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Mantled Gneiss Domes in the Albion Range, Southern Idaho

Abstract: The Albion Range, in southern Idaho east of the Antler orogenic belt and west of the Sevier orogenic belt, exposes a northeast-trending chain of four mantled gneiss domes. The Green Creek Complex (Precambrian [2.5 b.y.] gneiss and metasediments), which forms the cores of the domes, is unconformably overlain by the Paleozoic Dove Creek Group, consisting of sparsely fossiliferous metasediments approximately 22,000 feet thick. The basal quartzite and overlying schists, marbles, and thin quartzites are of probable Cambrian age. A massive quartzite and overlying schist and limestone may be Cambrian or Ordovician in age. Ordovician quartzite more than 7000 feet thick forms the middle part of the metasedimentary section, and this is overlain by massive pure dolomite, calcareous black schist, and quartzite of Ordovician through Mississippian(?) age. Devonian strata are thin or absent. At the top of the metasedimentary section are limestone, schist, and quartzite of the Pennsylvanian Oquirrh(?) Formation.

Younger Paleozoic sandstone, limestone, and chert, and Triassic(?) shale occur in fault contact overlying the metasediments. Cenozoic sedimentary and volcanic rocks unconformably overlie the deformed older rocks.

Metamorphic grade (greenschist and amphibolite facies) increases northwestward and downward in the area. Staurolite and kyanite occur in Cambrian rocks in the northern half of the range; cordierite, andalusite, and sillimanite occur in Precambrian rocks in the southern half of the range, but these may be due to Tertiary contact metamorphism.

Deformation during Mesozoic metamorphism produced two fabric systems; locally a Precambrian metamorphic fabric survived the younger metamorphism. Early bedding foliation and northeast-trending, northwest-vergent folds and lineations predated rise of the domes. Northwest-trending folds and lineations with northeast and southwest vergence were produced during and after doming; over much of the western half of the range these structures destroyed all older fabrics.

During the Oligocene (30 m.y.) a postkinematic adamellite stock—the Almo Pluton—and related granitic dikes were emplaced. Following emplacement of the pluton, uplift of the range accelerated to an average rate of .5 mm per year, bringing the gneiss domes to the surface from a depth of at least 10 km.

The Albion Range is part of a belt of rocks along the western part of the Cordilleran miogeosyncline which was affected by high-grade regional metamorphism during the middle of the Mesozoic. The metamorphic rocks are part of the Cordilleran infrastructure, which can be traced from California into southern British Columbia and beyond.

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INTRODUCTION

The Albion Range, which lies in Idaho south of the Snake River Plain (Figs. 1a and 1b), displays with unusual clarity, four domes like a string of beads trending north-northeast. These domes and the adjacent Raft River Range east-west elongate dome in Utah conform exactly to Eskola's (1948) classic conception of mantled gneiss domes with cores of ancient metamorphic and granitic rocks overlain unconformably by sedimentary rocks which have been regionally metamorphosed, domed, and cut by younger granites.

Distinct stratigraphic units, thousands of feet of relief, moderately good exposures, and a favorable climate for field work have been considerable advantages in working out the stratigraphic and structural relationships. Access is good; no point within the area is more than a few miles horizontally and a few thousand feet vertically from roads passable with a two-wheel-drive vehicle. The author has spent two field seasons, with the assistance at various times of P. A. Scholle, R. L. Stocker, and R. F. Wright, mapping, at a scale of 1:30,000, the area shown on Figure 2. Rb-Sr and K-Ar dating done in the geochemical laboratories of Yale University is reported in another paper (Armstrong and Hills, 1967). A more detailed report covering the entire Basin 30 minute quadrangle is in preparation.

ACKNOWLEDGMENTS

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REVIEW

The only previous study of the Albion Range was the reconnaissance work of Anderson (1931), who recognized the presence of granitic rocks (the "Cassia batholith") which he considered Mesozoic, and the widely exposed metasediments (the Harrison Series), considered to be pre-Beltian Precambrian, which he later renamed the Albion Range Group (Anderson, 1934). Both units are in fact composite, the Albion Range Group being mostly Paleozoic, but containing some older Precambrian metamorphic rocks which are separated from the Paleozoic by a major unconformity, and the Cassia batholith consisting of older Precambrian gneisses intruded by a Tertiary adamellite stock. Anderson's map reasonably represents the distribution of granites, metamorphic rocks, unmetamorphosed upper Paleozoic rocks, and Tertiary volcanic and sedimentary rocks, and he recognized the over-all domal character of the range, but his structural interpretation, that the metamorphic rocks and granite were thrust over unmetamorphosed upper Paleozoic strata, was incorrect. The unmetamorphosed upper Paleozoic overlies the metamorphic rocks on a tectonic contact, as has been pointed out by Hazzard and Turner (1957) and Misch (1960). Misch and Hazzard (1962) observed the gneissic granites and expressed the opinion that they were Precambrian, but details of their studies in this area remain unpublished.

The Albion Range metamorphic rocks are continuous, with exposures of metamorphic rocks in the Grouse Creek and Raft River mountains of northwestern Utah, and the same problems of age and regional relationships exist for both areas. Completely surrounding these exposures of crystalline rocks are many tens of miles of unmetamorphosed upper Paleozoic and Tertiary strata.

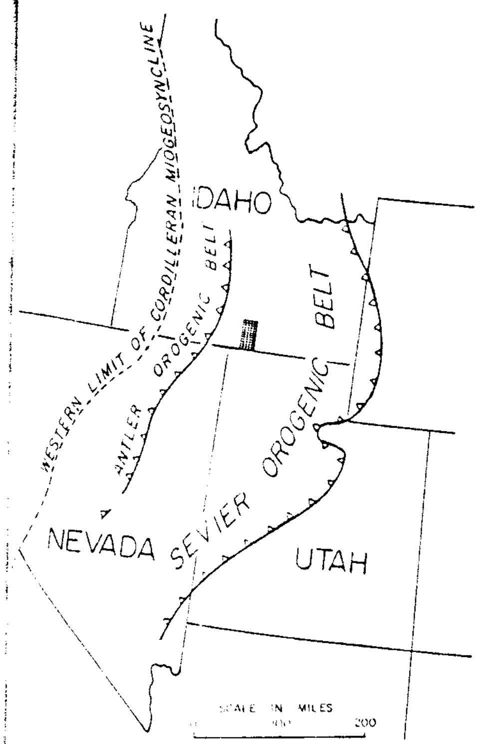

Figure 1a. Map showing location of Albion Range (shaded area) with respect to state boundaries and orogenic belts that involved the Cordilleran miogeosyncline (*from* Roberts and Thomasson, 1964; Churkin, 1962; John Riva, 1968, personal commun.; Armstrong and Oriel, 1965; and Armstrong, 1968).

Granitic and metamorphic rocks in northwestern Utah were noted by geologists of the King survey (Hague and Emmons, 1877), but the first detailed observations were those of Stokes (1952) who reported the presence of a Precambrian basal granitic complex overlain unconformably by metamorphosed Cambrian (?) quartzite conglomerate and sandstone which he thought was in turn overlain by unmetamorphosed Pennsylvanian sediments. The Cambrian-Pennsylvanian contact is actually a fault as was recognized by Felix (1956) when he mapped the eastern Raft River Range. His map is accurate as to distribution of rock types, but he ignored the unconformity recognized by Stokes and included both Precambrian and lower Paleozoic strata in his Harrison Series (Anderson's abandoned name), considered the granites to be Mesozoic, and did not mention an isoclinal recumbent fold which forms the south flank of the Range (Armstrong and Hansen, 1966). Felix did recognize a pre-Pennsylvanian unconformity, middle to lower Paleozoic dolomite, quartzite and limestone in fault contact with higher-grade metamorphic rocks, and the metamorphism of the lower part of his Paleozoic section. Misch (1960) and Misch and Hazzard (1962) emphasized the division of the metamorphic rocks into an older complex with schists, amphibolites, and granites separated from younger quartzitic and schistose metasediments of Precambrian or lower Paleozoic age by an unconformity, both groups of rock having been metamorphosed during the Mesozoic. Stringham (1962) and Stringham and others (1961) concur with the two-fold subdivision, retaining the name Harrison Formation for the older rocks, and Dove Creek Formation (also considered by Stringham to be Precambrian) for the younger quartzites, schists, and limestones in the Raft River Range. In his mapping of the Grouse Creek Range and exposures of metamorphic rocks immediately to the west, Stringham continued to use his nomenclature, but he mapped all rocks intruded by gneissic granite as Harrison Formation, so that much that is shown as Harrison on his map is actually Dove Creek which has been intruded by younger granite, as has been shown

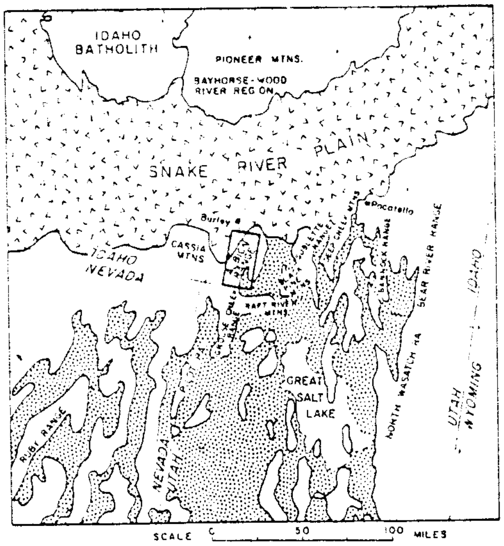

Figure 1b. Map showing location of Albion Range with respect to nearby geographic features mentioned in text. Stippled areas are alluvium-filled valleys of the Basin and Range province. Based on the tectonic map of the United States (Cohee and others, 1961).

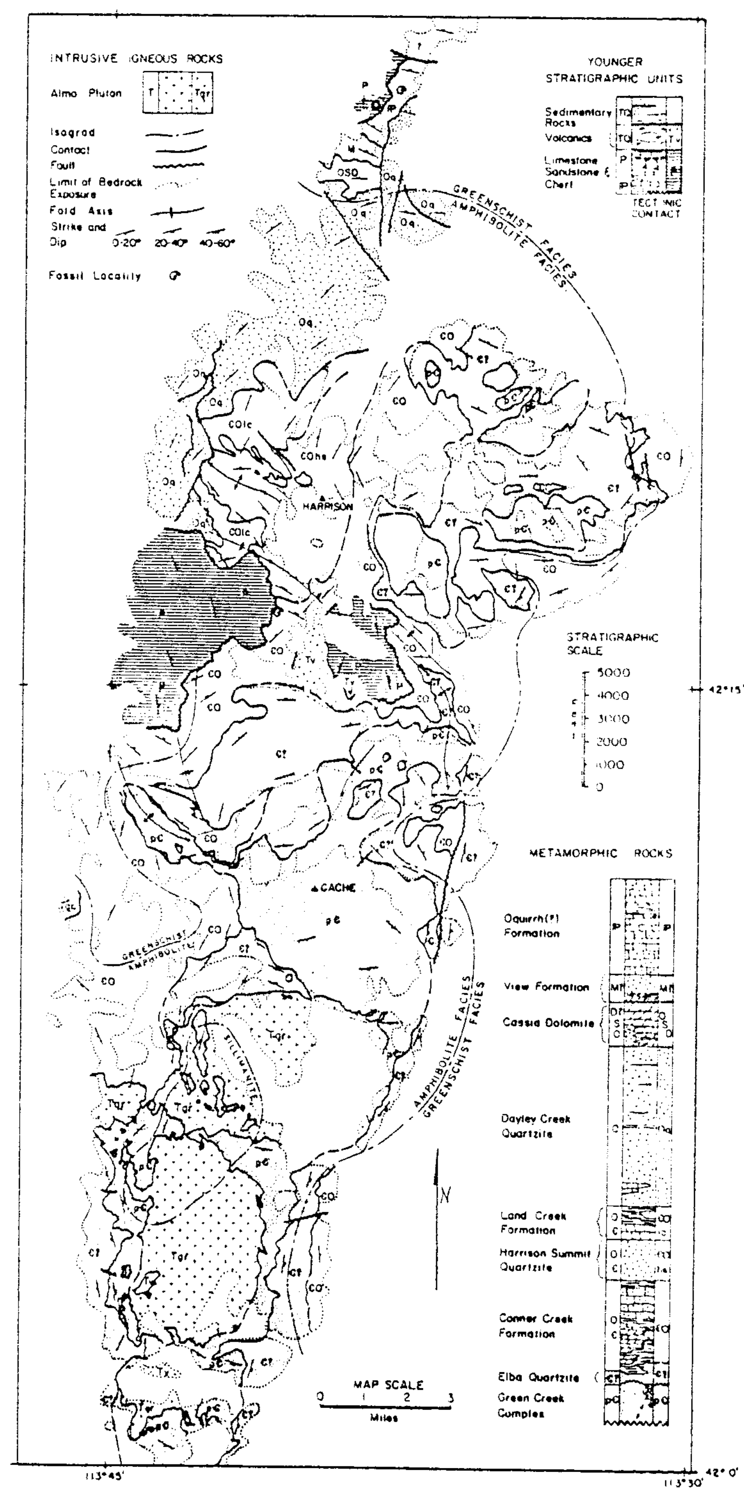

Figure 2. Geologic map of the Albion Range.

by recent detailed mapping by the Stanford Geological Survey (R. R. Compton, 1965, personal commun.). Compton (1968) reported that much, perhaps all, of the Dove Creek section is Paleozoic, with fossils found at a fairly high stratigraphic level in the metasediments; no important break occurs below the fossils until the previously mentioned unconformity is reached. This is in accord with the author's observations in the Albion Range. Sayyah (1965) has reported 2.4 and 3.7 b.y. Rb-Sr dates for two whole-rock samples from the core of the Raft River Range thus providing concrete evidence of the antiquity of the older metamorphic rocks.

The author's interest in the problems of this region began with K-Ar dating and reconnaissance examination of the metamorphic rocks of the Raft River Range, and an attempt to fit them into a regional synthesis. Armstrong and Hansen (1966) pointed out the fold on the south side of the Raft River Range and its relation to the regional metamorphic fabric, and they proposed that the rocks, whether Precambrian or not, had been regionally metamorphosed during the Mesozoic as part of a Cordilleran infrastructure—a zone of warm, fluid rocks deforming below a more rigid cover of unmetamorphosed upper Paleozoic strata.

The interpretation was, at that point, unsatisfactory in many ways; the most serious limitation was lack of detailed mapping accompanied by structural, petrographic, and isotopic studies. Anderson's description of the Albion Range made it seem an ideal place to work. The choice has been a most satisfactory one, and while learning more about the rocks many of my earlier ideas have been confirmed and others substantially modified or discarded.

SETTING

The Albion Range is a typical north-south trending range of the northern Basin and Range province. Except at the southward connection with the Grouse Creek Mountains in Utah, the range is surrounded by wide valleys floored by Tertiary and Quaternary sedimentary and volcanic rocks. To the west only a few poor exposures of upper Paleozoic and one of Ordovician (unmetamorphosed) rocks are known in the Cassia Mountains (Piper, 1923; Youngquist and Haegele, 1956). Farther west the Paleozoic rocks are lost beneath a sea of volcanics extending into Oregon. North of the Albion Range, actually lapping around it, is the basalt-covered Snake River Plain. To the east, across the Raft River valley, are the Sublette and Black Pine Ranges underlain by upper Paleozoic strata partially covered by Cenozoic sediment, volcanics, and loess.

The Albion Range lies within the Cordilleran miogeosyncline (Fig. 1a). The postulated trace of the Roberts Mountain thrust (Roberts and Thomasson, 1964; Churkin, 1962; John Riva, 1968, personal commun.) on which eugeosynclinal rocks overrode miogeosynclinal and mio-eugeosynclinal transition-zone rocks during the Mississippian lies a few tens of miles to the west. Proximity to this feature of the Antler orogenic belt may account for the unconformity recognized between Silurian(?) and Mississippian(?) strata in the Albion Range.

Approximately 90 miles to the east is the Idaho-Wyoming fold and thrust belt (Armstrong and Oriel, 1965), a northern continuation of the Sevier orogenic belt of Utah and Nevada (Armstrong, 1968). This zone of thrusts that place older rocks over younger was active through most of Cretaceous time, deformation eventually dying out during Paleocene and very early Eocene time. Here miogeosynclinal strata are thrust southeastward over the rigid mass of the craton with its thin, passively behaving sedimentary cover. In this belt only the deepest and westernmost Cambrian and older geosynclinal strata show the effects of regional metamorphism (greenschist facies, development of slaty cleavage) (Condie, 1966); this may be the same metamorphism observed in the Albion Range. Between the exposures of Cambrian and older geosynclinal strata in the Bannock Range at the west edge of the Idaho-Wyoming thrust belt and the Albion Range is a broad area of upper Paleozoic strata showing no sign of metamorphism except in the Sublette range, immediately east of the Albion Range, where Mississippian(?) strata have a well-developed slaty cleavage (Larry Rychener, 1965, personal commun.). Metamorphic minerals in Devonian and Mississippian strata encountered in wells drilled east and south of the Sublette Range were reported by Peace (1956). Thus, it is evident from previous work that isograds rise into the Paleozoic section as one moves west from the thrust belt—the Albion Range represents merely an exaggerated continuation of this phenomenon. A plate of unmetamorphosed upper Paleozoic strata more than 15,000 feet thick in the Sublette Range, and thickening eastward, probably also covered the Albion Range (and presumably included the unmetamorphosed Paleozoic strata now exposed within it) during the Cretaceous. Apparently these rocks were relatively cool and rigid and transmitted the push responsible for the thrust-belt deformation.

On strike to the north, across the Snake River Plain, is the Bayhorse-Wood River region (Umpleby and others, 1930; Ross, 1947, 1962), which shares several lower Paleozoic stratigraphic features with the Albion Range and is the location of another recently studied gneiss dome (Dover, 1967). The Raft River Range and Grouse Creek Mountains, and related areas farther south, are part of the hinterland of the Sevier orogenic belt described in the review by Armstrong (1968).

STRATIGRAPHY

The Precambrian basement complex, the Green Creek Complex, is exposed in the cores of the four domes which make up the Albion range. Unconformably overlying the Precambrian rocks are 22,000 feet of Paleozoic metasediments, the Dove Creek Group of Stringham (1962), which may be correlated in a general way with fossiliferous Paleozoic strata in nearby ranges. Metamorphic grade ranges from lower greenschist to upper amphibolite and increases from east to west and downward within the area so that isograds, before doming, dipped gently eastward. Fossils have been found in both greenschist and amphibolite facies rocks. In fault contact with the metamorphic rocks are isolated patches of unmetamorphosed upper Paleozoic and Triassic(?) sedimentary rocks.

Intruding the Precambrian and lower Paleozoic is an Oligocene stock, the Almo Pluton. Unconformably overlying all the older units are Pliocene-Pleistocene sediments and volcanics. Evidence of mountain glaciation and periglacial activity is widespread, and the glacial materials constitute the most serious limitation on bedrock mapping in the range. Deposits younger than the Almo Pluton are not discussed in this paper.

Green Creek Complex

The Green Creek Complex is defined by stratigraphic position below Paleozoic metasediments, by certain distinct lithologic types, and by the association gneiss-schist-amphibolite. The unit is named for Green Creek on the northeast side of Cache Peak where the three rock types are well displayed. Two of the samples used to date the unit were collected from this area (N½ section 12, T14S, R 24E).

The most widespread rock type, porphyroblastic biotite-quartz-plagioclase-microcline gneiss[1] (Pl. 1, fig. 1), upholds Cache Peak, the highest point in the region. Porphyroblasts range from 1 cm to more than 6 cm in length. No other unit in the area is so distinctively porphyroblastic. Associated with this gneiss are bodies of plagioclase-quartz-biotite schist and lenses, pods, and sheets of quartz-plagioclase-hornblende amphibolite. Quartzite is less widely distributed and absolutely indistinguishable from quartzite in younger rocks. Some green quartzite can be identified as belonging to the Green Creek Complex by its relationship to other map units. Exposures on Mount Harrison vaguely suggest that the gneiss intrudes the biotite schist; probably many of the amphibolite bodies represent metamorphosed basic sills and dikes younger than the gneiss.

The Green Creek Complex is equivalent to the lower part of the Harrison Group of Felix (1956) and the entire Harrison Formation of Stringham (1962) in the Raft River Range. A whole rock Rb-Sr isochron reported by Armstrong and Hills (1967) indicates an age of at least 2.4 b.y. for schist and gneiss of the Green Creek Complex. Rocks of similar or greater age have been found in southwestern Montana (Giletti, 1966) and are widespread toward the center of the North American craton.

Basal Paleozoic Unconformity

Green Creek rocks underlie the Elba Quartzite which can be traced throughout the Albion and Raft River Ranges, and clear stratigraphic and structural evidence at several localities shows the contact to be an unconformity. The exact contact is rarely exposed, and even when exposed the adjacent rocks are usually so deformed that no sedimentary structures are preserved, but mapping has demonstrated that Green Creek units are discordantly truncated at the base of the Elba Quartzite.

The contact is best exposed in the Albion Range in the cirque immediately northwest of Cache Peak. Well-bedded clean quartzite with a few interbeds of quartz pebble conglomerate, but no basal conglomerate, overlies coarse gneisses of the Green Creek Complex. Tens of feet of relief on the unconformity are evident; single beds may be followed from where they lie only a few feet above porphyritic gneisses to

[1] In all rock names, minerals are given in order of increasing abundance.

where they are more than one hundred feet above them. This relation is not due to deformation; pebbles in the quartzite conglomerates show only moderate distortion, mostly flattening.

Exposures of lower metamorphic grade in Utah display the unconformity best. In the north wall of Clear Creek Canyon of the Raft River Range, the contact is exposed for several miles and displays considerable relief, in harmony with the expected erosional resistance of underlying units in the Green Creek Complex; low areas are filled with tens of feet of quartz cobble and pebble conglomerate. Locally the basal conglomerate is in a schistose matrix at the top of what looks like a metamorphosed ancient weathered zone, and individual cobbles are stretched so that they weather out like grotesque sausages. A few cobbles of green quartzite have been observed.

Paleozoic Metasediments

An unbroken section of metasediments approximately 22,000 feet thick is exposed on Mount Harrison and on the ridge extending to the north. Relatively simple large-scale structure, locally preserved cross-bedding indicating stratigraphic facing, and good exposures have permitted the sequence of units to be worked out and the two fossil localities to be placed in their proper stratigraphic positions. Facies changes and the similar lithologies of several units, particularly the thick quartzites, prevent exact stratigraphic placement of some units isolated by faults. Much of the rock exposed is quartzite; distinctive Paleozoic rock types are carbonate rocks, which occur scattered throughout the section, quartz-muscovite schists, with or without graphite, and iron-rich schists.

Elba Quartzite. The most widespread and best exposed unit in the region is the quartzite at the base of the Paleozoic section. It may be traced into Utah and, being massive, is a key unit for structural and stratigraphic interpretations. It is well exposed in the hills, north and west of the town of Elba[2], for which it is named. Complete sections are exposed in the following localities: N½, section 8, T13S, R25E; center, section 24, T13S, R24E; and S½, section 1, T14S, R24E (type section). The upper contact is drawn at the base of the first mappable schistose or calcareous bed. On Mount Harrison a basal member approximately 100 feet thick, a very pure, medium-bedded, white quartzite with sporadic white-quartz-pebble conglomerate lenses, underlies several hundred feet of somewhat grayer, rusty-weathering, medium-bedded quartzite. Farther south this subdivision is less evident. The green quartzites of the Raft River Range (Felix, 1956) are members of this formation. The Elba Quartzite is commonly between 500 and 1000 feet thick, but it thins to less than 10 feet on the small elongate dome northwest of Cache Peak, much of the thinning being due to a facies change in which Elba Quartzite interfingers with and grades into muscovite-quartz schist of the Conner Creek Formation. Some of the variability in thickness is perhaps due to deformation during metamorphism, but cross-bedding is commonly well preserved, indicating everywhere that the formation is right-side up, and not too strongly deformed.

Conner Creek Formation. A thick sequence of mica schists, thin flaggy quartzites, and carbonate rocks, bounded above and below by massive quartzites composes the Conner Creek Formation, named for Conner Creek east of Mount Harrison. The lower part of the formation is widespread, good exposures being found south of Conner Creek (sections 16, 17, 20 and 21, T13S, R25E) and south of the Elba-Oakley road on the west side of the Range (sections 1, 2, 11 and 12, T14S, R23E); the upper part is exposed only on Mount Harrison near Lake Cleveland (sections 2 and 3, T13S, R24E).

Dramatic and abrupt changes in rock type occur along strike, apparently due to facies changes inherited from the time of deposition. The top and bottom of the formation are clearly defined by massive quartzites, and, although the Conner Creek has undergone more intense deformation during the Mesozoic than have any overlying or underlying rocks, the large scale structure is relatively simple. The lithologic changes along strike, including the lateral transformation of muscovite-quartz schists in the Conner Creek into Elba Quartzite west of Cache Peak, cannot be explained as having resulted from faulting or folding.

On the east side of the range the lower Conner Creek Formation is composed of light-colored, muscovite-K feldspar-quartz schists, interbedded quartzites (some strikingly green) and sparse thin calcareous sandstones and carbonate rocks. Equivalent strata on the west

[2] All local geographic names used in this paper are taken from the 1:250,000 Pocatello 1° × 2° AMS map, the 1:24,000 View, Idaho 7½ minute quadrangle, and Anderson's (1931) geologic map.

side of the range contain muscovite-quartz schists and quartzites at the base; these grade upward into graphitic staurolite-garnet-muscovite-quartz schist, tremolite-bearing marbles, sandy dolomites and limestones, and quartzites. Local magnetite-chlorite-quartz schists may represent metamorphosed siliceous iron formation. The upper part of the formation on Mount Harrison is composed of flaggy quartzite, sandy phlogopite marble, calcareous quartzite, and thin graphitic garnet schist. The upper contact is placed at the top of the last schist or carbonate unit below massive thick bedded quartzite of the Harrison Summit Quartzite.

On Mount Harrison the formation is approximately 4000 feet thick, but this is only a crude estimate of its original thickness.

Harrison Summit Quartzite. Forming the highest parts of Mount Harrison (sections 4 and 9, T13S, R24E), and present only on Mount Harrison is a massive quartzite approximately 1800 feet thick. Where well exposed, as in sections 6 and 7, T13S, R24E, the quartzite may be subdivided into a lower rusty-weathering half, and an upper gray-weathering half. The Harrison Summit Quartzite is generally somewhat less pure and more irregularly bedded than the Elba Quartzite. Lenses of quartz pebble conglomerate and mica schist are scattered throughout. The upper contact is drawn at the base of the lowest schist or carbonate bed of the Land Creek Formation.

Land Creek Formation. Between the saddle 1.3 miles north of Mount Harrison (E½, section 32, T12S, R24E) and the basin of Land Creek on the west side of the Range (E½, section 1, T13S, R23E, sections 6 and 7, T13S, R24E) another unit characterized by schist and carbonate that change along strike occurs between formations of massive quartzite.

Near Land Creek the formation is a fairly clean blue-gray limestone overlain by graphitic staurolite-garnet-muscovite-quartz schist. Only three miles away, north of Mount Harrison the only carbonate remaining in the section is porphyroblasts of calcite in biotite-muscovite-quartz schist near the base; overlying are garnet and staurolite-bearing, biotite-muscovite-quartz schist (without graphite) and micaceous conglomeratic quartzite interbeds. The formation is approximately 1500 feet thick. The upper contact is drawn at the base of the sequence of virtually continuous quartzite beds of the overlying Dayley Creek Quartzite.

Dayley Creek Quartzite. The massive, monotonous, thick quartzite that forms a high ridge several miles long, north of Mount Harrison, is named for Dayley Creek, a small stream that drains an area entirely within the formation. The type section extends along the ridge from NE 1/4, section 32 to SW 1/4 section 3 in T12S, R24E. A few thin lenses of staurolite-garnet-bearing, biotite-muscovite-quartz schist, and blue-gray limestone are the only interruptions of the thousands of feet of medium- to thick-bedded gray and tan quartzite, generally fairly pure but locally micaceous and sugary-weathering. Quartzite conglomerates composed of grit to small pebble-sized clasts in a quartz sand matrix are scattered through the formation.

The thickness appears to be about 7000 feet. Even though such a thick quartzite in the middle of a Paleozoic section raises problems of correlation, the great thickness could not be a result of folding or faulting. Cross-bedding, although uncommon, was always upright, so the quartzite was probably equally thick before metamorphism.

Cassia Dolomite. Named for the county within which the Albion Range lies, the Cassia Dolomite is a distinct stratigraphic unit of exceptional importance to correlations between Albion Range rocks and Paleozoic rocks elsewhere. On the ridge north of Mount Harrison the formation consists of 2000 feet of light-gray sugary dolomite, well exposed and uninterrupted by any other lithology (NW 1/4, section 3, T12S, R24E). The basal contact is transitional, a few yards of sandy dolomite separating clean dolomite from the underlying quartzites. Less than a mile westward, in the foothills of the range, several tongues of pure white quartzite extend eastward into the lower part of the unit, but they fail to reach the divide. The upper contact is placed at the base of the first graphitic or calcareous bed of the overlying View Formation.

View Formation. Overlying the sugary dolomite is several hundred feet of dark-colored, graphitic, muscovite-quartz-calcite schist and dolomitic quartz schist overlain by a thicker light-gray quartzite with scattered conglomeratic lenses and rusty staining on weathered surfaces. Exposures of this and younger units are so limited that no discussion of lateral variability is possible. The upper contact is placed at the base of the first limestone bed overlying the quartzite.

The View Formation is named for the community of View, in the irrigated lowlands of the

Snake River Plain a few miles west of the area exposure. Approximately 1200 feet of strata are present in the type section (SW 1/4, section 34, T11S, R24E), one-third calcareous schist, the remainder quartzite.

Oquirrh(?) Formation. The uppermost formation of the metasediments north of Mount Harrison is correlated (see the following section of this paper) with the Oquirrh Formation of Gilluly (1932), which has been recognized by Felix in the Raft River Range 30 miles to the south and by Carr and Trimble (in prep.) in the Deep Creek Mountains 48 miles to the east. The formation is composed predominantly of limestones, which range from pure, fine-grained, crinoid-fragment, clastic limestones to gray limestone marbles, and sandy micaceous limestone marbles. Thin pure quartzites, carbon-sericite-quartz black schists, ferruginous quartz sandstones, and impure dolomites are present. More than 4000 feet of strata are present in the ridge north of Mount Harrison (section 34 to section 23, T11S, R24E). A fault passing through the valley containing the Albion-Burley highway, close to the north edge of the map area, terminates the section. Marbles and quartzites lying north of the fault are not yet correlated with certainty with any of the described units.

Correlation of the Metasediments

Stratigraphic, fossil, and isotopic evidence agree that the thousands of feet of metasediments just described are of Paleozoic age. Differences in thickness, lithology, and the lack of diagnostic fossils prevent correlation of specific Albion Range units with others elsewhere, but the major relationships are not in doubt.

Two fossil localities, shown on the geologic map, are important. In the Conner Creek Formation southwest of Mount Harrison more than 20 specimens have been found that contain fragments of echinoderm columns in a stretched quartz-pebble conglomerate with a carbonaceous quartz siltstone matrix (Pl. 2, figs. 1 and 2). The calcite of the column fragments has been leached out, leaving molds, some of which show very fine ribbing and the five-fold symmetry of the original columns, which ranged from 4 mm to 12 mm in diameter. Some columns have been noticeably flattened and deformed, others lying parallel with the northeast-trending lineation show virtually no distortion. Every paleontologist who has examined these specimens considers them Paleozoic. Unfortunately, nothing more precise can be said, and an age of middle Cambrian or younger is possible; a Precambrian age as proposed by Anderson (1931), and commonly accepted, is impossible.

The Oquirrh(?) Formation (Pl. 3, figs. 1, 2, and 3), has produced crinoid stem fragments and silicified, poorly preserved coral and bryozoan fossils in blue-gray limestone, an assemblage representative of the Oquirrh Formation but hardly diagnostic—merely additional evidence of the Paleozoic age of the metasediment section. These rocks, now considered Oquirrh Formation, but originally part of Anderson's Harrison Series, form the uppermost unit of a succession of comformable strata, beginning with the Elba Quartzite. The fossiliferous upper Paleozoic rocks were affected by the same metamorphism that acted upon the older rocks.

The Oquirrh(?) Formation of the Albion Range is lithologically so like Carr and Trimble's (in prep.) Oquirrh Formation (cherty and sandy limestone with a few thin quartzite beds), that the correlation seems reasonable. It likewise resembles the Oquirrh of the Raft River section described by Felix (1956). In fact the only notable contrasts between the Raft River section, above the Eureka Quartzite, and the upper part of the Albion Range section are the presence of the View Formation and the higher metamorphic grade of the Albion Range units.

The correlation of the View Formation is uncertain. Lithologic similarity suggests a Mississippian age, correlating with shale and quartzite in the Manning Canyon Formation mapped by Carr and Trimble (in prep.) This is the only clastic unit containing thick shale and quartzite above the Fish Haven Dolomite. The possibility remains that the View Formation is Devonian in age, or even part of the Oquirrh Formation. In the Raft River Range, Pennsylvanian Oquirrh Formation directly overlies Fish Haven Dolomite and no Devonian or Mississippian rocks are present. Evidently, during some or all of this time interval, the Albion Range and the surrounding region was emergent and undergoing erosion.

A unit of special value in correlation is the Cassia Dolomite. Thick, pure dolomite overlies a quartzite in the middle of Paleozoic sections throughout the region: the upper Ordovician Fish Haven, Silurian Laketown, and Lower Devonian Jefferson dolomites overlie the middle Ordovician Swan Peak Quartzite in Carr and Trimble's (in prep.) map area to the east, and the Fish Haven-Laketown dolomites overlie the Swan Peak-Eureka Quartzite to the south in the Raft River Range. Thus it would appear reasonable to correlate the Cassia Dolomite, which overlies the Dayley Creek Quartzite, with the Fish Haven Dolomite and some or all of the Laketown and Jefferson dolomites.

The Dayley Creek Quartzite below the Cassia Dolomite must correlate with the Swan Peak Quartzite of Carr and Trimble (in prep.), at least in part. The Dayley Creek Quartzite is so thick that more than Swan Peak equivalents may be included and there is considerable uncertainty as to the correlation of the basal beds. In the Deep Creek Mountains, the Swan Peak Quartzite is more than 1000 feet thick, and thickening westward. For an exact correlation with the Dayley Creek Quartzite it would have to thicken another 6000 feet in 50 miles—a surprising and perhaps unlikely situation.

The total middle Ordovician quartzite section in the Raft River Range is only a few hundred feet thick. Field work just completed in Middle Mountain only 6 miles west of the Albion Range indicates that the Paleozoic section between the Idaho-Utah boundary and Mount Harrison undergoes a facies change in which carbonate strata (approximately lower Ordovician Pogonip Group) are replaced northward by increasingly sandy carbonate and intertonguing quartzite. This would imply that the Dayley Creek Quartzite is of Middle and Lower Ordovician age.

Across the Snake River Plain, approximately 100 miles north of the Albion Range, the Kinnikinic Quartzite lies below upper Ordovician dolomite. Originally more than 3000 feet of quartzite and subordinate interbedded shale and carbonate rock (Ross, 1962) were included in the formation, but recently the name Kinnikinic has been restricted to approximately 1000 feet of quartzite at the top of the section of quartzites which includes thousands of feet of strata, including Middle Cambrian to possibly Precambrian (Hobbs, personal commun., 1968). The upper part of the Dayley Creek Quartzite probably correlates with the Kinnikinic Quartzite (restricted) and the remainder with some of the underlying, unnamed strata.

The correlations of the Land Creek Formation and Harrison Summit Quartzite are uncertain. One possibility is that the Land Creek equals part of the Garden City Formation plus uppermost Cambrian formations, and Harrison Summit equals the Worm Creek(?) Quartzite of Carr and Trimble (in prep.). This correlation has the advantage that thickness relationships remain most reasonable, but present evidence does not exclude the possibility that both formations are Ordovician.

None of the Albion Range quartzites is notably feldspathic, and thus the quartzites themselves provide no petrographic clue to test any of the proposed correlations.

The problem of the source of the thick Ordovician quartzites in the Cordilleran eugeosyncline has been discussed by Ketner (1966) and Kay (1966). The Albion Range Ordovician quartzites provide a connection between a source of pure quartzite on the craton and the eugeosyncline to the west. During Ordovician time this area may have been the site of a broad channel between carbonate banks to the north and south; through this channel, clastics might have passed from craton to eugeosyncline.

The Conner Creek Formation must, with the restriction provided by the fossils and its stratigraphic position, correlate with some of the Cambrian shale, limestone, and quartzite section of Carr and Trimble (1965), and it may or may not include units as young as Ordovician Garden City Formation.

The Elba Quartzite, a basal clastic unit, may be correlated reasonably with the Brigham Quartzite at the base of Carr and Trimble's (1965) Paleozoic section, although it may not correspond exactly in age.

A most interesting and significant fact is that younger Precambrian or Eocambrian strata, which occur in the Pocatello area to the east (Ludlum, 1942; Trimble and Schaeffer, 1965) and in the Pilot Range to the south (Blue, 1960; Woodward, 1967) and elsewhere in the Great Basin (Condie, 1966), appear to be absent in the Albion Range region.

One other line of evidence concerning the age of the Albion Range metasediments is the whole-rock, Rb-Sr isochron of ~600 m.y. for Connor Creek Formation schists (Armstrong and Hills, 1967). Although crude and subject to uncertainties, this result is in satisfying agreement with the correlations discussed and can be considered an independent confirmation of the Paleozoic age of the rocks. The Albion Range Paleozoic metasediments correlate with Stringham's (1962) Dove Creek Formation west of Dove Creek. The name Harrison should probably be abandoned because of present confused usage and original composite character. The name Dove Creek remains a useful designation for the group of formations composed of Paleozoic metasediments in the northwest Utah-Albion Range region and is thus retained, but ...d to group status.

Unmetamorphosed Upper Paleozoic and Triassic(?) Strata

Sedimentary rocks of upper Paleozoic age are present in three areas, in fault contact with, and structurally overlying, the metasediments. On the west side of the range, east of the community of Basin and southwest of Mount Harrison, several square miles are underlain by well-bedded, alternating blue-gray limestone and blue-gray, light tan-weathering, calcareous sandstone several thousand feet thick, generally dipping east, and seemingly not amenable to subdivision. In the basin of Clyde Creek south of Mount Harrison is an area of steeply dipping deformed limestone, cherty limestone, and black chert. Deformation and poor exposure prevent subdivision into mappable formations. On the northwest flank of the range, just south of the Albion-Burley highway is another area of poorly exposed and complexly deformed, cherty limestone and black chert.

These strata are lithologically identical to Pennsylvanian and Permian strata of the Sublette Range 25 miles to the east (Larry Rychener, 1965, personal commun.). The best correlation, based on lithology alone, is that the limestone and sandstone east of Basin are Pennsylvanian or Permian (or both), and that the ...nestone and black chert of Clyde Creek and ... the northwest flank of the range are Permian.

Fault-bounded exposures of olive-brown shale with lenses of dark-gray limestone a few miles north of the map area are suspected to be of Triassic age, correlating with the Triassic Thaynes Formation present in the Sublette Range. These are the youngest pre-orogenic strata in the area.

ALMO PLUTON

The youngest rock unit of the gneiss-dome complex is a plutonic igneous mass that intrudes Precambrian and Paleozoic rocks, best exposed five miles west of the community of Almo, where it forms the City of Rocks. This is an area of granitic tors, promoted in tourist literature for its scenic splendor and historical importance as a meeting spot for transcontinental pioneers. The most abundant rock types are medium-grained, hypidiomorphic-granular muscovite adamellite, muscovite-biotite and biotite adamellite, and biotite granodiorite (Pl. 4, fig. 1). A distinct zoning of this pluton is evident—muscovite adamellite with unzoned plagioclase in the core, grades outward into muscovite-biotite and biotite adamellite with zoned plagioclase and, near contacts with schistose metasediments, biotite granodiorite with strikingly zoned plagioclase. Contacts between these gradational units are not mappable, but the outer contact of the pluton is sharp and cross-cutting (Pl. 4, fig. 2). Cutting the granitic rocks and nearby gneisses and schists are dikes of pegmatitic, muscovite granite and aplite. A few pods of muscovite-quartz-K feldspar pegmatite occur within the pluton.

Except for a foliated biotite granodiorite stock that intrudes lower Paleozoic strata on the edge of the map area west of Cache Peak, the granitic rocks and dikes are undeformed. The exceptional stock may be an older intrusive, but it is not yet dated. The undeformed granitic rocks have been dated as 30 m.y. old (Oligocene) by Armstrong and Hills (1967).

MAJOR STRUCTURAL FEATURES

The large-scale structure is outlined by massive quartzites, which preserve sedimentary bedding and cross-bedding. Most spectacular are the four large domes, from south to north: Moulton dome, City of Rocks dome, Independence Lakes dome, and Big Bertha dome (Figs. 2, 3 and 4). Extending northwest from the domes are smaller domes, noses, and synclines. The northern extension of Mount Harrison is stratigraphically important but structurally simple: a homocline dipping northwest to north and broken by north-trending faults. On the flank of the range west of Mount Harrison is a complex of low-angle normal faults with badly broken upper plates of metamorphosed Ordovician strata. The youngest faults in the Albion Range juxtapose nonmetamorphic upper Paleozoic and metamorphosed Paleozoic strata in three areas.

The three southern domes are actually separate culminations on a NNE.-trending anticline. There is only partial closure between these domes, so that Precambrian rocks may be traced continuously from one to another. The eastern flank of this triad of domes is remarkably straight, showing no deflection at all between the Independence Lakes and City of Rocks domes. The Big Bertha dome lies on the trend of the others but is isolated from them by a deep syncline and is elongated east-west, paralleling the trend of the even more elongate dome that forms the Raft River Range in Utah.

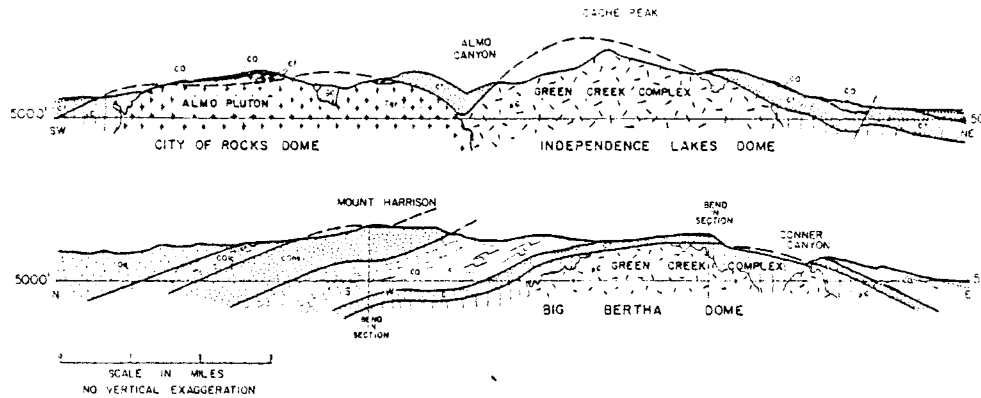

Figure 3. Structural profiles for the Albion Range.

The smallest dome, the Moulton, closes south of the Utah-Idaho line as shown on the map by the Stanford Geological Survey (R. R. Compton, 1965, personal commun.). Tertiary adamellite intrudes Precambrian rocks in its core producing a garbled, difficult-to-map mélange of blocks floating in granitic rock.

The largest dome, the City of Rocks dome, is subdivided by a ridge of Precambrian rocks which separates two culminations of the Tertiary granitic body, the southern one forming the City of Rocks, the northern one an area referred to as The Castles. The culminations are the only areas in the range where sillimanite has been found. Along the western side of the dome is a complex area where the Tertiary Pluton intrudes and engulfs Precambrian, and even Paleozoic strata. In some isolated xenoliths the source rock is indeterminable; this hardly affects the over-all structural pattern, however.

No Tertiary granite is exposed on the two northern domes. The Independence Lakes dome is cored by Green Creek adamellite with only small pods and blobs of schist and amphibolite. Topography and some moderate structural bumps and ripples are responsible for the pattern shown by the Precambrian-Paleozoic contact on the northwestern flank of the dome. Exposures of the Precambrian core of the Big Bertha dome are about equally divided between gneiss and schist with amphibolite pods. The Big Bertha dome, although slightly elongate east-west, is the most nearly ideal domical structure in the range; on all flanks the metasediments dip away approximately 20 degrees.

West of Mount Harrison and northwest of Cache Peak are two prominent northwest trending anticlinal noses, the second showing a small closure. A parallel tight syncline with a vertical to overturned southwest limb lies southwest of the northern nose. Parallel, more open synclines lie on both sides of the southern nose. The southernmost of these synclines becomes exceedingly tight and deep below the upper contact of the Elba Quartzite and forms the divider which separates the City of Rocks and Independence Lakes domes. All these intermediate scale structural features appear to change character markedly from one stratigraphic level to another. Apparently, the schist and carbonate units, being less competent than the massive quartzites, took up much of the strain resulting from differential movements of overlying and underlying rocks, thus leading to the development of disharmonic major folds. The greater structural complexity of the western side of the chain of gneiss domes is presumably a direct consequence of the westward increase in metamorphic grade and hence westward decrease in material strength.

The important faults shown on the map all appear to postdate the metamorphic recrystallization and are structurally relatively young. Armstrong and Hills (1967) concluded on the basis of K-Ar dates that the metamorphic fabrics are at least 80 m.y. old, but that diffusion and recrystallization resulting in loss of radiogenic argon continued in some areas until 30 m.y. ago. Thus these faults are at least as young as Late Cretaceous, and most probably Tertiary, in age. The faults on the east side of the range all dip steeply with small, normal displacement. The faults on the west side dip at low angles (10 to 20 degrees), but all may be interpreted reasonably as normal (relative movement of upper plate downward and westward). The nearly flat fault contact of upper Paleozoic limestone and chert with Cambrian quartzite and schist in the center of the range around Clyde Creek requires a more involved explanation. The contrast of metamorphic grade in upper and lower plates suggests that it is relatively young. The simplest explanation would appear to be that the rocks have slid into place, propelled by gravity, at a recent date. This would be compatible with their present position in a structural and topographic low, with the complex internal deformation (steep dips and a suggestion of imbrication), and with the nearly flat attitude of the fault, and brecciation associated with it. The most likely source of these rocks was the top of the structural block composed of unmetamorphosed upper Paleozoic limestone and sandstone which lies immediately to the west.

Hazzard and Turner (1957) and Misch (1960) have interpreted the faults which juxtapose Dove Creek Group metasediments with unmetamorphosed upper Paleozoic strata as parts of a regional décollement thrust. Profitable discussion of this alternative must await publication of their observations and explanation of the genesis of structures considered to be parts of the décollement.

MINOR STRUCTURES

Penetrative deformation has produced several generations of fabric elements in the metamorphic rocks. It is possible to recognize relict Precambrian structures in the Precambrian rocks and several fabric systems of Mesozoic age that occur in both Precambrian and Paleozoic rocks. The oldest Mesozoic structures, of northeast trend, were refolded during the rise of the domes. Northwest-trending structures formed during penetrative deformation concurrent with, and following, the rise of the domes. In a few restricted areas structures are observed that formed late in the metamorphic history as the rocks cooled.

In the more deeply dissected three southern domes, a foliation striking generally east-west and dipping south is developed in Precambrian gneiss and schist; it does not appear in younger rocks. This foliation is locally parallel with compositional banding in the rocks, and between the City of Rocks and Independence Lakes domes this banding, including a sheet of amphibolite, can be traced up to the contact with Paleozoic quartzite, where it is abruptly and discordantly terminated. Here, as the contact is approached, the foliation parallel to the banding is obscured and replaced by younger foliation parallel to the Paleozoic bedding.

This suggests that the east-west foliation is a relict Precambrian structure that has survived Mesozoic deformation. Any linear structural elements of Precambrian age present, must have northeast trends and be inseparable from the Mesozoic structures.

The oldest Mesozoic structures are a foliation parallel to bedding and linear elements that trend NE. to NNE. The linear features include mineral lineation, streaking, crinkles, chevron

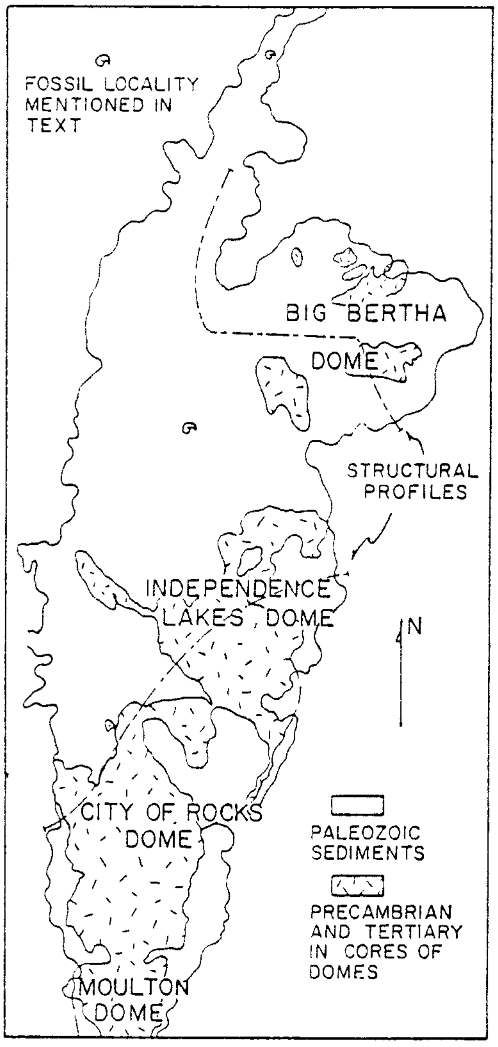

Figure 4. Structural index map, corresponding to the area of Figure 2.

folds and axes of disharmonic and similar folds, which have east-dipping axial planes and axial-plane foliation. These older elements are well preserved only on the eastern and upper parts of the domes. Few examples are known from the western side of the range, where younger structures transpose and obliterate older ones. The folds and linear elements of this generation have been folded by the doming and thus are older.

The most intense small-scale deformation that affected the Albion range rocks produced NW.-to-WNW.-trending folds and lineations, which are most prominent on the west flank of the range, but which also occur on the east side of the Big Bertha dome. Fold styles range from isoclinal to broad and open. Mineral lineation, streaking, crinkles, and mullions are linear features formed during this episode. Axial-plane foliation associated with folds of this trend is well developed, and in areas of schistose rocks it locally becomes dominant, obliterating all earlier structures. Most folds of this trend are overturned to the northeast (clockwise, looking down the usual westward plunge) with axial plane foliation dipping southwest approximately 25 degrees. In some areas folds of northwest trend are overturned southwest (counterclockwise, looking northwest) and the foliation dips northeast. These may represent a separate generation, but they seem inseparable from other folds of the same approximate trend, except on the basis of overturning.

Folds of northwest trend with southwest-dipping, axial-plane foliation are developed in Dove Creek strata on both sides of the Big Bertha dome, and the axial planes are approximately parallel in the two areas. This can be true only if these folds are younger than the doming. The northwest trend of noses and synclines parasitic to the domes would appear to indicate that the stress system that produced the NW.-trending minor folds was active at the time of doming or at least during its later stages. The northwest-trending structures are considered to be in part contemporaneous with the growth of the Big Bertha dome but outlasting it in time of development. By extrapolation this interpretation is applied to all the domes.

The only important younger structures are fracture cleavage of NE. strike and NW. dip in the metasediments above the Ordovician quartzites, and scattered kink bands with steep dips trending more or less parallel with the range. Both of these structures are clearly associated with the retrogression of metamorphic mineral assemblages in the rocks affected.

THE CONNER CREEK FORMATION, A ZONE OF MAXIMUM DEFORMATION

During the mapping and structural analysis, it has become evident that the Green Creek Complex is less deformed than the Conner Creek Formation. In the Green Creek Complex, Precambrian fabrics and structure are well preserved, except close to the contact with Paleozoic rocks. In contrast, the Conner Creek Formation shows intense internal deformation by several generations of Mesozoic structures, including small scale isoclinal folding and locally complete transformation of older into younger foliations.

Thus, deformation gradually increases with depth in the stratigraphic section, reaching a maximum in the Conner Creek schists and carbonate rocks. Then, in sudden contrast the deformation decreases—the Elba Quartzite is only mildly deformed, only near the top of the Precambrian is the foliation transposed to near parallelism with the oldest Mesozoic foliation. Farther down, in the Green Creek Complex, the Precambrian foliation is preserved unchanged. This change in degree of deformation occurs in spite of a continual increase of temperature with depth, as indicated by the first appearance of sillimanite below the base of the Elba Quartzite.

The premetamorphic state of the rocks may reasonably explain this. The Green Creek Complex was present as amphibolite facies metamorphic rocks, already largely dehydrated. The Cambrian and younger strata were water-saturated shales, carbonate rocks, and clastics. During progressive metamorphism the Green Creek rocks would have been only mildly affected, eventually returning to the pressure-temperature conditions under which they were originally crystallized and in the process having undergone negligible dehydration and probably few, if any, changes of phase assemblage. In contrast, progressive metamorphism of the overlying sedimentary rocks would have triggered many dehydration reactions, and reactions between phases—probably while fluid pressure approximately equaled total pressure.

During progressive metamorphism the sedimentary rocks would thus have little strength and would be readily deformed while the older crystalline rocks, in spite of their higher temperature, would remain much more competent. As the older rocks rose in domes, or moved *en masse* in any direction, the stresses arising would be accommodated by strain concentrated in the softer, water-saturated sediments, particularly the Conner Creek Formation. In this sense, the Conner Creek Formation may be interpreted as an Abscherungszone that responded to relative movements of the deep-seated crystalline rocks and the cool and relatively competent cover of upper Paleozoic strata. Successively higher zones of weak strata presumably also yielded preferentially to stresses, but not to the same extent as did the Conner Creek Formation.

METAMORPHISM

Within the 250 square miles of exposed metamorphic and plutonic rock in the Albion Range, the grade of metamorphism varies considerably, increasing with stratigraphic depth, and from east to west. Moderate impediments to tracing the grade changes are the abundance of quartzite and quartz-mica schist that lack diagnostic mineral assemblages and the compositional facies changes that occur in pelitic and carbonate units, which confuse the effects of changes in pressure and temperature.

The pelitic and carbonate rocks of the lower part of the Conner Creek Formation show that metamorphism increased from east to west. On the eastern sides of all the domes, the only index minerals associated with quartz and muscovite are garnet and chloritoid. The common mineral assemblage is biotite-muscovite-K feldspar-quartz; dolomite-muscovite-quartz is stable. These rocks are in the greenschist facies. Exactly correlative (but not compositionally identical) strata west of the domes contain assemblages such as kyanite-staurolite-garnet-muscovite-quartz, talc-calcite-quartz-dolomite, tremolite-quartz-calcite, and phlogopite-plagioclase-muscovite-quartz-calcite; these are lower amphibolite facies assemblages. Going stratigraphically upward on the west side of the range, greenschist facies assemblages are again encountered above the Dayley Creek Quartzite. At one notable locality, near the middle of the Dayley Creek, staurolite crystals in garnet-muscovite-quartz schist attain a length of 6 to 7 inches (Pl. 1, fig. 2); this is virtually the last appearance of staurolite going upward stratigraphically.

The Green Creek Complex is within the amphibolite facies, usual assemblages being garnet-muscovite-biotite-plagioclase-quartz and quartz-plagioclase-hornblende. The highest grade rocks are encountered in the City of Rocks dome. In its west-central portion (as would be expected with east-dipping isograds), cordierite, andalusite, and sillimanite occur. Near the center of the area enclosed by the sillimanite isograd, the assemblage sillimanite-muscovite-quartz-K feldspar indicates that the second sillimanite isograd is reached. The cordierite, andalusite, and sillimanite are restricted to the roof pendants in the Almo Pluton and may be either relicts of the Mesozoic regional metamorphism or products of contact metamorphism; sillimanite has not yet been found along the outer contacts of the Pluton. In fact, no observed contact with Precambrian adamellite, schist, and quartzite shows evidence of thermal contrast between pluton and country rock. Hornblende-diopside scarn a few feet thick was produced in one area where the pluton contacts Paleozoic limestone. There appears to be a gradation from higher pressure metamorphism in the northern part of the range where kyanite and staurolite are associated, to lower pressure and higher temperature in the City of Rocks dome where cordierite, andalusite, and sillimanite occur, and no staurolite or kyanite has been observed.

Recent experimental data can be related to these observations to derive a more exact pressure-temperature history. The pelitic rocks above the Elba Quartzite north of Cache Peak contain kyanite, staurolite, and garnet. Associated carbonate rocks contain tremolite and talc. Experimental data for dolomite plus quartz producing talc and for chloritoid producing staurolite in the stability field of kyanite (Metz and Winkler, 1963; J. Ganguly, 1967, personal commun.) lead to an interpretation of temperature slightly above 550° C, with pressure at least 4.5 kilobars. The absence of sillimanite and diopside indicate the temperature did not exceed approximately 580° C (Metz and Winkler, 1964; Newton, 1966a). To the south, where cordierite, andalusite, and sillimanite occur, the pressure must have been somewhat lower than 4.2 kilobars (Newton, 1966a, 1966b). At the time the Almo Pluton was emplaced, the pressure must have exceeded approximately 3.5 kilobars, at a temperature close to 650° C (intersection of the muscovite-plus quartz-dehydration curve of Evans ([1965] and the minimum melting temperature of granite curve of Tuttle and Bowen [1958]).

The change in pressure at the base of the Paleozoic section from north to south of Cache

Peak may be a direct consequence of the southward thinning of the Ordovician and Cambrian(?) quartzites, the magnitude and direction of change being reasonable. Alternately, there may be a difference in the age of the index minerals, the lower pressure-higher temperature assemblages being associated with emplacement of the Almo Pluton in middle Tertiary time when the area was less deeply buried than during the Cretaceous.

The pressure inferred above (4.5 kilobars, equivalent to a depth of 55,000 feet) is not too unreasonable. The over-all simplicity of the regional structure suggests that the only cover present during metamorphism was the unduplicated Paleozoic and Mesozoic stratigraphic column somewhat thickened by folding. The metasediment section above the Elba Quartzite exceeds 20,000 feet in thickness, and to this must be added at least 15,000 feet of Pennsylvanian and Permian strata and an unknown thickness of Mesozoic. With a minimum thickness of 35,000 feet, and a probable greater thickness during the Mesozoic, it appears possible that the stratigraphic cover was the only cover.

Why is there metamorphism here in the Albion Range and related areas on strike to the northeast and southwest, but not nearly to the same extent to the east or west? The present working hypothesis is that these areas, now the sites of amphibolite facies regional metamorphism of Cordilleran geosynclinal sediments, were, by the beginning of the Mesozoic, the most deeply buried. They were buried during the later half of the Paleozoic and early Mesozoic by clastics arriving from areas farther west undergoing orogenic deformation (Antler and Sonoma orogenies). As a consequence of these orogenies, lower Paleozoic strata to the west of the metamorphic belt were near, even at, the surface. To the east of the metamorphic belt, the total Paleozoic accumulation, on the average, was less. Thus in the metamorphic belt itself a thick blanket of material—the clastic product from Paleozoic orogenies—resulted in greater heating of the base of the Paleozoic. If the depth of burial in the Albion Range reached 50,000 feet, a typical geothermal gradient of 30° per km would bring the temperature to approximately 570° C—and the regional metamorphism now observed would have been produced.

TIME SPAN OF METAMORPHISM AND DEFORMATION

Armstrong and Hansen (1966) reviewed the evidence available for dating the regional metamorphism in the eastern Great Basin, and Armstrong and Hills (1967) have presented geochronometric data relating to the Albion Range. In a regional context, the metamorphism accompanied by deformation must be younger than Triassic and Jurassic(?) strata that occur in conformable succession above Paleozoic strata. In the Albion Range itself, all that can be said is that the metamorphism associated with the deformation that produced the northwest-trending fabric elements must be younger than the Triassic(?) sediments and at least as old as 80 m.y. This was the oldest K-Ar date reported by Armstrong and Hills (1967) for rocks containing the youngest penetrative fabric element. This Cretaceous date is in accord with evidence elsewhere in the region indicating a culmination of metamorphism before Early Cretaceous time. Future work must be directed toward narrowing these imprecise time brackets for the synkinematic stages of regional metamorphism.

Metamorphic recrystallization without deformation may have continued in rocks now exposed at the surface until as recently as 30 million years ago (the youngest K-Ar dates for metamorphic rocks reported by Armstrong and Hills, 1967). It is thus necessary to keep in mind that synkinematic metamorphism occurred much earlier than the last metamorphic recrystallization. The time span of synkinematic metamorphism is, however, what is of most interest in understanding the structural history of the Albion Range and the region in which it lies. It was during this time span (Triassic(?) to 80 m.y. ago) that the northeast-trending folds, domes, and northwest-trending folds were formed.

Although there is widespread evidence for Jurassic regional metamorphism in the Basin and Range region, it does not rule out the possibility that active metamorphism and deformation in deeper rocks may have begun earlier and continued until well into the Cretaceous, perhaps even later. In the eastern Great Basin metamorphism may have shifted eastward following the shift of thick clastic accumulations as orogenies advanced successively toward the craton. Rubey and Hubbert (1959) have described how the advance of successive thrust sheets may be controlled by fluid pressures built up by clastics eroded from the active sheets so that each sheet, shedding debris forward, causes the area in front to become unstable, then to yield and become the active thrust sheet itself. On a larger and much slower time scale, involving the buildup of heat in deeply buried sediments, older orogenic deformation [illegible] have predestined newer orogenic zones—each successively outward, in the present case toward the craton. The Jurassic clastic wedge may have been the cover that caused the basement east of the Jurassic metamorphic belt to become warm and to fail, leading to the formation of the Cretaceous fold and thrust belt. The metamorphic rocks deformed synchronously with the fold and thrust belt may not yet be exposed for our examination in this region, although they may be exposed elsewhere in the Cordillera, for example, in the Selkirk Mountains of British Columbia (Wheeler, 1966).

SUMMARY

A possible summary of the geologic history would start out with the burial of a 2.5 b.y.-old, Precambrian crystalline complex, beginning in Cambrian time. By the end of the Paleozoic the complex would have reached a depth of nearly 40,000 feet or more, and by the beginning of the Jurassic a depth of approximately 50,000 feet. With a geothermal gradient of 30° C/km, the temperature at the base of the Paleozoic would have already exceeded 550°. Metamorphism may have started even before the end of the Paleozoic. Deformation occurred mostly during the Jurassic and at the same time erosion began slowly to thin the stratigraphic cover. Recrystallization, and perhaps growth of [illegible]stkinematic" porphyroblasts, continued [illegible]epth through the Cretaceous and into the Tertiary. Rocks near the base of the Paleozoic section were still warm enough to lose their argon during the early Tertiary, although higher strata had cooled sufficiently so that argon diffusion had ceased. At the time of emplacement of the Almo Pluton the Precambrian rocks were still quite deep (~40,000 feet).

Subsequent uplift, which brought the rocks to the surface for observation today, must have been exceedingly rapid—a minimum average rate of uplift of .5 mm per year is necessary. This is in dramatic contrast to the slow uplift that preceded emplacement of the stock (< .05 mm per year).

The stratigraphic and structural interpretation presented in this paper represents a significant departure from conventional conceptions of the geology of this portion of the Cordillera. Until the work of Misch (1960), Misch and Hazzard (1962), Thorman (1962, 1965), Woodward (1964), Nelson (1966), Armstrong and Hansen (1966), and Howard (1966a and 1966b), the importance of regional metamorphism in the eastern Great Basin was seriously neglected. In the past, attention was focused on the widespread unmetamorphosed, fossiliferous, Paleozoic strata. All metamorphically higher-grade areas were automatically considered to be exposures of Precambrian metamorphic rocks, as represented on the recent Tectonic Map of the U.S. (Cohee and others, 1961), and the geologic maps of Nevada (Webb and Wilson, 1962), Utah (Stokes, 1963), and Idaho (Ross and Forrester, 1947). The situation is now being rectified and the Albion Range region may now be added as another area where regional metamorphism of Paleozoic strata has been unusually intense, reaching the highest stratigraphic level yet reported in the Great Basin miogeosyncline.

No nappe structures other than the fold on the south side of the Raft River Range have been recognized, but mantled gneiss domes are well exposed and a small-scale metamorphic fabric is regionally developed. Gneiss domes in the western Cordillera are by no means something new, but their frequency has only recently become evident—in southern California (Johnson, 1957; Lanphere and others, 1964), in central Idaho (Dover, 1968) and in British Columbia (Reesor, 1965; Wheeler, 1965, 1966). As work continues, additional published descriptions are to be expected.

The recognition of a complete and somewhat unusual Paleozoic section is also important, for this region is a blank, as far as knowledge of lower and middle Paleozoic rocks is concerned, on all paleogeographic maps. The area is exceptional for the recognition and dating of an ancient Precambrian basement far within a Paleozoic mobile belt.

Additional work will be necessary to bracket more precisely, if possible, the chronology of deformation and metamorphism so that an exact comparison of history with the adjacent fold and thrust belt will be possible—it may be possible ultimately to decide what has happened to cause the contrasting styles of deformation within, and at the edge of, the Cordilleran geosyncline.

REFERENCES CITED

Anderson, A. L., 1931, Geology and mineral resources of eastern Cassia County, Idaho: Idaho B Mines and Geology Bull. 14, 29 p.

—— 1934, Contact phenomena associated with the Cassia batholith, Idaho: Jour. Geology, v. 42, p. 37 392.

Armstrong, F. C., and Oriel, S. S., 1965, Tectonic development of Idaho-Wyoming thrust belt: Am. Ass Petroleum Geologists Bull., v. 49, p. 1847–1866.

Armstrong, R. L., 1968, The Sevier orogenic belt in Nevada and Utah: Geol. Soc. America Bull., v. p. 429–458.

Armstrong, R. L., and Hansen, E. C., 1966, Metamorphic infrastructure in the eastern Great Bas Am. Jour. Sci., v. 264, p. 112–127.

Armstrong, R. L., and Hills, F. A., 1967, Rb-Sr and K-Ar geochronologic studies of mantled gneiss dom southern Idaho: Earth and Planetary Sci. Letters, v. 3, p. 114–124.

Blue, D. M., 1960, Geology and ore deposits of the Lucin mining district, Box Elder County, Utah, a Elko County, Nevada: M.S. thesis, Utah, Univ., Salt Lake City, Utah.

Carr, W. J., and Trimble, D. E., in prep., Geology of the Rockland and Arbon Quadrangles, Idah U. S. Geol. Survey Bull.

Churkin, Michael, Jr., 1962, Facies across Paleozoic miogeosynclinal margin of central Idaho: Am Assoc. Petroleum Geologists Bull., v. 46, p. 569–591.

Cohee, G. V. and others, 1961, Tectonic map of the United States: U. S. Geol. Survey.

Compton, R. R., 1968, Metamorphosed Paleozoic sequence in the Raft River-Grouse Creek area, Uta (abs.): Geol. Soc. America Spec. Paper 101, p. 296.

Condie, K. C., 1966, Late Precambrian rocks of the northeastern Great Basin and vicinity: Jour. Geology v. 74, p. 631-636.

Dover, J. H., 1968, Bedrock geology and tectonic history of the Pioneer Mountains, Custer and Blain Counties, central Idaho (abs.): Geol. Soc. America Spec. Paper 101, p. 301.

Eskola, P. E., 1948, The problem of mantled gneiss domes: Geol. Soc. London Quart. Jour., v. 104, p 461–476.

Evans, B. W., 1965, Application of a reaction-rate method to the breakdown equilibria of muscovite an muscovite plus quartz: Am. Jour. Sci., v. 263, p. 647–667.

Felix, C. E., 1956, Geology of the eastern part of the Raft River Range, Box Elder County, Utah: Utah Geol. Soc. Guidebook to the Geology of Utah, no. 11, p. 76–97.

Giletti, B. J., 1966, Isotopic ages from southwestern Montana: Jour. Geophys. Research, v. 71, p. 4029- 4036.

Gilluly, James, 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U. S. Geol. Survey Prof. Paper 173, 171 p.

Hague, Arnold, and Emmons, S. F., 1877, Descriptive geology: U. S. Geol. Exploration 40th Parallel, v. 2, Prof. Papers Eng. Dept. U. S. Army, 890 p.

Hazzard, J. C., and Turner, F. E., 1957, Décollement-type overthrusting in south-central Idaho, northwestern Utah and northeastern Nevada: Geol. Soc. America Bull., v. 68, p. 1829.

Howard, K. A., 1966a, Large-scale recumbent folding in the metamorphic rocks of the northern Ruby Mountains, Nevada (abs.): Geol. Soc. America Spec. Paper 87, p. 210.

—— 1966b, Structure of the metamorphic rocks of the northern Ruby Mountains, Nevada: Ph.D. thesis, Yale Univ., New Haven, Conn., 170 p.

Johnson, B. K., 1957, Geology of a part of the Manly Peak quadrangle, southern Panamint Range, California: Calif. Univ. Pubs. Geol. Sci., v. 30, p. 353–424.

Kay, Marshall, 1966, Comparison of the lower Paleozoic volcanic and nonvolcanic geosynclinal belts in Nevada and Newfoundland: Bull. Canadian Petroleum Geology, v. 14, p. 579–599.

Ketner, K. B., 1966, Comparison of Ordovician eugeosynclinal and miogeosynclinal quartzites of the Cordilleran geosyncline: U. S. Geol. Survey Prof. Paper 550C, p. 54–60.

Lanphere, M. A., Wasserburg, G. J., Albee, A. L., and Tilton, G. R., 1964, Redistribution of strontium and rubidium isotopes during metamorphism, World Beater Complex, Panamint Range, California, Chap. 20 *in* Isotopic and cosmic chemistry: Amsterdam, Netherlands, North-Holland Publishing Co., p.269–320.

Ludlum, J. C., 1942, Precambrian formation at Pocatello, Idaho: Jour. Geology, v. 40, p. 81–95; v. 50, p. 85–95.

Metz, P. W., and Winkler, H. G. F., 1963, Experimentelle Gesteinsmetamorphose—VII Die Bildung von Talk aus Kieseligem Dolomit: Geochim. et Cosmochim. Acta, v. 27, p. 431–457.

—— 1964, Experimental investigation of the formation of diopside from tremolite, calcite, and quartz: Geochemistry International, v. 1, p. 388–389.

Misch, Peter, 1960, Regional structural reconnaissance in central-northeast Nevada and some adjacent areas: Observations and interpretations: Intermountain Assoc. Petroleum Geologists 11th Ann. Field Conf. Guidebook, p. 17–42.

Misch, Peter, and Hazzard, J. C., 1962, Stratigraphy and metamorphism of late Precambrian rocks in central northeastern Nevada and adjacent Utah: Am. Assoc. Petroleum Geologists Bull., v. 46, p. 289–343.

Nelson, R. B., 1966, Structural development of northernmost Snake Range, Kern Mountains, and Deep Creek Range, Nevada and Utah: Am. Assoc. Petroleum Geologists Bull., v. 50, p. 921–951.

Newton, R. C., 1966a, Kyanite-andalusite equilibrium from 700° to 800° C: Science, v. 153, p. 170–172.

—— 1966b, Kyanite-sillimanite equilibrium at 750° C: Science, v. 151, p. 1222–1225.

Peace, F. S., 1956, History of exploration for oil and gas in Box Elder County, Utah and vicinity: Utah Geological Society Guidebook to the Geology of Utah, no. 11, Geology of parts of northwestern Utah, p. 17–31.

Piper, A. M., 1923, Geology and water resources of the Goose Creek Basin, Cassia County, Idaho: Idaho Bur. Mines and Geology Bull. 6, 78 p.

Reesor, J. E., 1965, Structural evolution and plutonism in Valhalla gneiss complex, British Columbia: Canada Geol. Survey Bull. 129, 128 p.

Roberts, R. J., and Thomasson, M. R., 1964, Comparison of late Paleozoic depositional history of northern Nevada and central Idaho: U. S. Geol. Survey Prof. Paper 475 D, p. 1–6.

Ross, C. P., 1947, Geology of the Borah Peak Quadrangle: Geol. Soc. America Bull., v. 58, p. 1085–1160.

—— 1962, Paleozoic seas of central Idaho: Geol. Soc. America Bull., v. 73, p. 769–794.

Ross, C. P., and Forrester, J. D., 1947, Geologic map of the state of Idaho: U. S. Geol. Survey.

Rubey, W. W., and Hubbert, M. K., 1959, Overthrust belt in geosynclinal area of western Wyoming in light of fluid-pressure hypothesis: Geol. Soc. America Bull., v. 70, p. 167–206.

Sayyah, T. A., 1965, Geochronological studies of the Kinsley stock, Nevada, and the Raft River Range, Utah: Ph.D. thesis, Utah Univ., Salt Lake City, Utah, 112 p.

Stokes, W. L., 1952, Paleozoic positive area in northwestern Utah (abs.): Geol. Soc. America Bull., v. 63, p. 1300.

—— *Compiler*, 1963, Geologic map of northwestern Utah: Utah Geol. and Mineralog. Survey.

Stringham, B., 1962, Precambrian stratigraphy of the Grouse Creek Mountains, northwestern Utah (abs.): Geol. Soc. America Spec. Paper 68, p. 105.

Stringham, B., and others, 1961, Geologic map of the Grouse Creek Mountains and vicinity, Box Elder County, Utah: preliminary map, Utah state map project.

Thorman, C. H., 1962, Structure and stratigraphy of the Wood Hills and a portion of the northern Pequop Mountains, Elko County, Nevada: Ph.D. thesis, Washington Univ., Seattle, Washington, 259 p.

—— 1965, Biotized graptolites from northeastern Nevada: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 610–613.

Trimble, D. E., and Schaeffer, F. E., 1965, Stratigraphy of the Precambrian and lowest Cambrian rocks of the Pocatello area, Idaho: Geol. Soc. America Spec. Paper 82, p. 349.

Tuttle, O. F., and Bowen, N. L., 1958, The origin of granite in the light of experimental studies in the system $NaAlSi_3O_8 - KAlSi_3O_8 - SiO_2 - H_2O$: Geol. Soc. America Mem. 74, 153 p.

Umpleby, J. B., Westgate, L. G., and Ross, C. P., 1930, Geology and ore deposits of the Wood River region: U. S. Geol. Survey Bull. 814, 250 p.

Webb, B., and Wilson, R. V., 1962, Progress geologic map of Nevada: Nevada Bur. Mines map 16.

Wheeler, J. O., 1965, Big Bend map-area, British Columbia: Canada Geol. Survey Paper 64–32.

—— 1966, Eastern tectonic belt of western Cordillera in British Columbia, *in* Canadian Institute of Mining and Metallurgy, Special Volume 8, Tectonic History and Mineral Deposits of the Western Cordillera, Montreal, Quebec, Canadian Institute of Mining and Metallurgy, p. 27–45.

Woodward, L. A., 1964, Structural geology of central northern Egan Range, Nevada: Am. Assoc. Petroleum Geologists Bull., v. 48, p. 22–39.

—— 1967, Stratigraphy and correlation of late Precambrian rocks of Pilot Range, Elko County, Nevada and Box Elder County, Utah: Am. Assoc. Petroleum Geologists Bull., v. 51, p. 235–243.

Youngquist, W., and Haegele, J. R., 1956, Geological reconnaissance of the Cassia Mountain region, Twin Falls and Cassia Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 110, 18 p.

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