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TO ACCOMPANY MAP I-672

GEOLOGIC MAP OF THE YOST QUADRANGLE, BOX ELDER COUNTY, UTAH AND CASSIA COUNTY, IDAHO

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DESCRIPTION OF MAP UNITS

The rock units of Yost quadrangle may be divided into two broad categories: Cenozoic sedimentary and volcanic rocks that underlie the wide valleys; and older sedimentary and igneous rocks, now mostly metamorphosed, that form the mountain ranges. The older rocks are Precambrian and Paleozoic in age except for the granitic rocks, which are of unknown age. All of the older rocks were folded and cut by two major thrust faults; nonetheless, they are now mainly subhorizontal, with a structural order that appears also to be their stratigraphic sequence. The units were thinned considerably during metamorphism, as shown by flattened mineral grains that lie parallel to bedding. This thinning has not been taken into account in determining the unit thicknesses reported, which are the present thicknesses, generally measured where the formations are thickest.

QUATERNARY ROCKS

Modern alluvium.—Sedimentary deposits presently or recently in transit along streams were mapped only where an appreciable flood plain is present and were therefore omitted along the innumerable minor streams. The composition of the modern alluvium is complex and changes greatly from place to place because it has been derived from older alluvial deposits as well as from bedrock slopes. Generally, quartzite pebbles and cobbles predominate.

Landslide deposits.—The largest of seven landslides mapped is in upper Junction Valley (sec. 32, T. 13 N., R. 16 W.) and has an areal extent of half a square mile. This slide is younger than the older alluvium; some of the other slides are probably older. An especially interesting slide, exposed 1 mile north of the east end of the Upper Narrows of Raft River, consists entirely of fragments of locally derived schist, some of them many feet across. The deposit is largely covered by older alluvium and locally has the appearance of a thrust sheet lying on the Tertiary tuffaceous sediments.

Older alluvium and contiguous colluvium and fan deposits.—The various parts of this composite unit were not separated on the map because they grade into one another. By far the most abundant constituents are alluvial sands, gravels, and silts that have been dissected to depths of as much as 80 feet by the present streams. These deposits are especially well exposed in bluffs along Raft River and Dove Creek, where beds are lenticular, subhorizontal, and cemented locally by old caliche. Compositions vary greatly, but quartzite detritus is generally most abundant. Schist and marble fragments are scarcely more weathered than those in the modern alluvium. Locally, the older alluvium merges upslope with alluvial fans and colluvial aprons, some of which are only slightly dissected. Also included in the map unit are uneroded patches of upland alluvium, such as that in Clarks Basin.

TERTIARY ROCKS

Tuffaceous sediments and conglomerate.—These rocks are well exposed east and west of Yost, but in most places they are covered by younger gravels or are too friable to crop out. Elsewhere in the region similar rocks have been assigned to the Tertiary Payette Formation and to the Salt Lake Formation (Mapel and Hail, 1956), but the Yost quadrangle rocks cannot be correlated with these formations, even tentatively. The section exposed east of Yost is about 8,000 feet thick, and the alluvium under Yost probably conceals an additional several thousand feet of similar beds. Only about 1,000 feet of the rocks are exposed in Junction Valley, but gravity measurements indicate a deep central graben, perhaps filled with similar strata (Cook and others, 1964).

The exposed sections in Yost quadrangle are dominantly tuffaceous, the volcanic component being vitric ash of silicic composition. In the lower part of the section east of Yost, tuffaceous sandstones and siltstones are well lithified and colored various tints and shades of green, yellow, white, and brown. The abundant conglomerates in this part of the section are so poorly sorted and so coarse (1-3 feet) as to suggest torrential deposition on ancient alluvial fans. Up-section there are fewer conglomerate layers, and the tuffaceous silts and sands are friable and white to brown. In Junction Valley, the main sequence consists of friable tan tuffaceous sandstone and siltstone with lenses of pebble conglomerate; the conglomerate and lithified tuffaceous rocks near the base of the section are thin and discontinuous.

Welded dacite tuff.—Remnants of a welded-tuff sheet are exposed locally at the base of the Tertiary sequence in the northwest part of the quadrangle. The rock is similar to tuffs that crop out along the west side of the Albion Range, 12 miles to the north, for which R. L. Armstrong (oral commun., 1969) has obtained a K-Ar age of 8.5 m.y. The best exposures in Yost quadrangle, near the main road at the west end of the Upper Narrows, show 40 feet or so of brown-weathering, black vitrophyre and gray spherulitic welded tuff that resembles lava. Small phenocrysts of plagioclase and clinopyroxene make up about 5 percent of the rock.

The discontinuous nature of the remnants indicates that considerable erosion took place before the tuffaceous sediments were deposited on them. A different relation is found near Yost; here the tuffaceous sediments project under the lavas and tuffs of the Malta Range, 6 miles to the north (Anderson, 1931). The welded tuff near the Upper Narrows is therefore substantially older than the volcanic rocks of the Malta Range, or the tuffaceous rocks of Junction Valley are younger than those near Yost. In either case, the Tertiary history differed considerably from place to place.

PENNSYLVANIAN ROCKS

Oquirrh(?) Formation.—Fossiliferous limestone and sandstone similar to rocks of the Oquirrh Formation form numerous klippen in Yost quadrangle. These are remnants of a thrust plate that once extended over the entire area. Neither the upper nor the lower depositional contacts of the unit were found, and the thickest klippe exposes only about 1,000 feet of strata. Nonetheless, most klippen consist of two stratigraphic subunits, the lower mainly of limestone and the upper mainly of sandstone, and a contact was drawn between the subunits in many of the klippen. The limestone—typically dark gray, sandy, and crudely bedded—is interbedded with calcareous sandy siltstone and fine-grained orthoquartzite that weather brown or pinkish gray. The sandstone subunit consists mainly of brown-weathering gray orthoquartzite and calcareous sandstone with irregular interbeds of dark-gray limestone. Under the microscope, the sandstone proves to be fine grained and moderately well sorted, and to have many rounded grains. Most of the limestone has many sand-sized fossil fragments in a matrix of fine-grained recrystallized calcite. The rocks are generally unmetamorphosed, but light-gray or pale-tan calcitic and dolomitic marbles occur locally at the base of the klippen of the southern Dove Creek Mountains. Where folded, even the unmetamorphosed rocks have secondary cleavages that may be more apparent than bedding.

Fossil bryozoans, crinoids, and fusulinids are abundant locally but are silicified and too altered to be diagnostic. Fossil material described by Felix (1956, p. 85-86) indicates that most of the rocks are Pennsylvanian.

MISSISSIPPIAN(?) ROCKS

Metamorphosed Manning Canyon(?) Shale.—Up to 250 feet of dark-gray phyllite with subordinate amounts of gray quartzite and laminated dark-gray marble underlies the thrust plate of Oquirrh(?) Formation in the southern Dove Creek Mountains. Similar rocks form fault slices under the same thrust elsewhere in the quadrangle, but many are too small to show on the map. The phyllite commonly contains small porphyroblasts of chloritoid in a groundmass of quartz, muscovite, chlorite, and graphite. Thin-section study shows that the unit was originally carbonaceous sandy mudstone and poorly sorted sandstone. Lithology and structural position suggest the rocks may be correlative with the Manning Canyon Shale although Stringham (in Stokes, 1963) called the unit Chainman Shale. No fossils were found in the quadrangle, but the same unit on Vipont Mountain, a few miles west of the quadrangle, contains deformed brachiopod shells of unknown age.

ORDOVICIAN(?) ROCKS

The next three formational units are assigned a probable Ordovician age on the basis of their sequence, position, and intergradational relations. The lowest, a marble, grades upward into pure quartzite, and the quartzite grades into gray dolomite—a succession suggestive of the Pogonip Group, Eureka Quartzite, and Fish Haven Dolomite, and of no other contiguous Paleozoic formations known to the writer. Poorly preserved crinoid and other fossil fragments prove the marble and dolomite to be younger than Precambrian, but are otherwise undiagnostic. Felix (1956) found fossils in the same units in the eastern part of the Raft River Mountains, and noted the resemblance of the marble to metamorphosed Pogonip limestone in Nevada; however, he named the formations Units A, B, and C of the lower(?) Paleozoic. Stringham (in Stokes, 1963) included the formations in the upper(?) Precambrian Dove Creek Formation.

Metamorphosed Fish Haven(?) Dolomite.—The formation, questionably assigned to the Fish Haven Dolomite, is thickest (600 feet) in the Black Hills, on the southern flank of Raft River Mountains, where its succession is (1) several hundred feet of interlaminated silver-gray and dark-gray dolomite; (2) several hundred feet of massive cream-colored dolomite, commonly brecciated; and (3) about a hundred feet of gray laminated dolomite. Elsewhere the unit is represented by only the first subunit.

The grains of the gray dolomite are 0.5-1 mm in diameter and are interspersed with several percent of muscovite, quartz, and K-feldspar grains. Tremolite porphyroblasts are locally abundant, and white fossil fragments can be seen here and there. The upper part of the formation is in thrust contact with graphitic phyllite or with the Oquirrh(?) Formation.

Metamorphosed Eureka(?) Quartzite.—The Eureka(?) Quartzite is a strikingly white quartzite, 400 feet thick near the center of the quadrangle but represented by only a few thin lenses in the southern Dove Creek Mountains. Beds are 1 to 6 inches thick and generally discernible at the outcrop even though the rock is thoroughly metamorphosed and completely free of schist interbeds. Sparse muscovite, the only appreciable impurity, imparts a sparkling luster to broken surfaces. Quartz grains average 1 mm in diameter but cannot be seen without a polarizing microscope. At many places the quartzite is broken tectonically and recrystallized into a remarkably solid nonporous breccia. The unit normally grades into the overlying dolomite through a few feet of interbedded rocks, but a tectonic breccia of quartzite and dolomite commonly lies between the two units.

Metamorphosed limestone of the Pogonip(?) Group.—This unit is as much as 500 feet thick in Yost quadrangle. The lower two-thirds is mainly tan-weathering impure marble characterized by laminations that include numerous 2- to 5-mm porphyroblasts of muscovite, biotite (or chlorite), calcic plagioclase, and vesuvianite(?). These larger grains weather into relief against the finer (0.5 mm) groundmass, which is mainly calcite but includes several percent of dolomite, quartz, and K-feldspar. The upper third of the unit is mainly light gray, nearly pure marble, with grains about 1 mm in diameter. A layer of pale-brown quartzite, 5 to 20 feet thick, occurs locally in the upper 50 feet of the marble, and in the uppermost 10 to 30 feet, marble is interlayered with white quartzite like that of the overlying formation.

Nearly pure light-gray marble with grains as large as 5 mm forms thin lenses along the thrust surface under the quartzite of Clarks Basin, and green marble containing abundant epidote and chlorite occur locally near thrusts. Although they are probably metamorphosed Pogonip limestone, some could be limestone of unknown original stratigraphic position emplaced tectonically along the thrusts.

CAMBRIAN(?) ROCKS

Two formations of quartzite and schist lie conformably beneath the metamorphosed Pogonip(?) Group—a relation that suggests they may be Cambrian. Felix (1956) did not map these units separately, including both in the unit he designated Unit B of the Harrison(?) series, and Stringham (in Stokes, 1963) included both in his upper(?) Precambrian Dove Creek Formation.

Schist of Mahogany Peaks.—A distinctive schist unit, generally 50 to 200 feet thick, is well-exposed near the prominent Mahogany Peaks located near the center of the quadrangle. By far most abundant is dark-brown biotite-muscovite schist with porphyroblasts of garnet and staurolite; locally, the unit includes silvery muscovite schist and graphitic schist, both containing scattered mafic porphyroblasts. Quartz-rich interbeds are so scarce as to indicate that the rock was originally a homogeneous claystone. In the southern Dove Creek Mountains, however, the schist is intricately interlayered with the underlying quartzite where the two were mixed tectonically, and in these places the schist is knobby and silvery green, and consists mainly of chlorite and muscovite. Another tectonic variant occurs along a thrust near Charleston Creek, in the northeastern part of the area, where the unit is entirely phyllitic.

The upper part of the schist is interbedded with the overlying marble along the north side of the Raft River Mountains, where the contact was drawn at the base of the lowest marble. Elsewhere, the contact is sharp and is marked by a few feet of dark-gray graphite-chloritoid-quartz-muscovite schist.

Quartzite of Clarks Basin.—This unit is well represented around Clarks Basin, an upland valley near the center of the quadrangle, where it is about 400 feet thick. The quartzite is characterized everywhere by distinct thin beds separated by very thin but rather coarse-grained muscovite schist layers that are impressed on the surfaces of loose slabs of quartzite flagstone as oval shiny patches. The lower contact was drawn at the base of the lowest quartzite in the sequence—typically a medium-gray nonfeldspathic quartzite in layers 1 to 3 inches thick. In most places, this quartzite is overlain by 10 to 40 feet of schist like that of the underlying unit (schist of Stevens Spring), and then by essentially continuous quartzite, the lower two-thirds of which is gray to pale orange, contains 5 to 15 percent of K-feldspar, and includes a few beds 2-3 feet thick among the thinner beds. The remaining (upper) part of the formation is white or light gray, nonfeldspathic, and in beds no thicker than 3 inches. The contact with the schist of Mahogany Peaks is sharp and apparently conformable. All the quartzite in the unit contains a few percent of muscovite; the schist interlayers locally contain macroscopic kyanite, chloritoid, or biotite.

PRECAMBRIAN(?) ROCKS

Metamorphosed shale and sandstone that appear to lie conformably beneath the quartzite of Clarks Basin make up a subhorizontal sequence that is exposed over much of Yost quadrangle as well as for many miles to the east in the Raft River Mountains. In the quadrangle, the sequence averages 1,500 feet thick and consists of four formational units that are genetically related. All were included in the unit that Felix (1956) named Unit B of his Harrison(?) series, and the upper three were included by Stringham (in Stokes, 1963) in his upper(?) Precambrian Dove Creek Formation. The basal formation has been mapped into the southern part of the Albion Range, where it was mapped and named the Elba Quartzite by Armstrong (1968, p. 1301). The remaining three formations may be equivalent to the lower part of Armstrong's (1968, p. 1301-1302) Conner Creek Formation, but this correlation must be tested further.

Armstrong (1968) considered the Elba Quartzite to be Cambrian(?) and the Conner Creek Formation to be Cambrian or Ordovician; however, the Rb-Sr data cited by him permit rather than require these age assignments (Armstrong and Hills, 1967), and the fossiliferous Conner Creek described by him is similar to units in Yost quadrangle that are younger than the four formations considered in this section. A probable late Precambrian age is indicated for these four formations by certain distinctive rocks that are not known to occur in the Cambrian or Ordovician formations of the region, specifically: green quartzite, magnetite-rich and hematite-rich rocks, metadiabase, metamorphosed granite porphyry, and metamorphosed silicic tuffs and tuffaceous sedimentary rocks.

Schist of Stevens Spring.—The youngest late Precambrian(?) formation is a fine-grained schist exposed near Stevens Spring, 6 miles south of the village of Yost. The unit is 500 feet thick in the southwestern part of the quadrangle and about 300 feet elsewhere. Exposures are far poorer than those of the overlying and underlying quartzites. The main rock is fine-grained muscovite-quartz schist that contains abundant lenses of graphitic phyllite 0.5 to 2 inches across and 0.1 inch thick—apparently carbonaceous laminae that were disrupted tectonically. These rocks are interlayered with homogeneous muscovitic and graphitic phyllites and schists, some with garnet or chloritoid porphyroblasts. On the south side of the Raft River Mountains, the lower part of the formation is fine-grained biotite-muscovite-quartz schist. Dark-green satiny epidote-hornblende schist and plagioclase-hornblende schist form layers as much as 10 feet thick that occur locally throughout the quadrangle and are especially common near the top of the formation in the Dove Creek Mountains. Metadiabase with relict igneous texture forms a 30-foot sill in the upper part of the unit in upper Johnson Creek Canyon, and smaller bodies of metadiabase occur elsewhere. Almost every well-exposed section shows one or two subunits of feldspar-rich muscovitic quartzite, each only a few feet thick. These were almost certainly rhyolite tuffs or tuffaceous sediments.

Quartzite of Yost.—A unit of quartzite approximately 400 feet thick is well exposed in the Raft River Mountains due south of the village of Yost. The formation thins to 200 feet in the northwest and central parts of the quadrangle and pinches out in the southwest part. The upper contact is either sharp or grades rapidly from quartzite to the schist of Stevens Spring. The quartzite is characteristically white, sparsely to moderately muscovitic, and in beds a foot or less thick. Strikingly green quartzite, colored by chromian mica, occurs in the Upper Narrows in the northwest part of the area, and pale-greenish-gray variants can be found elsewhere. Magnetite-rich quartzites and hematitic schists form thin layers in the northwest part of the quadrangle. Some of the thicker beds along Johnson Creek contain small quartz pebbles and coarse grains of K-feldspar. Beds in the central part of the quadrangle contain as much as 10 percent of K-feldspar.

Schist of the Upper Narrows.—This unit is fully exposed in the steep-walled canyon called the Upper Narrows of Raft River, in the northwest part of the quadrangle. The unit is thickest, perhaps 1,500 feet, a few miles south of the Upper Narrows; from here it thins rapidly to the south and pinches out in the southern part of the quadrangle. Except for a muscovite-quartz schist member that has been mapped separately, the formation is characterized by dark-brown or gray rocks that form large slabby outcrops. Most abundant are fine- to medium-grained biotitic schist and fine-grained gneiss that contain appreciable quartz, K-feldspar, plagioclase, and muscovite. The gneiss and medium-grained schist commonly carry segregated quartz or quartz-feldspar lenses averaging an inch thick and a few feet across. In the upper part of the unit, thin phyllitic layers have been separated tectonically into dark-gray or silvery lenses measuring 1-2 inches across and 0.1 inch thick, which give the outcrops a patchy appearance. Garnet porphyroblasts are present locally, as are thin layers of quartzite. Small bodies of amphibolite (metadiabase) crop out in the Upper Narrows, and schists with considerable calcite or amphibole occur in the upper part of the formation here and elsewhere.

The muscovite-quartz schist member forms an extensive lens, roughly 500 feet thick at its center, in the northern Dove Creek Mountains. The silvery gray to light-tan rocks contain 20 to 40 percent of muscovite and locally appreciable K-feldspar, chiefly as large relict grains. The schist appears to have been bedded but differs so markedly from the adjoining dark schist as to suggest it was a separate body of rhyolite tuff or tuffaceous sedimentary rock. The upper contact of this member is nowhere exposed, and the stratigraphic relations in the upper part of the formation in the Dove Creek Mountains are confused by complex folding. The member is missing in the Raft River Mountains, where the main dark schist is overlain by the quartzite of Yost along a sharp contact.

Elba Quartzite.—The Elba Quartzite, named by Armstrong (1968, p. 1301) for exposures at its type section in S½ sec. 1, T. 14 S., R. 24 E., west of the town of Elba, Idaho, forms the most striking outcrops in Yost quadrangle. The white and tan dip slopes and cliffs of this quartzite characterize the Raft River Mountains and parts of the Dove Creek Mountains and the Grouse Creek Mountains. The formation is as much as 1,500 feet thick in the northwestern part of the quadrangle and no more than 50 feet thick near the center, averaging 500 feet over most of the area. Where the unit is thicker than average, most beds are 1 to 8 feet thick many are crossbedded on a large scale, and a few contain well-sorted quartzite-pebble conglomerate. Where the formation is no thicker than average, beds are rarely more than a few feet thick and much of the unit is thin bedded, even flaky and semischistose. The quartzite is white or pale tan, or very locally green. The tan pigment is residual to leached dolomite grains, which commonly formed distinctive ovules an inch or so long. These bodies were flattened and lineated tectonically, as were quartzite pebbles in conglomerate layers. Some of the white quartzite is nearly pure but most contains a few percent of muscovite, dolomite (or tremolite and diopside after dolomite), and sparse K-feldspar. Muscovite-quartz schist forms thin layers between some of the beds. Except for the conglomerates, the rocks are too metamorphosed to show original grains, but their purity indicates well-sorted mature quartz sands.

The formation grades upward through 10 to 100 feet of biotite-muscovite quartzite into the overlying unit—a relation especially well exposed in the Upper Narrows of Raft River. Although the Elba Quartzite was designated Cambrian(?) by Armstrong (1968, p. 1298), it is here considered late Precambrian(?) for reasons presented under the heading Precambrian(?) rocks.

PRECAMBRIAN ROCKS

Older schist.—Brown and silvery mica-rich schists, originally shales and sandstones, are apparently the oldest rocks in the quadrangle. Intruded by granitic bodies, they form extensive remnants as much as 300 feet thick along the borders of the granitic intrusions and also occur as inclusions in them. In the eastern part of the quadrangle, both schist and granite appear to be overlain unconformably by the late Precambrian(?) Elba Quartzite; however, the metamorphism of all the units makes this relation difficult to interpret. The unit consists of muscovite-biotite-quartz schist, mica-plagioclase-microcline-quartz schist, and muscovite-quartz schist. These rocks are lithologically similar to thicker and more extensive schist remnants in the eastern part of the Raft River Mountains, where they have been intruded by granitic rocks that have been dated provisionally as early Precambrian by R. E. Zartman (written commun., 1969). The schists there were named Unit A of the Harrison(?) series by Felix (1956), but no detailed correlations have been made between the Raft River Mountains and the Albion Range, where the Harrison Series was first described by Anderson (1931). R. L. Armstrong (written commun., 1969) noted the similarity of the older schist to Albion Range schists dated at 2.46 ± 0.3 billion years or older (Armstrong and Hills, 1967, p. 119).

INTRUSIVE IGNEOUS ROCKS

Metamorphosed adamellite.—Granitic rocks of undetermined age are exposed in all the more deeply eroded parts of the area and may well be present at moderate depth throughout the quadrangle. Two or more intrusive bodies are present, but because they were metamorphosed dynamothermally the usual igneous features could not be used to subdivide them in the time available. The principal rock in all the mapped exposures is metamorphosed adamellite, locally accompanied by granodiorite. All the rocks contain at least a few K-feldspar phenocrysts, and some are crowded with them. Rock textures were so affected by metamorphism that they vary greatly with depth. The deepest exposures show moderately foliated and lineated rocks; these grade upward into a zone of gneiss with feldspar augen; and the gneiss grades upward into a zone of schist, 10 to 100 feet thick, containing small ovoid relics of the large feldspar grains. In all the rocks, foliation and lineation are imparted by the shaped feldspar grains and by flattened and elongated aggregates of muscovite and biotite, some of which are secondary to garnet grains. The lineations are typically parallel to fold-axis lineations in the overlying metamorphic rocks, indicating that all the granitic rocks were emplaced before or during metamorphism.

Intrusive relations indicate that the youngest of the granitic rocks occur in the western part of the quadrangle. In Muddy Canyon, at the south edge of the quadrangle, dikes can be traced from the main adamellite body into the Elba Quartzite, and inclusions of the quartzite occur nearby in adamellite. At the west end of the Upper Narrows of Raft River, and in another locality 2.5 miles south of the center of the quadrangle, large granitic dikes are intrusive into the upper Precambrian(?) units. On Vipont Mountain, 4 miles west of the northwest corner of the quadrangle, lineated granodiorite and adamellite intruded the Cambrian(?) and Ordovician(?) formations, and Rb-Sr determinations on a suite of samples from this locality indicate a probable early Tertiary age (R. E. Zartman, written commun., 1969).

Evidence that some granitic rocks are older is somewhat more equivocal, but those in the eastern part of the quadrangle appear to lie unconformably beneath the Elba Quartzite. This relation is best shown in Corner Creek Canyon, on the south flank of the Raft River Mountains, where the Elba Quartzite lies with angular discordance across a steep contact between adamellite and older schist. It seems contrary that just to the east in Century Hollow the adamellite appears to include a large xenolith of quartzite, but this could be an older quartzite that originally lay beneath the older schist. Preliminary Rb-Sr determinations on adamellite and granodiorite 7 miles east of the quadrangle indicate an early Precambrian age (R. E. Zartman, written commun., 1969), and this could well be the same body as that exposed in Corner Creek Canyon.

In summary, at least some granitic rocks in the western part of the quadrangle are younger than the Elba Quartzite, and some in the eastern part of the quadrangle are older. All were emplaced before or during dynamothermal metamorphism, which deformed the upper parts of the bodies much more than the lower parts.

Metamorphosed granite porphyry.—A fairly extensive body of granite porphyry is exposed in Road Canyon, in the southern Dove Creek Mountains, where it lies between the schist of the Upper Narrows and the schist of Stevens Spring. Small lenses and dikes of the same rock have been mapped in about the same stratigraphic position for 2 miles to the south; and thin layers and lenses of similar rocks, often associated with feldspathic quartzites, occur widely in the schist of Stevens Spring. The porphyry is typically schistose, with relics of feldspar phenocrysts and variable proportions of biotite and muscovite. The mapped bodies have sharp boundaries, but some others grade to quartzites, as though they might have been tuffs. The mapped unit is probably a suite of hypabyssal intrusive rocks genetically related to volcanic rocks in the schist of Stevens Spring, although it could conceivably be much younger.

STRUCTURE

Although the formations are subhorizontal over large areas, they have undergone several episodes of deformation, including metamorphic flowage, folding, thrusting, and high-angle faulting. The first two episodes probably took place during the Cretaceous and early Tertiary, and resulted in metamorphic flowage and consequent thinning of the Paleozoic and older units, locally forming nearly recumbent folds of large size. Two major décollement-type thrusts developed at about the same time, one lying at the base of the Oquirrh(?) Formation and the other near the base of the Paleozoic sequence. Another episode of folding took place after metamorphism, accompanied and followed by more thrusting; however, the direction of transport was markedly different from those of the earlier episodes. Following the last thrusting, the area was pressed into broad anticlines and synclines that were subsequently broken along normal faults, some of which have been active recently.

Folds.—The characteristics of the older folds suggest solid-state flowage during metamorphism. They tend to be strongly overturned, to extend along strike for only a few miles or less, to have curved axial lines, and to show marked thinning of units on their gently inclined limbs. Folds with amplitudes greater than a foot occur only locally, but microfold lineations are widespread and are coaxial with elongate pebbles and metamorphic mineral grains. These folds can be divided into two major generations on the basis of refolded lineations observed at many outcrops. Folds of the first generation are developed mainly in the lower Precambrian and upper Precambrian(?) units, and their distribution and various trends are shown in figure 1. In almost all cases they are overturned toward the northwest and west. The second generation of folds and metamorphic lineations is developed equally in Paleozoic and older rocks. These folds are overturned toward the northeast and cross the older folds at various angles (fig. 1).

A third generation of folds started to form during the closing stages of metamorphism but is mainly postmetamorphic. It is represented locally by large folds in the Paleozoic units and by small corrugations in the older rocks. Axial trends are approximately north-south, and the larger folds are overturned strongly toward the east (fig. 2). The principal folds in the Oquirrh(?) Formation have this same trend but are not markedly overturned. The latter folds are cut off at the thrust fault underlying the Oquirrh(?) and must therefore have formed before the plate was fully emplaced.

Following thrusting, all the units and structures were deformed into widely spaced open symmetrical folds with limbs that typically dip 15° to 20°. The largest of these, the anticline that forms the Raft River Mountains, trends east-west for a distance of 22 miles, dying out at the west against the main north-south anticline of the Dove Creek Mountains, near the center of Yost quadrangle (fig. 2). Judged from relations seen at the east end of Raft River Mountains, the north-south folds are the older, but this cannot be proved in Yost quadrangle.

Faults.—Oldest and most extensive of the faults are the low-angle thrusts that divide the sequence into two principal thrust plates and an autochthon. The upper plate is deeply eroded and now consists only of the Oquirrh(?) Formation but probably once included younger strata. The lower plate extends from the top of the metamorphosed Manning Canyon(?) Shale down to a thrust that typically lies near the base of the quartzite of Clarks Basin or the top of the schist of Stevens Spring—a vertical distance ranging from nearly 0 to 2,000 feet and averaging 800 feet. Subsidiary thrusts divide the lower plate into several subparallel wedges, and the lenses of phyllite at the top of the plate are bounded entirely by thrust surfaces. Sheets of breccia or phyllonite are rarely seen along any of the thrusts, but the faults can be recognized where (1) beds are cut off by the underlying thrust, (2) older units overlie younger units, (3) overturned units lie directly on older upright units, and (4) formations are missing or are represented by minor slices. The complete absence of Silurian, Devonian, and most Mississippian units implies a major décollement-type fault at the base of the upper plate, and décollement faulting is also indicated by the tendency for younger units to be emplaced on older, and for the fault surface to lie along or near unit contacts.

Useful in determining directions of the latest thrusting are two high-angle strike-slip faults, one in the Black Hills and one east of Clarks Basin. These faults indicate that the lower plate was divided into steep-sided tongue-shaped bodies during a late stage of thrusting. Offsets on the faults indicate eastward thrusting near Clarks Basin and northeastward thrusting in the Black Hills, and sets of imbrications in the two areas indicate the same directions of movement.

The imbrications in the Black Hills carried lower-plate Paleozoic rocks over the Oquirrh(?) Formation of the upper plate and indicate several miles of displacement on the lower thrust after the upper plate was emplaced. There is no direct measure of earlier displacements, but the greatly abbreviated stratigraphic section beneath the Oquirrh(?) plate indicates that it has traveled far. The structural truncation at the lower thrust appears to require far less movement; however, the Cambrian(?) sequence is so atypical for the region as to suggest large-scale displacement. The coarsely recrystallized tectonic marble along the lower thrust indicates that much of this thrusting took place before or during metamorphism.

All the normal faults are much younger than the thrusts, for they cut the late Tertiary folds that deformed the thrusts. They strike in two preferred directions, N. 20° W. and N. 30° E., and their zigzag and branching traces and their steep basinward dips are similar to those of other faults of the Basin and Range province. The faults along the east side of the Dove Creek Mountains locally displace colluvium, but many of the other normal faults have been eroded deeply since they formed.

ECONOMIC DEPOSITS

Metals.—Judged chiefly from reports by Higgins (1909) and MacFarren (1909), approximately $500,000 worth of gold has been produced from quartz veins in Century Hollow and vicinity, on the south flank of the Raft River Mountains. Ore tenor ranged from $8 to $100 per ton in gold. The veins strike between east and northeast, and although they dip steeply they lie entirely within the granite. All production was from native gold in the upper parts of the veins, where primary iron sulfides were oxidized. Galena and high silver concentrations were found locally. Most of the gold was produced before 1913, and the mines have been virtually inactive since about 1934.

On the north side of the Raft River Mountains, several prospects have been opened along the lower reaches of Wildcat Creek, Johnson Creek, and Charleston Creek. The mineralized materials are quartz veins and lenses as well as associated schist and quartzite. The ore minerals appear to be galena and iron sulfides, and values are said to be mainly in silver and locally in gold. Production is unknown but probably small.

Quartzite.—Unusually handsome and durable flagstone has been quarried from the quartzite of Clarks Basin at a number of places. The Elba Quartzite and the quartzite of Yost have also been worked for flags and ornamental broken stone, and the metamorphosed Eureka(?) Quartzite has been quarried for ornamental aggregate. It would appear from the map that flagstone could be quarried at countless localities; however, the rocks are commonly too folded or fractured to be of value.

ACKNOWLEDGMENTS

Although I have mapped the entire area, the Stanford summer field class of 1965 mapped about half of it and worked out many of the structural and stratigraphic problems. Max Crittenden, Ralph Roberts, and Lowell Hilpert provided helpful suggestions during the course of the study, and the Forest Service, the Bureau of Land Management, and many ranchers helped me in various ways. Bronson Stringham and Richard Armstrong kindly supplied preliminary copies of maps. My son Andrew assisted me during the 1966 season, and Victoria Todd contributed data from studies made south of the area. Clark Blake and Edwin Tooker read the manuscript and suggested many improvements.

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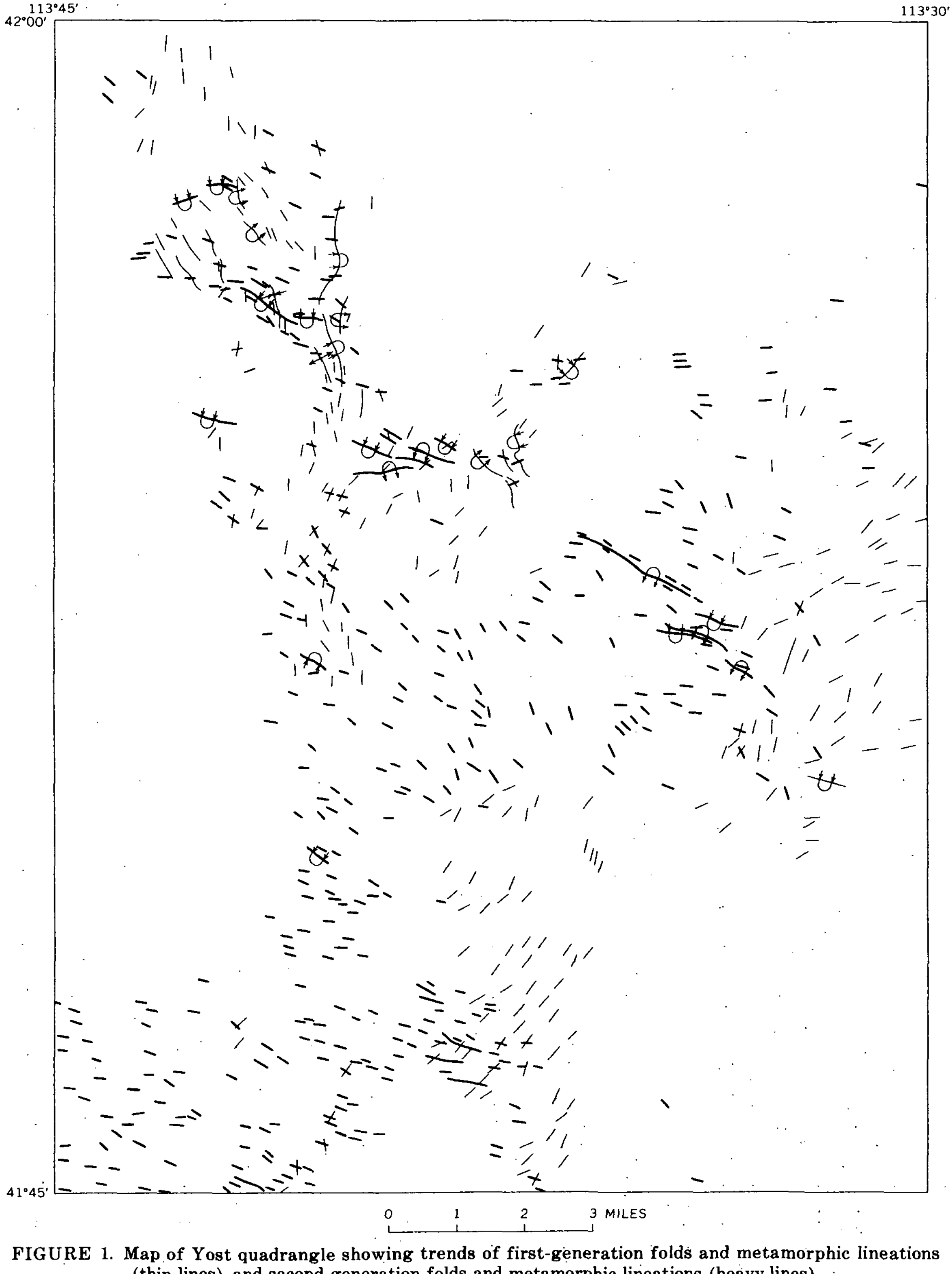

FIGURE 1. Map of Yost quadrangle showing trends of first-generation folds and metamorphic lineations (thin lines), and second-generation folds and metamorphic lineations (heavy lines).

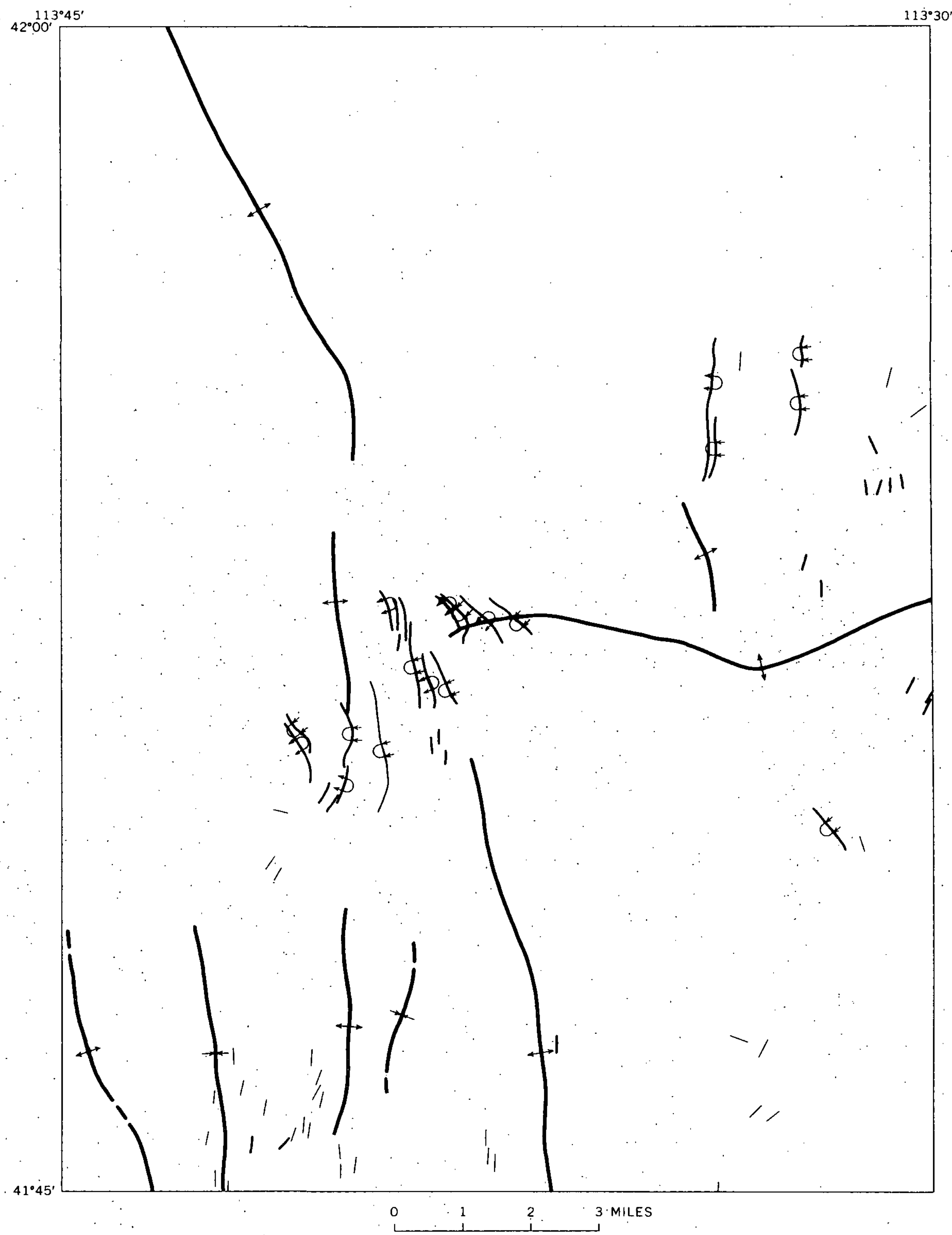

FIGURE 2. Map of Yost quadrangle showing trends of folds in Oquirrh(?) Formation (medium lines), third-generation folds in rocks older than the Oquirrh(?) Formation (thin lines), and late tertiary folds (heavy lines).

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TO ACCOMPANY MAP I-873

GEOLOGIC MAP OF THE PARK VALLEY QUADRANGLE, BOX ELDER COUNTY, UTAH, AND CASSIA COUNTY, IDAHO

By Robert R. Compton

DESCRIPTION OF MAP UNITS

With the exception of the Tertiary and Quaternary formations, the rocks of Park Valley quadrangle are so complexly deformed and so metamorphosed that they must be described in order to make the map truly useful. As the structure sections show, many of the rock units are cut by thrust faults that generally emplaced younger formations over older ones, so that the rudely layered makeup of the Raft River Mountains is generally in stratigraphic order. Nonetheless, many formations generally found in the region are missing and all those present have been thinned, drastically in some places. It is especially interesting that much of the metamorphism and deformation are of a kind normally associated with the Precambrian of the region yet here apparently are of Tertiary age, ending in the Miocene.

QUATERNARY ROCKS

Modern alluvium. — Deposits of present-day streams were mapped along One-Mile Creek and George Creek, both of which have cut small flood plains floored by silty sand and gravel. All other streams are entrenched in channel-flood-plain systems that are too narrow to map at the scale used.

Landslide deposits. — The nine mapped landslides are mainly on the high, steep slopes of the main ridge, especially on its north side. All are eroded to some degree, but most retain the hummocky character of recently active slides. Where exposed by streams they can be seen to be unsorted mixtures of soil and rock, the latter mostly Elba Quartzite.

Older alluvium and other deposits. — Grouped into this category are the following kinds of deposits, presented in order of decreasing abundance: (1) Extensive alluvial gravels and pebbly sands and silts that floor most valleys and form a dissected apron around the range, (2) lacustrine gravels, sands, and clayey silts deposited in the southern part of the quadrangle during high stands of Lake Bonneville, (3) colluvium — hiding large areas of bedrock in the higher parts of the range and grading to the alluvial apron around its borders, and (4) glacial moraines below the cirque containing Bull Lake and in the middle part of Rosavere Fork. These various deposits are not shown separately because they are too mixed and intergradational to be mapped accurately in the time that was available. Possibly, most of the deposits mapped in the high valleys on the north side of the range are till and colluvium.

Some parts of the deposits are forming presently, for example the colluvium and the upper parts of the alluvial apron. Most, however, have developed a soil and are entrenched by streams to depths of 10–40 feet. The older alluvium downslope from carbonate units along the south flank of the range is cemented heavily by calcium carbonate (caliche) to depths of more than 20 feet. There are also three parts of the alluvial gravel deposits that are more deeply eroded and older than other parts: (1) the low hills of dissected gravels near the northeast corner of the quadrangle, (2) gravel benches 1 mile southeast of Standrod that lie about 200 feet above the alluvial apron, and (3) high-lying gravels near the northwest border of the quadrangle (these are more extensive in the adjoining parts of the Yost quadrangle).

TERTIARY ROCKS

Dacite. — Gray glassy dacite with phenocrysts of andesine, ferropigeonite, and ferroaugite forms flows and possibly a small intrusion east of Standrod. The unit lies mainly on Oquirrh Formation but partly on poorly exposed Tertiary sedimentary rocks, suggesting that valleys were eroded to various depths in the Tertiary sequence before the dacite was erupted. A near-vertical contact with Tertiary sedimentary rocks at the east end of the exposures suggests part of an intrusive feeder. Younger Tertiary sedimentary rocks may well lie on the dacite, but that relationship is not exposed in the quadrangle. The rock is similar to welded dacite tuff in the Yost quadrangle (Compton, 1972) and to rocks in the Albion Range dated at 8.5–9 m.y. old by Armstrong (1970).

Mudstone, sandstone, and conglomerate. — Tertiary sedimentary rocks probably lie along the entire north and south edges of the Raft River Mountains but are eroded so easily as to be exposed only here and there. The sequence is at least several thousand feet thick and tends to be conglomeratic near its base and mainly finer grained at higher levels. Laminated tan limestone and dolomite are present locally.

The detritus in the conglomerate is almost entirely of the Oquirrh Formation or of lithologically similar sandstone and limestone. In the northwestern part of the quadrangle the basal deposits are poorly sorted breccia that is rudely bedded but otherwise difficult to distinguish from tectonically brecciated Oquirrh Formation. Higher in the sequence, silicic ash appears to be abundant in many of the sandy and silty rocks, some of which are quite friable and have a silvery aspect while others, especially the finest, are tough, recrystallized, and tinted pale green or yellow. The large outcrops in the southern part of the quadrangle are mainly sandy tuffaceous mudstone.

The amounts and stratigraphic positions of the textural types change rapidly along strike. Four miles northeast of Park Valley, thin beds of conglomerate and sandstone lie on the Oquirrh Formation but are overlain in a few tens of feet by mudstone and thinly laminated limestone beds. A few miles to the east, massive breccia and conglomerate dominate the lower thousand feet of the sequence. The deposits must have formed on steep alluvial fans that graded out to plains and lake-filled basins. No ages have been determined in the quadrangle but the rocks are like others nearby dated paleontologically as late Miocene (J. R. Firby, written comm., 1973).

Diabase. — Three small patches of coarse diabase lie under the lowest thrust sheet near the top of the range at the head of the South Fork of Indian Creek. Simple ophitic texture and largely unaltered pyroxene and plagioclase indicate the intrusions are postmetamorphic and probably Miocene. Diabase float 1½ miles south-southeast of VABM Indian must have come from another unmapped intrusive body that would lie well below the thrust. This suggests that the three mapped bodies were intruded in or near their present position rather than being emplaced tectonically from some distant locality.

Minette. — An irregular lamprophyre dike as much as 3 feet thick cuts the schist member of the Elba Quartzite on the northwest flank of the range, 1½ miles due south of Onemile Guard Station. It is so dark and fine grained that only its abundant biotite grains can be seen with a hand lens. The freshness and euhedral shapes of the biotite, seen under the microscope, indicate that the rock is post-metamorphic and therefore probably Miocene.

PENNSYLVANIAN ROCKS

Oquirrh Formation. — Sandstone and limestone locally metamorphosed to marble form relics of a thrust sheet that must once have extended over the entire quadrangle or most of it. These rocks, questionably assigned to the Oquirrh Formation in the adjacent Yost quadrangle (Compton, 1972), are here unequivocally assigned to the Oquirrh Formation on the basis of lithology and fossils. The unit is too deformed to measure but is at least 1,000 feet thick in the thickest of the eroded remnants. The lower part of the unit is chiefly dark-gray sandy limestone with interbeds, some very irregular, of brown-weathering sandstone and cherty siltstone. The upper part of the unit is chiefly calcareous fine-grained sandstone and lesser amounts of orthoquartzite, both rocks weathering reddish brown. Typical characteristics are the consistently fine grain size of the sand and the fairly abundant layers of coarse crinoid fragments in the limestone. The finer grained limestone commonly contains poorly preserved bryozoans and, locally, fusulinids. A sample with unusually well preserved specimens of *Pseudofusulinella* sp. and *Triticites* sp. suggests a Late Pennsylvanian (Virgilian) age (R. C. Douglass, unpub. data, 1972). The locality is marked at the west edge of the map, 1.8 miles from the north boundary. A Pennsylvanian age is also indicated by fossils collected by Felix (1956).

The rocks along the north side of the range are especially strongly deformed and are partly metamorphosed. A subunit of coarse (1–2 mm) calcitic and dolomitic marble was mapped near the base of the formation in the Bally Mountains, and similar rocks occur more sparsely between Standrod and Clear Creek. Less recrystallized but plastically deformed rocks with strong secondary cleavages form part of the outcrop west of George Creek and also that of the Bally Mountains as far south as Dipping Vat Spring. That these altered rocks are the Oquirrh Formation rather than some older calcareous unit is indicated by their lithology and by Mississippian rocks that lie immediately under them.

MISSISSIPPIAN ROCKS

Metamorphosed Chainman or Diamond Peak Formation. — Dark-gray phyllite, sooty black limestone, and gray sandstone form sheets and lenses as much as 300 feet thick under the Oquirrh Formation. Some may be in normal contact with the Oquirrh, but most are slices, bounded above and below by thrust faults. Similar rocks in the Yost quadrangle were called metamorphosed Manning Canyon(?) Shale (Compton, 1972), but Todd (1973) showed that more complete sections just south of the Yost quadrangle are exactly like the Chainman Shale and Diamond Peak Formation in Nevada. In the Park Valley quadrangle, graphite-chlorite-quartz-white mica phyllite is by far the most abundant rock. Minor patches of sooty soil and float suggest that small amounts of the unit underlie the Oquirrh Formation here and there, even where they were not mapped.

ORDOVICIAN ROCKS

Metamorphosed Fish Haven(?) Dolomite. — This unit everywhere overlies the Eureka(?) Quartzite in a gradational relationship and is overlain by a thrust sheet. As much as 300 feet was mapped in the northwest part of the quadrangle. The most characteristic rock is silver-gray laminated dolomite, but this is overlain by, and locally mixed with, massive, commonly brecciated pale-tan dolomite, parts of which might represent younger formations.

Metamorphosed Eureka Quartzite. — White quartzite as much as 400 feet thick is a widespread and distinctive unit that lies conformably above metamorphosed limestone assigned to the Pogonip Group. It is brecciated in about a third of its outcrop but elsewhere shows distinct tabular beds 1–6 inches thick. These are not separated by mica-schist interbeds but the quartzite itself contains sparse, disseminated white mica. The marked variations in thickness shown by the formation are probably tectonic in origin.

Metamorphosed Pogonip Group. — Marble, schist, and quartzite referred to the Pogonip Group are the most abundant rocks in the relics of a thrust sheet that must once have extended over the whole range. The group is represented by two lithologic facies that were not mapped separately. One of them is like the metamorphosed limestone of the Pogonip(?) Group of the central Yost quadrangle: tan mica-rich marble below and light-gray purer marble above, the latter including a thin member of pale-brown quartzite. This facies makes up the lowest thrust sheet of Bald Knoll, near the east edge of the Park Valley quadrangle. The other facies, a less metamorphosed one, is widespread along the north side of the range. Its marbles are generally gray and laminated, containing fairly abundant crinoid fragments and only small (less than 1 mm) metamorphic micas. As much as half of these marbles are altered to thick layers and irregular patches of pale-tan massive dolomite. The pale-brown quartzite member near the top of the less metamorphosed facies is as thick as 100 feet, and other quartzites and a phyllitic metashale occur elsewhere but cannot be placed stratigraphically. The second facies thus carries more noncarbonate sediments and much more dolomite than the first.

Lenses of marble less than 50 feet thick lie on the lowest thrust fault north of Bald Knoll and in the northwestern part of the quadrangle. These are probably Pogonip limestones that served as ductile zones during thrusting and metamorphic flowage; however, they could be tectonically emplaced marbles of some other unit.

CAMBRIAN(?) ROCKS

The two informally designated formations of questionable Cambrian age were first mapped in the Yost quadrangle (Compton, 1972). They had previously been included by Felix (1956) in his Unit B of the Harrison(?) Series and by Stringham (in Stokes, 1963) in his upper(?) Precambrian Dove Creek Formation. The Cambrian age is suggested by the local interlayering of the upper formation, the schist of Mahogany Peaks, with fossiliferous rocks of the Pogonip Group. It is possible, however, that the interlayering could be caused by tectonic mixing along a premetamorphic thrust, so that the units might be Precambrian. The latter possibility is somewhat strengthened by interlayering between the lower formation, the quartzite of Clarks Basin, and the directly underlying schist of Stevens Spring, which is similar to Precambrian rocks elsewhere (see the section on "Precambrian(?) Rocks").

Schist of Mahogany Peaks. — This unit is represented by some 50–300 feet of dark schists that crop out only along the northwest and southeast flanks of the range. The rock is characterized by its lack of bedding and by its abundance of mica, garnet, and staurolite. It must originally have been an exceptionally aluminous and ferruginous claystone.

Quartzite of Clarks Basin. — The gray to white flaggy quartzites of this unit form parts of thrust sheets along the northwest and southeast flanks of the range. They are typified by abundant white mica, commonly in large (1–3 cm) patches or in thin layers separating the quartzite beds. Kyanite and chloritoid occur in these interlayers here and there. Where complete, the unit is about 400 feet thick and consists of a lower part that is medium gray and rather thick bedded (up to a foot or so) and an upper part that is white and in distinct beds 1–2 inches thick. The lowest strata appear interbedded with the underlying schist of Stevens Spring on the southeast flank of the range, exactly as they are in some parts of the Yost quadrangle.

PRECAMBRIAN(?) ROCKS

Metamorphosed sedimentary and igneous rocks beneath the quartzite of Clarks Basin and above Precambrian rocks dated as 2,200 m.y. old and older constitute an interwedging, genetically related sequence that once extended across the entire quadrangle and at least 30 miles to the southwest, west, and northwest. The lowest and most prominent formation, the Elba Quartzite, was named by Armstrong (1968, p. 1301) for exposures at its type section in the S½ sec. 1, T. 14 S., R. 24 E., west of the town of Elba, Idaho. The other units were considered informally named formations in the text describing the rocks of the Yost quadrangle (Compton, 1972). Previously, Felix (1956) placed these rocks in his Unit B of the Harrison(?) Series, and B. F. Stringham (written commun., 1965) mapped a new unit, the Dove Creek Formation, so as to include the upper three of the formations in the area west and southwest of the Park Valley quadrangle. In using Felix's and Stringham's mapping, Stokes (1963) showed the formations in two different color patterns for the western and eastern parts of the Raft River Mountains.

The ages of the formations remain in question. Crittenden, McKee, and Peterman (1971) determined that similar rocks in the Wasatch Range near Brigham City are older than approximately 1,700 m.y., suggesting that the Raft River Mountains rocks are also that old. The rocks were considered late Precambrian in the Yost quadrangle (Compton, 1972) because the uppermost unit, the schist of Stevens Spring, is interlayered near its top with the quartzite of Clarks Basin, suggesting a stratigraphic gradational contact. The same kind of contact seems to join each of the succeeding formations, up into the fossiliferous Ordovician rocks. Possibly, one or more of the interlayered contacts could represent mixing along premetamorphic thrusts, but this seems unlikely because all the units are in the same order over a large area. For the same reason it is difficult to imagine where a major unconformity could lie in the sequence.

Metamorphosed granite porphyry. — An intrusion of granite porphyry a few tens of feet across is enclosed in the schist of Stevens Spring 1 mile east of Bald Knoll. Microcline phenocrysts, 1–2 mm in diameter, are the only abundant relics of an igneous texture, and besides a few recrystallized plagioclase and biotite phenocrysts, the rest of the rock is a semischistose aggregate of quartz, microcline, sodic oligoclase, white mica, and biotite, all typically 0.1–0.2 mm in diameter. Petrographically, it is almost identical with metamorphosed granite porphyry in the Grouse Creek Mountains, 20 miles to the west (Compton, 1972). Because the granite porphyry in the Yost quadrangle is associated with what appear to have been tuffs, the porphyry is probably only a little younger than the schist of Stevens Spring.

Schist of Stevens Spring. — At the southeast edge of the range, by Bald Knoll, the lowest of three thrust sheets includes as much as 600 feet of this schist unit. Most abundant is graphite-bearing quartz-white mica schist with dark-gray phyllitic lenses ½ inch, or so, across and 1/10 inch thick. The rocks locally contain garnet, chloritoid, and biotite porphyroblasts. A 10-foot layer of dark hornblende schist is included in the unit, and a mapped lens of metamorphosed granite porphyry intrudes it, just as in the Grouse Creek Mountains 20 miles to the west. The formation is thrust over schist of the Upper Narrows, so that the unit that would normally overlie it, the quartzite of Yost, is missing.

Schist of the Upper Narrows. — This unit overlies the Elba Quartzite in much of the quadrangle. The contact is truly sharp in a few places and generally gradational over only 10 feet or so; however, gradations through quartz-rich schists are locally as thick as 100 feet and look exactly like that at the Upper Narrows of the Yost quadrangle. The normally overlying formation, the quartzite of Yost, is not exposed in the Park Valley quadrangle, and the upper part of the schist of the Upper Narrows is also not exposed. The greatest stratigraphic thickness of the formation is about 600 feet; this figure is increased by isoclinal folding like that shown in structure section *D–D′*.

The lower part of the formation, typically biotitic and feldspathic fine-grained gneiss and schist, is mapped as a separate member in this quadrangle. As in the Yost quadrangle, these rocks commonly contain veins and lenses of quartz, potassic granite, and carbonate-bearing syenite that are apparently metamorphic segregations. The member consists of fine-grained gneiss in the western part of the quadrangle and grades eastward to fine-grained cataclastic schist and, near Indian Creek, to mylonite. A 6-foot layer of white quartzite occurs in the dark schist along the southeast flank of the range, and quartz-rich laminations elsewhere show that the member was originally a sandy or silty mudstone, apparently a mafic and feldspathic one.

The upper contact of the lower member is drawn in the middle of a gradation to muscovite-rich schist that make up the greatest part of the formation. The latter schists are medium-gray fine-grained rocks, characterized by many thin lenses of dark-gray phyllite, each about an inch across, that impart a phacoidal cleavage and a shiny aspect. These metaclaystones are 200–400 feet thick and are overlain by about 100 feet of pale-gray muscovite-quartz schist and feldspathic quartzite. These are overlain, in turn, by more gray muscovitic schist with interlayers of chlorite-albite schist, feldspathic quartzite, and carbonate-bearing chloritic schist—rocks that were probably originally mafic and silicic tuffs.

Elba Quartzite. — The Elba Quartzite is well exposed over a large part of the Park Valley quadrangle, and its lithology becomes increasingly variable in the eastern half of the quadrangle. One variant, a fine-grained mica-feldspar-quartz schist, was mapped as a separate member over much of the range. It was originally a thinly laminated siltstone that is now 600 feet thick in the most complete exposures but thins southward and wedges out along a line that crosses the high part of the range somewhat obliquely, with a bearing of N. 75° W. Another feature of the Elba Quartzite that has about the same trend is a remarkably thin segment that lies just north of the large recumbent folds along the south flank of the range (see structure secs. *A–A'*, *B–B'*, and *C–C'*).

The stratigraphy of the formation in the eastern half of the quadrangle is notably different north and south of the thin segment, suggesting two sedimentary basins separated by a higher area. At or near the base of the formation in the northeastern part of the range is 10–50 feet of pebble and cobble conglomerate; the clasts are all of quartzite and some are green. This is overlain by 100–150 feet of white crossbedded quartzite containing white mica, and then by 100–250 feet of tan-weathering feldspathic quartzite that is capped by the schist member already described. One or two brown-weathering gray quartzite layers, a few feet thick, are hematite-bearing and probably variants of hematite-rich schists found on the southeast flank of the range.

The sequence on the southeast flank is as follows: (1) 30–60 feet of white crossbedded quartzite with one or two gray hematitic layers, (2) a few feet of white-mica schist, commonly feldspathic and associated with very feldspathic quartzite and hematite-rich schist, (3) 15–50 feet of white and green quartzite, overlain by another thin layer of white mica and (4) 20–200 feet of tan-weathering feldspathic quartzite, essentially like that on the north flank of the range. The layers of white-mica schist on the south flank swell locally to 100 feet or so and commonly are chloritic; a prominent layer west of Pine Canyon grades to metabasaltic greenschist. Some of the other feldspathic or muscovitic rocks may well be derived from silicic tuffs.

Broadly, however, the formation is metasedimentary, and most of the variants disappear westward as the unit thickens toward the Yost quadrangle. Fine-pebble layers are common, and the relict-rounded zircon grains seen under the microscope are so nearly one size as to indicate that most of the quartzites were originally well sorted 0.5-1 mm sands. The dark-gray cross laminations are concentrations of heavy minerals, chiefly ilmenite and zircon with some tourmaline.

A final variant worth special mention is a white-mica-rich schist that commonly lies below the lowest quartzite or conglomerate layer and always on Precambrian adamellite. Samples with well-preserved textures show that it was an arkosic sand derived from the adamellite and altered greatly during metamorphism. This schist is important because it shows that the base of the Elba Quartzite is an unconformity.

PRECAMBRIAN ROCKS

Metamorphosed adamellite. — Adamellite is exposed in most of the deep canyons in the range and probably extends at depth under most of the quadrangle. It is all metamorphosed, but in the eastern half of the quadrangle it looks almost like a normal igneous rock, its texture there being nearly granular and locally porphyritic. In detail, however, plagioclase is altered to sodic plagioclase and white mica, and biotite has recrystallized into aggregates that give the rock a vaguely gneissose structure. The structure becomes more marked to the west, as does the recrystallization of most of the other minerals. The unit thereby grades into the gneisses and schists that typify metamorphosed adamellite in the Yost quadrangle and the southern Grouse Creek Mountains (Compton, 1972; Todd, 1973). In all parts of this broad area, the foliation becomes more marked upward, whether the upper contact is with older or younger rocks.

Near its east boundary in Clear Creek Canyon, the adamellite grades outward to fine-grained porphyritic rocks that are now white-mica-rich semischists in contact with metagabbro. These zones are probably relict chilled margins, indicating not only an age relationship but also that the original adamellite intrusions in the Clear Creek area were emplaced at a shallow level.

Six samples of adamellite from Clear Creek Canyon gave a whole-rock isochron age of approximately 2,200 m.y. by the Rb-Sr method (Robert Zartman, written commun., 1969). The rocks show some evidence of chemical alteration that may have reduced the age slightly so that the adamellite is probably part of an extensive 2,500-m.y.-old basement present in northwestern Utah and adjacent Idaho (Armstrong and Hills, 1967).

Metamorphosed trondhjemite and pegmatite. — Nearly white silicic rocks consisting almost entirely of sodic plagioclase and quartz form roughly conformable sheets and irregular bodies in the older schist and the metamorphosed basic igneous rocks. Sparse biotite in the trondhjemite was altered to foliated aggregates of chlorite and white mica, and the resulting pale gneiss is laced by pegmatite at every outcrop, the latter rock locally containing K-feldspar. The pegmatite makes up almost all of some outcrops and is itself deformed and altered. Contacts with older rocks are sharp, and large plates of schist included in the white rocks lie parallel to the foliation in the host. The trondhjemite and pegmatite are intruded by small dikes of the Precambrian adamellite in upper Rosavere Fork.

Metamorphosed mafic igneous rocks. — Hornblende schist and schistose to granular amphibolite make up a large proportion of the pre-adamellite rocks in the eastern third of the quadrangle. All appear nearly black from a distance, contrasting with the brown outcrops of older schist and the white ledges of metamorphosed trondhjemite and pegmatite. Some of the hornblende schist bodies are tabular and conformable with bedding in the older schists. Some even grade to mica schist through hornblende-bearing varieties, and these are probably metatuffs. Other bodies have fine schistose or semischistose outer zones and granular interiors, suggesting lava flows or small intrusive masses. Still others are hundreds of feet thick and have textures suggesting recrystallization of coarsely ophitic gabbros and diabases. Besides hornblende, the rocks contain moderate amounts of quartz, epidote, and sodic plagioclase. Those near the contact with the Elba Quartzite are commonly altered to chloritic schist.

Older schist. — Especially well exposed in the Park Valley quadrangle, is a sequence of metasedimentary rocks that occur widely in the Yost quadrangle and the southern Grouse Creek Mountains (Compton, 1972; Todd, 1973). They are definitely older than the Precambrian igneous units. Relict features indicate the rocks were once shale, argillaceous and feldspathic sandstone and siltstone, and pebbly to cobbly mudstone. On the northeast flank of the range, in the vicinity of Rice and Jim canyons, nearly continuous exposures show that 200 feet of semischistose crossbedded metasandstone makes up the lowest part of the sequence, and that this is overlain by about 200 feet of metamorphosed massive mudstone intercalated with pebbly and cobbly mudstone, and then by about 600 feet of metamorphosed mudstones with interbedded laminated siltstone and sandy shale. The metamorphic minerals in all these rocks are typically biotite, muscovite, quartz, oligoclase, and K-feldspar, with hornblende appearing in gradations to mafic metatuffs intercalated with the mica schists. Grain sizes are generally 0.1–0.5 mm.

STRUCTURE

Most of the rock units and thrust faults are arched into the broad anticline that defines the Raft River Mountains. The rocks are also deformed more complexly, both in the autochthon and in each of the rudely stratiform thrust sheets. The lowest thrust fault cuts upward from the schist of Stevens Spring so as to intersect rocks locally as high as the Pogonip Group. Small folds and associated linear features are widespread, many being superimposed by two or more periods of deformation. The thrusts themselves are strongly folded in some places. The map and structure sections show only the largest of these structures clearly and do not generally indicate the sequence of the deformations. The descriptions that follow are therefore organized so as to clarify age relationships, by presenting the youngest features first and proceeding in order to the older, more complicated ones. Because folds and faults are commonly related in origin, they are described in age groups rather than separately.

The broad east-west anticline of the Raft River Mountains is apparently the youngest of the folds. The late Miocene sedimentary and volcanic rocks are affected by it, so that its age must be Pliocene or early Pleistocene. The only tectonic features that might be younger are normal (gravity) faults that cut across it with trends ranging from N. 30° E. to N. 15° W. In addition to the mapped high-angle faults there are countless minor faults and fractures with the same trends, and it is very likely that these fractures formed during the growth of the anticline.

Broad folds that trend roughly north-south are also Pliocene and probably older than the east-west anticline. The ridge of the Bally Mountains and the Tertiary rocks flanking it constitute the main anticline of this age. The trough of a north-south-trending syncline is partly preserved in Tertiary strata just east of the Bally Mountain ridge and in one outcrop next to Onemile Guard Station. Tertiary rocks elsewhere that dip east or west probably also record this folding. A thrust in the extreme northwest corner of the quadrangle probably formed concurrently, for it emplaced the Oquirrh Formation and metamorphosed Chainman or Diamond Peak Formations over the late Miocene beds. The thrust surface dips 30°–40° W. and is completely exposed at the place where the dip of 37° is shown on the map.

Before the late Miocene and Pliocene rocks were deposited, the allochthonous rocks, especially the Oquirrh Formation, were rather strongly folded and rocks of the autochthon were buckled moderately in many places. The thrust faults at the north end of the Bally Mountains were deformed into a northeast-overturned anticline at this time. All of these folds trend between about N. 30° E. and N. 35° W. and tend to be overturned toward the east. Those in the autochthon are open and have wavelengths of 1–30 inches. Many have chevron shapes. Mica flakes, hornblende prisms, and kyanite crystals were crimped rather than recrystallized, but some quartzites flowed plastically, suggesting that the deformation took place in the waning stages of metamorphism and just afterward, most likely during the middle Miocene.

Considerable thrusting must have taken place during this deformation because some thrust sheets show a distinctly greater or lesser degree of metamorphism than the rocks on which they lie. The most metamorphosed parts of the Oquirrh Formation were thrust over the least metamorphosed parts of the underlying thrust sheet in the Bally Mountains. Elsewhere, unmetamorphosed Oquirrh Formation was commonly thrust onto metamorphosed rocks of the lower thrust sheet or the autochthon. At Bald Knoll, near the southeast edge of the range, the lowest thrust sheet is identical in metamorphic and other characteristics with autochthonous rocks in the western part of the Yost quadrangle, suggesting 15–30 miles of eastward transport after metamorphism or during its waning stages. Concordant fission-track ages from sphene and apatite of the Precambrian adamellite indicate that the upper part of the autochthon in Clear Creek Canyon cooled below 400°C no more than 20 m.y. ago (Charles Naeser, written commun., 1972). This means that metamorphism ended no sooner than early Miocene.

The next oldest event, the youngest distinctly metamorphic deformation in Park Valley quadrangle, is represented by a few folds that trend northeast-southwest and are overturned toward the southeast. These are developed in quartzites in which both quartz and white mica recrystallized during the deformation. The folds are all in the autochthon and are of interest because they have the same trends and sense of overturn as widespread late metamorphic folds in the southern Grouse Creek Mountains, 30 miles to the southwest. The age of this deformation is probably early Miocene.

The next older deformation took place during metamorphism and had profound effects on all rocks in the quadrangle older than Tertiary. The east-west-trending recumbent folds along the south flank of the range, shown in all the sturcture sections, formed during that metamorphism. The best evidence for their age comes from petrofabric studies of the Elba Quartzite in the folds: quartz *c*-axis fabrics are coaxial with the folds and are so strong that they could not have been annealed extensively after folding.

Small-scale folds and associated lineations of this episode are widespread, the most abundant being ridges less than 1 mm high on bedding surfaces of quartzite and marble. Folds with amplitudes of a foot or so can be seen here and there, and almost all are overturned toward the north, many of them being recumbent. Schistosity lies parallel to the axial planes of the folds, and pebbles and quartz grains are typically flattened into these planes. Pebbles, quartz grains, micas, hornblende, and kyanite also tend to be elongated parallel to the axes of the folds, especially near fold hinges. The folds and lineations trend close to east-west in most of the quadrangle, becoming less consistent in the deeper parts of the autochthon.

Thrusting apparently took place during the metamorphic folding. The cataclastic schist overlying the Elba Quartzite (the lower member of the schist of the Upper Narrows) is locally crimped and buckled on axes that trend east-west, and local thrusts that strike east-west and dip 30° S. cut the schist near the head of Indian Creek canyon. The widely occurring schist under the mapped thrusts is commonly phyllonitic (recrystallized cataclastic rock), so that metamorphism must have followed part of the thrusting. The asymmetry of the metamorphic folds indicates that this thrusting would have been from south to north.

An earlier period of metamorphic deformation that is clearly recognizable in the Yost quadrangle (Compton, 1972) and central Grouse Creek Mountains (Todd, 1973) was detected locally in the western part of Park Valley quadrangle but not in the eastern part. This may be due to the orientations of the earlier folds and other lineations, which swing from northeast-southwest in the western part of Raft River Mountains to approximately east-west in the central part, so as to be nearly parallel to the younger folds. The two deformations also had nearly the same sense of movement in the central part of Raft River Mountains. However, no refolded recumbent folds were found in the eastern part of the quadrangle, so that deformation and metamorphism may have been continuous through the two episodes recorded farther west.

ECONOMIC DEPOSITS

Several mine adits in Twin Canyon, near the west edge of the quadrangle, are part of the Century Hollow mining district, which lies near the south edge of the range mainly in the Yost quadrangle. The district produced about $500,000 worth of gold but has been inactive since the early 1930's. In Twin Canyon, quartz veins in Precambrian adamellite appear to have contained the gold, but these occurrences add little information to that given in the descriptions of the deposits of the Yost quadrangle (Compton, 1972).

Green Elba Quartzite is quarried for ornamental building stone near the south edge of the range in the canyons of Indian Creek and Fisher Creek.

Acknowledgments. — I am greatful to many ranchers for their hospitality and help, and to the U.S. Forest Service for providing campsites for Stanford field classes in 1967 and 1969. Students and instructors in those classes helped greatly in the overall geologic study, and visits by Max Crittenden, Lowell Hilpert, Robert Zartman, and Richard Armstrong were also most helpful. Rb-Sr studies by Robert Zartman and fission-track studies by Charles Naeser were essential to dating the rocks and the metamorphism. Philip Blacet and Roger Hope kindly read and criticized the original typescript.

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BOX ELDER

UGMS + DOG+M

1 ● 48.3°C/km

2 ◉

3 ○

4 △

5 △

Metric

Sec	T	R	d (meters)	°C	°C/km	Amb
17	8N	7W	1067	61.1	48	9.4

Total all wells : 5

Total anomalous : 1

DIV OIL, GAS & MINING
(ABANDONED WELLS)

BOX ELDER CO.

	Well No	Sec	T	R	Depth	°F	GRAD
1964	49 1 *	17 NE NW NE	8N	7W	3500	142	✓✓✓ ~~2~~ (49° 26.5)
1963	50 2	18 SE	11N	5W	8966	166	✓
1956	49 3	6	14N	9W	7568	186	✓ 18.6

*also in UGMS

VERY INCOMPLETE

above wells are

1. Gulf Oil — State Rozel #1
2. Gulf — Adams Fee #1
3. Utah Southern — Federal #2

NOTE: Lots of wells in 8N-7E — Rozel Point

FROM UGMS

	Sec	T	R	Depth	°F		
49 (4)	14	6N	16W	2890	95	✓	△
49 (5)	17 SW SW NE	10N	7W	2854	80	✓	△
				6303	108		

For Scott Holmgren

This is the gradient Hole that is talked about in the attached pages from Utah Geological + Min Survey - It started a 66°F @ Dec. 1978 at 350 GPM - It now is 101°F and still flows around 350 GPM.

WASATCH FRONT

13 UDY WELL-1

ELEMENT		CONCENTRATION (PPM)
NA Sodium		2041
K Potassium		92
CA Calcium		185
MG Magnesium		52
FE Fe		0.09
AL Aluminum	<	0.625
SI Silicon		25
TI Titanium	<	0.125
P Phosphorus		0.9
SR Strontium		5.20
BA Barium		0.7
V Vanadium	<	1.25
CR Cromium	<	0.050
MN Manganese	<	0.250
CO Cobalt		0.03
NI Nickel	<	0.125
CU Copper	<	0.063
MO Molybdenum	<	1.25
PB Lead	<	0.250
ZN Zinc	<	0.125
CD Cadmium	<	0.063
AG Silver	<	0.050
AU Gold		0.11
AS Arsenic	<	0.625
SB Antimony	<	0.750
BI Bismuth	<	2.50
U Uranium	<	6.25
TE Tellurium	<	1.25
SN Tin	<	0.125
W Tungsten	<	0.125
LI Lithium		0.94
BE Beryllium	<	0.005
B Boron		0.8
ZR Zirconium	<	0.125
LA Lanthanum	<	0.125
CE Cerium	<	0.250
TH Thorium	<	2.50
TDS - Total Dissolved Solids		6420
SO_4 Sulfur Dioxide?		72
Cl Clorine		3540
F Florine		1.0

Field Measurements

Temp. 36°C = 96.8

pH 6.81

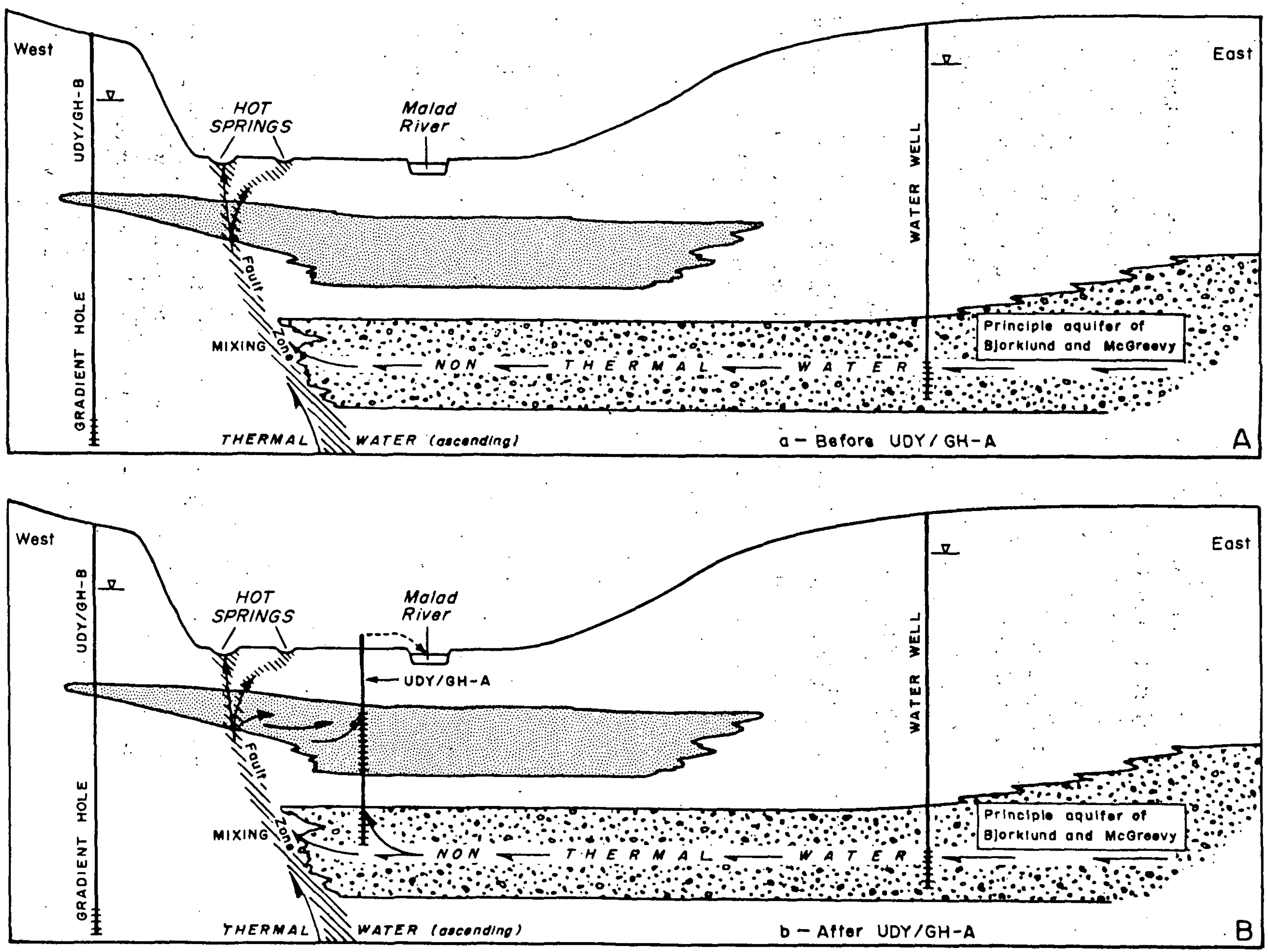
Alkalinity 20 grains/gallon

Sulfate 78 mg/l

Salinity 6.8 ‰

Conductivity 150 @ 100x

UNIVERSITY OF UTAH
RESEARCH INSTITUTE
EARTH SCIENCE LAB.



A model of hydrologic relationships at Udy Hot Springs, Box Elder County, Utah

Figure 12

Prior to any drilling activities by UGMS the condition presented in figure 12 a prevailed. Water from the principle aquifer mixed with the thermal waters and the resulting water mixture rose to the surface through weaknesses in the clay. Although some thermal water might have entered the overlying sand wedge, the wedge was essentially sealed by the clay and the thermal water could not displace the water already present in the sand lens.

When UDY/GH-A was drilled, the hydrologic conditions were slightly altered (figure 12 b). Non thermal water from the principle aquifer immediately flowed from the bottom of the hole in large volumes. At the same time, the head in the sandy body was lowered allowing thermal water to flow in the direction of the hole through the sand body. The increasing temperature and conductivity of the water flowing from the hole is an indication that component of thermal water reaching the hole through the sand has increased with time. The component of thermal water mixing with the principle aquifer water in the hole should reach a maximum that is dependent upon the permeability of the sand body.

One very important implication of this model is that the maximum temperature of the geothermal system might be significantly higher than any of the measured temperatures. Although to date there has been no direct indication of much higher temperatures in the near surface, if mixing is indeed occurring, higher temperatures should be anticipated below the zone of mixing.

LITTLE MOUNTAIN–SOUTH GEOTHERMAL AREA

Description

The Little Mountain geothermal area is about 24 km (15 miles) west of Ogden on the eastern shore of the Great Salt Lake. Bear River Bay flows into the Great Salt Lake immediately west of the area. Little Mountain is a triangular shaped exposure of Precambrian rock that strikes north-south. Elevations are greatest at the southern end of the mountain and decrease northward until only a few low lying outcrops are visible at the surface. The mountain is surrounded by valley fill that extends for miles in all directions. West of the mountain the valley fill is covered by solar evaporating ponds and the Great Salt Lake.

The solar evaporating ponds (figure 13) are part of the Great Salt Lake Mineral Corporation's (GSLM) salt processing plant. Buildings for the GSLM plant are located on the northeastern flank of Little Mountain. Other developments in the area include a newly constructed American Zirconium plant, and a Hill Air Force Base facility, both at the southern end of the mountain.

About 200 GPM

WASATCH FRONT

18 UDY-6 *Morning Glory Pool*

ELEMENT		CONCENTRATION (PPM)
NA		3203
K		134
CA		202
MG		62
FE		0.04
AL	<	0.625
SI		11
TI	<	0.125
P		0.9
SR		6.50
BA		0.9
V	<	1.25
CR	<	0.050
MN	<	0.250
CO		0.03
NI	<	0.125
CU	<	0.063
MO	<	1.25
PB		0.3
ZN	<	0.125
CD	<	0.063
AG	<	0.050
AU	<	0.100
AS	<	0.625
SB	<	0.750
BI	<	2.50
U	<	6.25
TE	<	1.25
SN	<	0.125
W	<	0.125
LI		1.33
BE	<	0.005
B		1.3
ZR	<	0.125
LA	<	0.125
CE	<	0.250
TH	<	2.50
TDS		*9185*
SO_4		*91*
Cl		*5250*
F		*1.2*

Field Measurement

Temp. 50°C + ~100°

pH 7.60

Alkalinity 19 grains/ga[illegible]

Sulfate 99 mg/l

Salinity 9.6 ‰

Conductivity 229 @ 100x

About 900 GPM

WASATCH FRONT

14 UDY LAKE-2 Main Lake by Swimming Pool

ELEMENT		CONCENTRATION (PPM)
NA		2856
K		96
CA		181
MG		45
FE		0.05
AL	<	0.625
SI		11
TI	<	0.125
P	<	0.625
SR		5.88
BA	<	0.625
V	<	1.25
CR		0.06
MN	<	0.250
CO	<	0.025
NI	<	0.125
CU	<	0.063
MO	<	1.25
PB	<	0.250
ZN	<	0.125
CD	<	0.063
AG	<	0.050
AU		0.17
AS	<	0.625
SB	<	0.750
BI	<	2.50
U	<	6.25
TE	<	1.25
SN	<	0.125
W	<	0.125
LI		1.09
BE	<	0.005
B		0.9
ZR	<	0.125
LA	<	0.125
CE	<	0.250
TH	<	2.50
TDS		7940
SO_4		83
Cl		4510
F		1.2

Field Measurements

Temp. 37°C = 98.6

pH 7.51

Alkalinity 20 grains/gallon

Sulfate 105 mg/l

Salinity 7.6 ‰

Conductivity 185 @ 100x

Two other Springs not included flow about 1200 GPM