porphyritic. The gneissose structure is marked by aligned mafic minerals. K-feldspar and quartz constitute the megacrysts of the coarsely porphyritic phase.

Although the plutonic rocks vary considerably in composition and texture from place to place, these variations are gradational and the rock is quite homogeneous at any one locality. The subtle gradations occur over distances of several miles. Sampling during the present study permits delineation of the major compositional varieties only within very wide limits. However, there is a general transition from west to east across the outcrop belt from the gneissose quartz diorite - mafic granodiorite phase to the directionless quartz monzonite phase. Deviations from this trend occur locally. All of these rocks are considered to have been emplaced during a single intrusive event.

FIELD RELATIONS

Field evidence establishes the intrusive character of the granitic rocks. They show clear cross-cutting relations with the two adjacent metamorphic units. Fault contacts separate the plutonic rocks from all other map units.

The intrusive contact with the underlying Wildhorse Canyon migmatites is

irregular but generally sharp. Little or no reaction has occurred along this contact, probably owing to the low reactivity of the country rocks.

The contact with the overlying metasedimentary rocks is much more variable. The contact with gneissose quartzite members is sharp; only small, irregular granitic apophyses project into the quartzite. Near the main intrusive mass, the banded calc-silicate member is characterized at most places by thin- fine-grained granitic layers parallel to the banding. The contact with the pelitic schist member is marked by abundant sills and lenses of intrusive material and by a wide assimilation zone containing lenticular schist inclusions and schlieren in all stages of digestion (Fig. 25). Some andalusite schist inclusions contain late fibrolite that probably reflects a pressure increase rather than a temperature rise. The pressure increase may mark a time when the pluton achieved a degree of consolidation sufficient to transmit shearing stresses. Huskier sillimanite needles also occur in the feldspar of intrusive material within a few centimeters of the schist inclusions (Fig. 26). This sillimanite crystallized under metamorphic conditions either from alumina released from pelitic schist assimilated in situ, or from alumina that migrated from adjacent inclusions. A variety of hybrid rocks and feldspathized schistose cognate inclusions also occurs in the assimilation zone.

Assimilation zone. In the assimilation zone occur all gradations between (1) fresh and andalusite-muscovite-biotite schist with incipient retrogression of andalusite to muscovite and biotite to chlorite, (2) feldspathized schist with more advanced andalusite alteration and incipient segregation of biotite, and (3) hybrid igneous rocks enriched in quartz and having somewhat higher color index than usual. The hybrid rocks contain small biotite schlieren up to a few cms. long which are "basified" schist remnants; a few muscovite pseudomorphs after andalusite are also preserved. Schist-derived tourmaline occurs in the hybrid rocks. Faint "ghosts" of nearly digested leucocratic schist lenses can be detected in the pluton near the assimilation zone.

Fibrolite stringers clearly cross-cut and therefore postdate poikioblastic andalusite in some schist inclusions; in other samples retrogressive muscovite around andalusite obscures the fibrolite relationship. Sillimanite occurs in adjacent intrusive rocks as radiating needles and as needles aligned along crystallographic directions in plagioclase.

Schistose leuco-biotite amphibolite occurs locally in the assimilation zone. Lenticular clusters of small hornblende grains aligned along the schistosity may represent breakdown of larger crystals. The amphibolite contains large feldspar porphyroblasts with identical composition (An30 to An40), euhedral oscillatory zoning and blocky growth twinning as adjacent igneous feldspar. Some samples contain 5-10 per cent of plagioclase porphyroblasts. Irregular zones of amphibolite with lower color index give the rock a mottled appearance. The amphibolite is probably an early border phase of the pluton that underwent extensive metamorphic recrystallization and later incipient felspathization related to intrusions.

A "giant breccia zone" is spectacularly displayed in the cirque at the head of East Fork Canyon (Fig. 12). Huge blocks and aligned slabs up to 1500 feet long of dolomitic marble and reddish-weathering quartzitic schist are surrounded and injected by the

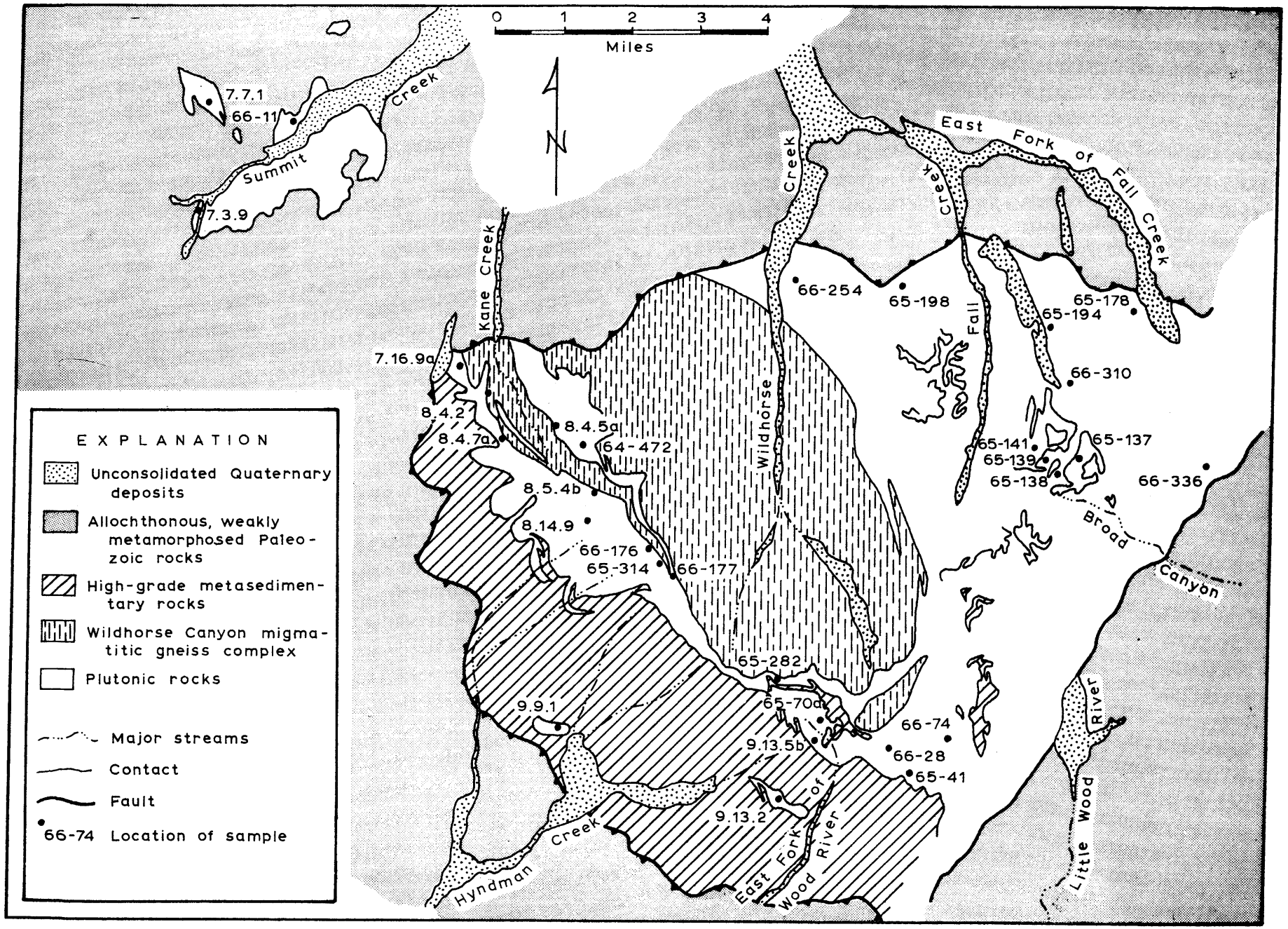


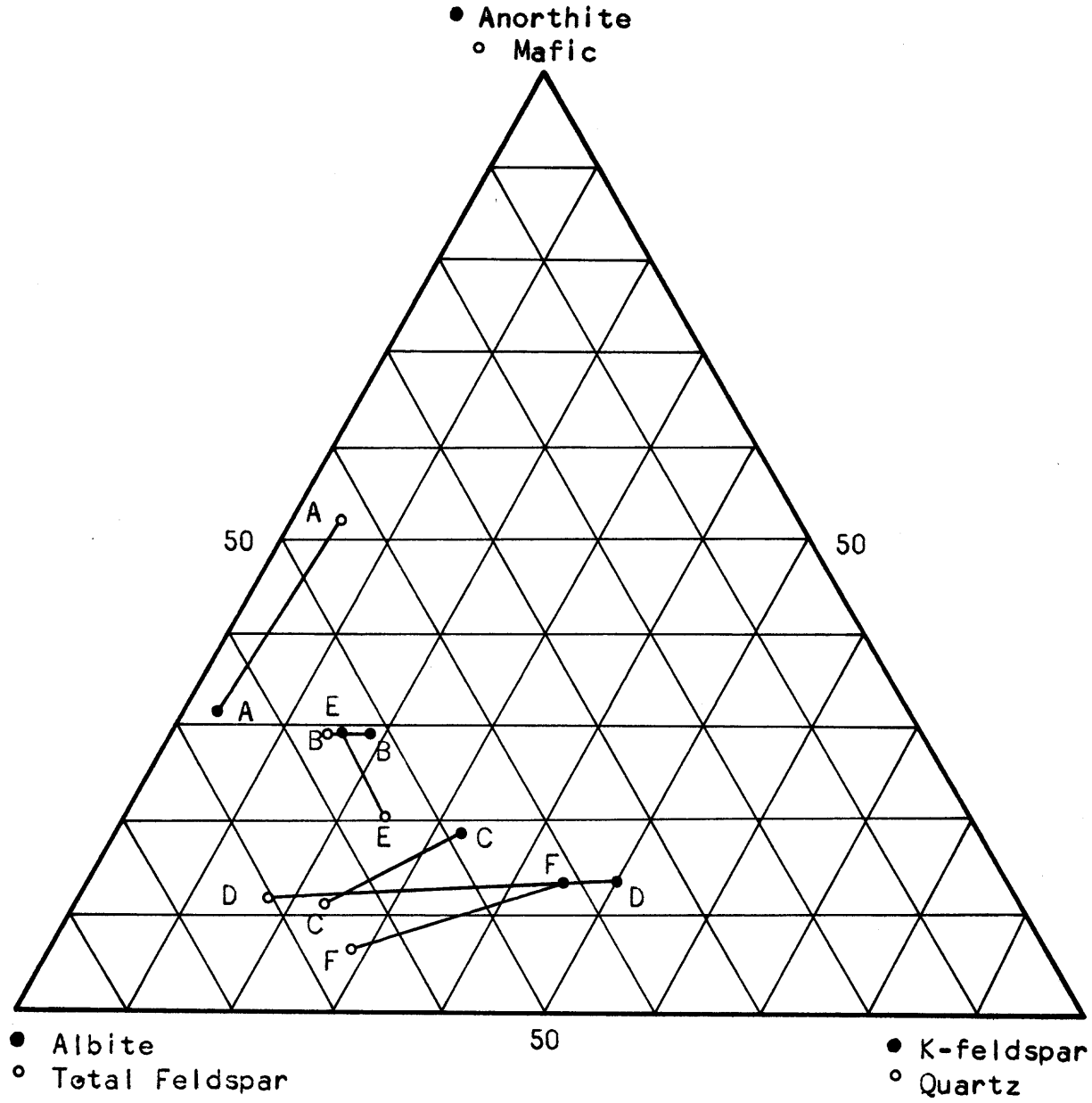
Figure 22. Distribution of samples of plutonic rocks in the Pioneer Mountains

FIELD DESIGNATION (*) indicates thin-sections examined	66-177*	65-282*	7.16.9a	8.4.2	8.4.5*	8.4.7a*	64-472*	8.5.4b*	8.14.9	65-314*	66-176*	66-254	66-198	65-194*	9.13.5b	65-138*	65-178*	65-70a	66-28*	65-41*	66-74*	66-310	65-139	66-336*	65-137*	65-141*	66-11*	7.7.1*	7.3.9*	9.9.1*	9.13.2*
MINERAL COMPOSITION																															
Quartz	5	5	11	8	13	18	12	12	11	19	16	18	20	20	23	25	21	10	12	20	19	29	13	27	21	29	27	35	30	25	30
Total Feldspar	35	50	50	62	55	42	57	58	58	63	59	54	59	56	62	68	68	73	72	70	68	62	79	64	57	53	65	60	65	70	65
Mafic	60	45	39	30	32	40	31	30	31	18	25	28	21	24	15	7	11	17	16	10	13	9	8	9	22	18	8	5	5	5	5
AVERAGE PLAGIOCLASE COMPOSITION (% An)	40	38	35	35	35	35	32	35	35	32	33	35	35	35	25	25	28	30	25	30	22	30	30	28	35	35	25	25	25	25	20
FELDSPAR PERCENT OF WHOLE ROCK																															
Anorthite	14	18	14	19	16	13	27	14	17	16	14	16	17	15	11	12	12	10	9	8	8	11	12	10	15	17	10	9	10	9	6
Albite	21	30	26	34	29	24	25	27	31	35	29	29	31	27	32	34	32	24	27	17	29	27	27	25	29	31	28	26	30	26	24
K-feldspar	--	2	10	9	10	5	5	17	10	12	16	9	11	14	19	22	24	39	36	45	31	24	40	29	13	5	27	25	25	35	35
Total	35	50	50	62	55	42	57	58	58	63	59	54	59	56	62	68	68	73	72	70	68	62	79	64	57	53	65	60	65	70	65
FELDSPAR PERCENT OF TOTAL FELDSPAR																															
Anorthite	40	36	28	31	29	31	47	24	29	25	24	30	29	27	18	18	18	14	12	11	12	18	15	16	26	32	15	15	15	13	9
Albite	60	60	52	54	53	57	44	47	54	56	49	53	53	48	51	50	47	33	38	25	43	43	34	39	51	59	44	44	47	37	37
K-feldspar	--	4	20	15	18	12	9	29	17	19	27	17	18	25	31	32	35	53	50	64	45	39	51	45	23	9	41	41	38	50	54
DEGREE OF GNEISSOSE STRUCTURE DEVELOPMENT	d	d	w	w	s	m	s	w	m	s	s	s	m	w	ms	m	w	m	ms	ms	w	vw	d	d	d	d	d	d	d	d	w

d - directionless vw - very weak w - weak m - moderate ms - moderately strong s - strong

Summary of data illustrated in Larsen variation diagram (Fig.)	A	B	C	D	E	F
	Ave. 2 samp. qtz. dior.	Average of 12 samples of mafic granodiorite	Ave. 3 samples leuco-grano-diorite	Average of 7 samples of quartz monzonite	Ave. 2 samp. cogn. incl.	Average of 5 samples of post-orogenic qtz. monzonite
	Q 3	Quartz 15	Q 23	Quartz 18	Q 25	Quartz 29
	TF 43	Total Feldspar 56	TF 66	Total Feldspar 70	TF 55	T.F. 65
	M 52	Mafic 29	M 11	Mafic 12	M 20	Mafic 6
	An 38	Anorthite 29	An 18	Anorthite 14	An 29	Anor. 13
	Ab 60	Albite 52	Ab 49	Albite 36	Ab 55	Alb. 42
	K 2	K-feldspar 19	K 33	K-feldspar 50	K 16	K-spar 45

Figure 23. Tabulated data on compositional and textural variations in the granitic rocks of the Pioneer Mountains. Modes determined by point counts on stained slabs.



A Gneissose quartz diorite
B Gneissose mafic granodiorite
C Weakly gneissose leucocratic granodiorite
D Weakly gneissose to directionless porphyritic quartz monzonite
E Granodioritic cognate inclusions

} Late-synorogenic rocks of the Pioneer Mountains Pluton

F Post-orogenic quartz monzonite intrusions

Figure 24. Larsen diagram showing compositional variation of granitic rocks in the Pioneer Mountains (based on data tabulated in Fig. 23).

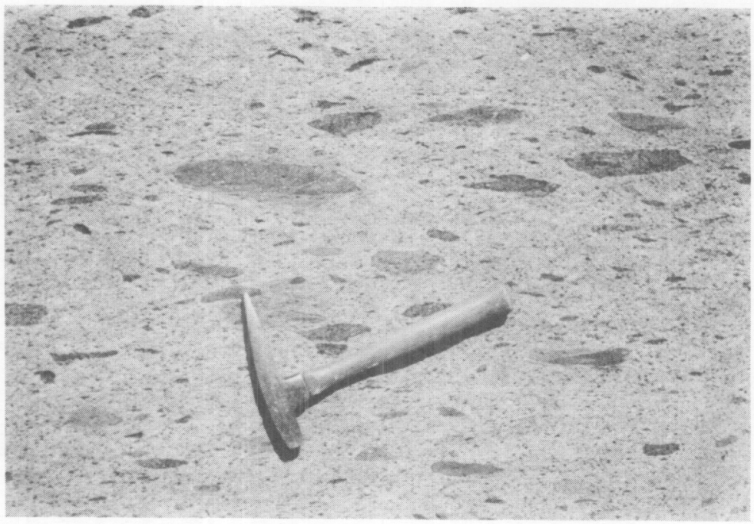


Figure 25. Partially digested lenticular inclusions of pelitic schist (metasedimentary member A) in assimilation zone of the Pioneer Mountains pluton at the head of East Fork Canyon.

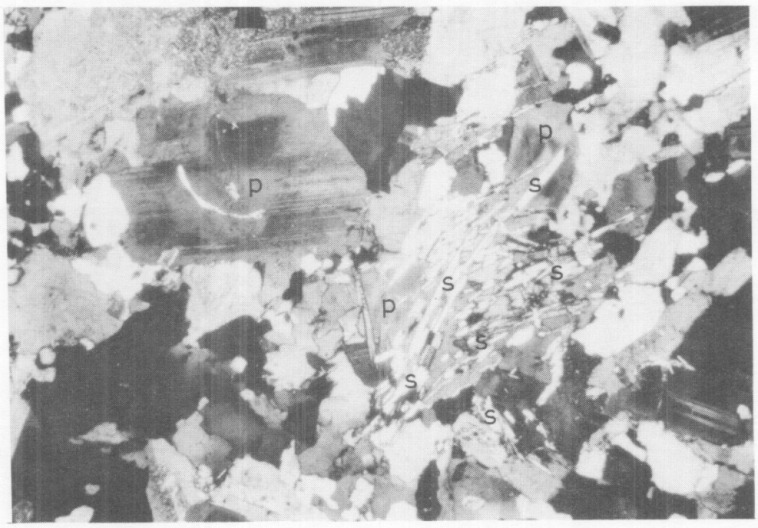


Figure 26. Photomicrograph of acicular sillimanite (s) in plagioclase (p) of intrusive granitic material within the assimilation zone. The sillimanite crystallized under metamorphic conditions either from Al_2O_3 released from pelitic schist by assimilation in situ, or from Al_2O_3 that migrated from adjacent schist inclusions. (Crossed nicols, X 25)

granitic rocks. The colorful metamorphic blocks are visible from a great distance in the uniform light gray color of the granitic matrix.

PETROGRAPHY

In thin sections, all compositional and textural varieties of the pluton display obvious igneous features. Typical plagioclase textures indicative of igneous origin include: (1) synneusis texture, (2) euhedral to subhedral oscillatory zoning superimposed on a normal trend, (3) patchy zoning and associated filling of resorption cavities with poikilitic inclusions of late-magmatic quartz, K-feldspar and biotite, and (4) blocky primary growth twinning. Mafic minerals exhibit the Bowen reaction sequence: clinopyroxene → ferrohastingsitic hornblende → biotite. Glomeritic clusters of mafic and accessory minerals are common.

The igneous fabric of all of the rock varieties has been modified to a greater or lesser degree by cataclasis and recrystallization in the solid state. Weak to moderately strong cataclasis produced broken crystals and, locally, pronounced microshear zones and mortar consisting mostly of quartz and plagioclase. Abundant glide twinning in plagioclase suggests that much additional movement has been absorbed within crystals. Samples that have undergone cataclasis show all degrees of healing by quartz recrystallization and development of K-felspar megacrysts. In incipient stages of healing, small groups of mortar quartz granules about 0.05 mm. in diameter coalesce to form a mosaic of larger sutured grains averaging 0.5 to 1.0 mm. in size. In more advanced stages of healing, the presence of former mortar is demonstrated by recrystallized lenticular zones and stringers containing large elongated quartz grains. Recrystallized mortar is invariably associated with and occasionally cuts through broken primary crystals.

Quartz. Quartz constitutes up to 30 per cent of the granitic rocks. Quartz locally replaces plagioclase. Some quartz phenocrysts are rounded and equidimensional. Quartz is locally abundant in myrmekite.

Plagioclase. Plagioclase commonly exhibits simple, normal, euhedral to subhedral zoning with a maximum composition range from calcic andesine (An47) to calcic oligoclase (An27). Up to five thin delicate euhedral oscillations are locally superimposed on the normal zoning trend. Incipient sericitization of relatively calcic cores is common; sericitization is extensive in a few sections. Small grains of pistacite are locally related to plagioclase alteration. In many sections, patchy zoning is associated with small blocky inclusions of quartz, K-feldspar and biotite. The inclusions may have crystallized from late-magmatic fluids trapped in resorption cavities. Some plagioclase has cloudy albitized margins.

Microcline is by far the most common K-feldspar in the plutonic rocks; perthitic orthoclase occurs locally and appears to pre-date microcline. Both varieties of K-feldspar are typically poikilitic and replace plagioclase (Fig. 27). Textural criteria for replacement include: (1) systematic parasitic invasion of host plagioclase along cleavages, fractures, grain boundaries, or other zones of weakness, (2) isolated remnants of optically and texturally continuous host plagioclase within

the K-feldspar, and (3) cross-cutting relations of replacing K-feldspar with pre-existing cataclastic zones in the plagioclase and/or in the host rock. K-feldspar occurs interstitially and as megacrysts which form Carlsbad and Baveno twins. The megacrysts attain a maximum size of 1 cm. The microscopic evidence indicates that K-feldspar crystallized late in the history of the pluton. It is probably a late-magmatic and deuteric mineral that continued to crystallize after the bulk of the rock was solid.

K-feldspar. The K-feldspar:plagioclase ratio in the plutonic rocks ranges from about 7 per cent through 75 per cent. Most microcline ($2V_x=80^o$) has characteristic grid twinning; perthitic orthoclase ($2V_x=70^o$) is subordinate. Borders of replacement K-feldspar commonly are marked by myrmekite. In one stained slab, impoverishment of K-feldspar in a zone about 1 cm. wide around a microcline megacryst suggests local migration toward a growth center. In one section, microcline exhibiting typical replacement textures also shows euhedral oscillatory zoning. This zoning may have been produced by some poorly understood solid diffusion or ionic transfer mechanism rather than by crystal growth.

The time relation between cataclasis and growth of K-feldspar varies considerably from section to section. In some rocks, the K-feldspar is just as broken, sheared and granulated by cataclasis as quartz and plagioclase. In other samples, however, essentially undeformed K-feldspar megacrysts appear to have grown across pre-existing mortar, at some places selectively replacing the mortar. At such places, cataclasis may have facilitated movement of deuteric fluids and favored localization of K-feldspar in the mortar. Locally megacrysts of K-feldspar are aligned parallel to the gneissose structure. It appears that cataclasis and crystallization of deuteric feldspar proceeded essentially simultaneously, with one preceding the other at a given locality.

The gneissose structure of the granitic rocks is marked by thin glomeritic stringers of mafic and accessory minerals and by parallel alignment of second-generation recrystallized biotite(biotite II) that post-dates the primary igneous reaction series: clinopyroxene → ferrohastingsitic hornblende → biotite I. The aligned biotite II also post-dates cataclasis and is therefore latest-kinematic (Fig. 28).

Mafic minerals. Thin sections of quartz diorite and mafic granodiorite contain highly sieved remnants of clinopyroxene that has been partially converted under magmatic conditions to ferrohastingsitic hornblende. The hornblende in turn has undergone very minor alteration to brown biotite I. All of these reaction products are pre-cataclasis. Second generation biotite (biotite II) occurs as large, only slightly bent flakes that cut across mortar zones. Biotite II is extensively altered to penninite in some sections.

Accessory minerals. Sphene, apatite, magnetite, monazite, zircon, pistacite, allanite, and muscovite occur in accessory amounts. The accessory minerals commonly are associated with glomeritic clusters of mafic minerals.

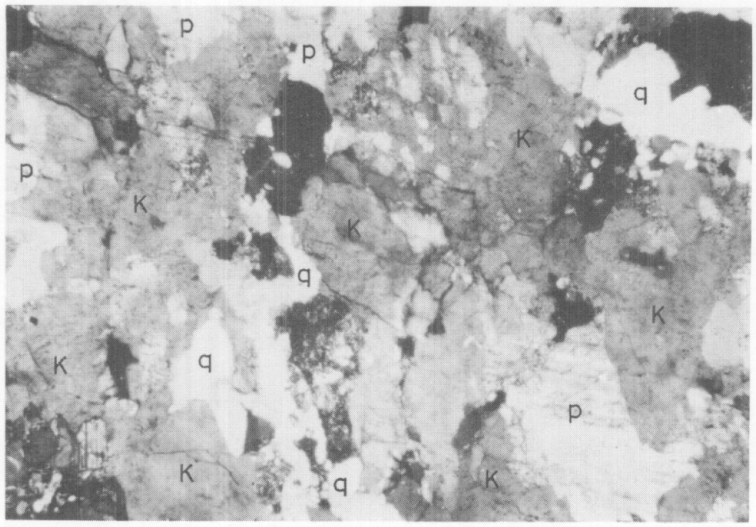


Figure 27. Photomicrograph of irregular post-cataclastic K-feldspar mass (K) replacing plagioclase (p) and granulated quartz (q) aggregate in quartz monzonite of the Pioneer Mountains pluton. (Crossed nicols, X 25)

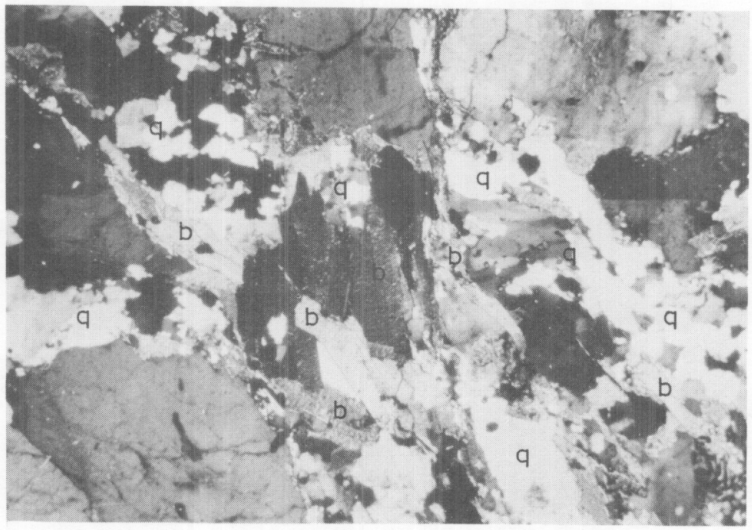


Figure 28. Photomicrograph of essentially undeformed biotite II (b) growing across partly recrystallized quartz mortar (q) in granodiorite of the Pioneer Mountains pluton. The post-cataclastic biotite II grew in a solid state under metamorphic conditions. (Crossed nicols, X 25)

All of the minerals in the plutonic rocks, including recrystallized mortar quartz, post-cataclastic K-feldspar megacrysts and biotite II, exhibit minor crystal bending. This final relatively weak deformation may reflect a final readjustment after nearly complete consolidation of the intrusive body.

COGNATE INCLUSIONS

In the upper Broad Canyon, Surprise Valley and Fall Creek areas, relatively dark, fine-grained irregular masses of granodiorite are surrounded by more leucocratic phases of the main intrusive mass. Included masses several thousand feet across can be distinguished in the field and on aerial photographs on the basis of color. Although the color distinction appears sharp from a distance, closer examination shows the boundaries of the inclusions to be gradational with the surrounding more leucocratic rocks. The mineralogy and nearly directionless texture of the inclusions resemble those of the main intrusive body in that area in gross aspect, but in detail, the inclusions have: (1) higher color index, (2) finer grain size, (3) abnormally high sphene content (up to 1 per cent), (4) slightly more calcic plagioclase compositions (ranging to a maximum of An55), and (5) a relatively low K-feldspar content. These inclusions appear to be large blocks of a marginal phase of the intrusion that were incorporated in the main intrusive body. A somewhat more advanced state of consolidation may have retarded the introduction of late-magmatic and deuteric K-feldspar in these cognate inclusions.

Small xenoliths averaging one foot in length occur as lenticular bodies scattered sparsely throughout marginal portions of the pluton and as layers and lenses in the assimilation zone along the upper intrusive contact. The zenoliths contain plagioclase with a composition of An25 to An35, hornblende, biotite and up to 2 per cent sphene. Quartz is minor or absent. These moderately well-foliated inclusions contain lenticular clusters of small hornblende grains that may have formed by breakdown of larger hornblende or pyroxene crystals. The lenticular hornblende clusters parallel the gneissose structure of the pluton. The xenoliths are probably cognate inclusions.

LATE- TO POST-INTRUSIVE DIKES

Directionless diorite dikes cut the granitic rocks in the eastern part of the pluton. The diorite contains 25 per cent of poikilitic augitic? clinopyroxene, 10 per cent of green-brown, lath-shaped hornblende, 10 per cent of biotite and 50 per cent of extensively sericitized plagioclase with subhedral normal zoning from An47 to An25. Sphene and acicular apatite occur in accessory amounts.

Irregular networks of post-diorite aplite and granite pegmatite dikes occur in the pluton and throughout the metamorphic country rocks. These injections are a few inches or less in width. They crystallized from volatile-rich late-magmatic fluids related to the main Cretaceous pluton or later Tertiary intrusions.

CONTACT METAMORPHISM

Except for minor feldspathization of schist and cognate inclusions in assimilation zones, contact metamorphic effects appear to be absent around the pluton. Neither static contact minerals nor systematic retrogression were observed in the metamorphic rocks along the intrusive contacts.

JOINTS

Poles to 177 joints in the pluton define at least five joint sets listed in order of decreasing prominence: N60W, 35NE (sheeting); N45E, steep (highly variable); N10W, 85NE; N65W, 80SW; and N20W, 55SW (Fig. 29). Rose diagrams on Plate I show the orientation of joints measured from aerial photographs in parts of the pluton not examined in detail in the field. Joints in the pluton probably formed at the same time and in the same stress field as those in the Wildhorse Canyon migmatite domes (see Chap. II and Fig. 11H); small variations in attitude reflect differences in composition and internal structure between these two major rock units.

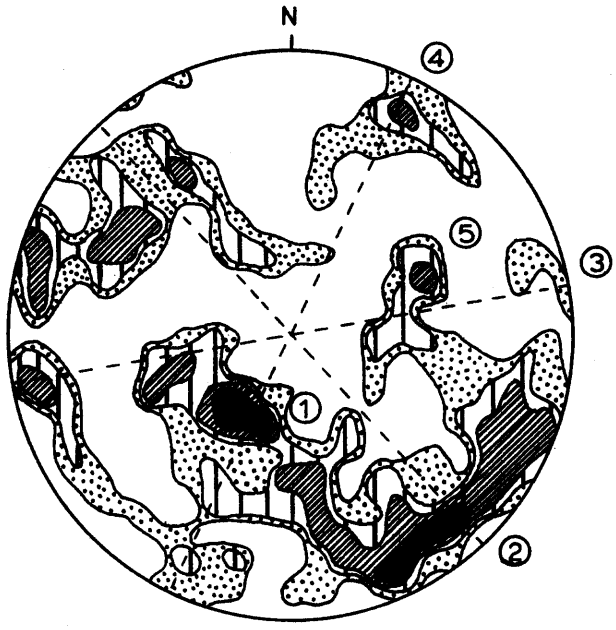
ORIGIN OF THE GNEISSOSE STRUCTURE

The gneissose structure of the granitic rocks was interpreted as flow structure by Umpleby, et al. (1930) because it is best developed in the western part of the outcrop belt where the intrusive sheet is relatively narrow. Field and petrographic evidence invalidates the flow structure hypothesis. The cataclastic features described indicate that the rock was already crystalline when it was being deformed. Post-cataclastic aligned biotite II must therefore have grown in a solid medium. Moreover, there is no systematic relation between degree of gneissose structure development and proximity to intrusive contacts. Although obvious gneissose structure diminishes to the northeast where the outcrop belt of the pluton widens, this textural change coincides with the overall compositional change to leuco-granodiorite and quartz monzonite. Most rocks from this area that have a weakly-gneissose or directionless appearance show microscopic evidence for weak cataclasis and recrystallization of biotite II. At many places, the near-absence of megascopically visible gneissose structure may be a result of a scarcity of mafic minerals and of healing of cataclastic features by quartz recrystallization and devlopment of K-feldspar megacrysts.

The relatively weak deformation, recrystallization and development of gneissose structure that characterize the pluton prove that it is not a pre-metamorphic intrusion that has been subjected to the full effect of the intense regional metamorphism that affected the wallrocks.

The two alternatives are that the gneissose structure is a result of (1) late-intrusive protoclasis (Waters and Krauskopf, 1941) or (2) late-synorogenic intrusion. A protoclastic origin is rejected by these reasons:

(1) Apophyses in wallrocks have the same composition and gneissose texture as the main intrusive body. Such apophyses should have been shielded by their location in the wallrocks from any friction between the main pluton and the wallrocks such as produces protoclasis.



Average joint sets

① N 60 W, 35 NE (sheeting)
② N 45 E, steep (variable)
③ N 10 W, 85 NE
④ N 65 W, 80 SW
⑤ N 20 W, 55 SW

Contours represent 0.6%, 1.1%, 1.7% and 2.8%, respectively, per 1% area

Figure 29. Equal-area projection showing distribution of poles to 177 joints throughout the Pioneer Mountains Pluton. (See Plate I for rose diagrams of additional joints measured from aerial photographs in parts of the pluton not examined in detail).

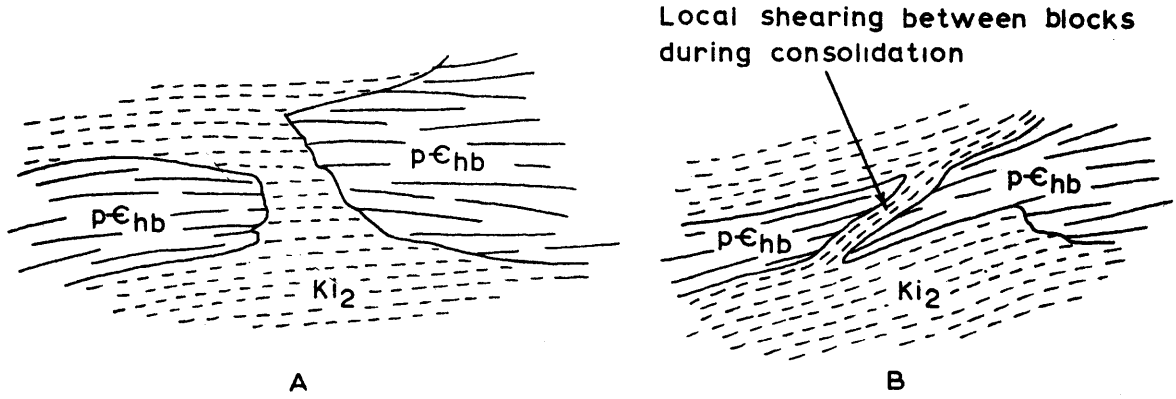


Figure 30. Relation of foliation in locally discordant apophyses of the Pioneer Mountains Pluton (Ki_2) to intrusive contacts and regional foliation in the metasedimentary wallrocks ($p\text{-}\epsilon_{hb}$ = quartzite of member B of the Hyndman Formation) in the Box Canyon area.

(2) Where gneissose structure is prominent, it is distributed uniformly throughout the pluton rather than being concentrated along the margins where friction with wallrocks should be localized.

(3) The gneissose structure in locally discordant cross-cutting apophyses parallels the regional schistosity of the metasedimentary wallrocks rather than the intrusive contacts (Fig. 30). This relationship cannot be demonstrated on a larger scale because regional schistosity and intrusive contacts are more or less parallel throughout the range.

(4) Other intrusions in the Pioneer Mountain region are directionless and show no evidence of protoclasis.

(5) Finally, comparable gneissose quartz dioritic rocks in the main body of the Idaho Batholith to the west are subordinate to, and invariably pre-date directionless, more leucocratic rocks. Workers in the Idaho Batholith (Anderson, 1952; and others) attribute the gneissose rocks to intrusion in a regional stress environment, and a similar origin is postulated for the Pioneer Mountains pluton.

The intense orogenic metamorphism that affected the country rocks is the only event recognized that could have produced such an environment over so large an area. The pluton is therefore considered to have been emplaced in a late stage of that metamorphism.

The late-synorogenic origin is supported by the fact that except for minor feldspathization in local assimilation zones, there are no contact metamorphic effects around the pluton such as occur around much smaller post-orogenic quartz monzonite intrusions in the area. This suggests that the metamorphic rocks were still hot at the time of emplacement of the pluton. Moreover, the occurrence of late euhedral sillimanite in the intrusive rocks of these assimilation zones indicates crystallization under metamorphic conditions (Fig. 26).

Strong support for late-synorogenic intrusion is also indicated by a comparison of foliation in the migmatitic gneiss domes of the Wildhorse Canyon complex and in the surrounding Pioneer Mountains pluton. In all four sub-areas (Fig. 11), poles to foliation in the pluton fall on the well-defined girdles formed by poles to foliation in the gneiss domes. This suggests that the foliations of both rock units are genetically related.

Variations in the degree of gneissose structure developed in different parts of the pluton are considered to be more a function of small differences in time of progressive intrusion and/or crystallization relative to orogenic metamorphism, and to degree of later deuteric modification, than to spatial variations in the intensity of deformation. The presence during metamorphism of a large mass of granitic magma incapable of transmitting stress might account for the general low pressure character of the metamorphism.

Localization of the plutonic sheet between the two metamorphic units indicates that it was injected along a zone of local weakness. Truncation of metasedimentary units above the pluton suggests a pre-intrusive tectonic contact. Prominent pre- or

synmetamorphic faults of the type envisioned occur elsewhere in the metasediments. Slabs and blocks of metasediments in the "giant breccia zone" (p. 78) may be remnants of tectonic slivers partially engulfed by the pluton.

REGIONAL CORRELATION AND AGE

The Croesus quartz diorite and Hailey granodiorite near Hailey, just south of the map area (Schmidt, 1961), are similar to respective parts of the Pioneer Mountains pluton. In that area, however, the granodiorite intrudes and therefore post-dates the gneissose quartz diorite. Local variations in the composition and texture of the Hailey granodiorite are attributed by Schmidt to stresses during consolidation and to healing of cataclasis by crystallization of late-magmatic and/or deuteric quartz and K-feldspar. A Pb-alpha age of 114 m.y. was obtained by Schmidt on the Croesus quartz diorite.

The Pioneer Mountains pluton also is mineralogically and petrographically similar to rocks in the main body of the Idaho Batholith 20 miles to the west. The two are considered to be genetically related and probably are directly connected at depth. Numerous Pb-alpha and K/ar dates from many parts of the Idaho Batholith average 110 m.y. (Larsen, et al., 1958a and 1958b). Most dates fall within 10 m.y. of the average. Pb-alpha ages of 131 m.y. and 94 m.y. were obtained in the Sawtooth Mountains area near Stanley on gneissose quartz diorite and granodiorite, respectively (Jaffe, et al., 1959).

Thus, middle-Cretaceous would appear to be a good first approximation for the age of the Pioneer Mountains pluton. Then the middle-Cretaceous also marks a younger limit for the age of regional metamorphism in the range. If, as appears likely, the pluton was intruded during a waning stage of that metamorphism, then the middle-Cretaceous marks a time of diminishing Mesozoic orogenic metamorphism that culminated in emplacement of this satellite of the Idaho Batholith. Such a conclusion is compatible with Heitanen's (1961 and 1962) suggestion that the rocks of the Idaho Batholith in north-central Idaho crystallized from magmas generated by partial melting at the climax of Mesozoic regional metamorphism. Mesozoic orogenic metamorphism is also widely recognized in the northeastern Great Basin (Misch, 1960; Misch and Hazzard, 1962).

POST-OROGENIC QUARTZ MONZONITE INTRUSIONS

AREAL DISTRIBUTION

Three relatively small intrusions of quartz monzonite crop out near the crest of the Pioneer Mountains (Fig. 3). The largest and best exposed of the bodies occupies about three square miles along the valley of Summit Creek. Smaller isolated offshoots from the main Summit Creek intrusion occur in the canyon of Little Falls Creek and on the ridge northeast of the Big Falls Creek. Another poorly exposed intrusion occurs eight miles to the southeast on the divide between the two main forks of Hyndman Creek. The third intrusion occupies a small cirque on the west side of East Fork Canyon.

FIELD RELATIONS

Exposed contacts of the intrusive bodies cut across country structures. The Summit Creek pluton made room for itself by doming up the Ordovician country rocks; post-orogenic intrusion probably was accompanied by uplift throughout the range. An offshoot of the Summit Creek pluton is injected across a major thrust fault into coarsely clastic rocks of the northeastern Pioneer Mountains succession (see Sections, Plate I). The Hyndman Creek and East Fork intrusions are in medium- to high-grade metasediments. Surface exposures of the Summit Creek and Hyndman Creek bodies are altered and crumbly; the East Fork intrusion is fresh.

PETROGRAPHIC DESCRIPTION

The Summit Creek and Hyndman Creek intrusions consist of directionless, medium- to coarse-grained biotite-quartz monzonite (Fig. 22, 23, 24). The East Fork intrusion is similar in composition but is finer grained and very weakly gneissose. Typical samples from all of these bodies consist of 25 to 35 per cent quartz, 25 to 35 per cent microcline, 30 per cent to 40 per cent plagioclase, and 5 per cent or less biotite. Some samples contain sieved remnants of biotitized ferrohastingsitic hornblende. Plagioclase is subhedral and shows blocky primary growth twinning, synneusis texture and simple subhedral to patchy normal zoning from An30 to An20. Relatively calcic cores are extensively altered to sericite and minor pistacite in some sections. Late-magmatic quartz and perthitic anorthoclase megacrysts appear to have formed by replacement from deuteric fluids enriched in sodium. Advanced alteration to kaolinite? imparts a dusty appearance to the anorthoclase. Magnetite, apatite, allanite, muscovite and euhedral sphene occur in traces.

The quartz monzonite is entirely igneous in character. Minor crystal bending, weak undulatory extinction, and occasional broken crystals reflect final adjustment in the nearly consolidated bodies.

A comparison with the syn-orogenic Pioneer Mountains pluton indicates that the post-orogenic quartz monzonite contains (1) a more sodic plagioclase, (2) anorthoclase, (3) only 5 per cent biotite, (4) less abundant heavy minerals, and (5) some accessory muscovite. Only the East Fork intrusion displays evidence of cataclasis. Its weak gneissose structure may result from emplacement during a time intermediate between that of the syn-orogenic Pioneer Mountains pluton and the directionless post-orogenic intrusions.

CONTACT METAMORPHISM

Weak contact metamorphism within 200 feet of the Summit Creek intrusion produced minor silicification, hornfelsing and incipient crystallization of radially-twinned cordierite porphyroblasts in the Phi Kappa slate.

Intense contact metamorphic effects as much as 2000 feet from the Hyndman Creek intrusion indicate that a far larger body underlies this area at shallow depth than appears at the surface. Mineral assemblages indicate recrystallization in the hornblende hornfels facies. Near the exposed intrusion, dolomitic marble of member E is converted to unusually coarse-grained diopsidefels. The bluish-gray diopside occurs in masses and as radial clusters of crystals as much as six inches long. The crystals are highly fractured and crumbly. Some samples contain 95 per cent diopside; the matrix consists of feathery, retrogressive tremolite and up to 10 per cent quartz and calcite. At the mouth of the cirques south of Hyndman Peak, member G consists of a fine-grained, directionless, matrix of pale-green-brown biotite, chlorite, clinozoisite, and magnetite with non-aligned actinolite porphyroblasts up to one cm. long. The actinolite has hornblende rims. Subordinate coarsely recrystallized calcite pods and lenses up to several inches long are aligned parallel to the schistosity and bedding of the metasediments. Calcite also fills small fractures in actinolite porphyroblasts. At other places near the Hyndman Creek intrusion, members E and G are bleached and silicified.

AGE

The quartz monzonite bodies clearly post-date Mesozoic metamorphism and post-metamorphic thrusting. They are regarded as Tertiary intrusions unrelated to the Pioneer Mountains pluton.

A sample of the Summit Creek quartz monzonite gives a K/Ar date of 46.7 m.y. (R. L. Armstrong, oral communication). The Eocene thus marks a younger limit for its emplacement. Unfortunately, seven samples from the Pioneer Mountains pluton and various metamorphic units in the core of the range also yield erratic Tertiary dates with relative ages based on geologic evidence is thought by Armstrong to reflect significant argon loss. Reheating associated with the widespread Tertiary intrusion and volcanism known to have affected this region may have "reset" the "K/Ar clock" of these older rocks. Alternatively, the presumably pre-Tertiary rocks may have remained hot enough to lose argon following Mesozoic metamorphism until Early Tertiary regional uplift promoted cooling and more advanced crystallization of mineral lattices capable of retaining argon. A more complete study of similar effects in other parts of the west is underway by Armstrong.

GRANITIC DIKES

Porphyritic dikes ranging in composition from granite to quartz diorite are common throughout the map area. Quartz diorite predominates; phenocrysts are mostly plagioclase and biotite. None of the dikes exceeds 10 feet in thickness. One dike west of Upper Trail Creek can be traced for a mile along the Wood River thrust. Most other dikes extend only a few hundred feet.

Umpleby, et al. (1930, pp. 57-58) regards these dikes as Tertiary (Miocene?) in age on the basis of their similarity in composition and spatial relations with porphyritic Tertiary intrusions and/or Challis volcanic rocks.

TERTIARY VOLCANIC ROCKS

Relatively small patches of volcanic rocks in the map area (Fig. 4) are isolated remnants of a far more extensive volcanic terrain that once covered most of central Idaho. Similar volcanics were first described in the Challis region about 50 miles north by Ross (1934b, 1937). Rocks correlated with the Challis volcanics occur in many areas around the Pioneer Mountains, such as the Sawtooth region to the west (Umpleby, 1915), the Lost River Range to the east (Umpleby, 1917; and Ross, 1947b), and the Hailey region to the southwest (Schmidt, 1961).

Time allowed only superficial examination of the volcanic rocks. The stratigraphy of the Challis volcanics is a separate problem requiring systematic study over a broader region.

JOHNSTONE CREEK VOLCANICS

Andesitic and latitic volcanic rocks are exposed in the area north of Johnstone Creek (Fig. 3). Red-purple to gray porphyritic flowrocks with plagioclase and quartz phenocrysts are intercalated in greenish-colored crystal-lithic tuff and conglomeratic tuff. The lavas are resistant and locally display flow structure. Conglomeratic tuff beds are mostly crumbly and contain rounded, porphyritic boulders of purple flowrocks averaging one foot and locally attaining three feet in diameter. Dark, fine-grained to glassy rocks locally mark the chilled bases of the flows. In this area, the volcanics generally have gentle northeasterly dips, but dips of as much as 30° northeast were measured in places. Thus the volcanics have been tilted in a direction opposite to the pre-Tertiary dips.

WHITE MOUNTAINS VOLCANICS

A larger patch of volcanic rocks east of the Pioneer Mountains pluton was examined in the White Mountains and Bellas Canyon areas (Fig. 3). These rocks were mislabelled by Umpleby, et al. (1930, Plate 1) as "Cretaceous granodiorite" of the Pioneer Mountains pluton. At the head of the Little Wood River, the base of the White Mountains volcanics is marked by a thin zone of dark, orange-weathering, glassy porphyry with slabby fracturing. Above this basal member is a heterogeneous succession of greenish tuffaceous beds and dark porphyritic flows. These rocks are very crumbly and extensively brecciated, bleached and silicified near the high-angle fault that separates them from the Pioneer Mountains pluton to the northwest. The upper part of the volcanics, which forms the summit of the White Mountains, consists of white to pink rhyolite and rhyolite breccia with flow banding and layering that vary in attitude from EW, 5-15N to N45E, 30SE. The volcanic rocks in upper Bellas Canyon resemble the lower, heterogeneous part of the White Mountains succession. The thickness of the White Mountains volcanics is at least 2000 feet.

OTHER VOLCANICS

Volcanic rocks mapped in the north and northwestern parts of the area were not examined in detail.

CONTACT RELATIONS AND AGE

The volcanic rocks overlie all other stratigraphic units in the map area along a major angular unconformity (Fig. 4). The moderate to high relief of the deposition surface is well exposed by modern stream dissection. The relief also is reflected by the coarsely conglomeratic tuff beds. The amount of material removed from the top of the volcanic pile by erosion is not known.

The volcanic rocks are presumed to be Tertiary in age because they truncate post-mid-Cretaceous thrust faults. The accuracy of Umpleby's Miocene? age assignment is uncertain.

STRUCTURE

STRUCTURAL CHARACTER OF THE WILDHORSE CANYON MIGMATITIC GNEISS COMPLEX

A preliminary structural analysis of the migmatitic gneiss domes is included in Chapter I. Doming appears to be a relatively late feature imparted by Mesozoic orogenic metamorphism and late-orogenic intrusion. Additional data will be required to determine the structural evolution of the migmatites prior to doming.

STRUCTURES IN THE MEDIUM- TO HIGH-GRADE METASEDIMENTARY SUCCESSION

Schistosity

Strong crystallization schistosity (s_1) parallel to bedding characterizes argillaceous parts of the metasediments. This schistosity is marked by compositional layering and by elongated quartz, aligned micas and trains of opaque inclusions. Locally, incipient s_2 formed parallel to the axial planes of overturned micro-folds.

Pre- or Syn-metamorphic Thrust Faults

Faults imbricate and truncate the metasedimentary succession. At most places, the faults parallel the southwest dip of bedding and schistosity. However, in the East Fork Canyon area, bedding, schistosity and thrust faults all dip southeasterly. The faults are low-angle thrusts in the northwestern and southeastern parts of the metasedimentary belt. The most spectacular example of imbrication occurs on the ridge between upper Wilson and Kane Creeks where the upper part of the succession is repeated in two thrust slices dipping 20° southwest (Fig. 31). In the cirques southwest of Hyndman Peak, the thrusts grade along strike into reverse faults dipping up to 60° southwest.

The faults are sharp and remarkably free of breccia, gouge or evidence of shearing. They usually are detected only on the basis of stratigraphic repetition and truncation. Samples from a thrust zone between schist and quartzite members consist of blastomylonite and fully recrystallized biotite-muscovite-quartz schist. Parallel crests of microfolds marked by synkinematic micas plunge southwest down the dip of the fault zone. The synkinematic micas indicate that deformation and recrystallization occurred simultaneously. The orientation of b-lineation marked by the microfolds indicates that tectonic transport was parallel to the present strike of the fault planes. The magnitude of thrusting was probably small, because details of stratigraphy are identical in adjacent fault blocks. The metasedimentary succession is thus regarded as parautochthonous. Metamorphic grade appears to be independent of faults.

Folding

On the divide between lower East Fork Canyon and Hyndman Creek, members B, C, D, and E form several nearly isoclinal folds with wave lengths of about 1500 feet. Axial planes trend north-south and are overturned to the west; the west limbs of the synclines are tectonically thinned. Small drag folds are common on both limbs. These folds are restricted to a block bounded on the north by a high-angle normal fault and on the south by allochthonous Paleozoic rocks. The allochthon did not participate in folding and its emplacement therefore post-dates this

deformation. The folds may be related to pre- or syn-metamorphic thrusting.

Folds presumed to be of the same generation occur in members C and D south of Box Canyon. These were examined only in reconnaissance.

East Fork Canyon Arch

The southeasterly dips in the East Fork Canyon area reflect arching along an axis that lies east of the canyon (Fig. 12). The pre- or syn-metamorphic thrusts participated in the arching; weakly metamorphosed allochthonous Paleozoic rocks truncate the arch. The arch is a southern extension of the Wildhorse Canyon migmatite dome, which formed in a late stage of Mesozoic orogenic metamorphism and intrusion.

POST-METAMORPHIC AND PRE-CHALLIS DEFORMATION OF WEAKLY METAMORPHOSED PALEOZOIC ROCKS

The crystalline rocks of the Pioneer Mountains are exposed in a window, modified by high-angle faults, through weakly metamorphosed Paleozoic rocks. Major thrust faults can be demonstrated below and within the allochthonous rocks at many places in the map area.

Thrust Faults in Ordovician and Silurain Rocks

Churkin (1963) described thrust faults in the Ordovician Phi Kappa Formation in the Park Creek area. These faults are inconspicuous and difficult to detect without paleontological evidence. The Park Creek Thrust, as defined by Churkin (p. 1614), appears to pass beneath a thrust below the Wood River Formation east of Trail Creek (Fig. 32). The Park Creek Thrust emerges near the head of Kane Creek and terminates at the high-angle fault marking the southeastern limit of Ordovician outcrop.

The probable occurrence of Kinnikinic Quartzite (member H) at the top of the parautochthonous metasedimentary succession appears to require an allochthonous origin for the lower structural unit of the Phi Kappa black shale facies, as well as the upper. Its emplacement along a thrust buried at shallow depth can most reasonably account for the sharp metamorphic break across the high-angle border fault with the medium- to high-grade metasediments. Eastward thrusting on the order of miles may have occurred. The alternative of pure vertical displacement sufficient to have produced the extreme contrast in Mesozoic metamorphism seems unlikely for a structure of such limited extent as the boundary fault.

Allochthonous Nature of the Milligen Formation

The following evidence indicates that the Milligen Formation was emplaced by thrusting:

(1) Low-angle faults mapped below the Milligen Formation by Umpleby, et al. (1930) in and beyond the northwestern part of the map area, although not specified as thrusts, are identical in geometry to low-angle thrust faults below the Wood River Formation. These faults were not examined in detail.

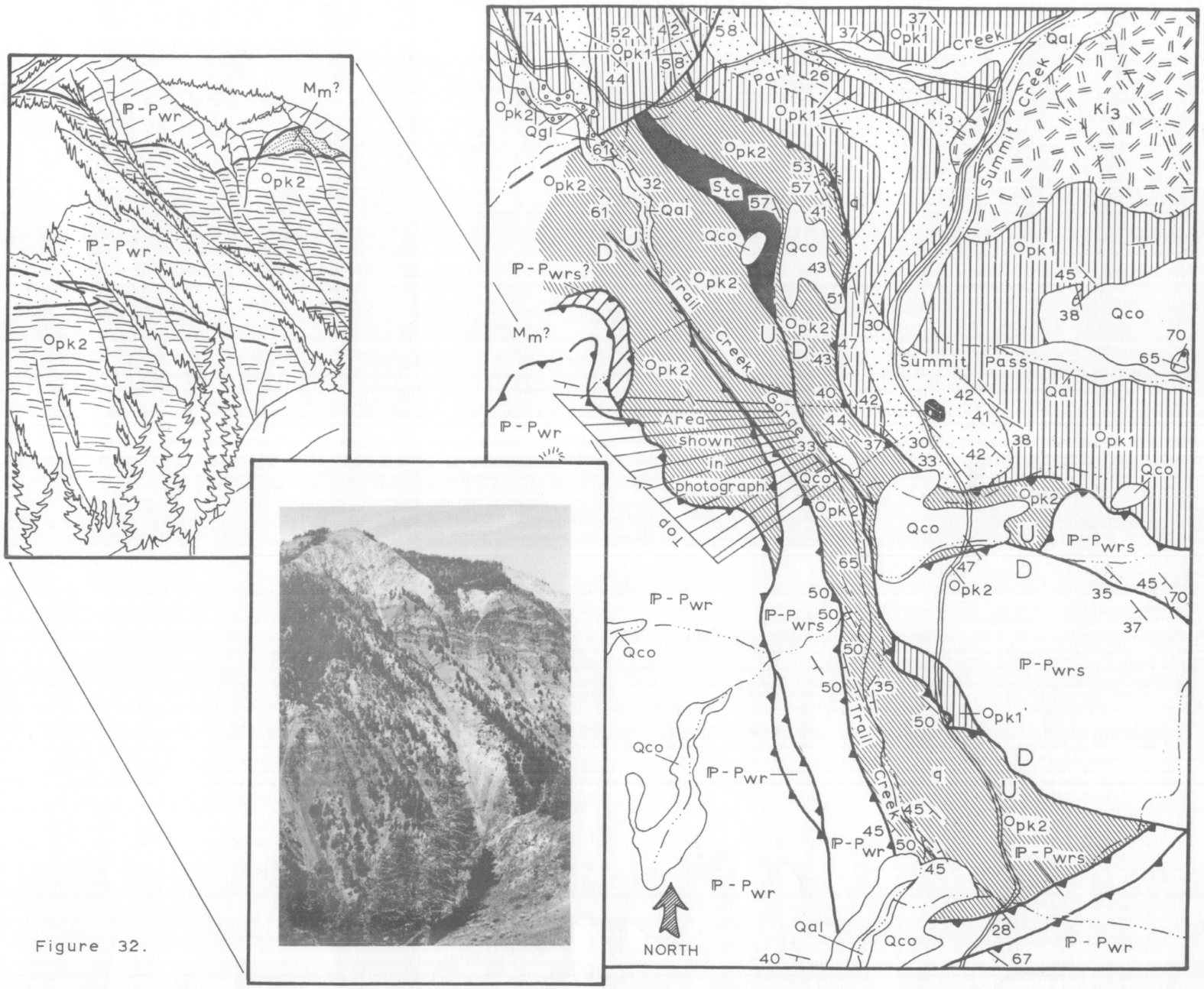


Figure 32.

Enlarged geologic map (3" per mile) of the Trail Creek and Summit Creek areas showing complex thrust relations in the weakly metamorphosed allochthonous Paleozoic rocks. (Qco - colluvium; see Plate I for legend) Photograph and sketch show imbrication below the Wood River Thrust on the ridge west of Trail Creek Gorge.

a25



Figure 31.

Enlarged geologic map (3" per mile) of the Devil's Bedstead area showing structural pattern of pre- or syn-metamorphic (recrystallized) thrust faults in the metasedimentary belt. (Qco - colluvium; see Plate I for legend) Photograph and sketch show imbrication of metasedimentary units on the ridge north of upper Wilson Creek.

(2) Accepting that phyllitic Milligen strata and uppermost medium- to high-grade metasediments underwent one and the same episode of Mesozoic metamorphism, there is not sufficient distance between them to account for their sharp contrast in metamorphism without postulating post-metamorphic displacement.

(3) The Milligen Formation appears to be more complexly folded than any other rock unit in the southwestern Pioneer Mountains.

(4) No stratigraphic contacts of the Milligen Formation are present in the map area, and re-examination of the one locality where a conformable section of Milligen and Wood River rocks was reported by Umpleby, et al. (1930, p. 28) indicates that relationships are structurally complex and inconclusive.

Wood River Thrust

The base of the Wood River Formation is a major thrust fault throughout the map area. An excellent exposure of the Wood River Thrust on the high ridges west of Trail Creek gorge is visible from the Trail Creek road near Summit Pass (Fig. 32). Light-colored Wood River calcareous sandstones dipping 40°-60° south override dark shales of the Phi Kappa Formation that dip only 10°-15° southwest. An imbricate zone below the main thrust may contain some Milligen rocks.

Other good exposures of the Wood River Thrust are:

(1) on the ridge between upper Trail Creek and Little Falls Creek, and on the ridge southeast of Phi Kappa Mountain, where the Wolfcampian (?) siltstone member rests on black Phi Kappa shale and slate;

(2) on the ridge between Trail Creek and Wilson Creek, where a small klippe of southwest-dipping calcareous rocks override contorted Milligen;

(3) on the ridge between upper Wilson and Corral Creeks, where calcareous sandstone beds truncate metasedimentary members F, G and H (?) of the East Fork Formation; and

(4) on the ridge southeast of East Fork Canyon, where similar calcareous sandstone truncates the Hyndman Formation.

The thrust zone is characterized by black, sooty fault gouge at most places. Dark brecciated or sheared limestone containing irregular networks of calcite, quartz or aplite veinlets occurs locally. The fault zone is 50 feet wide on the ridge between upper Wilson and Corral Creeks, but it is very sharp and truncates broad folds in both plates on the ridge southeast of Phi Kappa Mountain. Minor drag folds are rare to absent in the thrust zone.

Wilson Creek Reverse Fault

The Wilson Creek Fault trends about N50W through the southwestern part of the map area. The fault can be traced at least 10 miles from the East Fork of the Big Wood River to the head of Lake Creek. Its surface trace in an area with 3000 feet

of relief indicates a steep southwest to vertical dip. Two small klippen of the Wood River Formation cap ridges on the uplifted southwestern block, indicating that the sub-Wood River Thrust has been displaced at least 2000 feet vertically. The Wilson Creek Fault is truncated by the sub-Challis unconformity near Johnstone Creek.

Thrust Faults in the Northern Pioneer Mountains

Two major structural discontinuities are recognized in the northeastern part of the map area (Plate I):

Fall Creek Fault.

The lowest structure can be traced from Copper Basin, where it is concealed by Pleistocene gravels, west to the Moose Lake area. The fault dips 35°-50° north. It separates crystalline rocks of the Wildhorse Canyon complex and the Pioneer Mountains pluton in the footwall from Upper Paleozoic sedimentary rocks in the hanging wall. The fault is quite sharp and marked by only minor evidence of shearing. Granitic rocks are sericitized and chloritized near the fault; the sedimentary rocks are locally silicified, particularly in the Fall Creek area. A small outcrop of banded, siliceous rocks near the head of the East Fork of Fall Creek probably is a patch of hornfelsed sediments incorporated in the footwall.

Wildhorse Creek Thrust.

The higher structure dips more gently to the northeast. Contorted Upper Paleozoic clastic rocks in the upper plate truncate a homoclinally east-dipping chert-bearing carbonate section of probable "Brazer" affinity. Upper and lower plate lithologic and structural character are well-exposed on the ridge northeast of the junction of Wildhorse and Fall Creeks. Klippen of the contorted clastic rocks also occur on ridges in the Fall Creek area. The fault zone itself is largely covered by talus.

Summit Creek Thrust.

Map patterns indicate that the two structural discontinuities of the northeastern Pioneer Mountains merge in the Moose Lake region. Which, if either, of the two faults dominates is not clear.

The resulting fault can be traced from Moose Lake west to the Summit Creek area. On the ridge between Big Falls Creek and Summit Creek, contorted Upper Paleozoic clastic rocks truncate northeast dipping Phi Kappa slate and limestone along a low angle fault (Fig. 33). Across Summit Creek, on the ridge north of Phi Kappa Creek, the same thrust is characterized by a zone of isoclinally folded and silicified Phi Kappa argillite. Skarn zones probably related to the adjacent Summit Creek intrusion are localized in limey interbeds along the thrust zone. These were being actively mined for lead, zinc and silver in 1966 according to Roy Dondero of the Federal Resources Corporation (oral communication). The skarn layers are offset by small northeast-trending faults in the Phi Kappa mine.

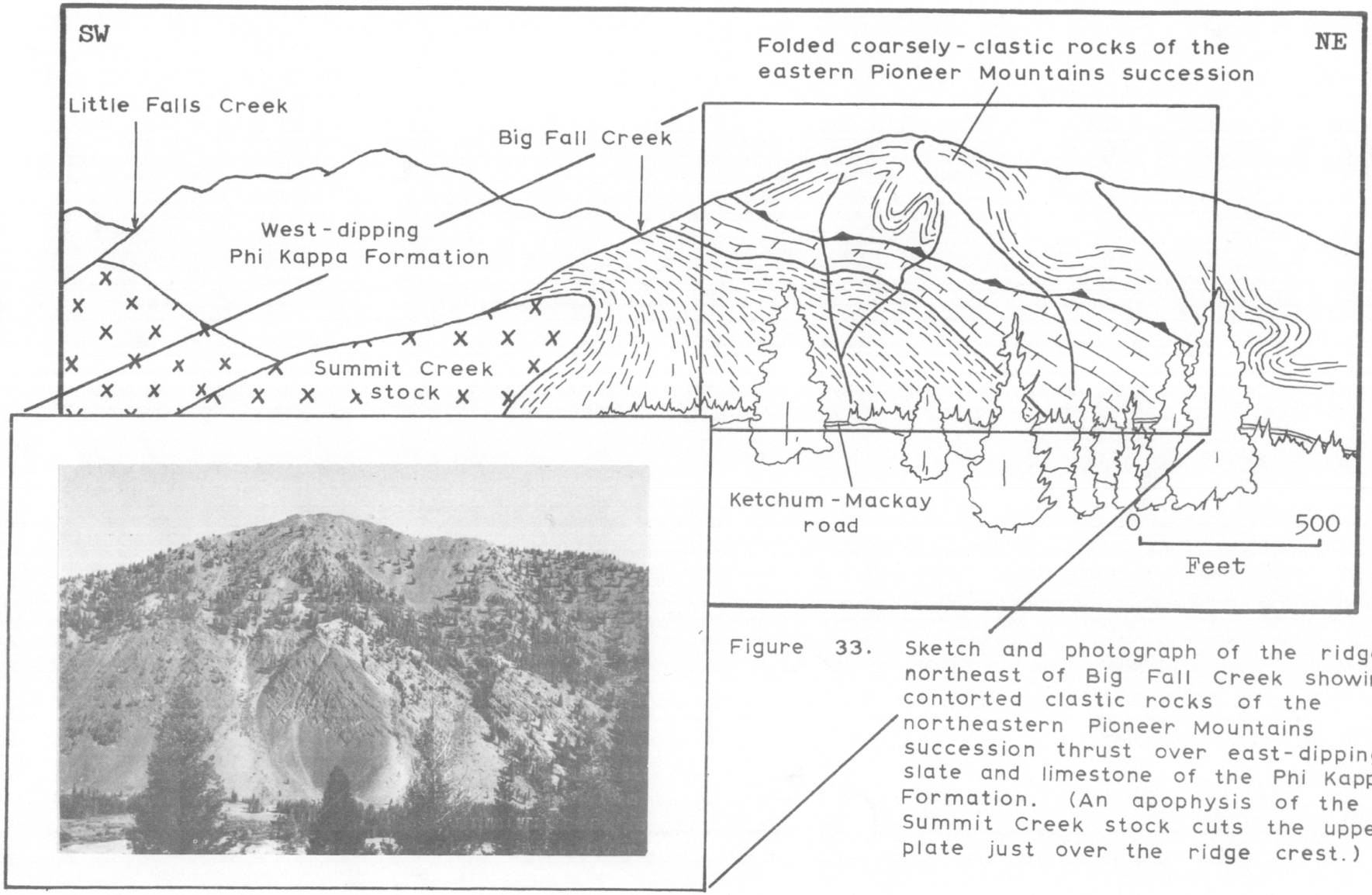


Figure 33. Sketch and photograph of the ridge northeast of Big Fall Creek showing contorted clastic rocks of the northeastern Pioneer Mountains succession thrust over east-dipping slate and limestone of the Phi Kappa Formation. (An apophysis of the Summit Creek stock cuts the upper plate just over the ridge crest.)

Tentative Structural Interpretation.

All three major faults in the northern Pioneer Mountains are regarded as thrusts; however, their mutual relations are uncertain. Tentatively, the Wildhorse Creek and Summit Creek thrusts are thought to be equivalent because both dip gently northeast and contain only contorted clastic rocks in the upper plate. The Fall Creek Fault is considered a lower thrust that was slightly tilted to the northeast and later truncated by the Wildhorse Creek-Summit Creek thrust.

Correlation of these faults with similar structures on the southwestern slope of the range is even more dubious because the faults in these two regions are not in contact in the area mapped. Most likely, the Fall Creek Fault in the north and the sub-Wood River thrust in the southwest are equivalent structures marking the base of an allochthonous sheet that once covered the entire Pioneer Mountains region (see Sections, Plate I). This thrust sheet appears to have been warped by post-thrusting uplift of the crystalline core of the range along an axis parallel to the range crest; uplift was most likely related to post-orogenic Tertiary? intrusion. The klippe of Summit Creek Breccia (see Fig. 21) in the west central part of the map is most likely a remnant of the higher and somewhat later Wildhorse Creek-Summit Creek thrust plate which truncated the underlying warped allochthon.

Extent and Magnitude of Thrusting

Thrust faults were observed by the writer in an area of at least 500 square miles in and adjacent to the map area. Umpleby, et al. (1930), reported thrusting throughout the Hailey 30-minute quadrangle, only part of which overlaps the map area. Thrust faults also have been mapped by graduate students of the University of Wisconsin in the southeastern Pioneer Mountains near the Snake River Plain (Richard Paul, oral communication, 1965). Thus the thrust belt covers an area of several thousand square miles in the Wood River and Pioneer Mountains regions alone. Recent mapping by the U. S. Geological Survey in the Lost River Range indicates that possibly contemporaneous thrust faulting occurred at least that far east (William Hays, oral communications, 1966). Clearly, this thrust belt is a major structural element of east-central Idaho.

The magnitude of the thrusting is uncertain, but displacement was sufficient to produce major metamorphic breaks across thrust zones and to at least partially account for abrupt east-west Paleozoic facies changes across this part of central Idaho. Displacement of at least several miles seems required; movement may have been much greater.

Direction of Yielding

Small- and medium-sized folds are common in the Milligen Formation and in clastic rocks of the northeastern Pioneer Mountains succession (Fig. 32), but large folds are rare in the map area. Open folds 50 to 200 feet across in the Wood River Formation tend to be asymmetrical to the east. However, exposures of the Wood River and Milligen Formations are so poor that major isoclinal folds may have been missed. Aerial photographs suggest that large isoclinal folds may occur in the Wood River Formation on the ridges west of Trail Creek and east of

the East Fork of the Big Wood River. Asymmetrical and overturned folds in the map area tend to confirm the eastward movement postulated by Umpleby, et al. (1930).

Age of Thrust Faulting

The post-metamorphic age of the main thrusting in the Pioneer Mountains is demonstrated by the abrupt metamorphic break between the allochthonous Paleozoic rocks and the autochthonous crystalline core and by the fact that the main thrust zone between these two major units is not recrystallized. If the middle-Cretaceous Pioneer Mountains pluton was emplaced near the end of Mesozoic metamorphism, then the middle-Cretaceous also gives an older age limit for the main thrusting. Thrust faults between individual formations in the allochthonous Paleozoic belt on the southwest slope of the range cannot be directly dated but these faults probably are imbrications that formed at the time of the main post metamorphic thrusting. However, it is possible that they are earlier structures carried in on the main post-metamorphic thrust(s) below the allochthonous succession. Radiometric dating of the post-orogenic Summit Creek intrusion would provide a younger limit for the Summit Creek Thrust. Tertiary Challis volcanic rocks unconformably overlying the Wood River thrust in the Johnstone Creek area also mark a younger age limit for the thrusting. Nowhere in the Pioneer Mountains are Tertiary volcanic rocks involved in thrust faulting.

POST-CHALLIS HIGH-ANGLE FAULTS

Several prominent high-angle faults displace thrust faults in Paleozoic rocks and, locally, cut Tertiary Challis volcanic rocks. Three major faults are recognized: (1) the Kane Creek Fault, (2) the Pioneer Fault, and (3) the White mountains Fault.

Kane Creek Normal Fault

The Kane Creek Fault strikes approximately N15E and, from its surface trace, dips about 70° northwest. It separates Ordovician Phi Kappa shale and slate on the northwest from medium- to high-grade metasediments on the southeast. Because the fault zone is mostly covered by sliderock and Pleistocene gravels, a detailed description is not possible. Moreover, the fault could not be traced with confidence either north or south, and its relation to post-metamorphic thrust faults is uncertain. It appears to displace the Wood River Thrust less than 1000 feet on the ridge between upper Wilson and Corral Creeks. It is tentatively concluded that displacement at the Kane Creek Fault has not been sufficient to account for the major metamorphic break between the rocks it separates.

Pioneer Reverse Fault

The Pioneer Fault maintains a trend of N55W through both crystalline and sedimentary rocks for a distance of nearly 20 miles from upper Trail Creek to the Little Wood River. The fault dips 55° to 75° southwest. Displacement of metasedimentary members and the Wood River Thrust indicate a relative uplift of the southwest side of less than 1000 feet.

White Mountains Normal Fault

The White Mountains Fault trends N30E and dips 70° southeast. It can be traced at least eight miles from the head of the Little Wood River to Bellas Canyon. West of the White Mountains, on the divide between the Little Wood River and Broad Canyon, quartz monzonite of the Pioneer Mountains pluton has been raised against rhyolitic to andesitic Tertiary Challis volcanic rocks southeast of the fault. Bold outcrops of siliceous breccia and massive silica marking the fault zone have prominent fractures parallel to the trend of the fault. Both the quartz monzonite and the volcanic rocks are altered and crumbly for a distance of several hundred feet from the fault.

The White Mountains fault is the most prominent of a N30E-trending system that may represent the youngest structures in the map area. Smaller faults of this set in the northwestern part of the area along upper Trail Creek have displacements of a few hundred feet or less. Although no other faults were found, the persistence of the N30E direction in the drainage pattern of the region suggests structural control by fracture zones parallel to the major fault system (see Umpleby, et al., 1930, p. 72).

Other Faults

Three steeply-dipping to vertical faults radiating from the Hyndman Creek intrusion displace the Wood River Thrust, the Wilson Creek Fault, and in one case, the Johnstone Creek volcanics. Slickensides on one fault with an attitude of N60W, 35SW plunge in a N75W direction, indicating late state oblique-slip movement. The relation of these faults to the intrusion is not known, owing to poor exposures in the area.

Significance of Displaced Tertiary Volcanic Rocks

Regional displacement of Challis volcanic rocks demonstrates that the present relief of the Pioneer Mountains is partly, if not entirely, a result of uplift associated with Tertiary and/or younger high-angle faulting. The structure of the Challis volcanic rocks thus holds the key to understanding the Tertiary and later deformation of central Idaho. The stratigraphy of the Challis volcanics is critical and needs to be studied in detail.

SUMMARY OF GEOLOGIC HISTORY AND SOME REGIONAL IMPLICATIONS

Although erosion undoubtedly has erased the record of much of the geologic history of the Pioneer Mountains, this study leads to the following conclusions concerning the evolution of the range:

(1) Dominantly quartzitic sediments with subordinate arkosic and argillaceous admixture and minor calcareous interbeds, which now constitute the bulk of the Wildhorse Canyon migmatite complex, were probably deposited in Late(?) Precambrian time. The deformational history of these rocks prior to Mesozoic metamorphism is uncertain.

(2) Quartzitic, pelitic, and rhythmically banded calcareous rocks of the Hyndman Formation were most likely deposited in latest Precambrian time, but may be part of the earlier Belt Series.

(3) Concordant deposition of relatively pure dolomitic limestone and quartz sandstone of the East Fork Formation probably began in Early Paleozoic time. These rocks resemble Cambrian and Ordovician rocks of southeastern Idaho. The amount of Paleozoic section that was eroded or tectonically eliminated from above the East Fork Formation is unknown, but the missing section might be considerable, because Middle and Upper Paleozoic rocks occur both east and west of the Pioneer Mountains. The complete depositional and erosional history of the Pioneer Mountains autochthon cannot be determined from the evidence available.

(4) Deposits of Upper Paleozoic rocks in central Idaho are probably marked by several major unconformities. Clastic tongues in the Upper Paleozoic rocks of this region reflect periodic uplift somewhere to the west of the Pioneer Mountains. The active area probably represents the northern extension of the Antler Orogenic Belt of central Nevada.

(5) Intense Mesozoic regional orogenic metamorphism caused pronounced doming and isochemical recrystallization in the upper-almandine-amphibolite facies in the Pioneer Mountains autochthon. Production of feldspathic gneiss from more quartzitic rocks by metasomatic granitization may have occurred during metamorphism in the more deeply buried Wildhorse Canyon migmatite complex. Rocks in adjacent areas, perhaps in shallower crustal levels, underwent only incipient recrystallization and low-grade metamorphism.

The Pioneer Mountains lie in a belt of Mesozoic orogenic metamorphism that extends at least from northwestern Idaho (Hietanen, 1961, 1962, and 1963) to southeastern Nevada (Misch and Hazzard, 1962).

(6) Thrust faults that imbricate the metasedimentary rocks probably formed during Mesozoic metamorphism, but may have occurred prior to the metamorphism.

(7) Middle-Cretaceous intrusion of the Pioneer Mountains pluton marked the end of the Mesozoic orogenic metamorphism. Earlier quartz dioritic rocks that were affected by a waning stage of the metamorphism are gneissose in the Pioneer Mountains and throughout the nearby Idaho Batholith. At most places, emplacement of the gneissose rocks was closely followed by intrusion of weakly gneissose to

directionless, more leucocratic and more potassium-rich post-orogenic rocks. The directionless, porphyritic quarz monzonite in the eastern part of the Pioneer Mountains pluton probably represents this slightly later intrusive phase.

The close association in time of Mesozoic orogenic metamorphism and emplacement of the composite Idaho Batholith and its satellites, and the spatial relation of the batholith to the region of most intense metamorphism and metasomatism, suggest that the two events were genetically related. Late-synorogenic intrusion in the Pioneer Mountains is compatible with the idea that the intrusive granitic rocks of the batholith crystallized from magmas generated at depth by partial melting at the climax of metamorphism (Hietanen, 1961 and 1962). In any case, the Mesozoic regional metamorphism certainly is not a contact effect around the Idaho Batholith, as suggested by some earlier workers (Ross, 1937; Umpleby, et al. (1930; and others). In the Salmon area, for example, a relatively narrow zone of dense, fine-grained hornfels characterizes Upper Paleozoic rocks near the batholith (William Hays, oral communication, 1966). Mesozoic regional metamorphism, on the other hand, produced synkinematic schistose rocks, even in regions where Cretaceous intrusive rocks are absent.

Major unconformities and clastic wedges in Cretaceous rocks to the east reflect repeated uplift in this general area of central Idaho during the time of emplacement of the Idaho Batholith (Silver, 1966). Some doming of the migmatite complex and the overlying metasedimentary rocks in the Pioneer Mountains (East Fork Canyon Arch) may have occurred at the end of metamorphism during late-synorogenic intrusion of the Pioneer Mountains pluton.

The southern end of the Idaho Batholith may obliterate the northern extension of the Upper Paleozoic Antler Orogenic Belt.

(8) Post-metamorphic (middle-Cretaceous or later) thrust faulting brought weakly metamorphosed Paleozoic sedimentary rocks from the west(?) into contact with medium- to high-grade crystalline rocks of the Pioneer Mountains autochthon. All of the Paleozoic rocks of the western Mountains, including the Milligen Formation and lower unit of Phi Kappa rocks, are allochthonous; the coarsely-clastic rocks of the northeastern Pioneer Mountains are allochthonous, as well. Thrust faults within the allochthonous succession are probably related to the main post-metamorphic thrust(s) below the allochthonous succession, but may be earlier structures carried "piggy-back" on the basal thrusts. The latter may be true if the Late-Paleozoic Antler Orogenic Belt is intersected or truncated by the belt of Mesozoic orogeny in this part of central Idaho. The magnitude of the thrusting was sufficient to produce the major metamorphic break at the basal thrust(s) and to at least partially account for abrupt east-west Paleozoic facies changes across this part of central Idaho. Displacement on the order of at least several miles seems required; movement may have been much greater. Regional interpretations of Paleozoic stratigraphic patterns of central Idaho that fail to consider these major tectonic complications cannot be valid.

(9) Small post-orogenic quartz monzonite plutons probably were emplaced during the Tertiary. The Summit Creek intrusion cuts both plats of a post-metamorphic thrust fault and thus post-dates the thrusting. The quartz monzonite also made room for itself by bowing up the country rocks. Doming of major thrust faults probably

is related to uplift along the range crest during this phase of post-orogenic Tertiary intrusion.

(10) Uplift and erosion following post-metamorphic thrusting and intrusion was of sufficient intensity and duration to produce the moderate- to high-relief surface on which the Tertiary Challis volcanic rocks were deposited.

(11) The youngest structures in the range are high-angle faults that displace gently-tilted Challis volcanic rocks. Some faults have stratigraphic displacements of a few thousand feet. The faults parallel prominent NW and NE joint sets existing in all of the major rock units of the range. It is not known if the joints are late features formed at the same time and under the same stress conditions as the faults, or if they are earlier structures utilized by the later faults. The present relief of the range can be attributed mostly to uplift associated with Late-Tertiary and/or Quaternary block faulting.

(12) Recognition in the Pioneer Mountains of several major stratigraphic and structural features typical of the northeastern Great Basin, such as uppermost Precambrian rocks, Mesozoic orogenic regional metamorphism and thrusting, in large part younger over older rocks, and Basin-Range-type block faulting, suggest that the intervening Late Cenozoic Snake River depression and no prior structural expression.

The merging of several distinct geologic elements in the Pioneer Mountains renders the range particularly critical to an understanding of the geologic evolution of central Idaho. Moreover, the presence of several units of igneous rocks datable by standard radiometric methods affords an excellent opportunity for precise dating of major metamorphic, tectonic and intrusive events.

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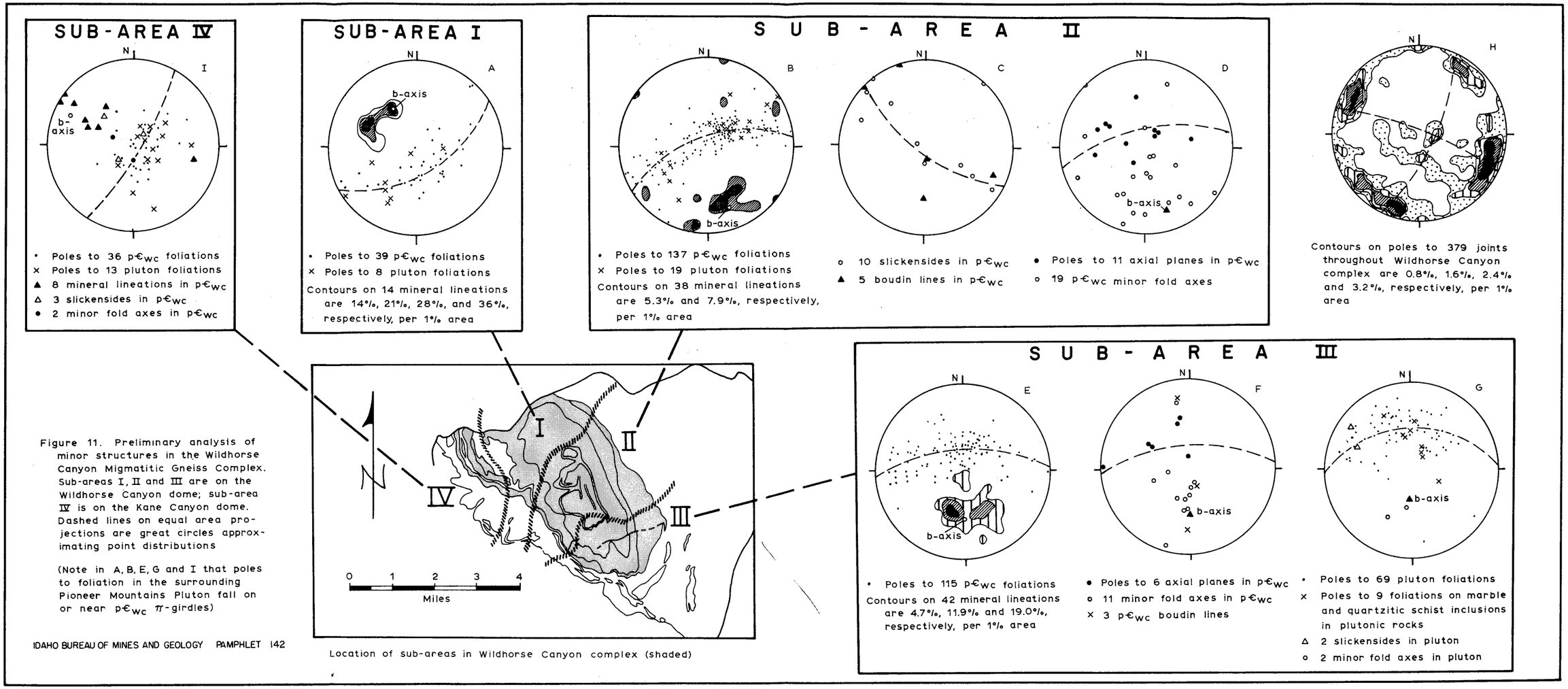


Figure 11. Preliminary analysis of minor structures in the Wildhorse Canyon Migmatitic Gneiss Complex. Sub-areas I, II and III are on the Wildhorse Canyon dome; sub-area IV is on the Kane Canyon dome. Dashed lines on equal area projections are great circles approximating point distributions

(Note in A, B, E, G and I that poles to foliation in the surrounding Pioneer Mountains Pluton fall on or near p€wc π-girdles)

IDAHO BUREAU OF MINES AND GEOLOGY PAMPHLET 142

GEOLOGIC MAP and SECTIONS of the PIONEER MOUNTAINS, CUSTER and BLAINE COUNTIES, CENTRAL IDAHO

EXPLANATION

SURFACE ACCUMULATED ROCKS

Quaternary

- Qal — Recent stream deposits
- Qrg — Rock glaciers
- Qgl — Undifferentiated glacial deposits (mostly terrace gravels but may include some till)

Major unconformity

Tertiary

- Tvc — Undifferentiated Challis volcanic rocks

Major unconformity

Southwestern Pioneer Mountains

Late Paleozoic?

- Pscb — Summit Creek Breccia (allochthonous mass of presumably Upper Paleozoic age)

Tectonic contact

Pennsylvanian (Desmoinesian) to Early Permian (Wolfcampian)

- P-Pwr — Wood River Formation undifferentiated - mostly sandy limestone
  - P-Pwrs — Tan siltstone member
  - lms — Crinoidal limestone member
  - bc — Basal chert-quartzite conglomerate and breccia member

Tectonic contact

Mississippian?

- Mm — Milligen Formation - dark, carbonaceous, phyllitic argillite and chert

Tectonic contact

Silurian

- Std — Trail Creek Formation - shale and limestone

Ordovician

- Opk2 — Upper structural unit of Phi Kappa Formation - black, graptolitic shale
  - q — Gray quartzite

Tectonic contact

- Opk1 — Lower structural unit of Phi Kappa Formation
  - Slate members
  - Banded quartzite members
  - Limestone member

Middle Ordovician (Canadian)

Tectonic contact

Northeastern Pioneer Mountains

Late Paleozoic ?

- uPal — Undifferentiated Upper Paleozoic rocks
- uPals — Dominantly coarsely clastic rocks

Tectonic contact

- uPalc — Dominantly calcareous rocks
- h — Hornfels

(Base not exposed)

Pioneer Mountains Autochthon

Early Paleozoic?

- pCeh — Member H - Kinnikinic? quartzite
- pCeg — Member G - gray, banded marble
- pCef — Member F - vitreous quartzite
- pCee — Member E - tan, dolomitic marble

East Fork Formation

Latest Precambrian?

- pCnd — Member D - gneissose quartzite

? Minor? unconformity

- pCnc — Member C - green, banded calc-silicate rock
- pCnb — Member B - gneissose quartzite
- pCna — Member A - pelitic schist

Hyndman Formation

? ? ? Tectonic? contact occupied by granitic rocks of the Pioneer Mountains Pluton

- s — Quartzitic schist inclusions and layers of uncertain affinity
- m — Dolomitic marble inclusions and layers of uncertain affinity

? ? ? ? ? ? Tectonic? contact occupied by granitic rocks of the Pioneer Mountains Pluton

Precambrian

- pCwc4 — Quartzite and granitic gneiss unit
- pCwc3 — Dark, quartzitic to mafic gneiss unit
- pCwc2 — Quartzitic to granitic gneiss unit
- pCwc2 — Dolomitic marble marker unit
- pCwc1 — Quartzitic gneiss unit
- a — Orthoamphibolite dikes
- og — Quartz monzonite orthogneiss

Wildhorse Canyon Migmatitic Gneiss Complex

INTRUSIVE ROCKS

Plutonic Rocks

Tertiary

- Kl3-2 — Post-orogenic quartz monzonite

Cretaceous

- Kl2 — Pioneer Mountains Pluton - ranges from gneissose quartz diorite and granodiorite to directionless, porphyritic quartz monzonite (pattern shows degree of gneissose structure development)
- px — Pyroxenite
- Kl1 — Hybrid rocks of the Pioneer Mountains Pluton in the East Fork Canyon area (see Fig. 12)

Dike Rocks

- gd — Granitic dikes
- ma — Mafic dikes

GEOLOGIC SYMBOLS

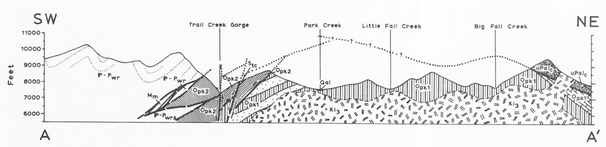
- Contact (dashed where approximate)
- U / D 76 — High-angle fault, showing dip (dashed where approximate) U on upthrown side, D on downthrown side
- Recrystallized / Unrecrystallized — Thrust fault (dashed where approximate) Sawteeth on upper plate
- Axis of anticline — Shows trace of axial plane and direction of plunge
- Axis of syncline
- Axis of overturned anticline
- Axis of overturned syncline
- 34 — Strike and dip of bedding
- 67 — Strike and dip of overturned beds
- Strike of vertical beds
- 23 — Strike and dip of joints
- Strike of vertical joints
- 45 — Strike and dip of foliation
- Strike of vertical foliation
- 12 — Bearing and plunge of lineation

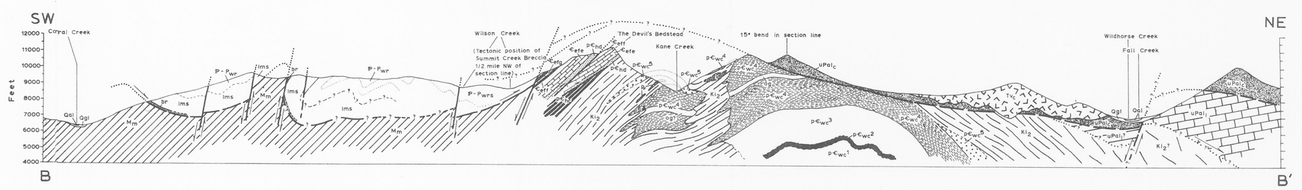
Rose diagrams show principal strike directions of joints measured from aerial photographs in parts of the Pioneer Mountains Pluton not visited in the field.

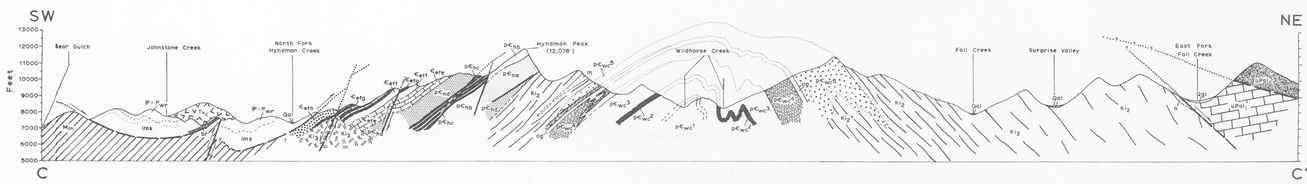
True North 18° Magnetic North

GEOLOGIC SECTIONS

No Vertical Exaggeration







Base map reduced from U.S. Forest Service 2 inches per mile (1:31,680) planametric series. Includes parts of Hailey 1, Hailey 2, Hailey 3 and Hailey 4 sheets.

Geology 1964 - 1967
by James H. Dover

0 1 2 3
Scale in Miles