UNITED STATES DEPARTMENT OF THE INTERIOR

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PRELIMINARY GEOLOGIC MAP OF THE PILOT PEAK AND ADJACENT QUADRANGLES, ELKO COUNTY, NEVADA, AND BOX ELDER COUNTY, UTAH

BY

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INTRODUCTION

The north-trending Pilot Range is located along the Nevada-Utah border about 80 km (50 mi) south of Idaho (Fig 1). It lies on the western edge of an expanse of salt flats that extends eastward to Great Salt Lake. North-trending ranges spaced approximately 20 km (12 mi) apart, typical of the northern Basin and Range province, extend westward and southward from the Pilot Range throughout most of Nevada (Fig. 1). Northward and northwestward from the Pilot Range the typical basin-range topography of Nevada is subdued in a regional highland that contains extensive tracts of Tertiary volcanic rocks.

Rocks in the Pilot Range belong to the Proterozoic Z and Paleozoic miogeocline. The tectonic setting is that of the "hinterland" of the Sevier orogenic belt. Eastward, in the Wasatch Mountains area, large-scale thrust faults, primarily of late Mesozoic age, displace miogeoclinal strata eastward over cratonal strata of equivalent age (Fig. 1). The hinterland region of the thrust belt is generally characterized by low-angle faults that thin or remove stratigraphic units, sparse granitoid bodies, and locally intense metamorphism and ductile deformation (Armstrong and Hansen, 1966; Armstrong, 1972). A number of features of the hinterland have remained poorly understood primarily because they have not been adequately documented. Much recent work in the northeastern Great Basin portion of the hinterland has focused on the nature of metamorphic core complexes, which are characterized by a complicated Cenozoic history of metamorphism, ductile and brittle deformation, and granitoid plutonism. Glimpses of earlier deformational events in these metamorphic terranes provide clues to an extensive Mesozoic metamorphic and deformational history (Misch and Hazzard, 1962; Armstrong and Hansen, 1966; Armstrong, 1968; Lee and others, 1970; Howard, 1980; Miller, 1980; Snoke, 1980).

This study of the Pilot Peak quadrangle and adjacent quadrangles is part of an investigation of the stratigraphic and structural setting of the Pilot Range, which is in turn to be related to a regional investigation of the tectonic history of northern Utah through study of several mountain ranges between the Pilot Range and the thrust belt structures exposed in the Wasatch Range. The Pilot Range is ideal for study of hinterland tectonics because a) Tertiary metamorphism and deformation are less severe compared with nearby "core complex" metamorphic terranes, enabling one to examine Mesozoic events, b) stratigraphic units are easily recognized and correlated throughout the region, c) a long igneous history permits radiometric dating to place tectonic events in an absolute time frame, and d) exposures are excellent. The only recent geologic studies of the Pilot Peak area were by Woodward (1967), who outlined the stratigraphy of the Proterozoic Z rocks, and O'Neill (1968), whose mapping accurately outlined rock units in most of the Pilot Peak quadrangle. Preliminary results of my mapping and laboratory work on the metamorphic rocks in the Pilot Range are presented here along with tentative interpretations of the structural history of the range.

DESCRIPTION OF MAP UNITS

Quaternary sedimentary rocks and unconsolidated material unconformably overlie Mesozoic igneous rocks and Paleozoic and Proterozoic Z miogeoclinal strata in the Pilot Range. The main range in the Pilot Peak quadrangle is composed of metamorphosed Middle(?) and Lower Cambrian and Proterozoic Z strata. Outcrops of rock units younger than Middle Cambrian are sparsely distributed in dissected pediments flanking the range. Near the southwestern corner of the map area a decollement places unmetamorphosed Ordovician rocks

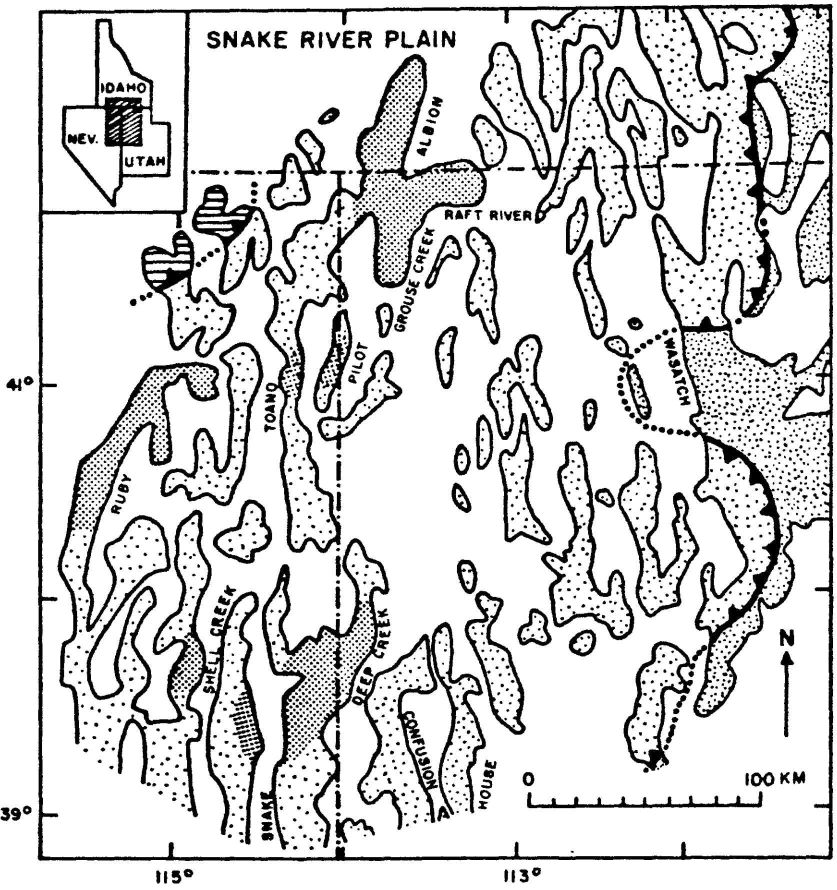

Figure 1. Location map, showing pre-Cenozoic rocks east of westernmost thrust of the Sevier Orogenic belt (heavy stipple), the hinterland (light stipple), and eugeoclinal rocks of the Antler Orogenic belt (horizontal ruling). Metamorphosed rocks in the hinterland are shown in dark pattern. Names of selected mountain ranges are given.

on the metamorphosed sequence. This decollement surface is an important reference surface and is distinguished from other low-angle faults because 1) it separates metamorphosed from unmetamorphosed rocks, and 2) it truncates a thick section of Paleozoic strata. It will henceforth be referred to as "the decollement". Brief descriptions of the sedimentary, igneous, and metamorphic rock units based on field studies and thin section examinations are given below.

Quaternary Deposits

Alluvium (Qa).-- Stream gravel and sand, and fanglomerate of Holocene and Pleistocene age were mapped along the flanks of the range. Most of the alluvium and fanglomerate lies above the high stand of Lake Bonneville. Other stream deposits overly the Bonneville lake deposits and occur in washes that dissect older, raised alluvial surfaces.

Talus and Slopewash (Qts).-- Talus slopes are abundant in the higher elevations of the range and are particularly well developed on the Prospect Mountain Quartzite. One unusually large talus slope leading into Wendover Canyon contains lobate features and closed depressions in its lower reaches, indicating a possible rock glacier origin. Slopewash also occurs on many of the slopes at lower elevations.

Landslide deposits (Qls).-- Seven small landslides were identified by their hummocky morphology. They occur along the western flank of the range and consist of disaggregated material, as opposed to features mapped as gravity slide blocks, which are composed of coherent blocks of a single stratigraphic unit.

Gravel beaches and bars (Qb).-- High stands of Lake Bonneville in areas of high sediment influx are characterized by prominent gravel and cobble beach and bar complexes. Bars were built to as much as 40 m above the lake bottom. The beaches and bars occur at about 4600, 4800, 5000 and 5200 ft (1400, 1460, 1525, and 1585 m) elevation; the modern playa surface 3 km east of the eastern limit of the map is at about 4245 ft (1294 m).

Bonneville lake deposits (Ql).-- Sand, silt, clay, and white, calcareous, clayey deposits of Lake Bonneville form veneers over older alluvium on both sides of the range. These deposits are generally less than one meter thick, with local accumulations as thick as 10 m. The highest Bonneville shoreline is at about 5200 ft (1585 m) elevation; its height fluctuates nearly 50 ft (15 m) over the length of the quadrangle.

Older alluvium (Qoa).-- Pleistocene deposits in terraces incised by streams and capping pediments are extensively developed along the eastern flank and to a lesser extent the western flank of the range. The deposits throughout the map area are characterized by large, white-weathered boulders of quartzite, which are sometimes imbricate. Older alluvium deposits are cut by the high stand of Lake Bonneville. Calcified zones are common near the base of the unit.

Tertiary Rocks

Quartz Porphyry (Tqp).-- Dikes of quartz porphyry containing subhedral quartz, plagioclase and potassium feldspar phenocrysts in an aphanitic, pale gray groundmass are present, but uncommon, in the Pilot peak quadrangle. The dikes generally trend northward. North of the quadrangle dikes of this unit are more extensive; there they cut a pluton for which radiometric ages of 31 m.y. (biotite K-Ar) and 30 ± 10 m.y. (Pb-α) were determined by Coats and others (1965) and 36.6 ± 0.5 m.y. (biotite K-Ar) was determined by Hoggatt and Miller (1981). Some dikes provisionally assigned to this unit are sericitized and contain few remnants of the distinctive phenocrysts.

Cretaceous(?) Rocks

Granodiorite of Bettridge Creek area (Kgb).-- The first major drainage north of Bettridge Creek contains a body of granodiorite approximately 1.5 km in length and 0.6 km in width. It is a weakly to moderately foliated, biotite-hornblende granodiorite, and contains biotite, quartz, plagioclase, potassium feldspar and hornblende as major phases, and minor amounts of apatite, zircon and opaque iron oxides. Biotite and quartz grains are deformed. The pluton is less resistant than adjacent metamorphic rocks and is, therefore, poorly exposed. It creates a wide, flat-floored valley in contrast with the steep-walled, V-shaped canyons typical of the range. Satellitic pods and dikes occur within several km of the pluton. A radiometric age of 91 m.y. (hornblende K-Ar) for the unit (Hoggatt and Miller, 1981) suggests that it is Early Cretaceous.

Granodiorite dikes (Kg).-- Dikes ranging considerably in composition and texture, and distributed over nearly the entire map area, are grouped in this unit. They are approximately granodiorite in composition, and contain biotite, plagioclase, potassium feldspar and quartz as major phases. Many also contain abundant hornblende and sphene. Minor phases are zircon and apatite. The smaller dikes typically have a medium gray aphanitic matrix. One small body about 2 km south of China cove contains abundant phenocrysts of plagioclase and oikocrysts of hornblende in a finer grained matrix of biotite, hornblende, potassium feldspar and quartz. The granodiorite dikes generally intrude low-angle fault zones and are slightly deformed. Lithologic similarity with the granodiorite of Bettridge Creek area suggests a Cretaceous age for this unit. K-Ar data are inconclusive because biotite ages of about 30 m.y. for this unit (Hoggatt and Miller, 1981) are similar to the reset biotite age of the granodiorite of Bettridge Creek area, and most likely are also reset "ages".

Jurassic(?) Rocks

Muscovite syenogranite (Jg).-- This unit, which occurs as dikes nearly concordant with bedding and schistosity in the enclosing metamorphic rocks, is characterized by its aluminous composition and its foliation. Typical dikes are foliated and lineated due to the preferred orientation of micas, and are equigranular and partially recrystallized. Some occurrences are pegmatitic and nearly lacking in mafic minerals. Muscovite and biotite are probably metamorphic. Quartz is completely recrystallized, and margins of feldspar crystals are commonly recrystallized to smaller grains. Minor phases are apatite, zircon, sphene, garnet(?), and opaque iron oxide. In one thin section, clinozoisite was abundant, but it was not observed elsewhere in this unit. Most occurences of the muscovite syenogranite are in the metamorphosed Cambrian(?) schist and marble near Wendover Canyon. Two dikes near China Cove Pass are pegmatitic, mafic-poor rocks that lack muscovite and are unfoliated; they are provisionally included in this map unit. Because dikes of this unit are foliated and folded like their host rocks, and those structures are cut by granodiorite of Bettridge Creek area, the muscovite syenogranite must be more than 91 m.y. old. K-Ar dating of muscovite from the syenogranite yielded a nominal age of 56.2 ± 0.8 m.y., which was interpreted as indicating partial retention of argon from an earlier metamorphic event (Hoggatt and Miller, 1981). Plutons of similar aluminous composition occur in the northern Toano Range, 20 km west of Pilot Peak, and in the northern Silver Island Mountains 27 km east-northeast of Pilot Peak (Fig. 1). Based on structural criteria, the pluton in the Toano Range is probably older than a nearby pluton for which radiometric ages of 180 ± 20 m.y. (Pb-α) and 148 m.y. (biotite K-Ar) have been determined by Coats and others (1965). The pluton in the Silver Island Mountains is older than 140 m.y. (Allmendinger and Jordan, 1981). The muscovite syenogranite in the Pilot Range is therefore most probably Jurassic.

Pennsylvanian Rocks

Ely Limestone (₽e).-- Highly fossiliferous, argillaceous, dolomitic, and cherty limestone exposed in the pediment south of Wendover Canyon is assigned to the Pennsylvanian Ely Limestone of Lawson (1906) on the basis of fossils and stratigraphic position. The unit is a heterogeneous assemblage of (a) medium- to thick-bedded, medium gray to brownish gray, fine-grained limestone, (b) brown, shaly, thin-bedded limestone, (c) blue-gray to medium gray dolomite and dolomitic limestone, and (d) bioclastic limestone. Red-brown chert nodules are common in zones parallel to bedding. Immediately south of the Pilot Peak quadrangle, rocks exposed near the top of the Ely include pale gray limestone underlain by darker limestone, bioclastic limestone, and thin limestone-chert sedimentary breccias. The Ely is unconformably overlain by Permian (Leonardian) cherty, dark, bioclastic dolomite and limestone. The base of the Ely is not exposed because the lower part of the unit is faulted against marble along a north-trending normal fault. Total thickness is about 250 m.

Argillaceous limestone from Ely Limestone, sampled near the top of the unit about 400 m south of the Pilot Peak quadrangle, yielded bryozoans, brachiopods, and echinoderms indicating a Des Moinesian age (M. Gordon, Jr., 1980, written comm.) Bryozoans from four samples about 50 m stratigraphically below the top of the unit yielded Mississippian to Permian ages for three samples and Carboniferous for the forth (O. L. Karklins, 1980, written comm.). Conodants in the same samples were examined by J. Repetski (1980, written comm.), who determined that three samples were limited to the Pennsylvanian, and one of them was further limited to the Morrowan to Des Moinesian. The Ely is therefore Lower to Middle Pennsylvanian.

Mississippian Rocks

Chainman and Diamond Peak Formations, undifferentiated (Mcd).-- About 235 m of interbedded dark shale, sandstone and impure limestone assigned to the Chainman and Diamond Peak Formations undifferentiated (Nolan and others, 1956) occur in pediment exposures south of Wendover Canyon, where the rocks are in low-angle(?) fault contact with the underlying Ordovician Fish Haven Dolomite. The rocks are assigned to the Chainman-Diamond Peak on the basis of lithology. Conglomerate beds as much as 2 m thick contain quartzite, siltstone, and chert pebbles less than 8 cm in diameter in an arkosic sand and silt matrix. Graded arkosic sandstone beds generally underlie the conglomerate, and are in turn underlain by sandy to silty, dark limestone. Dark to light gray, fissile shale occurs in the easternmost exposures.

Devonian Rocks

Guilmette Formation (Dg).-- Light to medium gray, thick-bedded, cliff-forming limestone of the Guilmette Formation (Nolan, 1935) is exposed in the pediment southwest of Pilot Peak. The limestone is faintly laminated, fine grained and sparsely fossiliferous. About 700 ft (213 m) of Guilmette overlie interbedded dolomite and limestone that are believed to belong to Devonian Simonson Dolomite. A high-angle fault truncates the upper part of the Guilmette Formation. A coral sampled from the base of this unit yielded a Middle to early Late Devonian age, most likely early Late Devonian (W. A. Oliver, Jr., 1980, written comm.). Based on lithology and age, this unit is believed to correlate with the Guilmette.

Simonson Dolomite(?) (Ds).-- Thick alternating units of light and dark carbonate rocks underlying the cliffy, massive, light gray limestone of the Guilmette Formation are thought to represent Simonson Dolomite (Nolan, 1935) on the basis of lithology. Dark bluish-gray dolomite, and light to medium bluish-gray shaly to silty limestone are common rock types. Bedding is thin to thick; lamination is present locally. Less common lithologic types are calcite-cemented sandstone and cherty carbonate. The overall appearance of the unit is similar to interbedded limestone and dolomite at the top of Simonson Dolomite cropping out 10 km north of the Pilot Peak quadrangle. Approximately 185 m of Simonson are exposed.

Conodants from samples analyzed by A. G. Harris (1980, written comm.) were latest Middle Devonian to early Late Devonian, suggesting that this limestone/dolomite sequence may properly belong in the Guilmette Formation. However, the large-scale color alterations and silty and sandy beds are suggestive of Simonson Dolomite.

Ordovician Rocks

Fish Haven Dolomite (Ofh).-- Black, dark- and medium-gray, unbedded, crystalline dolomite occurring in the pediment south of Wendover Canyon is assigned to the Fish Haven Dolomite (Richardson, 1913) on the basis of lithology. The Fish Haven is in fault contact with highly fractured Eureka Quartzite. The geometry of the fault blocks involving Eureka and Fish Haven is complex and, apparently, faults with both low- and high-angle orientations are present. As a result, thickness of the Fish Haven is undetermined. The Fish Haven is overlain by a low-angle(?) fault block of Mississippian rocks. A pediment exposure of Fish Haven(?) in the southwestern corner of the quadrangle consists of dark gray, sandy dolomite; it may alternatively belong to a Silurian unit.

Eureka Quartzite (Oe).-- The white to bluish gray or charcoal gray orthoquartzite assigned to the Eureka of Hague (1883) is commonly highly fractured or brecciated in pediment exposures on both sides of the Pilot Range. It is exceptionally well-sorted, consisting of well-rounded, medium sand-sized grains in a silica cement. Recrystallization and stress solution have altered the grains locally. The maximum thickness of Eureka exposed is 150 m.

Lehman Formation (Ol).-- The Swan Peak Quartzite, which typically underlies the Eureka Quartzite and the intervening Crystal Peak dolomite, is not present in Pilot Peak quadrangle. The approximately 61 m of carbonate rocks below the Eureka and above the Kanosh Shale are therefore assigned to the Lehman Formation (Hintze, 1951). The upper part of the unit contains dark dolomite and sandy, shaly, and pure limestone similar to O'Neill's (1968) description of the Crystal Peak Dolomite in the southern Pilot Range. The remainder of the unit is medium gray, silty to pure, limestone. These two portions of the Lehman are not generally separable, and it is therefore mapped as a single unit.

Kanosh Shale (Ok).-- About 92 m of Kanosh Shale (Hintze, 1951) underlies the Lehman. It is a bench-forming unit consisting of green and brown, calcareous shale with thin interbeds of gray limestone. The Kanosh is correlated on the basis of lithology and stratigraphic position.

Garden City Formation (Ogc).-- The upper part of the Garden City Formation is exposed near Wendover Canyon, where dark gray limestone and brown silty limestone lie under the Kanosh, and in the southwestern corner of the quadrangle. The limestone is laminated, thick bedded, and contains cherty zones. In the southwestern corner of the quadrangle the Garden City is a medium gray to bluish gray, thick to thin bedded limestone containing shaly laminae or mottled texture. It is fossiliferous, and contains rare beds with abundant white, light to dark gray, and tan chert lenses. Maximum thickness of the Garden City in the Pilot Peak quadrangle is about 200 m. Conodants from the Garden City in a fault block west of the main range and east of the Simonson(?) Dolomite fault block are of middle to late Early Ordovician age (J. Repetski, 1980, written comm.). Lithologically similar rocks, also assigned to the Garden City, occur above the decollement on Pioche Shale east of the fault block from which conodants were examined. The rocks are correlated with the Garden City on the basis of lithology and fauna.

Cambrian(?) Rocks

Cambrian(?) Limestone (€l).-- Two isolated exposures of ooidal limestone near Wendover Canyon are thought to be Middle or Upper Cambrian based on lithologic similarity to rocks underlying Upper Cambrian Dunderburg(?) Shale 4 km to the southwest. In the Pilot Peak quadrangle, the limestone is dark blue-gray and fine to medium grained, with silty and shaly bed partings. The unit contains zones of echinoderm and brachiopod remains (A. K. Armstrong, 1981, written comm.), but no condodants were recovered from one small sample. The limestone is faulted against marble and schist to the west and probably underlies, or is faulted against, Ordovician rocks that crop out to the east in the pediment.

Marble (€m).-- This unit forms white, tree-covered slopes north and south of Wendover Canyon. It consists of white to tan or gray, slightly micaceous marble, schistose marble, calcareous schist and minor calcareous quartzite. Metamorphic minerals include muscovite, biotite, hornblende, and actinolite-tremolite. The unit is strongly foliated at low angles to bedding, and is tightly folded in places. The marble appears to gradationally overlie schist assigned to the Cambrian Pioche Formation, and therefore the marble is probably Middle Cambrian. Where large folds are not mapped, thickness is estimated as about 330 m. The top of the unit is in fault contact with sedimentary rocks.

Cambrian Rocks

Pioche Formation (€p).-- Slope-forming dark phyllite, schist, calcareous quartzite, and calcareous schist overlying Prospect Mountain Quartzite and underlying Cambrian(?) marble is considered to be metamorphosed Pioche Formation of Hintze and Robison (1975), based on general lithologic similarity and stratigraphic position. The lower part of the unit corresponds to the Pioche Shale as recognized in the nearby Silver Island Mountains (Schaeffer, 1960) and the upper, quartzite member correlates with the Busby Quartzite in that range.

The quartzite member, of uncertain thickness due to repetition by folding and faulting, is a heterogeneous assemblage mainly consisting of interlayered quartzite, impure marble, and calcareous schist. Two marker zones -- a tan, pelitic schist and a black marble, each about 20 m thick -- permit low-angle faults and large folds to be identified. The schist contains retrogressed porphyroblasts of staurolite, garnet and cordiorite in a matrix of quartz, white mica and plagioclase. Retrogression of the schist is to chlorite - white mica ± biotite assemblages, as it is throughout the Pioche and in other units throughout much of the quadrangle. The black marble contains graphite-calcite-white mica assemblages with a wide range in modal tremolite and quartz. The remainder of the quartzite member is thin- to medium-bedded and consists of interlayered calcareous quartzite, quartzose and/or schistose marble, calcareous schist and greenschist (metamorphosed siltstone). Tremolite, hornblende, and white mica are ubiquitous metamorphic minerals. Only rarely do detrital calcite or feldspar grains remain, because the rocks are highly foliated and recrystallized. The upper part of the quartzite member is typically greenish or brown schist interlayered with schistose marble; it grades into overlying Cambrian(?) marble. Quartz- and carbonate-rich beds rapidly decrease in abundance at the base of the quartzite member, where it locally grades(?) into underlying schist of the lower member of the Pioche. Where the contact is well exposed, however, beds are truncated at the boundary between the members and the lower member pinches out southward. As a result, the contact is interpreted as tectonic with little or no disruption locally.

Schist and phyllite exposed beneath the quartzite member in the Wendover Canyon area, near the Pinnacle, and beneath the Garden City Formation south of Pilot Peak are homogeneous, dark, and graphitic, and contain rare dark quartzite and conglomerate beds, and calcareous phyllite. Graphite - quartz -white mica ± tremolite ± calcite ± hornblende ± phlogopite ± chlorite metamorphic assemblages are typical. Retrogressed porphyroblasts are cordierite, garnet(?), and staurolite(?).

The high carbon content of the Pioche in the Pilot Range is at variance with published descriptions of the unit in most of the eastern Great Basin, where it consists of green shale and siltstone. It is probable that the black shale in the Pilot Range is not strictly correlative with the Pioche and represents offshore, euxinic deposition of approximately the same age, and as such should be correlated with a Lower and Middle Cambrian shale from central Nevada. The shales overlying the Prospect Mountain Quartzite in the nearby Silver Island and Toano Ranges are also carbon-rich and black.

Cambrian and Proterozoic Z Rocks

Prospect Mountain Quartzite (restricted) (€Zpm).-- As restricted by Misch and Hazzard (1962), the Prospect Mountain Quartzite is the topmost thick quartzite in a sequence of interlayered argilllaceous rock and quartzite, the lower part of which they named the McCoy Creek Group. The Prospect Mountain, about 955 m thick, is overlain by Pioche at a contact that is interpreted as a low-angle fault because quartzite beds are truncated at about 5 degrees to bedding. The Prospect Mountain is not substantially thinned by this fault and the Pioche is only cut out where other faults are also present near Wendover Canyon. We therefore interpret that the fault separating Pioche and Prospect Mountain truncates little stratigraphic section in most areas. The McCoy Creek Group concordantly underlies the Prospect Mountain Quartzite.

The Prospect Mountain is recognized by its great thickness, cliff-forming nature, and thick-bedded and prominently cross-laminated gray quartzite. Quartz is partly to completely recrystallized. Detrital plagioclase and microcline compose 0-20% of the rock, and white mica and biotite are common minor components. Fine-pebble conglomerates containing white quartz pebbles less than 1 cm in diameter are common. Darker quartzite beds and schistose beds are present near the top and base of the Prospect Mountain, close to overlying and underlying fine grained argillaceous rock units. Detailed descriptions of the Prospect Mountain are given by Miller (1981).

Proterozoic Z Rocks

Woodward's (1967) correlation of Pilot Peak rock units underlying Prospect Mountian Quartzite with McCoy Creek Group of Misch and Hazzard (1962) is followed here. Alternating phyllitic and quartzitic units below the Prospect Mountain are assigned descending unit letters G through C; the lower units, tentatively assigned to Units B and A (following O'Neill, 1968), are structurally isolated from younger rocks.

McCoy Creek Group, Unit G (Zg).-- The schist, phyllite and marble of Unit G, in total about 480 m thick, concordantly underlie Prospect Mountain Quartzite. Unit G as a whole is slope-forming, in marked contrast with the cliffs and steep talus slopes characteristic of the quartzite units above and below. A basal zone of interbedded conglomerate and phyllite, and a distinctive thinly interbedded zone of marble and schist occurring near the middle of Unit G, provide convenient markers for mapping. The conglomerate is broken out as a member, and the remainder of Unit G is informally subdivided into a lower phyllite, middle calcareous zone, and upper phyllite.

The conglomerate member in the south consists of two or three, 10 to 20 m thick conglomerates beds occurring together about 80 m above the base of Unit G. The member generally increases in thickness northward to a point a few km south of China Cove, where it includes the basal 120 m of Unit G and consists of interbedded phyllite, fine grained micaceous guartzite, and pebble conglomerate. The conglomerate is poorly sorted and contains arkosic to graywacke matrix material. Rip-up clasts of phyllite are common. Intervening brown phyllite and micaceous quartzite are thin bedded to laminated, and contain ripples and flute casts. The phyllite and quartzite typically contain quartz - white mica - biotite - feldspar - chlorite metamorphic assemblages.

Above the conglomerate member, the remainder of Unit G comprises: 1) A lower zone of gray and green metasiltstone, containing micas and quartz and, rarely, calcite. Amphibole schist, about 1 m thick, is a conspicuous rock type. 2) A middle zone, about 60 m thick, is characterized by thinly interbedded calcite marble, calcareous phyllite, and phyllite or metasiltstone. The marble is white, tan, dark-gray or blue-gray weathering, and slightly micaceous. Intervening beds are dark-gray, green, or brown micaceous quartzite, commonly calcareous. 3) An upper zone, about 200 m thick, consists of gray, green, and brown, laminated to thin-bedded, metasiltstone.

McCoy Creek Group, Unit F (Zf).-- Unit F is a cliff-former made up of gray, well-bedded, commonly cross-laminated quartzite. The main body of the 300 to 360 m thick unit is homogeneous for the most part. The basal 40 m of Unit F consists of moderately to poorly bedded gray quartzite that generally contains 10 to 20% feldspar as clasts. Conglomerate containing pebbles as large as 2 cm is locally an important constituent of the lower part of the section. A few thin mica schist beds occur in the upper 80 m of the section. Commonly, channel(?) conglomerate as much as 30 m thick also occurs at the top. This conglomerate is quartzitic, massive to very thickly bedded, contains clasts as much as 6 cm in diameter, and is poorly sorted. Rip-up wedges of phyllite and feldspar clasts are common.

McCoy Creek Group, Unit E (Ze).-- Slope-forming, brown metasiltstone and phyllite about 70 m thick are assigned to Unit E. The unit contains laminated and thin beds of metasiltstone, phyllite, micaceous fine-grained quartzite, and, uncommonly near the base, conglomerate. The phyllite contains white mica, biotite and quartz; secondary chlorite ranges from absent to completely replacing biotite.

McCoy Creek Group, Unit D (Zd).-- Unit D is a cliff-forming massive quartzite that ranges in thickness from about 220 m near Debbs Canyon to nearly twice as thick in the northernmost exposures. The base of the unit is poorly bedded, medium-grained, light gray quartzite with as much as 20% detrital feldspar. The quartzite grades upward, through an interval of quartzite with intercalated thin conglomerate beds, into massive, light colored conglomerate that is clast-supported. Clasts are white and blue quartz, and white and gray quartzite, and typically are smaller than 1 cm. Rip-up clasts of phyllite are increasingly common toward the top of the massive conglomerate, where interbeds of metasiltstone and phyllite occur. Sedimentary structures such as flute casts, graded beds and soft sediment folds are present near the top of Unit D. The contact with Unit E is drawn at the top of the last quartzite bed thicker than 1 m.

McCoy Creek Group, Unit C (Zc).-- The slope-forming phyllite of Unit C crops out poorly in two areas along the western base of the range. A minimum thickness of 35 m is indicated by exposures near Debbs Canyon. The base is not exposed in the Pilot Range. The unit is composed of yellowish green and silvery brown phyllite, metasiltstone and slate; it is commonly laminated.

McCoy Creek Group, Unit B(?) (Zb).-- About 155 m of marble of Unit B(?) forms steep slopes east of China Cove Pass. The marble is clean, containing at most 10% white mica, quartz and iron oxide minerals. The white and gray marble, commonly with bluish tinges, is generally laminated and medium to coarse crystalline. Massive, white, coarsely crystalline marble occurs locally. The top of the unit is truncated by the Pinnacle Fault, adjacent to which the marble is highly deformed and extremely fine grained. At its base, the marble grades into schistose tremolite-calcite marble and calcareous quartzite. The unit is interpreted to be equivalent to Unit B of the McCoy Creek Group in the Schell Creek Range as defined by Misch and Hazzard (1962), on the basis of rock type and stratigraphic position (O'Neill, 1968).

McCoy Creek Group, Unit A(?) (Za).-- Unit A(?), more than 450 m thick, is a heterogeneous clastic unit of impure quartzite, metasiltstone, and amphibole schist. The upper portion contains a distinctive green amphibole schist that is overlain by brown mica schist. This upper part, which pinches out along strike, is designated as the schist member.

The schist member consists of green, crenulated tremolite/ actinolite schist and, locally, brown, quartzose schist and steel gray graphitic schist. The tremolite schist is up to 95% coarse tremolite/actinolite with minor interstitial feldspar. Other rocks are biotite-white mica schist, locally containing minor tremolite/actinolite. Near the southernmost outcrops of the schist, metadiorite(?) occurs immediately beneath Unit B. This rock, together with the tremolite/actinolite schist, is suggestive of metamorphosed igneous sills or flows.

Flaggy quartzite, schist, conglomerate, and mixtures of these rock types are interbedded in the lower part of Unit A(?). The dominant rock type is schistose, tan, bedded quartzite. No internal stratigraphy was ascertained, although distinctive steel gray, graphitic schist occurs in the lower part of the exposed sequence. The schist contains a biotite - white mica - quartz -plagioclase metamorphic assemblage. Aggregates of felted white mica have recrystallized from an unknown porphyroblast. The base of Unit A(?) is unexposed.

The heterogeneous quartzite and schist of Unit A(?) are lithologically similar to Unit A in the type area of Misch and Hazzard's (1962) McCoy Creek Group in the Schell Creek Range. Unit A is overlain bv marble in both ranges. We therefore follow O'Neill (1968) in assigning the rocks underlying the marble of Unit B(?) to Unit A(?) of the McCoy Creek Group.

METAMORPHISM

Rocks below the decollement were metamorphosed to approximately middle greenschist facies with local nodes of amphibolite facies metamorphism. Semipelitic rocks contain assemblages indicative of biotite (albite-epidote-biotite) zone, micaceous carbonate rocks contain tremolite, and quartzite and strongly quartz-rich rocks are recrystallized but contain less diagnostic mineral parageneses due to their quartzose composition. Chlorite porphyroblasts in most pelitic rocks indicate that they were not in the amphibolite facies. The local nodes of higher facies metamorphism (Fig. 2) spatially associated with plutons contain garnet, staurolite, cordierite, hornblende and cummingtonite(?), indicating low pressure amphibolite facies metamorphism of the Abakuma-type (Winkler, 1967). Virtually all of the thin sections examined showed evidence of retrogression, most commonly manifested as chlorite after biotite. Porphyroblasts of staurolite and cordierite are largely replaced by white mica-chlorite assemblages, and garnet is entirely replaced by chlorite; the garnet was identified on the basis of its shape and the composition of the retrogressive assemblage.

Relict prograde assemblages of minerals are generally readily identified in the greenschist facies rocks. Typical assemblages in metasiltstone and phyllite are:

quartz - white mica - biotite ± epidote ± chlorite ± albite(?).

In some thin sections, biotite is pale and may perhaps be phlogopite. Plagioclase composition is ambiguous; determinations of plagioclase composition by

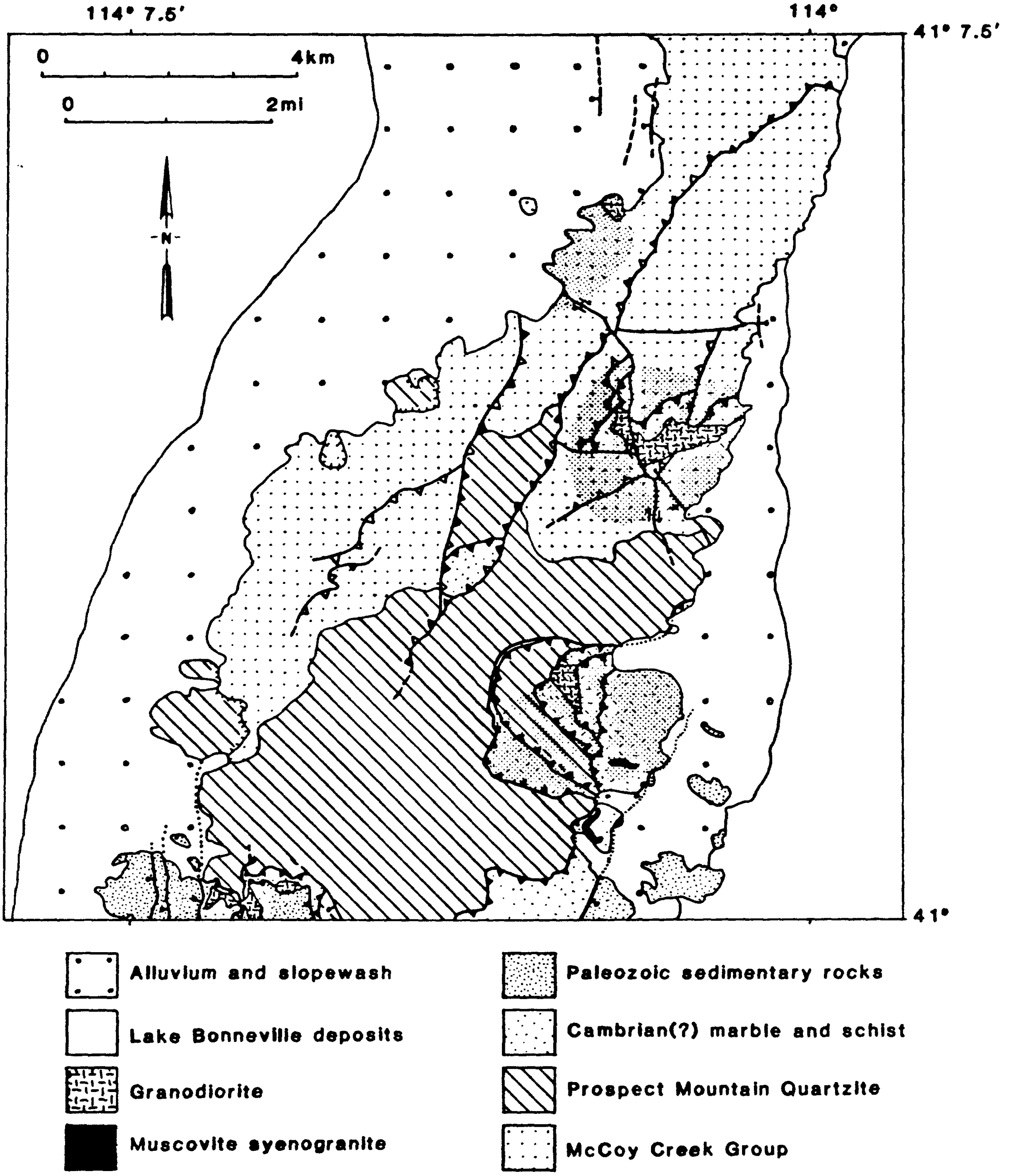

Figure 2. Metamorphic facies in the Pilot Peak quadrangle and parts of adjacent quadrangles. Shaded areas are approximate outcrops of amphibolite facies rocks. Other strata are greenschist facies except for Paleozoic sedimentary rocks, which occur above the decollement. Symbols are explained on Plate 1.

the Michel-Levy method indicated compositions of albite or oligoclase. Albite is consistent with assemblages containing epidote and chlorite. White mica may be either muscovite or pyrophyllite. Mafic schist yielded an assemblage:

biotite - plagioclase - hornblende - white mica.

Micaceous carbonate rocks contain:

calcite - quartz - white mica ± chlorite ± biotite/phlogogite ± epidote ± tremolite.

Tremolite is colorless in thin section and therefore probably has little actinolite component. Coexistence of tremolite and calcite, and the presence of chlorite and epidote, indicates greenschist facies metamorphism. These assemblages are appropriate for Abakuma-type (low pressure), Barrovian-type (high-pressure) or hornfels-type ("contact") metamorphism. In all cases the temperatures required for the mineral parageneses are in excess of about 400° C and less than about 500° C (Winkler, 1967), but pressures are not constrained by the mineral assemblages. We consider that the broad extent of these assemblages and their uniformity (with the exception of higher grade nodes near plutons) throughout the quadrangle indicates that the metamorphism is regional in scope.

Nodes of amphibolite facies assemblages (Fig. 2) have complicated histories that indicate two prograde events followed by retrogression. Semipelitic rocks contain mineral parageneses of:

quartz - white mica - biotite ± staurolite ± garnet ± cordierite.

Staurolite is replaced by white mica + chlorite, garnet is replaced by biotite + white mica + chlorite, and cordierite is replaced by white mica and/or sericite. Impure calcareous rocks contain:

calcite - white mica ± biotite ± tremolite ± hornblende(?) ± plagioclase.

Plagioclase is oligoclase or andesine, as determined by the Michel-Levy method. Hornblende(?) is black or dark brown in hand sample, but white/pale brown pleochroic in thin section, perhaps indicating a solid solution composition low in Na, Al and Fe. Tremolite is colorless or pale green, indicating little actinolite (Fe-rich) component in the solid solution series. Staurolite and cordierite in the semipelites, and hornblende in the calcareous rocks, indicate amphibolite facies metamorphism, as does the higher An content of plagioclase. However, coexisting tremolite and calcite is indicative of greenschist facies (Winkler, 1967). This apparent contradiction is probably caused by overprinting of greenschist facies assemblages by amphibolite facies conditions. Unoriented hornblende grows piokiolitically from old, flattened and elongated porphyroblasts of uncertain mineralogy in the tremolite-calcite rocks, indicating that a post-deformation event caused growth of minerals in amphibolite facies. This is compatible with the localized nature of the amphibolite facies rocks and their association with plutonic rocks (Fig. 2). We consider the amphibolite facies metamorphism to be a late, relatively short, thermal pulse localized near invading plutons which, in many locations, apparently did not completely re-equilibrate the pre-existing greenschist facies assemblages. Temperatures must have exceeded about 530° C in order for cordierite and staurolite to be stable, and pressures were less than about 6 kb because kyanite is not present and cordierite was stable (Winkler, 1967).

Retrogression generally resulted in partial replacement of biotite by chlorite throughout the quadrangle. Staurolite, garnet, cordierite, and (rarely) amphibole were generally replaced by chlorite-white mica assemblages, but in a few cases they were replaced by biotite-white mica.

The prograde regional metamorphism occured at about 450 ± 50° C and at uncertain pressures. Higher grade nodes formed at temperatures between ~520° C (cordierite and staurolite stable) and 580°C (muscovite unstable), and at less than 6 kb or about 22 km depth. Using an "average" thermal gradient of 30° C/km, 15 km depth is required for the regional metamorphism. This is probably a maximum figure of the depth required, because the thermal gradient used here is probably lower than one for an active orogenic belt. The total thickness of rocks overlying the McCoy Creek Group in and near the Pilot Range is estimated as 10.2 ± 1.0 km, and thus no substantial thinning or thickening of tectonic origin is required to explain either the pressures or temperatures estimated for regional metamorphism. Near the higher facies nodes the thermal gradient must have been locally increased to greater than 100° C/km. Perhaps this local metamorphism should, therefore, be viewed as "contact" metamorphism of the hornblende-hornfels facies (Winkler, 1967), which has diagnostic assemblages compatible with those in the Pilot Range.

Timing of metamorphism can only be partly constrained. The regional metamorphism affected muscovite syenogranite that probably is Jurassic. Fabrics and structures developed during the metamorphism are post-dated by the emplacement of the granodiorite of Bettridge Creek area, which has a minimum age of 91 m.y. Greenschist facies minerals therefore probably developed during the Jurassic and/or Early Cretaceous. Higher grade metamorphic nodes produced recrystallization of older, oriented minerals into unoriented aggregates, indicating that this localized metamorphism must have post-dated much or all of the deformation associated with greenschist facies metamorphism. The nodes are spatially associated with larger bodies of granodiorite, one of which has a minimum age of 91 m.y. The late, high-temperature event was therefore probably Early Cretaceous. Retrogression is interpreted as approximately Oligocene on the basis of reset biotite K-Ar ages of 30 to 27 m.y. (Hoggatt and Miller, 1981).

STRUCTURAL HISTORY

The structures in the Pilot Peak quadrangle are divided by geometry, associated metamorphism, and timing into three groups: (1) Bedding-plane faults and tight folds, (2) Low-angle faults and kink folds, and (3) High-angle Tertiary faults. The first two groups formed during the Mesozoic and involved considerable ductile deformation with an increase in brittle structures in the second group. Structures of the third group are brittle.

The structural history described below is mainly based on relations in the metamorphic rocks in the Pilot Peak quadrangle. Lying above the metamorphic rocks, and separated by a major low-angle fault (the decollement), are Paleozoic sedimentary rocks. High-angle and low-angle faults occurring in the sedimentary rocks are poorly understood at present, and cannot be integrated into the structural history of the metamorphic rocks below the decollement.

(1) Bedding-plane faults and tight folds

Synchronous with or following the intrusion of the muscovite syenogranite of probable Jurassic age, regional metamorphism and two phases of small-scale folding occurred in the Wendover Canyon area. The two phases of folding cannot be systematically separated on the basis of geometry or orientation, and they cannot be correlated with the development of larger folds or low-angle faults. Axial plane foliations and penetrative lineations are developed in both fold sets; metamorphic minerals that crystallized synchronously with these structures are regionally developed.

Bedding-plane faults are common in the schist and micaceous marble of the Wendover Canyon area. The faults duplicate and remove thin sections of the schist and marble. Bedding-plane faults also occur within the McCoy Creek Group north of Bettridge Canyon. Thin stratigraphic sections are removed by these faults, and quartzite is locally mylonitic in the fault zones.

Elsewhere, a somewhat simpler early structural history is evident. South of Bettridge Creek the Prospect Mountain Quartzite is folded to a vertical orientation with strike of about N.60°E. This fold geometry is similar to the geometry of the limbs of a major, northeast trending fold in the Prospect Mountain that occurs 5 km north of China Cove Pass. There, bedding-plane faults are folded by the southeast-vergent major folds, and minor folds associated with the faults also verge southeastward, suggesting that fault movement may have displaced higher sheets southeastward over lower ones (Miller, 1981). East-trending penetrative lineations are folded about northeast trending folds in Unit B(?) of the McCoy Creek Group east of China Cove Pass. Locally developed, but penetrative, lineations elsewhere in the quadrangle generally trend east-northeast to northeast, parallel to the major fold axes. The lineations are differently oriented where they are related to later structures, as in the Bettridge Creek area, and where they are affected by low-angle faults. Lineations developed in mylonitized quartzite trend S. 50° E. in bedding-plane fault zones developed on the Prospect Mountain Quartzite beneath the decollement in the southeastern corner of the quadrangle. These mylonitic lineations are perpendicular to axes of overturned folds possibly related to bedding-plane faulting and are therefore interpreted as indicating the movement direction during faulting.

In the southwestern corner of the quadrangle the decollement occurs in the highly strained and locally shattered Pioche Formation. Prospect Mountain Quartzite below the Pioche is locally mylonitic and is typically truncated. Above the Pioche is brecciated Ordovician Garden City Formation. The decollement therefore truncates a thick section of Cambrian and Ordovician strata. Elsewhere in the quadrangle, Cambrian(?) marble overlies the Pioche, and Cambrian(?) limestone (Ꞓl) underlies the Garden City; the decollement must therefore remove a highly variable thickness of strata.

In summary, the first group of structures are ductile in character and regionally developed. The first of two sets of minor folds is complexly refolded and of uncertain significance. The second set of folds is interpreted as having formed due to low-angle faulting and decollement development, indicating southeastward movement of the upper plate over the lower plate. Bedding-plane faults in most cases remove less than 100 m of stratigraphic section. The decollement in the southwestern corner of the quadrangle is basically a movement zone in the Pioche Formation phyllite; a considerable thickness of strata above the Pioche has been eliminated by the fault.

(2) Low-angle faults and kink folds

Bedding-plane faults, tight folds, and lineations belonging to the first group of structures are deformed by a second group of more open, kink-style folds, and by faults that break nearly parallel to axial planes of the kink folds. These later folds and faults are extensively developed in the vicinity of Bettridge Creek, and similar structures occur in the southwestern corner of the quadrangle. The folds trend north to north-northeast, have nearly planar limbs and tight hinges, and verge eastward on the east side of the Pinnacle Fault and westward west of the fault (Plate 2, section C-C'). Small scale folds are rare; they have no axial plane foliation and minerals such as biotite and quartz in the hinge zones are deformed but not recrystallized. Low-angle and moderate-angle faults that break near the hinges of the kink folds have normal separations and apparently were developed as the asymmetric folds broke along surfaces nearly parallel to axial planes in the tight hinge zones.

The Pinnacle fault, a low-angle (dip 30° west), normal fault whose trace trends northward and nearly follows the present crest of the range, is probably a member of group 2 structures because: 1) the fault separates regions of opposing vergence in group 2 kink folds, 2) metamorphic fabrics are present in Unit B(?) rocks dragged into parallelism with the fault, indicating that faulting occurred at metamorphic temperatures, and 3) the fault strikes parallel to fold axes and faults of group 2. Thick quartzite units are truncated by the fault, but schist and marble wrap into parallelism with the fault as thin, highly deformed wedges. Deformation in marble resulted in extreme flattening of the calcite grains and a reduction in grain size of nearly two orders of magnitude. East-dipping faults west of, and intersecting, the Pinnacle fault are interpreted as antithetic faults (Fig. 3).

East-trending fault traces in each of the two main drainages immediately north of Bettridge Creek are interpreted as traces of tear faults. These faults are conjectural because exposure is poor, but they are required in order to account for repetition, in one case, and omission, in the other, of major parts of the McCoy Creek Group. The inferred faults do not cut the Pinnacle fault. The stratigraphic section is difficult to identify unambiguously due to a) rapid changes in metamorphic facies, b) complex structure, and c) complex stratigraphic facies changes. However, the map relations are best explained by tear faults that cut the hanging wall of an unexposed low-angle fault inferred at depth. In this interpretation, the tear faults are contemporaneous with, or predate, movement on the Pinnacle fault. The alternative interpretation, that the faults are low-angle and dip southward, is difficult to reconcile with geometrical constraints imposed by the meager exposures and with the geometry of other structures in the range.

Group 2 folding and low-angle faulting is interpreted as thinning above a rising arch whose axis was approximately centered under the Pilot Range, (Fig. 3). The opposing vergence of folds on either side of the range requires opposing flow directions. Low-angle faults in the fold hinges are interpreted as conjugates of the master faults at depth, one of which is exposed as the Pinnacle fault. The Pinnacle fault dies out southward and upward in the section in the thick, competent Prospect Mountain Quartzite, which is arched in a large, complex, north-trending fold that refolds earlier folds. The maximum separation on the Pinnacle Fault, near the northernmost exposures, is about 1.5 km. The termination of the Pinnacle fault southward is apparently compensated by complex kink folding within the Prospect Mountain Quartzite. The faulting above the arch results in net thinning of the stratigraphic section and complex rotation of strata in individual fault blocks. The location of the basal low-angle fault shown in Figure 3 is unknown, and whether it occurs in miogeoclinal strata or crystalline basement is also unknown.

High-angle Tertiary faults

High angle faults of presumed Tertiary age occur as two general sets: 1) early strike-slip and oblique-slip, north-northeast to north-northwest striking faults, and 2) later normal faults parallel to the range fronts. The early set is best developed in the China Cove Pass area. Right-slip faults

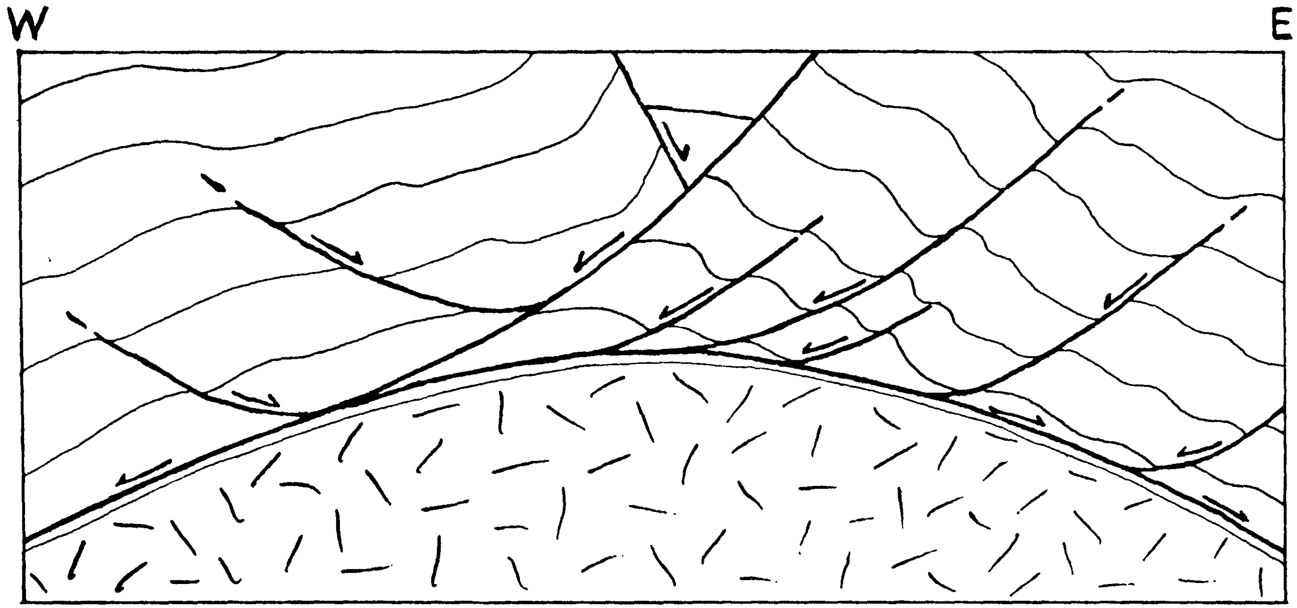

Figure 3. Diagrammatic east-west cross-section through the Pilot Range area before Tertiary high-angle faulting, showing interpretive model for development of Pinnacle Fault and related folds and faults above an arch. West-dipping fault is inferred to extend to sole (above crystalline basement?), and analogous faults occur on the east flank of the arch. Antithetic faults formed in fold "cores" accommodate flattening within the layered sequence.

there strike north and north-northwest, as do faults of probable oblique-slip, with a large component of dip-slip (west side down). Later faults parallel to the margins of the range are normal, down-to-basin faults with steep dips. Along the southwestern and northwestern margins of the range, systems of parallel faults successively downdrop blocks toward the basin (Plate 2, section B-B'). Faults in the northern part of the quadrangle offset alluvium by one to two meters in dry washes (in China Cove) and truncate low alluvial terraces (east of China Cove Pass). Scarps cutting alluvium are rounded and, therefore, probably are older than several hundred years. Near Wendover Canyon range-bounding faults do not cut older alluvium.

Slump blocks of quartzite from Units D and F of the McCoy Creek Group and from the Prosepect Mountain Quartzite are common along the western side of the range. They are not cut by range-bounding faults, and, therefore, are probably Quaternary and/or latest Tertiary.

Numerous high-angle and low-angle(?) faults cut the Eureka Quartzite and Fish Haven Dolomite near Wendover Canyon, producing breccia and highly fractured rock throughout the exposures. The faulting and fracturing is not understood at present.

Timing of Structures

Bedding-plane faulting and tight folding was contemporaneous with regional metamorphism, and therefore was probably Jurassic or Early Cretaceous. Granodiorite dikes cross cut the decollement, indicating a pre-91 m.y. age for movement on it. Kink folding and development of the Pinnacle Fault system apparently closely predated intrusion of the granodiorite of Bettridge Creek area and related dikes because they intrude along low-angle faults and tear faults, and yet are only slightly deformed. The kink folds and faults therefore were probably formed during the Early Cretaceous.

Range-bounding normal faults in the Pilot Peak quadrangle are known only as post-Cretaceous and largely pre-Quaternary, with some faults apparently as young as Holocene. Northward in the Pilot Range, strata of Late Miocene or earliest Pliocene age (Blue, 1960) are cut by similar normal faults, indicating that much of the separation on these faults was latest Tertiary and/or Quaternary.

ECONOMIC DEPOSITS

Unconsolidated gravel and sand are abundant in Lake Bonneville beach and bar complexes. Marble in the range is generally of low quality for building stone, with the possible exception of coarsely crystalline, nearly pure marble in parts of McCoy Creek Unit B(?). Base and precious metals were heavily prospected in the Pilot Range both north and south of the Pilot Peak quadrangle, but no prospect pits are present in the quadrangle and no noteworthy occurrences of metallic minerals were discovered during the course of mapping. Potential petroleum deposits in basins adjacent to the Pilot Range are impossible to evaluate at this time because the structure and stratigraphy of the basins are poorly known.

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