GEOLOGIC MAP OF THE JARVIS PEAK QUADRANGLE WASHINGTON COUNTY, UTAH

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ABSTRACT

The Jarvis Peak Quadrangle in southwesternmost Utah encompasses the southern portion of the Beaver Dam Mountains and lies within the transition zone between the Colorado Plateau and Basin and Range physiographic provinces. The Beaver Dam Mountain uplift is a northwest-trending, doubly-plunging anticline bounded on the east by the Shivwits syncline. These major folds were developed during the late Mesozoic-early Cenozoic Sevier-Laramide orogeny and are truncated on the east by the Grand Wash-Reef Reservoir-Gunlock fault zone. The Grand Wash fault is a major normal fault that extends southward from the quadrangle to the Grand Canyon. Late Cenozoic (late Miocene to Quaternary) extension also caused gravity sliding and attenuation faulting along both sides of the range. The stratigraphic section exposed in the quadrangle ranges in age from Precambrian to Triassic and totals approximately 14,000 feet. The Silurian and Ordovician are the only periods not represented. Surficial units include Quaternary-Tertiary and Quaternary alluvial gravels, pediments, talus, colluvium and landslide materials. Commodities mined from or occcurring in the quadrangle include lead, zinc, silver, copper, gallium, germanium, gypsum and sand and gravel.

INTRODUCTION

The Jarvis Peak Quadrangle is located approximately 8 miles west of St. George in Washington County, Utah. It lies within the transition zone between the Colorado Plateau and Basin and Range physiographic provinces and is situated along the eastern margin of the Beaver Dam Mountains, a major northwest-trending anticline, and the western margin of the St. George Basin.

Strata ranging in age from Precambrian to Triassic are exposed in the quadranlge. The strata have been subjected to late Mesozoic-early Cenozoic compressional deformation and late Miocene to Quaternary extension. Structures in the quadrangle include major folds, reverse faults, thrust faults, normal faults, grabens and attenuation faults. Surficial units include Quaternary-Tertiary and Quaternary alluvial gravels, pediments, talus, colluvium and landslide materials.

The first geological survey of southwestern Utah was led by J.W. Powell (1875). Dobbin described the structures in the St. George area in 1939. Reber (1951) mapped the northern part of the quadrangle as a part of his graduate thesis. Cook published a geologic map of Washington County in 1960. Lovejoy (1976) studied faulting along the east side of the Beaver Dam Mountains. Hintze (1985, 1986) first mapped the Jarvis Peak area in detail. Adjacent and nearby areas have been mapped by Hintze (1985, 1986), Steed (1980) and Moore (1972).

STRATIGRAPHY

Rocks ranging in age from Precambrian to Triassic are exposed in the Jarvis Peak Quadrangle. The Silurian and Ordovician are the only periods not represented in the Beaver Dam Mountains. The sedimentary section totals approximately 14,000 feet. Some of the reported thicknesses of the formations have been inferred from measured sections in adjacent quadrangles because of attenuation and faulting within the Jarvis Peak quadrangle. The stratigraphic nomenclature used in this paper is that of Hintze (1986).

Precambrian Eonothem

Precambrian (pC) rocks, which are exposed in the western part of the Jarvis Peak Quadrangle, consist of interrelated gneiss, schist and pegmatite. Dark gray dioritic gneiss is the most resistant and abundant rock type, and it consists mostly of amphibole with lesser feldspar, quartz and pyroxene. The schist contains principally either mica or amphibole with lesser feldspar, quartz, garnet and sillimanite (Reber, 1951). Granitic pegmatites are common and intrude both the gneiss and schist. The Precambrian rocks form the core of the Beaver Dam Mountains and can be correlated with the Vishnu and Brahma schists of the Grand Canyon, which are Middle Proterozoic (King, 1976). Olmore (1971) reports a 1.7 billion-year K-Ar date on pegmatite in similar Precambrian rocks 15 miles to the southwest in the East Mormon Mountains of Nevada. An unconformity separates the Precambrian rocks from the overlying Cambrian strata.

Cambrian System

Tapeats Quartzite (Ct)

The Tapeats Quartzite consists of orange to dark reddish-orange quartzite and sandstone with some pebble conglomerate layers. It is a ledge former and is approximately 1,300 feet thick. The upper contact with the Bright Angel Shale is gradational. A complete, undisturbed section of the Tapeats Quartzite is found only along the extreme north edge of the quadrangle.

Bright Angel Shale (Cba)

The Bright Angel Shale consists of olive green micaceous shale, siltstone, sandstone and quartzite. It is nonresistant and forms strike valleys. It is often thinned or absent in the quadrangle due to attenuation faulting. Hintze (1985) measured 260 feet of Bright Angel Shale just north of the quadrangle. It is probably late Early Cambrian or early Middle Cambrian based on fossils found in the Grand Canyon area and in eastern Nevada. No fossils have been found in this formation in the Beaver Dam Mountains (Hintze, 1986).

Bonanza King Formation (Cbk)

The Bonanza King Formation is a medium- to light-brownish-gray, fine- to medium-grained dolomite, which is mostly medium-bedded. Some beds consist of light-gray, very-fine-grained boundstone. The Bonanza King Formation has a characteristic appearance of contrasting light and dark beds. Some beds contain irregular tubular structures or trace fossils. The formation is exposed along the western edge of the quadrangle, but is extensively brecciated and/or faulted. Hintze (1985) measured a thickness of 2,600 feet several miles to the north near Horse Canyon. Wernicke

(1982) mapped this formation in detail in the Mormon Mountains 30 miles west of the quadrangle.

Nopah Dolomite (Cn)

The Nopah Dolomite consists of fine- to coarse-grained, thick-bedded, light-gray to brownish-gray dolomite. It is more resistant than the Bonanza King Formation and forms steep slopes. The Nopah Dolomite contains algal stromatolites and small tubular trace fossils. This formation is also extensively brecciated and faulted in the Jarvis Peak Quadrangle. The Nopah Dolomite lies beneath a regional Ordovician-Silurian-Early Devonian unconformity and is 1,380 feet thick several miles north of the quadrangle (Hintze, 1985).

Devonian System

Muddy Peak Dolomite (Dm)

Slope member (Dms) - The slope member of the Muddy Peak Dolomite is a fine- to medium-grained, light- to medium-olive-gray, silty dolomite. It is medium-bedded and contains silicified stromatoporoidal structures. A few thin beds in the upper part contain pelletoidal structures and some biohermal mounds of crinoid, gastropod and brachiopod fragments (Hintze, 1985). This member forms a ledgy slope between more resistant units.

Pinnacle member (Dmp) - The pinnacle member consists of medium- to coarse-grained, light-gray, massive, crystalline dolomite, which contains abundant chert nodules. This member is extensively silicified in exposures north of U.S. Highway 91.

The informal members of the Late Devonian Muddy Peak Dolomite were differentiated on the map only where exposure and structure permitted. The formation is between 500 and 700 feet thick where it has not been attenuated.

Mississippian System

Redwall Limestone (Mr)

The Redwall Limestone is an abundantly fossiliferous, medium- to dark-gray, massive, crystalline limestone. The lower part is very cherty. Some of the beds are bioclastic and contain numerous crinoid fragments, sponges and corals. This formation was not differentiated into the members as divided by McKee and Gutschick (1969) because there are only small differences in resistance and color between the members in the quadrangle. The Redwall Limestone is resistant and forms impressive cliffs. Steed (1980) measured 600 feet of Redwall Limestone south of the quadrangle in the Virgin Gorge.

Pennsylvanian System

Callville Limestone (Pc)

The Callville Limestone is a fossiliferous, fine- to medium-grained, light- to medium-gray limestone. It is thick-bedded and contains some chert nodules. The Callville Limestone is interbedded with fine-grained sandstone toward the top and is fossiliferous, containing corals, brachiopods and bryozoans. It weathers to form ledgy slopes that resemble steps and is 1,520 feet thick in the quadrangle (Hintze, 1986).

Permian System

Pakoon Dolomite (Pp)

The Pakoon Dolomite consists of a light-gray, medium- to thick-bedded, fine-grained dolomite with some chert nodules. The formation represents cyclic deposition, but rarely contains fossils. Near Bulldog Pass the formation contains gypsum and minor sandstone beds in its upper part. The Pakoon Dolomite is between 650 and 820 feet thick (Hintze, 1985).

Queantoweap Sandstone (Pq)

The Queantoweap Sandstone is a light-orange to grayish-pink, fine- to medium-grained, crossbedded sandstone. It is usually cemented with calcite. It is well exposed in the Jarvis Peak Quadrangle and is between 1200 and 1500 feet thick. The Queantoweap Sandstone can be correlated with the Esplanade Sandstone of the Supai Group in the Grand Canyon (Nielson, 1986).

Toroweap Formation (Pt)

The nomenclature used is that defined by Nielson (1981, 1986), Sorauf (1962) and Rawson and Turner-Peterson (1979). The Toroweap Formation contains three members representing a marine transgression separated by two recessions.

Seligman Member (Pts) - The Seligman Member contains gypsiferous siltstone, with minor white gypsum and light-olive-gray, fine-grained sandstone. It generally forms a covered slope and is often attenuated in the southern portion of the quadrangle. Nielson (1981) measured an average thickness of 80 feet for this member.

Brady Canyon Member (Ptb) - The Brady Canyon Member consists of fossiliferous, light-gray, fine- to medium-grained, massive limestone. It contains reddish-orange chert nodules. Brachiopod, gastropod, coral, crinoid, and sponge fragments are common. The Brady Canyon Member resembles the Fossil Mountain Member of the Kaibab Formation and forms prominent cliffs. It is approximately 250 feet thick (Nielson, 1981).

Woods Ranch Member (Ptw) - The Woods Ranch Member contains grayish-orange to yellowish-orange gypsiferous siltstone, with thin interbeds of white gypsum and light-gray, fine-grained dolomite. This member is recessive and generally forms a slope beneath the massive cliff of the Fossil Mountain Member. Dolomite beds near the top of the member are mappable as low white ledges on aerial photographs. Nielson (1981) measured five sections of this member in the quadrangle. It ranges from 130 to 230 feet thick.

Kaibab Formation (Pk)

Nomenclature and subdivisions are that of Nielson (1981 and 1986), Reeside and Bassler (1922) and Sorauf (1962). Detailed measured sections of the Kaibab Formation in this area are found in Nielson (1981, 1986) and Jenson (1986).

Fossil Mountain Member (Pkf) - The Fossil Mountain Member of the Kaibab Formation is an abundantly fossiliferous, yellowish-gray, fine- to medium-grained limestone. The silicified fossils include brachiopods, crinoids, bryozoans and corals. This member forms a prominent cliff in the quadrangle between the less resistant gypsiferous units above and below and generally forms a cap rock or dipslope. It is 250 feet thick (Nielson, 1981).

Harrisburg Member (Pkh) - The Harrisburg Member consists of interbedded laminated gypsum, fossiliferous limestone, silty gypsum, and thin-bedded dolomite. Chert occurs as reddish-brown nodules in the limestone and dolomite. The gypsum is light gray and is usually recessive creating rounded hills. Large solution collapse features are common. Gypsum prospecting has occurred within the Harrisburg Member in Blake's Lambing Grounds on the east side of the quadrangle and in the area north of Mine Valley. The thickness of the Harrisburg Member ranges from 0 to 350 feet.

Considerable relief developed on the Harrisburg Member after its deposition during the time interval represented by a significant unconformity. The unconformity is expressed as an erosional surface with paleochannels and hills, which were later buried by the Triassic Moenkopi Formation. The unconformity covers more than 78,700 square miles (McKee, 1954) and represents a break in the geologic record between the Permian Leonardian stage and the middle stage of the Lower Triassic (Hamblin, 1970a).

The Seligman, Woods Ranch and Harrisburg Members are slope-forming members and are often attenuated along faults. The gypsum is easily dissolved and slumping is common on steep slopes.

Triassic System

Moenkopi Formation (TRm)

The Moenkopi Formation has been mapped following the subdivisions of Stewart and others (1972b). Where members could not be differentiated in the Mine Valley area due to extensive faulting, the formation was mapped simply as the Moenkopi Formation.

Rock Canyon Conglomerate Member (TRmr) - The Rock Canyon Conglomerate Member contains angular to subangular limestone and chert clasts derived principally from the Permian Kaibab Formation. It consists of light-brown to yellowish-gray conglomeratic siltstone, sandstone and limestone. The Rock Canyon Conglomerate rests directly on the Fossil Mountain Member wherever it is exposed. As it is a channel-fill deposit, it ranges from 0 to 50 feet thick (Hintze, 1986).

Conglomerate-filled channels and karst topography are extensively developed at the top of the Kaibab Formation. In places these channels cut down into the Fossil Mountain Member. Reeside and Bassler (1922) proposed the name, Rock Canyon Member of the Moenkopi Formation, for the channel-filling conglomerates. Other workers, Gregory (1950) and Gregory and Williams (1947), recommend abandoning the Rock Canyon Conglomerate and suggest the conglomerates are of Permian age. Nielson (1986, p. 48) proposes that the Rock Canyon Conglomerate be removed from the Moenkopi Formation and elevated to formation status because "the Rock Canyon Conglomerate is a conglomerate and breccia that is associated with the erosion that occurred during the late Permian and early Triassic. It is not associated with the marine deposition that produced either the Kaibab or Moenkopi Formations."

The lower red member (TRml) - The lower red member of the Moenkopi Formation is discontinuous in the quadrangle as it was deposited in valleys developed during the erosional period represented by the unconformity. It consists of interbedded reddish-brown shale, mudstone and siltstone with both bedded and secondary gypsum and minor beds of dolomite. Small-scale crossbeds and ripple marks are common. The lower red member ranges from 0 to 250 feet thick and forms slopes with minor ledges.

Virgin Limestone Member (TRmv) - The Virgin Limestone Member consists of yellowish-brown to olive-green, slope-forming shale and mudstone, with lesser light yellowish-gray, oolitic limestone ledges. Shale and mudstone make up approximately 70% of this member. There are 3 to 4 fossiliferous limestone ledges, which contain brachiopods, pentacrinoids, gastropods, pelecypods and ostracodes. The limestones also contain stromatolites, pelloids, ooids, intraclasts and minor chert nodules. A complete (240-foot) section is exposed in the quadrangle. The basal limestone ledge of the Virgin Limestone Member was affected by the unconformity in localized areas as it pinches out against a paleohill of the Harrisburg Member near Laub Reservoir.

Middle red member (TRmm) - The middle red member consists of interbedded reddish-brown mudstone and siltstone, with thin beds of gypsum and dolomite. Gypsum makes up about 20 percent of the member (Hintze, 1986). This member is unfossiliferous. It is well exposed in the northeast corner of the quadrangle where it is 340 feet thick.

Shnabkaib Member (TRms) - The Shnabkaib Member consists of banded white and red gypsiferous mudstone and siltstone with lesser light-gray dolomite and pale yellow limestone. The limestone ledges are generally thinly bedded and contain chert nodules, oolites, clay clasts and algal structures. Fossils in the limestone beds include gastropods, crinoids, and echinoderms. Several limy, crossbedded yellow-gray sandstone beds occur in the basal part. The gypsum and dolomite beds are usually laminated and are more common near the top of the member. A thick, undisturbed section (800 feet) was measured in the adjacent quadrangle to the north.

Upper red member (TRmu) - The upper red member consists mainly of reddish-brown, thin-bedded siltstone. A massive, pale reddish-orange sandstone ledge occurs near the top. Thin gypsum beds are present, but make up less than 1% of the member. Ripple marks are common in the siltstone. The upper red member is not well exposed in the Jarvis Peak Quadrangle as it occurs only in a narrow, faulted zone beneath and to the east of the Reef Reservoir fault. The upper red member is 500 feet thick in a section measured by the author several miles to the north.

Chinle Formation (TRc)

The Chinle Formation consists of resistant stream channel conglomerate and sandstone and variegated mudstone, siltstone, and sandstone. Fossil wood is common. This formation is usually divided into two members, the Petrified Forest Member and the Shinarump Conglomerate (Stewart and others, 1972a), but this was not possible in the Jarvis Peak Quadrangle because it is exposed only in a narrow, faulted band on the east side of the Reef Reservoir fault and at its thickest is only 80 feet. The Chinle Formation was measured to be 1,000 feet thick just north of the quadrangle (Hintze, 1986). The Shinarump Conglomerate Member of the Chinle Formation is made up of stream channel deposits. It is very resistant and usually forms mesa caprocks and cuesta dipslopes. The Petrified Forest Member is made up of variegated mudstone, siltstone and sandstone. It is prone to slumping due to bentonitic clays derived from volcanic ash.

Quaternary-Tertiary Systems (Pleistocene-Pliocene?)

Limestone and Chert Breccia (QTbr)

A limestone and chert breccia, which appears to be derived from the Fossil Mountain Member of the Kaibab Formation, is found along the southernmost exposures of the Reef Reservoir fault in Mine Valley. This breccia is very resistant and forms small mounds marking the location of the fault.

Landslide Materials (QTms)

Landslide materials consist of mostly coherent slumped bedrock masses. Detached blocks of the Fossil Mountain Member and the Brady Canyon Member have moved downslope over the gypsum units along the east side of the Grand Wash fault scarp in Cedar Pockets Wash. Several of these blocks crossed the Grand Wash fault as they slid to the west. A large coherent block of Redwall Limestone has moved downslope on the west side of the Beaver Dam Mountains. These masses vary in size. The source formation is identified in parenthesis below the QTms symbol.

High-level Alluvial Gravels (QTag)

High-level alluvium consists of consolidated, coarse pediment gravels. These gravels are a common caprock in the Jarvis Peak quadrangle and form extensive surfaces that generally slope towards Beaver Dam Wash, which is to the west. Deposits consist of silt, sand, gravel, and boulders derived mostly from the Precambrian metamorphic and Paleozoic sedimentary rocks of the Beaver Dam Mountains, but also include clasts of volcanic rocks derived from the Bull Valley Mountains to the north (Hintze, 1985). Calcite is the most common cementing agent. These high-level gravels have been relatively dated as upper Pliocene and early Pleistocene by comparing their distribution with the Gunlock basalt flow, which has been radiometrically dated at 1.6 $\pm$ 0.1 Ma (Hintze, et al., 1991). These gravels attain thicknesses of up to 150 feet and are quite extensive at Utah Hill Summit and in the western portion of the quadrangle.

Quaternary System

Alluvium (Qal)

Alluvium consists of low-level alluvial deposits of flood plains and stream channels containing rounded boulders, gravels, sand and silt. Qal_1 is found in present stream channels, and Qal_2 forms older stream benches and terraces. The alluvium is up to 40 feet thick in places.

Alluvium/colluvium (Qac)

Alluvium/colluvium is alluvial material having a large colluvial (slopewash) component. It occurs on hillslopes or along low-order ephemeral streams. Alluvium/colluvium consists of soils and angular rock fragments and is up to 25 feet thick. Gravelly colluvium (Qcg), poorly-sorted colluvial material containing cobbles and boulders, and fine-grained colluvium (Qcf), soils and small angular fragments of rocks, have been differentiated.

Talus (Qmt)

Talus consists of rock-fall debris most commonly derived from the Fossil Mountain Member of the Permian Kaibab Formation.

Alluvial Gravels (Qag)

Alluvial gravels consist of coarse alluvial deposits of stream gravels above the level of present drainages. These gravels occur mainly in the Mine Valley area and near Reef Reservoir and are up to 40 feet thick.

Pediment alluvium (Qap)

Pediment alluvium consists of sand, gravel and boulders. Extensive pediments have developed on the Queantoweap Sandstone in the area between Bulldog Pass and Bulldog Knolls in the southern part of the quadrangle. Pediment surfaces have also developed in Cedar Pockets Wash. These pediment surfaces are up to 75 feet thick.

STRUCTURE

The Jarvis Peak Quadrangle is in a transitional region between the Basin and Range and Colorado Plateau provinces. In Arizona the province boundary is relatively clear and sharp. However, the boundary is not easily defined in southwestern Utah. The transition zone is an intermediate step between the structural styles of the Colorado Plateau and the Basin and Range (Petersen, 1983).

The Colorado Plateau province is characterized by horizontal to subhorizontal strata, widely-spaced faulting and broad monoclinal folding. It is bounded on the west by north-striking, high-angle normal faults. The lengths of these faults are from tens to hundreds of miles (Lucchitta, 1986). The large blocks between the faults have been slightly tilted.

The Basin and Range province is a broad zone, up to 650 miles wide, of elongate ranges of regionally parallel trend separated by basins filled with Quaternary-Tertiary sediments. It contains highly tilted strata and closely spaced faults (Lucchitta, 1986). The range-bounding faults displace young volcanic units and tend to strike north (Anderson, 1971). The province is a region of active crustal spreading characterized by high heat flow and thin crust (Vetter and Ryall, 1983). Models of Basin and Range extension include: 1) the classic horst and graben geometry with steeply-dipping normal faults, and 2) the tilted block model with downward-flattening listric faults that merge into regional, subhorizontal zones of detachment (Stewart, 1978).

The boundary between the Colorado Plateau and Basin and Range provinces is differentiated on the basis of late Cenozoic block faulting, regional uplift and tilting to the northeast, and basaltic volcanism (Best and Hamblin, 1978). The Grand Wash fault is considered to mark the western edge of the Colorado Plateau in Arizona (Anderson and Mehnert, 1979 and Lucchitta, 1986). The Hurricane-Wasatch fault zone is regarded as the classical physiographic boundary (Fenneman, 1931) in northern, central, and southern Utah. The two great boundary faults, the Grand Wash and Hurricane, are arranged en echelon in southwestern Utah (Longwell, 1952). Since the time of Dutton (1882), most geologists have regarded the Hurricane fault zone in Utah as the boundary between the two provinces. This requires the boundary to pass south of the St. George Basin. However, "the St. George Basin is structurally the northern part of the Shivwits Plateau, the height of which decreases northward with increasing downthrow on the Hurricane fault" (Longwell, 1952, p. 28). Basin and Range structure begins at the east flank of the Beaver Dam Mountains (Gardner, 1941). Anderson and Mehnert (1979) believe the province boundary swings eastward from the Gunlock fault zone along the north side of the Pine Valley Mountains.

Strata in the Jarvis Peak Quadrangle have been subjected to two principal deformations: a late Mesozoic-early Cenozoic compressional phase and a late Cenozoic (late Miocene to Quaternary) extensional phase (Hintze, Embree and Anderson, 1991). A period of relative quiescence with limited extension occurred in this region during Oligocene-Miocene time. This period was accompanied by extensive silicic and explosive volcanism to the northwest in the Caliente-Indian Peaks calderas (Best and Christiansen, 1991). During the late Miocene, extension and the eruption of basalt flows became dominant. Utah's paleogeologic hingeline also passes through southwestern Utah. The region formed a transitional zone between stable shelf to the east and miogeosyncline to the west during the Paleozoic. Baer (1987) calls the Beaver Dam Mountains a "rosetta stone" because of this diversity.

The major structural feature of the Beaver Dam Mountains is the northwest-trending Beaver Dam Mountains anticline, which is bounded by the Shivwits syncline. These large folds are truncated on the east by the Grand Wash-Reef Reservoir-Gunlock fault zone.

Late Mesozoic-Early Cenozoic Compression

Strata in the Beaver Dam Mountains were folded, thrusted and locally overturned during the Sevier-Laramide orogeny. The structure reflects the more-or-less continuous compressional effects of the late Mesozoic to Paleocene Sevier orogeny (150 to 60 Ma) and overlapping Laramide deformation (75 to 40 Ma) (Arabasz and Julander, 1986). The Beaver Dam Mountains anticline, the Shivwits syncline, the Reef Reservoir Fault, and thrust faults were produced during this late Mesozoic-early Cenozoic compressional phase.

Beaver Dam Mountain Anticline

The Beaver Dam Mountain anticline is a northwest-trending doubly-plunging anticline. The western limb was more tightly compressed than the eastern limb producing more intense folding and attenuation on the west side of the mountains. Precambrian rocks make up the core of the Beaver Dam Mountain anticline. The west flank of the anticline is only partially exposed as it is truncated by faulting along the west side of the range where it is mostly buried by alluvium. Moore (1972) mapped a anticline similar to the Beaver Dam Mountains anticline about 10 miles to the south in the

Virgin Mountains.

Shivwits Syncline

Paleozoic and Mesozoic strata on the east limb of the Beaver Dam Mountains anticline form the west limb of the Shivwits syncline. The southern end of the syncline is located in the Jarvis Peak Quadrangle. It is truncated at a 45 degree angle by the Reef Reservoir fault near Reef Reservoir. The synclinal axis trends northward from the Jarvis Peak Quadrangle for approximately 9 miles. The lower red member of the Moenkopi Formation is the youngest formation exposed in the syncline in the quadrangle.

Reef Reservoir Fault

The Reef Reservoir fault is a curious structure. It is on strike with the Grand Wash and Gunlock faults, which are major down-to-the-west normal faults. However, movement on the Reef Reservoir fault has been down to the east. The Reef Reservoir fault has been variously interpreted as a fault with initial normal movement that was reversed by later differential uplift of the central Beaver Dam Mountains (Cook, 1960), a Laramide gravity-glide fault (Lovejoy, 1976), and a reverse fault related to late Mesozoic compressional deformation (Hintze, 1986). The Reef Reservoir fault probably formed as a reverse fault in response to compressional stresses, but was reactivated during the late Cenozoic.

The Reef Reservoir fault extends northward for over 8 miles from Mine Valley to just north of U.S. Highway 91. Along its length the fault strikes from N 18 E to N 13 W. It dips steeply west to vertical. The fault trace curves gently across the topography. The resistant Fossil Mountain Member on the upthrown block forms a steep fault-line scarp above the downthrown Triassic units. The fault strikes roughly parallel to the trend of the Shivwits syncline in the northern portion of the quadrangle as it truncates the steep eastern limb of the syncline. The fault cuts the axis of the syncline at an angle of 45 degrees just south of Reef Reservoir. Southward to Mine Valley the fault cuts down section through the Permian strata dipping off the east limb of the Beaver Dam Mountain anticline. This oblique truncation of the folds creates complications in interpreting displacement along the fault. The large stratigraphic displacements observed are not wholly associated with movement along the fault.

The southernmost exposure of the Reef Reservoir fault is located in Mine Valley. A zone of breccia, which appears to be derived primarily from the Fossil Mountain Member, marks the fault. Stratigraphic displacement at this point is approximately 1,400 feet. Displacement increases to the north and reaches a maximum of 3050 feet near Reef Reservoir. North of Reef Reservoir displacement on the fault decreases rapidly. The termination of the fault occurs near Camp Spring 4.5 miles north of the quadrangle.

The actual fault plane is rarely observable. It is usually covered by colluvium and talus derived from the Fossil Mountain Member, which is exposed on the upthrown block for most of the length of the fault. South of Quail Reservoir, resistant limestone beds of the Brady Canyon Member dip vertically into the fault. The

Harrisburg Member of the Kaibab Formation and the Moenkopi Formation on the downthrown block have been differentially eroded back giving the appearance of a vertical fault surface.

The fault plane is exposed in one location a mile north of the quadrangle near Wittwer Canyon. Here beds of the Shnabkaib and middle red members are in fault contact with the Chinle Formation. Displacement is approximately 1,400 feet, and the trace of the fault V's slightly to the west in the wash indicating a steep westward dip.

Thrust Faults

North of Utah Hill Summit at the extreme northern edge of the quadrangle the Devonian Muddy Peak Formation has been overturned and thrust from the west over the Mississippian Redwall Limestone. The Redwall Limestone has also been thrust over itself in this location doubling the section.

Late Cenozoic Extension

In this region, late Miocene to Quaternary extension produced major north-trending fault systems and related basins which filled with thick accumulations of syn-extensional sedimentary deposits (Hintze, Embree adn Anderson, 1991). Extensional features in the quadrangle include normal faults, grabens, and attenuation faults.

Grand Wash Fault

The Grand Wash fault marks the western edge of the Colorado Plateau province in Arizona. It is a major normal fault that extends northward for over 110 miles from the Cottonwood Cliffs, which are south of the Grand Canyon, to its mapped termination in the Jarvis Peak Quadrangle. Throw of the Grand Wash fault near the Grand Canyon is at least 4,900 feet and may be as much as 16,000 feet (Lucchitta, 1966). Recurrent movement along the Grand Wash fault in Arizona has formed a prominent scarp, the Grand Wash Cliffs.

In the quadrangle, resistant limestone of the Kaibab Formation is exposed on both the upthrown and downthrown blocks. This produces an impressive fault-line scarp 1440 feet high. Cedar Pockets Wash developed along its base.

The Grand Wash fault cuts the eastern flank of the Beaver Dam Mountain anticline. Strata dip between 20 and 30 degrees into the fault zone off of the anticline. The Permian Queantoweap, Toroweap, and Kaibab Formations on the eastern fault block dip gently eastward into the St. George Basin forming a continuous homocline.

The Grand Wash fault zone consists of 5 subparallel, north-striking faults each down to the west at the southern edge of the quadrangle. These 5 faults gradually merge or die out to the north. There is an excellent exposure of the easternmost fault plane at the Utah-Arizona border. Here the fault strikes north-south and dips steeply to the west. The Brady Canyon Member, which dips 75 degrees to the west, is exposed in the downthrown block and rests on the Seligman Member, which has been attenuated approximately 70%. Stratigraphic displacement across this fault is approximately 725 feet and across the zone, 1,580 feet.

One half mile north of the state line total displacement on the easternmost fault has decreased to 260 feet. The fault plane is vertical (Fig. 1). The Seligman Member of the Toroweap Formation is again attenuated. Displacement on the easternmost fault ends in a drag structure 660 feet north of this point. Displacement in the fault zone now shifts to faults to the west.

At one locality in Cedar Pockets Wash the Grand Wash fault dips 65 degrees to the east as an apparent reverse fault. It is possible that the strong eastward dip may be anomalously high due to slippage of the gypsum beds on the upthrown block. At other localities mapped, the fault plane dips steeply west to nearly vertical. Kurie (1966) noticed the same phenomenon along the Hurricane fault.

Normal drag on the upthrown block is common along major faults in the western Colorado Plateau. The Grand Wash fault is no exception. Normal drag develops from dip-slip movement along fault planes, which bends or flexes the rocks in the direction opposite displacement. Permian strata on the upthrown block dip gently to the east into the St. George Basin. However, within 0.3 mile of the fault trace, beds of the Kaibab and Toroweap Formations locally dip as much as 45 degrees to the west. The beds are not broken but bend westwards into the Grand Wash fault zone forming a drag flexure. The Woods Ranch and Seligman Members are attenuated in this drag zone. Displacement is locally decreased along the Grand Wash fault by the drag on the eastern block.

The Kaibab Formation on the downthrown block dips between 20 and 30 degrees off of the Beaver Dam Mountain anticline. Measured dips within 650 feet of the fault zone are as high as 70 degrees to the east. This oversteepening near the fault is due to reverse drag. Hamblin (1965) concluded that reverse drag develops along the downthrown block of major normal faults in the western Colorado Plateau because of curvature of the fault plane at depth. Vertical movement along a curved fault plane will pull the blocks apart as well as displace them vertically. This leaves a gap along the fault plane which must be filled either by faulting or folding of the downthrown block. Flexure into this gap forms a reverse drag structure.

Fourteen NE- to ENE-striking faults were mapped in the downthrown block in Cedar Pockets Wash. In all but one case the sense of offset is normal. The faults have displacements ranging from 30 to 160 feet and they do not pass through the Grand Wash fault. The faults break the Kaibab Formation into a series of blocks. Dobbin (1939, p. 135) recognized the faulted nature of the Kaibab dipslope on the western block and referred to it as a "comparatively narrow zone of minor distributive faulting occurring just west of the main fracture forming a complicated mosaic of Kaibab Limestone blocks." The Woods Ranch Member of the Toroweap Formation is attenuated beneath the Kaibab Formation.

These faults are not antithetic to the Grand Wash fault as, for the most part, they do not dip towards it. The faults are interpreted to be subsidiary to the Grand Wash fault as they are bounded by it and could have formed as adjustment faults contemporaneous with movement on the Grand Wash fault. It is also possible that the faults record a younger faulting event in response to the present-day stress field, which is characterized in this area by NW-SE directed least principal stresses (Zoback, et al., 1981).

At the north end of Cedar Pockets Wash, steeply dipping strata of the Harrisburg, lower red and Virgin Limestone Members are overlain by gently east-dipping beds of the Fossil Mountain Member (Fig. 2). The Moenkopi beds are overturned by drag and dip west indicating an eastward movement of the Fossil Mountain Member block. Permian-Triassic strata on the downthrown block were oversteepened due to reverse drag, and the Fossil Mountain Member probably slid off of the Beaver Dam Mountain anticline along gypsum planes in the Woods Ranch Member. The Kaibab block slid out over the Moenkopi Formation and up against the Grand Wash fault scarp. As a consequence, apparent displacement along the Grand Wash fault at this location is less than 230 feet, but the actual displacement is at least 1,150 feet as the Triassic Moenkopi Formation is exposed in the downthrown block on either side of and beneath the Fossil Mountain Member slide block. Sliding of the Kaibab block must have taken place relatively late in the history of movement along the fault zone.

Two similar masses of badly brecciated and recemented Fossil Mountain Member overlie the middle red member of the Moenkopi Formation in Cedar Pockets Wash. These have slid off the eastern fault block and crossed the fault. Above the two masses strata on the upthrown block dip 25 degrees to the west due to normal drag.

Faulting probably oversteepened the scarp causing the competent Fossil Mountain Member to slide across the Woods Ranch Member and down into Cedar Pockets Wash. Gravity sliding related to relief developed by late Tertiary extensional faulting is common in the eastern Great Basin (Armstrong, 1972). Smaller coherent bedrock masses which have slumped along the eastern side of the fault scarp were mapped as QTms.

In Mine Valley, displacement on the Grand Wash fault decreases rapidly as the fault splays into a number of smaller faults (Fig. 3). The splays branch off to the northeast and repeat the Kaibab section. The main fault continues northward with diminishing throw subparallel to the Reef Reservoir fault for another mile.

Mine Valley Graben

The strikes of the Grand Wash and Reef Reservoir faults veer away from each other in Mine Valley. They then parallel each other for approximately 2 miles. Otherwise, the faults would intersect in a continuous north-south line. The Triassic Moenkopi Formation is exposed in the graben between the two faults. The Grand Wash fault drops the Moenkopi Formation down to the west and the Reef Reservoir fault drops it down to the east. The Moenkopi Formation is generally nonresistant and forms the valley. Exposures are rare as alluvial cover is thick. Critical relationships in this structurally complex overlap zone are obscured.

The members of the Moenkopi Formation could not be differentiated by mapping in the graben. Exposures are primarily of the lower red, Virgin Limestone, and middle red members.

Probable limestones of the Shnabkaib Member are located just north of Mine Valley Reservoir. Isolated, broken Virgin Limestone blocks dip at various angles to the east, west and south. It is apparent from the scattered exposures that the Moenkopi Formation is extensively faulted and locally overturned.

A small isolated hill of bedrock crops out in the southern part of Mine Valley (Fig. 3). The southwest side of the hill exposes the Brady Canyon Member of the Toroweap Formation while the Virgin Limestone Member of the Moenkopi Formation is exposed on the northeast side. The trace of the fault trends straight across the small hill. The dip of the fault plane is steep to vertical. The northeast side is downthrown and stratigraphic displacement on the fault is significant, approximately 900 feet. The fault could be a northwest-striking splay from the Grand Wash fault, but this is not probable as the east side of this fault is downthrown. However, if this fault is a splay of the Grand Wash fault, then the reversal of offset suggests scissor movement. It is also possible that it is the southern end of the Reef Reservoir fault veering eastward to meet the Grand Wash fault. The Reef Reservoir fault is covered by alluvium south of the Apex Mine road in Mine Valley. It probably continues striking SSW towards Bulldog Pass, but no offset is observed south of Mine Valley. The possibility exists that the fault is not related to either the Grand Wash or Reef Reservoir faults, but because the displacement is so great, it probably continues to the southeast to join with the Grand Wash fault and, perhaps, to the northwest to intersect the Reef Reservoir fault.

Graben East of the Reef Reservoir Fault

Subparallel to the Reef Reservoir fault and located to the east 0.6 mile is a steep east-dipping fault, known as the Wittwer fault (Hammond, 1988). The fault is reverse as the west side is downthrown. It extends for 2.5 miles and attains a maximum stratigraphic displacement of 260 feet. Observed displacement on the fault is restricted to the Harrisburg Member of the Kaibab Formation and to the Moenkopi Formation. Only the southern 0.5 mile of the Wittwer fault is exposed in the Jarvis Peak Quadrangle as south of Laub Reservoir fault relationships are obscured in the interval representing the Permian-Triassic unconformity. West of Laub Reservoir the Wittwer fault branches into a series of small breaks which drop the basal ledge of the Virgin Limestone Member down to the west. One mile north of the Jarvis Peak Quadrangle the fault dips 80 degrees to the east and juxtaposes the middle red member against the Virgin Limestone Member. A small drag flexure is present in the upthrown block, as well as several small antithetic faults.

Between the Reef Reservoir and Wittwer faults is an area of complexly-faulted geology. Three sets of faults were differentiated. The faults are second order to the Reef Reservoir and Wittwer faults as they are bounded by them.

The first set of faults strike north-south and dip within 15 degrees of vertical. Most of the faults dip west, are normal and are located within a 650 ft-wide zone east of the Reef Reservoir fault. The west-dipping members of the Moenkopi and Chinle

Formations are each faulted down to the west by these major faults. The Triassic section has been greatly thinned by these faults. Directly west of Quail Reservoir the Reef Reservoir fault is covered by colluvium. East of the fault the characteristic purple clay of the lower Chinle Formation crops out in a zone less than 3.5 ft wide. Next to this is a 25 ft-wide zone of reddish brown mudstone and siltstone and minor gypsum and limestone fragments recognizable as being derived from the Moenkopi Formation. These zones appear to have been sheared. Farther to the east a thin sliver of the basal limestone ledge of the Virgin Limestone is in fault contact with the Moenkopi Formation melange. The limestone ledge is underlain by the lower red member, which is part of the normal stratigraphic sequence. South of this point 0.3 miles the Triassic units have been faulted out, and the Harrisburg Member of the Kaibab Formation is exposed on the downthrown block.

Most faults in the second set strike between 50 and 85 degrees east of north and are normal. They occur only in the Virgin Limestone, middle red and Shnabkaib Members of the Moenkopi Formation and are bounded on the east by the Wittwer fault. These faults are fairly systematic and drop strata down to the northwest.

The basal limestone ledge of the Virgin Limestone caps a ridge that parallels the Apex Mine road southward from Laub Reservoir for 1 mile. The ridge is cut by 28 small faults. These faults strike WNW to NW. They dip steeply and have displacements ranging from less than 3 ft to 35 ft. Twenty-one of the faults are normal and seven are reverse. These faults are probably minor adjustment features.

Hell Hole Graben

The Hell Hole graben extends into the northern part of the Jarvis Peak Quadrangle, but is best exposed in the Shivwits Quadrangle. The eastern boundary fault, however, is clearly exposed north of Utah Hill Summit at the extreme northern edge of the quadrangle. Here the fault displaces thrusted and overturned Devonian and Mississippian strata. The graben-bounding faults become either buried by the Quaternary-Tertiary alluvial gravels in the vicinity of Utah Hill or obscured by brecciation in the Cambrian and Devonian strata as they are traced to the south.

Other Normal Faults

A series of 12 normal faults displaces the Devonian through Permian strata east of Bulldog Knolls in the southern portion of the Jarvis Peak Quadrangle. This is along the south flank of the Beaver Dam Mountain anticline. These faults strike N to NW and have moderately steep dips (70 degrees). Most of the faults drop strata down to the east, but several blocks have been dropped down to the west forming horsts and grabens.

Attenuation Faulting

Attenuation refers to a thinning of strata caused by faulting subparallel to bedding planes. Slippage occurs along or at a low angle to the bedding plane during deformation, and the younger-on-older stratigraphic relationship is preserved. Attenuation has been observed at various localities in the Great Basin and is usually ascribed to thrust or detachment faulting

(Hintze, 1986 and 1978). Strata in the Jarvis Peak Quadrangle have been attenuated due to dissolution of gypsum, deformation associated with fault movement and drag, and gravity-sliding.

Steed (1980) mapped attenuation faults in the slope-forming units of the Kaibab and Toroweap Formations in the Virgin Gorge, which is immediately south of the quadrangle. He observed that the amount of attenuation was roughly proportional to the degree that the Kaibab-Toroweap cliffs were fractured or faulted and concluded that the thinning was due to east-directed thrusting. However, Nielson (1982) suggests that attenuation seen in the Virgin Gorge and on the east side of the Jarvis Peak Quadrangle may have been caused by dissolution of gypsum in the Woods Ranch and Seligman Members by water migrating down dip to the Virgin Gorge, causing slumping of the Brady Canyon and Fossil Mountain Members.

The thinning observed in the Woods Ranch and Seligman Members near the Grand Wash and Reef Reservoir faults appears to be closely associated with deformation caused by drag.

In contrast, attenuation on the west side of the quadrangle occurs in the more resistant units such as dolomite and limestone as well as in shale and gypsum. This attenuation was probably caused by deformation associated gravity-sliding during the Tertiary. Sheets and blocks of Paleozoic rocks have been emplaced along the southwestern flank of the Beaver Dam Mountains. This was noted as early as 1939 by Dobbin and 1952 by Reber.

The best example of gravity-sliding is near Welcome Spring several miles to the west in the Castle Cliff Quadrangle. Breccia blocks of Mississippian Redwall Limestone (Cook, 1960) have slid westward and ended on top of Precambrian basement rocks and the Tertiary Muddy Creek Formation indicating Pliocene to Holocene movement (Carpenter, et al., 1989). The blocks rest on greatly attenuated sections of highly brecciated Cambrian and Devonian strata. These blocks are rootless and seem to rest in part on higher density bedrock and, in part, on lower density valley fill (Baer, 1986). Cook (1960) was the first to interpret these blocks as westward-moving slide blocks.

The Castle Cliff detachment is located in the western portion of the Jarvis Peak Quadrangle. Beneath brecciated but coherent Callville Limestone at Castle Cliff there are severely attenuated and brecciated remnants of the Mississippian Redwall Limestone and Devonian and Cambrian formations. These formations are present in their proper stratigraphic sequence, but some 4600 ft of strata have been reduced to an attenuated zone 650 to 1000 ft thick (Hintze, 1985). Hintze (1986) states that the Castle Cliff detachment and Welcome Spring breccia blocks are low-angle down-to-the-southwest blocks caused by gravity rather than compressional thrusting. Jones (1963) supports westward movement and gravity gliding of these detachments based on small-scale structures he observed at Castle Cliff. Wernicke (1982) described the occurrence of a westward-moved sheet, the Mormon Peak detachment, in the central Mormon Mountains approximately 25 miles west of the Beaver Dam Mountains. The Castle Cliff detachment extends to Bulldog Knolls at the southern edge of the quadrangle (Fig. 4).

Gravity-sliding has occurred in other places in the Jarvis Peak Quadrangle. The gravity-slide blocks in Cedar Pockets Wash along the Grand Wash fault were discussed previously. Near the center of the quadrangle massive blocks of Mississippian Redwall Limestone rest on top of Cambrian strata. These blocks probably slid from the east off the Beaver Dam Mountain high.

Age of Deformation

There has been no significant demonstrable movement on the Grand Wash fault since Pliocene time. Age dates on the middle Miocene Peach Spring Tuff south of the Colorado River suggest initial movement on the Grand Wash fault at about 18 Ma (Young, et al., 1975). Luchitta (1972) found that most of the displacement (over 3 miles) on the Grand Wash fault south of the Colorado River in Arizona occurred between 18 and 11 Ma. Along the southern part of its length the Grand Wash fault has not moved since deposition of the exposed upper Miocene part of the middle to upper Miocene Muddy Creek Formation. The Muddy Creek includes basalts which have been dated at 5 to 6 Ma (Anderson, 1978, and Damon, et al, 1978) and 10.9 Ma (Blair, 1978). However, the Muddy Creek Formation has been offset by the Grand Wash fault north of its junction with the Wheeler fault (Lucchitta, 1966). At the north end of the Grand Wash Trough 6.9 Ma basalts have been displaced 1000 ft by the Grand Wash fault (Hamblin, 1984). This indicates a northward migration of fault activity.

The eastern, upthrown block of the Grand Wash fault forms a prominent cliff in the quadrangle. This fault scarp has retreated eastward less than 0.3 miles from the trace of the fault and is only slightly dissected by erosion. This is due to the resistance of the Kaibab Limestone caprock, but it also shows that faulting in the study area is younger than along the Grand Wash fault in the Grand Canyon area. There the upper scarp of the Grand Wash Cliffs has been dissected by canyons and eroded back over 9 miles from the cliff face (Hamblin, 1970b).

The Reef Reservoir fault cuts the eastern edge of the Shivwits syncline and the Beaver Dam Mountain anticline as does the Grand Wash fault and also the Gunlock fault to the north. Reber (1951) stated that the Reef Reservoir and Gunlock faults are younger than the folding because they clearly displace the folded beds. The folding has traditionally been ascribed to the late Cretaceous-early Tertiary Sevier orogeny. Wernicke (1985) and Wernicke and Axen (1988) interpret the anticline as part of a broad zone of uplift resulting from isostatic adjustment to late Tertiary tectonic denudation. The Claron Formation is involved in the folding north of the town of Gunlock. The Claron Formation could either be Paleocene or Oligocene in age (Hintze, 1986). There is no direct evidence as to the age of folding in the quadrangle as the youngest rocks exposed (except surficial deposits) are Triassic. In either case, movement on Reef Reservoir fault can only be post-folding or post-late Cretaceous.

The Gunlock fault, which is north of the quadrangle, displaces the 24 Ma Leach Canyon Formation so movement on that fault is post-Oligocene (Rowley, et al., 1978). Embree (1970) determined that most displacement on the Gunlock fault predates deposition of the Gunlock basalt, which has been dated radiometrically at 1.6 Ma. He found that the surface of the basalt shows normal offset of only 25 ft.

Lithologic Response to Stress

Strata of various lithologies have responded differently to stress. Cambrian and Devonian strata are extensively brecciated in the quadrangle. The Mississippian Redwall Limestone is brecciated, but tends to reheal. Except for the limestones in the Virgin and Shnabkaib Members, the Moenkopi Formation usually deforms plastically along bedding planes and shaly partings. Along the Grand Wash and Reef Reservoir faults the Fossil Mountain Member and the Brady Canyon Member consist of a recemented limestone breccia. Even the chert fragments have been severely shattered. The Woods Ranch and Seligman Members contain large amounts of gypsum and flow when placed under stress. As a result, they are often attenuated in fault zones. South of the Arizona-Utah state line the Queantoweap Sandstone has been pulverized to sand in a zone 50 feet wide along the easternmost fault in the Grand Wash zone.

CLASTIC DIKES

Lovejoy (1964, p. 122) observed that "at almost every outcrop the fault contact contains a silicified vein or stringer". These "quartz veins" (Lovejoy, 1964, p. 122) are clastic dikes associated with movement on faults.

Clastic dikes are tabular bodies of clastic material which cut across sedimentary bedding and were formed by forceful injection (Potter and Pettijohn, 1977). The liquefied sediment that solidified into the dike may have been injected upwards, downwards, laterally or in some combination of these. The majority of infills are sandstone, but range from conglomerate to mudstone (Boulter, 1986). Clastic dikes are commonly found in thick sections of sedimentary rocks, and they generally intrude shales or other rocks of low permeability (Smyers and Peterson, 1971). The dikes usually form perpendicular to bedding (Borradaile, 1984).

A fissure must be present prior to the injection of clastic material. A tensile fracture can develop from the local tension accompanying an earthquake, from the shrinkage of unconsolidated sediments, or from fracturing associated with faulting and folding. The pressure necessary to mobilize and intrude the sediment into a fissure may arise from hydrostatic pressure or from high fluid pressures (Duncan, 1964). The clastic material cannot flow unless it is dilated by fluid so that the grains no longer interlock. Earthquakes can produce the differential dilation and compaction necessary for fluidization (Duncan, 1964).

Several clastic dikes are located along small NE-striking faults near Reef Reservoir in the quadrangle, and one small outcrop of clastic dike was located near Quail Reservoir. A dike striking N 6 E and dipping steeply to the east is exposed along the Wittwer fault. The dikes intrude mudstone units of the Virgin Limestone, upper red, and middle red members of the Moenkopi Formation. They are more resistant than the country rock and usually form small ridges. The contact between the host rock and dike is sharp and pieces of shale are included within the dike. This suggests that the shale was cohesive before dike emplacement.

The dikes are composed of a fine-grained, moderately-sorted quartz sandstone which ranges from very pale orange to dark yellowish orange. The orange stain is due to the presence of iron oxides, which locally form networks of intersecting veinlets. The sandstones are well cemented with silica and iron oxide in varying proportions. The grains are 99% quartz, equant and subrounded to rounded. In hand sample the quartz grains are frosted. The source for the dike material could be the Permian Queantoweap Sandstone.

It is possible that movement along the faults opened fissures, which were quickly intruded by liquefied clastic material. Fluids could have been trapped under the impermeable gypsum and shale units of the Kaibab and Toroweap Formations creating abnormally high pressures in and dilation of the Queantoweap Sandstone. The fissuring released the pressure and liquefied sand was injected into the Triassic strata above. A similar mechanism is less likely for downwards injection of Navajo Sandstone. It is also possible that an earthquake shock caused the dilation and subsequent injection.

As the dikes crop out along the traces of faults, they must be related to faulting in the area. The dikes are interpreted as having been injected along the fault planes concurrent with faulting. The orientation of the clastic dikes can be inferred to be the orientation of the fault planes.

ECONOMIC GEOLOGY

The locations of mines and prospects within the quadrangle are shown on Figure 5.

Metals

The Jarvis Peak Quadrangle is located in the Tutsagubet mining district, which encompasses the central part of the Beaver Dam Mountains. Lead, zinc, silver and copper ores have been mined from both the east and west sides of the range. The mining district was organized on June 2, 1883, but locations had been made as early as 1871 in the area (Perry and McCarthy, 1977). The district has been worked intermittently since 1884.

Apex Mine

The Apex Mine has been known by several names, a few of which are the Pen, Dixie, Dixie-Apex, and Utah-Eastern mine. The property consists of 22 patented claims (Perry and McCarthy, 1977). The mine was originally developed as a high grade copper operation and was mined intermittently from its discovery in 1872 to the end of World War II. Estimates of total production during this period range from 75,000 to 100,000 tons of ore with grades ranging from 10% to 35% copper (Musto Explorations Ltd., 1984). The first organized effort to work the mine was made about the year 1884 (Salt Lake Mining Review, 1901). The mine was operated intermittently until 1962 producing over 7,700 tons of copper, 440 tons of lead, 180,000 troy oz. of silver, and minor zinc and gold (Bernstein, 1986).

The presence of significant amounts of gallium and germanium in the ore was recognized during the 1950's. The rare elements are used in a number of high technology applications. Germanium is a semi-conducting metalloid that is used in X-ray and gamma-ray detectors, in high-frequency integrated circuits, and in infrared optical components. Gallium is a semi-metal that is also used in high-frequency integrated circuits. The Apex Mine was the first mine in the world to be operated primarily for gallium and germanium (Bernstein, 1986). It was operated by Musto Exploration Ltd. principally for gallium and germanium recovery from 1985 until September of 1987 when it was purchased by Hecla Mining Corporation. At this writing (May, 1991) the mine is idle due milling difficulties and a drop in market prices.

Mineralization occurs in the form of a subvertical, elliptical breccia pipe of leached, residual iron oxide within a dolomite/limestone host rock. The pipe is developed in the Pakoon Dolomite and the Callville Limestone, and its downward termination is unknown (Bowling, 1988). The mineralized zone contains from 1% to 2% copper and zinc, together with gallium, germanium, and minor amounts of antimony, bismuth, cadmium, cobalt, lead, molybdenum, nickel, titanium, tungsten and silver (Musto Explorations Ltd., 1984). The ore consists of goethite, limonite, hematite, jarosite, azurite, malachite, conichalcite, and several other metal oxides, carbonates, arsenates and sulfates (Bernstein, 1986). The germanium is concentrated mostly in goethite, hematite, and limonite, whereas the gallium is concentrated chiefly in jarosite and in some limonite. The abundance of copper, germanium, gallium, and arsenic in the supergene ore implies the former presence of sulfides and sulfosalts containing these metals in the primary ore (Bernstein, 1986). The country rock surrounding the breccia pipe has been extensively silicified and is now concentrically zoned around the pipe.

K/Ar dating of hydrothermal muscovite yielded an age of 200+7 m.y. for main stage mineralization. K/Ar measurements on jarosite gave mid- to late Miocene ages corresponding closely to the timing of Basin and Range extension in southwestern Utah (Petersen and Mahin, 1988). Bowling (1988) and Petersen and Mahin (1988) infer that either the Bright Angel Shale or Precambrian basement rocks are the source.

Paymaster Mine

This vertical shaft was located in the first draw south of the Apex Mine and was developed along a mineralized northwest-trending fracture (Butler, 1920). The original shaft is now collapsed, but the workings have been integrated into the Apex Mine. Minerals in the mine consist of cerussite, jarosite, malachite, azurite, plumbojarosite, limonite and hematite. A small smelter erected to treat the ore from this mine was never successfully operated (Butler, 1920).

Black Warrior Mine

The Black Warrior mine is located on the west side of the Beaver Dam Mountains. This mineralization was discovered at about the same time as that of the Apex mine, and moderate amounts of high grade lead-silver ore were mined. Cerussite mineralization, accompanied by abundant limonite, is associated with an extensive cave, which extends into the Redwall Limestone on a gentle dip for more than 200 feet (Butler, 1920). The cave originally contained many stalagmites, stalactites and columns of calcite. The ore was found in fissures in the sides and top of the cave.

Jessie Mine

Mineralization occurs as a replacement of the Mississippian Redwall Limestone and consists of malachite, azurite, and cerussite in a gangue of limonite and manganese oxides (Butler, 1920). The mineralized zone ranges in width from 2 inches to 3 feet and was followed to a depth of 50 feet (Perry and McCarthy, 1977). Lead, copper and silver ore were mined. Geochemical analyses (Table 1) were performed in the spring of 1989 on a grab sample taken from the adits and the dumps.

West Jessie Mine

Mineralization occurred in the Mississippian Redwall Limestone along a gravity-slide fault contact. Limonite, plumbojarosite, and jarosite are present.

Westside Mine

Mine workings consist of an upper and lower adit. The upper adit, the most extensive, consists of 1000 feet of drifting and crosscutting. The mine is located in the Mississippian Redwall

Limestone and the mineralization includes amounts of cerussite and limonite.

Unknown Mine

Mine workings consist of a shaft 30 feet deep and a 200-foot adit driven beneath it. Minerals in the mine include malachite, cerussite, limonite and manganese oxides along a mineralized fracture. This deposit is in the Mississippian Redwall Limestone.

Jose Cuervo Claims

Two inclined shafts are located in an iron-stained limestone breccia (the Bonanza King Formation and the Fossil Mountain Member of the Kaibab Formation). Samples from the shafts contain copper, silver zinc, gallium, and uranium (Harris and Ryan, 1984).

Jubilee Prospect

The Jubilee mine consists of an adit containing some lead, zinc and silver mineralization.

Other Prospects and Mines

Numerous other prospects and small mines occur throughout the Jarvis Peak quadrangle. Both the Surprise Mine and the Dewey Prospect were located for copper, lead, silver, and germanium. Others prospects followed signs of color into the hillsides, but were quickly abandoned.

Gypsum

There has been no commercial production of gypsum from the quadrangle. However, a gypsum mine in the Pakoon Dolomite is located just south of the quadrangle in Arizona. Nielson (1981) reported more than 30 feet of gypsum in the Bulldog Pass area.

Samples from this area assayed 29% CaO and 44% SO4, which is concrete-wallboard grade (Harris and Ryan 1984). The Harrisburg Member of the Kaibab Formation has been extensively prospected in Blake's Lambing Grounds along the eastern edge of the quadrangle. Samples taken from this area by Harris and Ryan (1984) were of pharmaceutical grade, over 99% CaSO4. Other gypsum prospects are located in the Curly Hollow Wash area north of Mine Valley. Bulldozers have cut prospects into the hillsides on both sides of the Apex Mine road.

Sand and Gravel

Extensive gravel deposits occur in the Quaternary-Tertiary alluvial gravels near Utah Hill Summit. One small sand and gravel pit has been developed within the quadrangle. It is in a low-level alluvial stream deposit just north of Castle Cliff Wash in the northwest portion of the quadrangle.

GEOLOGIC HAZARDS

Mass-Movement

The greatest geologic hazard in the quadrangle is probably from landslides and slumps along the eastern edge of Cedar Pockets Wash. The abundance of ancient landslides in this area suggests that they could be a future hazard. Considerable slumping has occurred along the upthrown block of the Grand Wash fault. There has been recurrent fault movement and slumping along the scarp. Detached blocks of the Fossil Mountain and Brady Canyon Members have moved

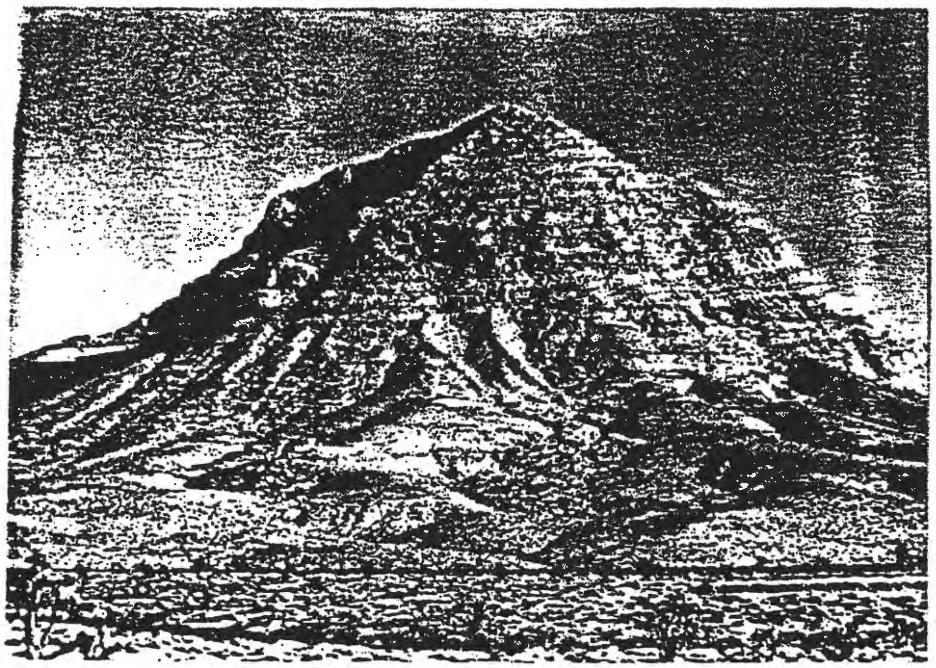

Figure 4

downward over gypsum and shale units of the Woods Ranch and Seligman Members. The Fossil Mountain Member of the Kaibab Formation is most commonly involved in this slumping. Based on many observations in southwestern Utah, Nielson (1982) concluded that slumping of the Brady Canyon Member is not as common as slumping of the overlying members because gypsum deposits are less common in the underlying Seligman Member and joint patterns are not as well developed.

Rock-fall debris at the bases of many slopes also indicate a hazard.

Earthquakes

The Jarvis Peak Quadrangle is located in a seismic source zone with Late Quaternary but no known Holocene faulting. The maximum magnitude earthquake expected is predicted to be 7.3 (Christenson, Harty and Hecker, 1987). The principal earthquake hazards include ground shaking and rock fall, but surface fault rupture and landsliding may also occur (Christenson, 1987). The magnitude and frequency of recorded earthquakes in the region is low, and no damage to man-made structures has been experienced.

Flash Flooding

Flash floods can occur after sudden spring or summer rainstorms. Washes that are normally dry can quickly fill with water. Flooding can be hazardous to individuals or livestock and damaging to equipment in the narrow washes. Roads on the west side of the quadrangle near the Black Warrior Mine have been washed out by the erosion of flash floods.

Problem Soils

Expansive clays derived from the Chinle Formation can cause foundation problems in this region. Other problems have resulted from gypsiferous and calcium carbonate-rich soils and piping (Christenson, 1987).

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TABLE 1

GEOCHEMICAL LAB REPORT FOR GRAB SAMPLE FROM THE JESSIE MINE

	oz./ton
Au	.024
Ag	.051
As	64
Bi	.064
Co	14.72
Cr	0.416
Cu	64
Mn	2.144
Mo	2.944
Ni	2.624
Pb	10.816
Sb	0.32
Se	0.192
W	0.32
Zn	10.144
Hg	0.00032
Ba	0.64

Analyses performed by Bondar-Clegg & Company, British Columbia

FIGURES

DESCRIPTION OF MAP UNITS

QUATERNARY

Qal_1 Low-level alluvial deposits of present flood plains and channels.

Qal_2 Low-level alluvial deposits of older stream benches and terraces.

Qac Alluvium having a large colluvial (slopewash) component; on hillslopes or along low-order ephemeral streams.

Qcf Fine-grained colluvium; poorly sorted.

Qcg Gravelly colluvium, including cobbles and boulders; poorly sorted.

Qag Alluviual gravels.

Qap Pediment alluvium, consisting of sand, gravel and boulders.

Qmt Talus (rock-fall debris).

QUATERNARY-TERTIARY (PLEISTOCENE-PLIOCENE?)

QTag High-level consolidated pediment gravels.

QTbr Limestone and chert breccia found along the southernmost exposures of the Reef Reservoir fault.

QTms Large coherent slumped bedrock masses.

TRIASSIC

Chinle Formation (TRc)

Resistant stream channel conglomerate and sandstone and variegated mudstone, siltstone, and sandstone. Fossil wood is commonly found.

Moenkopi Formation (TRm)

The members of the Moenkopi Formation could not be differentiated in the Mine Valley area and were mapped simply as TRm.

Upper red member (TRmu) Reddish-brown, thin-bedded siltstone, with ripple marks being common. A massive, pale reddish-orange sandstone ledge occurs near the top.

Shnabkaib Member (TRms) Banded white and red gypsiferous mudstone and siltstone with lesser laminated, light-gray dolomite and pale yellow limestone.

Middle red member (TRmm) Interbedded reddish-brown mudstone and siltstone; contains some thin beds of gypsum and dolomite.

Virgin Limestone Member (TRmv) Yellowish-brown to olive-green, slope-forming shale, with lesser light yellowish-gray, oolitic limestone ledges. The limestone is fossiliferous and contains brachiopods and penta-crinoids.

Lower red member (TRml) Interbedded reddish-brown shale and siltstone; contains gypsum both bedded and secondary.

Rock Canyon Conglomerate (TRmr) Light-brown to yellowish-gray conglomeratic siltstone and sandstone, containing angular to subangular limestone and chert clasts derived principally from the Permian Kaibab Formation.

UNCONFORMITY

PERMIAN

Kaibab Formation (Pk)

Harrisburg Member (Pkh) Interbedded laminated gypsum, fossiliferous limestone, silty gypsum, and thin-bedded dolomite; usually slope forming. Chert occurs as reddish-brown nodules in the limestone and dolomite beds.

Fossil Mountain Member (Pkf) Abundantly fossiliferous, yellowish-gray, fine- to medium-grained limestone. The fossils include brachiopods, crinoids, bryozoans and corals and have all been silicified.

Toroweap Formation (Pt)

Woods Ranch Member (Ptw) Grayish-orange to yellowish-orange gypsiferous siltstone, with thin interbeds of white gypsum and light-gray, fine-grained dolomite.

Brady Canyon Member (Ptb) Fossiliferous, light-gray, fine- to medium-grained limestone; contains reddish-orange chert nodules, massive.

Seligman Member (Pts) Gypsiferous siltstone, with minor white gypsum and light-olive-gray, fine-grained sandstone.

Queantoweap Sandstone (Pq)

Light-orange to grayish-pink, fine- to medium-grained, crossbedded sandstone; usually cemented with calcite.

Pakoon Dolomite (Pp)

Light-gray, medium- to thick-bedded, fine-grained dolomite; contains some chert nodules. Gypsum and minor sandstone beds occur in the upper part.

PENNSYLVANIAN

Callville Limestone (lPc)

Fossiliferous, fine- to medium-grained, light- to medium-gray limestone; thick-bedded; contains some chert nodules; interbedded with fine-grained sandstone toward the top.

MISSISSIPPIAN

Redwall Limestone (Mr)

Fossiliferous, medium- to dark-gray, crystalline limestone; massive. The lower part is very cherty.

DEVONIAN

Muddy Peak Dolomite (Dm)

The informal members of the Muddy Peak Dolomite were differentiated on the map only where exposure and structure permitted.

Pinnacle member (Dmp) Medium- to coarse-grained, light-gray, crystalline dolomite, which contains abundant chert nodules; massive. Extensively silicified in exposures north of Highway 91.

Slope member (Dms) Fine- to medium-grained, light- to medium-olive gray, silty dolomite; medium-bedded; contains stromatoporoidal hemispherical structures, which have been silicified.

UNCONFORMITY

CAMBRIAN

Nopah Dolomite (Cn)

Fine- to coarse-grained, thick-bedded, light-gray-to brownish-gray dolomite; extensively brecciated and/or faulted.

Bonanza King Formation (Cbk)

Medium- to light-brownish-gray, fine- to medium-grained dolomite, which is mostly medium-bedded; extensively brecciated. Some beds consist of light-gray, very-fine-grained boundstone.

Bright Angel Shale (Cba)

Olive green micaceous shale, siltstone, sandstone and quartzite; nonresistant; forms strike valleys.

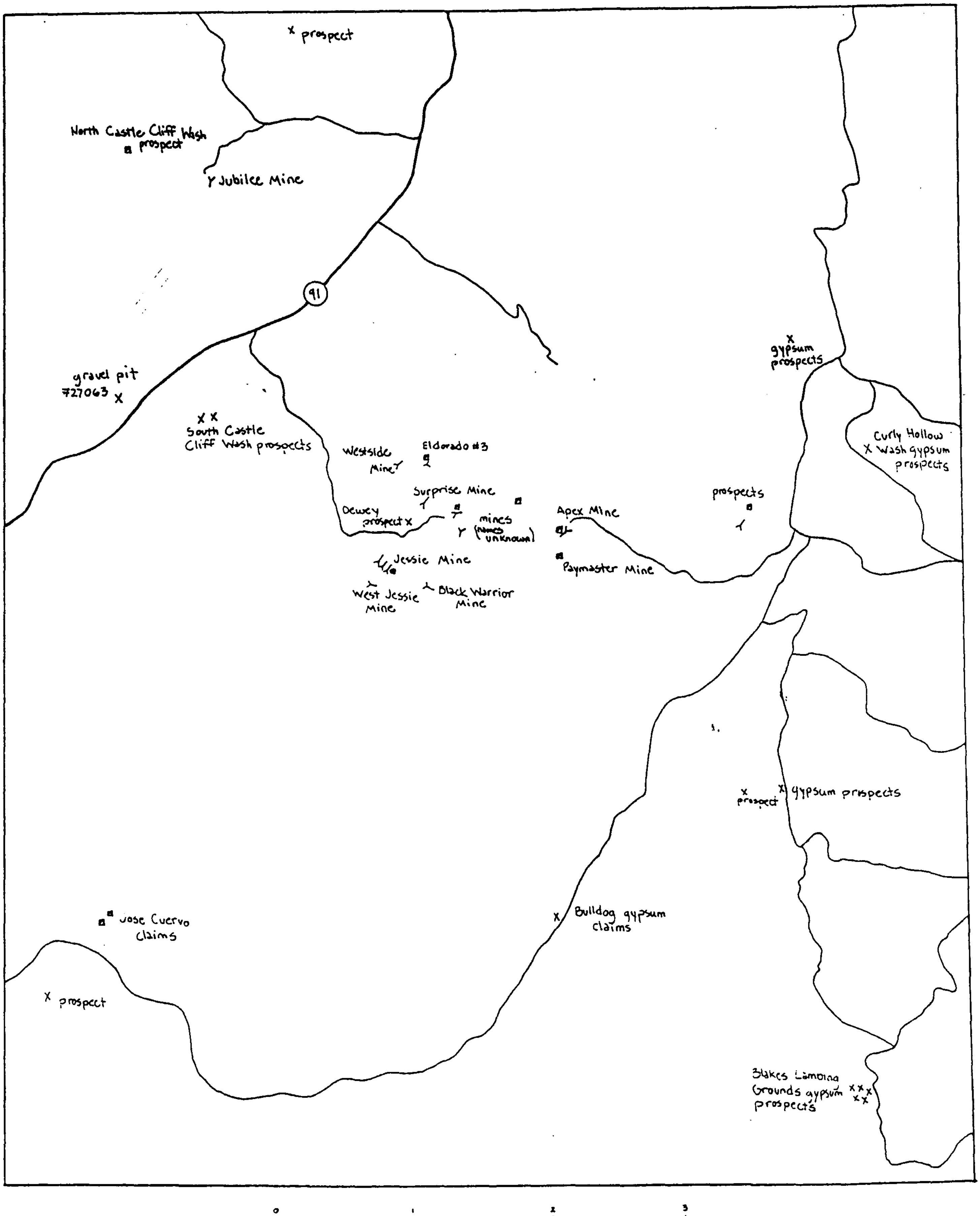
Tapeats Quartzite (Ct)

Orange to dark reddish-orange quartzite and sandstone, with some pebble conglomerate layers; ledge former.

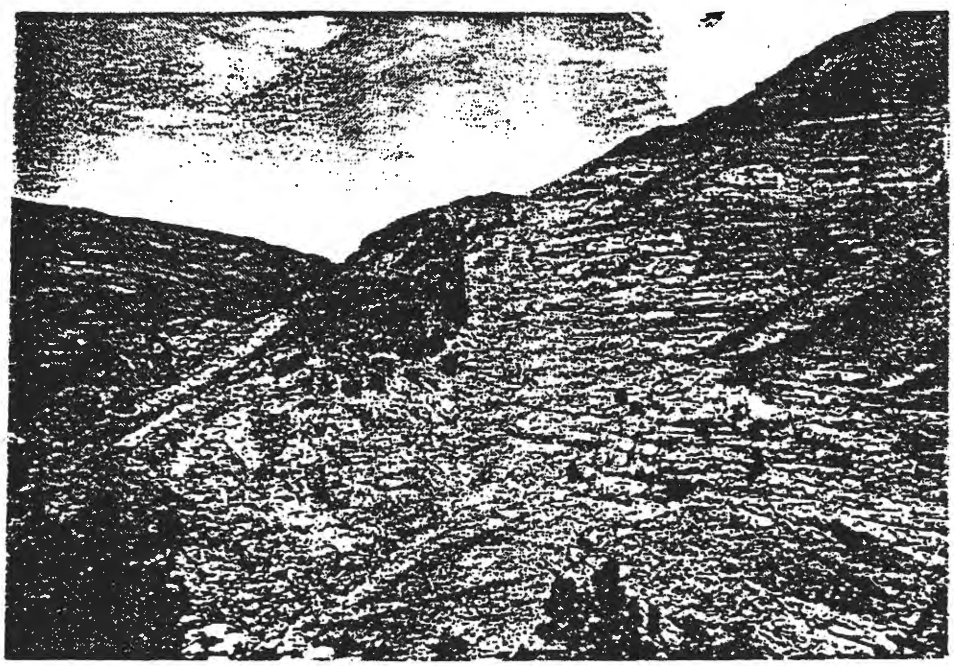
UNCONFORMITY

PRECAMBRIAN

Interrelated gneiss, schist and pegmatite. Dark gray dioritic gneiss is the most resistant and abundant rock type. Pegmatites are common and intrude both the gneiss and the schist.



prospect
North Castle Cliff Wash
prospect
Jubilee Mine
91
gravel pit
727063
South Castle
Cliff Wash prospects
Westside
Mine
Eldorado #3
Surprise Mine
Dewey
prospect
mines
(names
unknown)
Apex Mine
prospects
Jessie Mine
Paymaster Mine
West Jessie
Mine
Black Warrior
Mine
gypsum
prospects
Curly Hollow
Wash gypsum
prospects
prospect
gypsum prospects
Jose Cuervo
claims
Bulldog gypsum
claims
prospect
Grounds gypsum
prospects
0
1
2
3



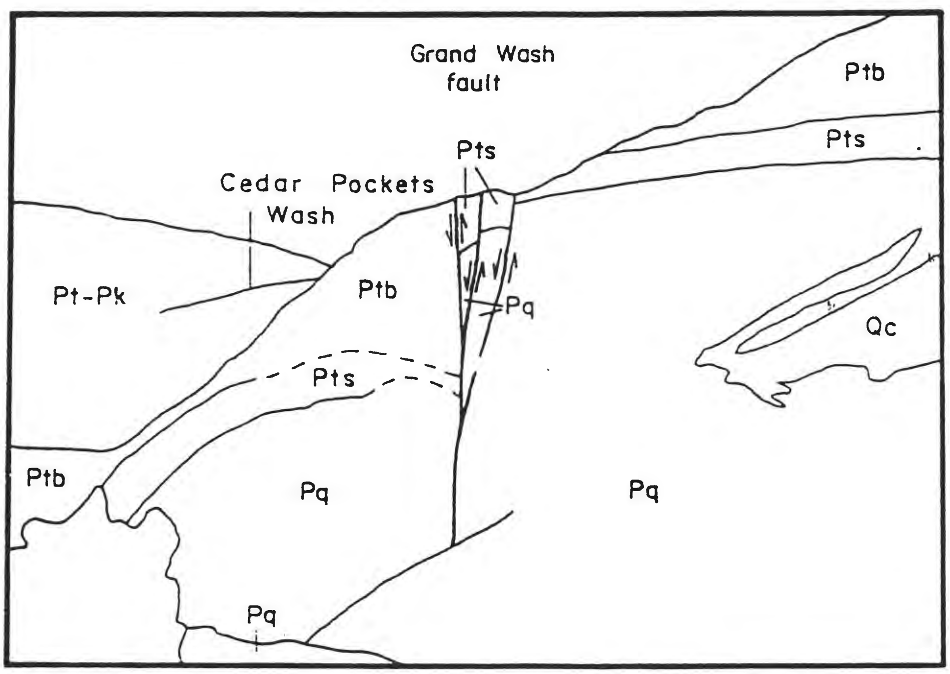

Grand Wash
fault
Ptb
Pts
Pts
Cedar Pockets
Wash
Pt-Pk
Ptb
Pq
Qc
Pts
Ptb
Pq
Pq
Pq

Figure 1

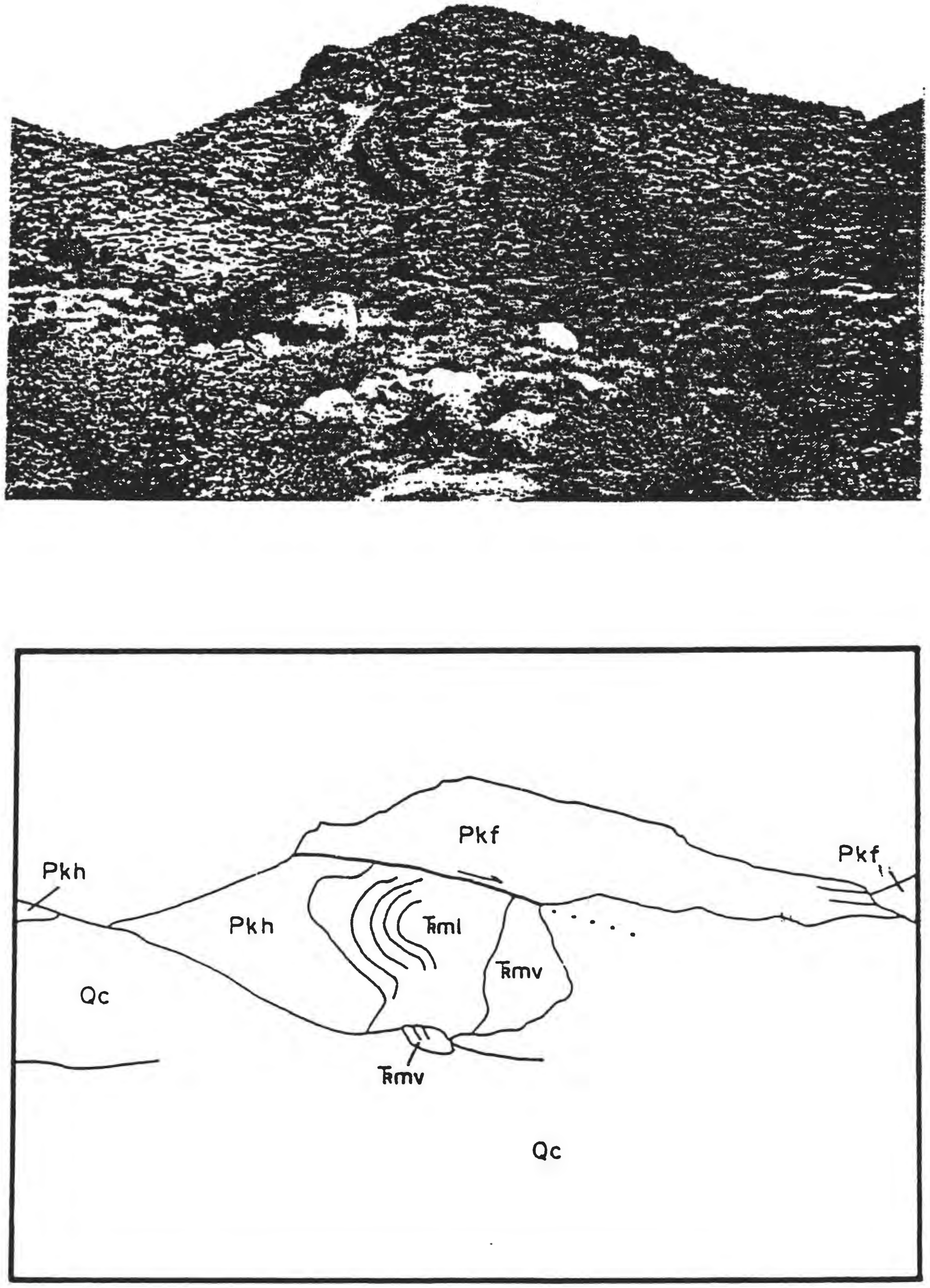
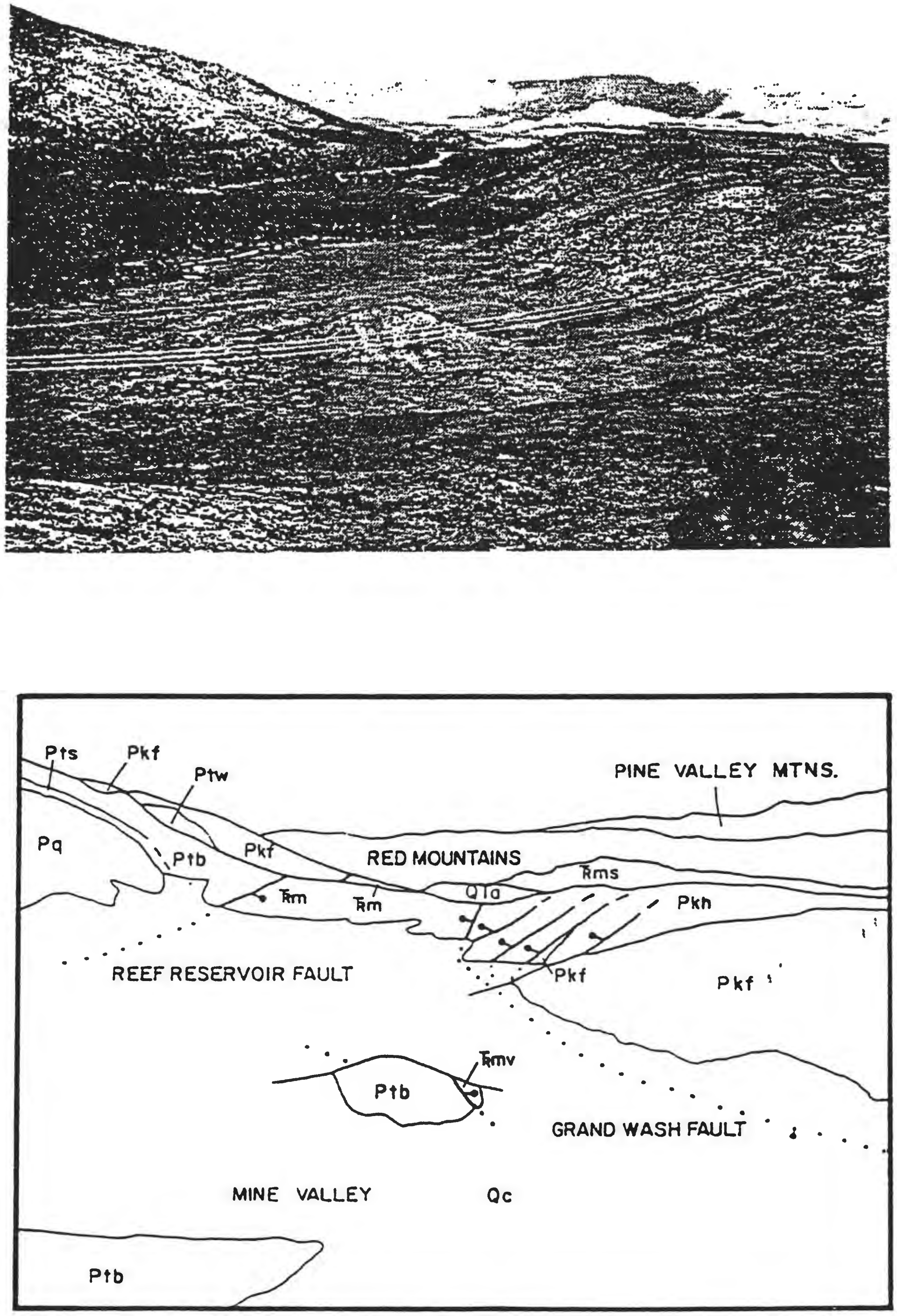


Fig. 2

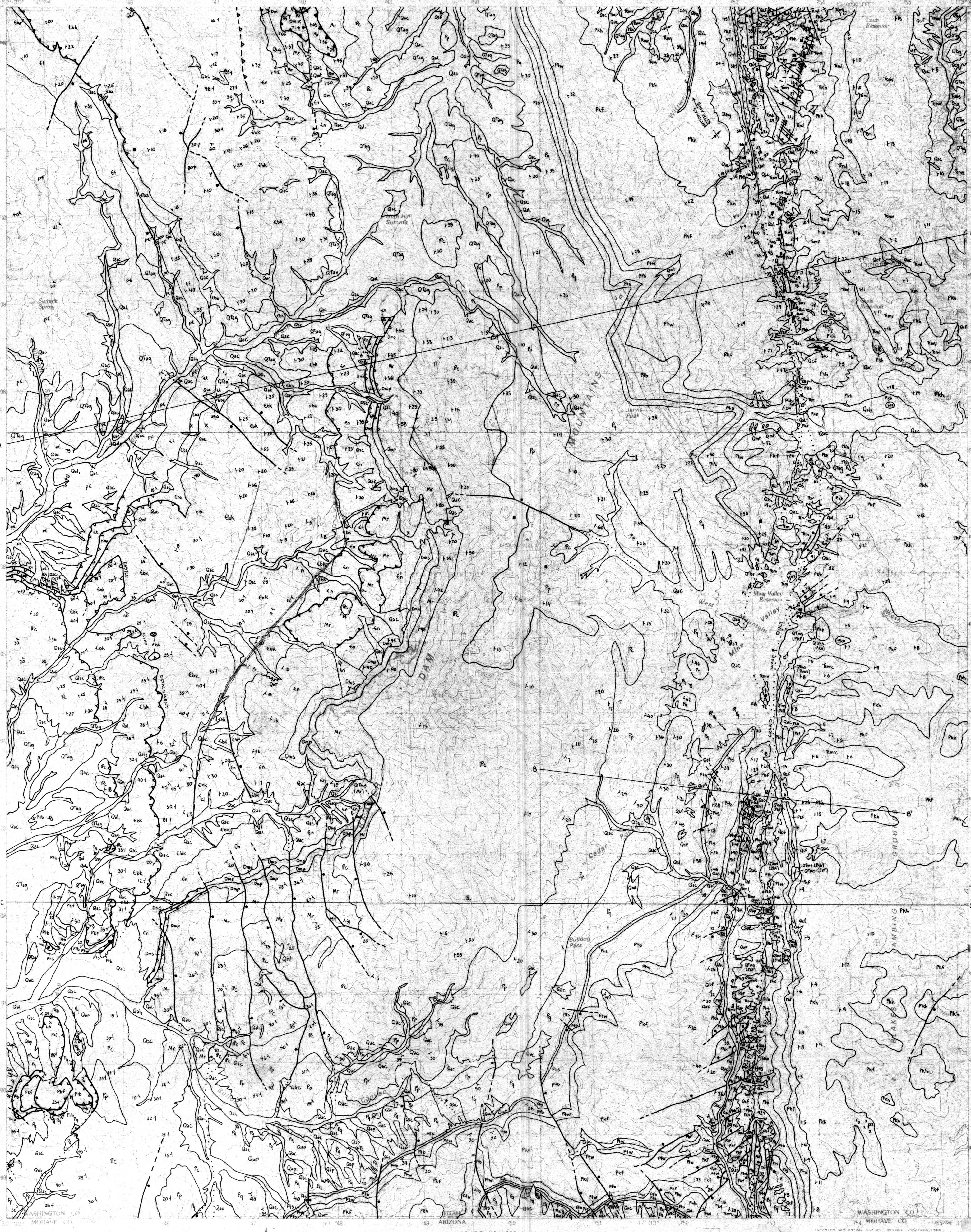


Pts
Pkf
Ptw
PINE VALLEY MTNS.
Pq
Ptb
Pkf
RED MOUNTAINS
TRms
TRm
TRm
QTa
Pkh
REEF RESERVOIR FAULT
Pkf
Pkf
TRmv
Ptb
GRAND WASH FAULT
MINE VALLEY
Qc
Ptb

Fig 3

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

JARVIS PEAK QUADRANGLE
UTAH-ARIZONA
7.5 MINUTE SERIES (TOPOGRAPHIC)



PRODUCED BY THE UNITED STATES GEOLOGICAL SURVEY
CONTROL BY USGS, NOS/NOAA
COMPILED FROM AERIAL PHOTOGRAPHS TAKEN 1975
FIELD CHECKED 1978 MAP EDITED 1983
PROJECTION LAMBERT CONFORMAL CONIC
GRID: 1000-METER UNIVERSAL TRANSVERSE MERCATOR ZONE 12
10,000-FOOT STATE GRID TICKS UTAH, SOUTH ZONE
UTM GRID DECLINATION 1°42' WEST
1983 MAGNETIC NORTH DECLINATION 14° EAST
VERTICAL DATUM NATIONAL GEODETIC VERTICAL DATUM OF 1929
HORIZONTAL DATUM 1927 NORTH AMERICAN DATUM

To place on the predicted North American Datum of 1983, move the projection lines as shown by dashed corner ticks (6 meters north and 71 meters east)

There may be private inholdings within the boundaries of any Federal and State Reservations shown on this map

All marginal data and lettering generated and positioned by automated type placement procedures

PROVISIONAL MAP
Produced from original manuscript drawings. Information shown as of date of field check. 3

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225
OR RESTON, VIRGINIA 22092

QUADRANGLE LOCATION

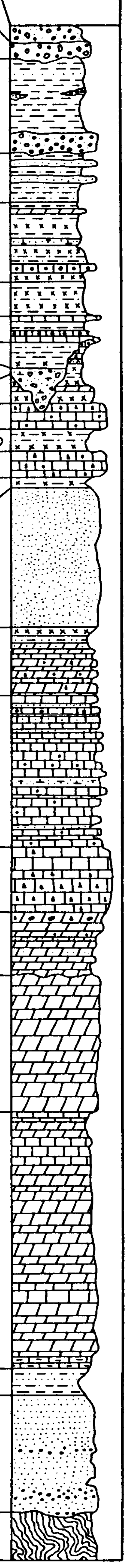
ADJOINING 7.5' QUADRANGLE NAMES

PLATE 1
Interim Geologic Map of the Jarvis Peak Quadrangle
Washington County, Utah
Open-File Report 212 July 1991
UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

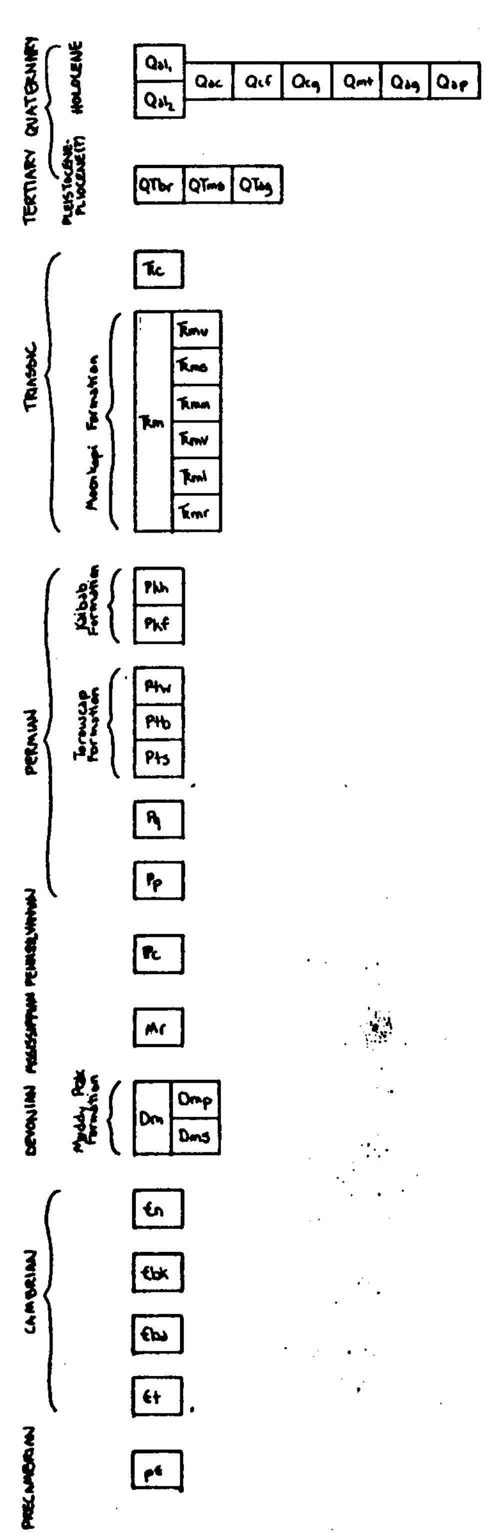
Becky J. Hammond
4/93

AB 2050

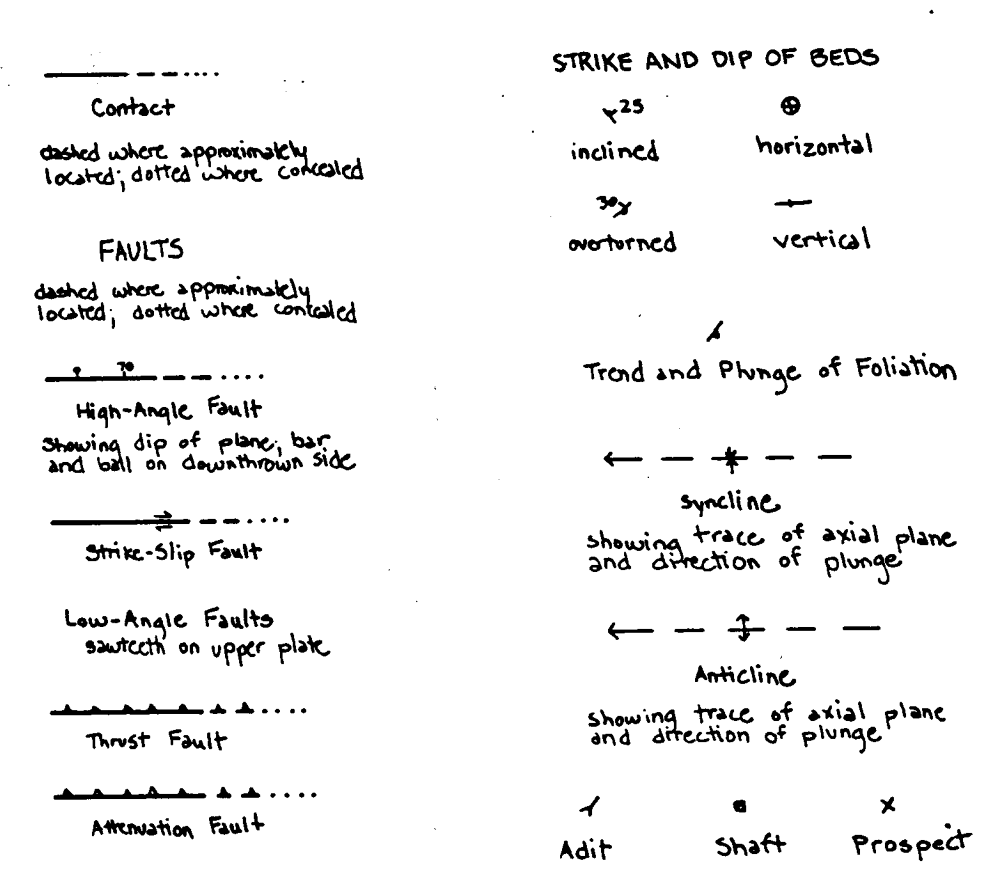
AGE	FORMATION		SYMBOL		THICKNESS (in feet)	LITHOLOGY
QUATERNARY	Alluvium, alluvium/colluvium, colluvium, talus, gravel and pediment alluvium		Qal, Qal₂ Qac Qcf Qcg Qmt Qag Qap		0-75	
PLIOCENE-PLEISTOCENE	Chert breccia, landslide materials and alluvial gravels		QTbr QTms QTag		0-150	
TRIASSIC	Chinle Formation	Petrified Forest Member	TRc	TRcp	1000	
		Shinarump Congl. Member		TRcs		
	Moenkopi Formation	Upper red member	TRm	TRmu	500	
		Shnabkaib Member		TRms	800	
		Middle red member		TRmm	340	
		Virgin Limestone Member		TRmv	240	
		Lower red member		TRml	0-250	
		Rock Canyon Congl. Member		TRmr	0-50	
PERMIAN	Kaibab Formation	Harrisburg Member	Pkh		0-350	
		Fossil Mountain Member	Pkf		250	
	Toroweap Formation	Woods Ranch Member	Ptw		130-230	
		Brady Canyon Member	Ptb		250	
		Seligman Member	Pts		80	
	Queantoweap Sandstone		Pq		1200-1500	
	Pakoon Dolomite		Pp		650-820	
PENNSYLVANIAN	Callville Limestone		IPc		1520	
MISSISSIPPIAN	Redwall Limestone		Mr		600	
DEVONIAN	Muddy Peak Dolomite	Pinnacle member	Dm	Dmp	500-700	
		Slope member		Dms		
CAMBRIAN	Nopah Dolomite		Єn		1380	
	Bonanza King Formation		Єbk		2600	
	Bright Angel Shale		Єba		260	
	Tapeats Quartzite		Єt		1300	
PRECAMBRIAN	Interrelated gneiss, schist and pegmatite		pЄ			

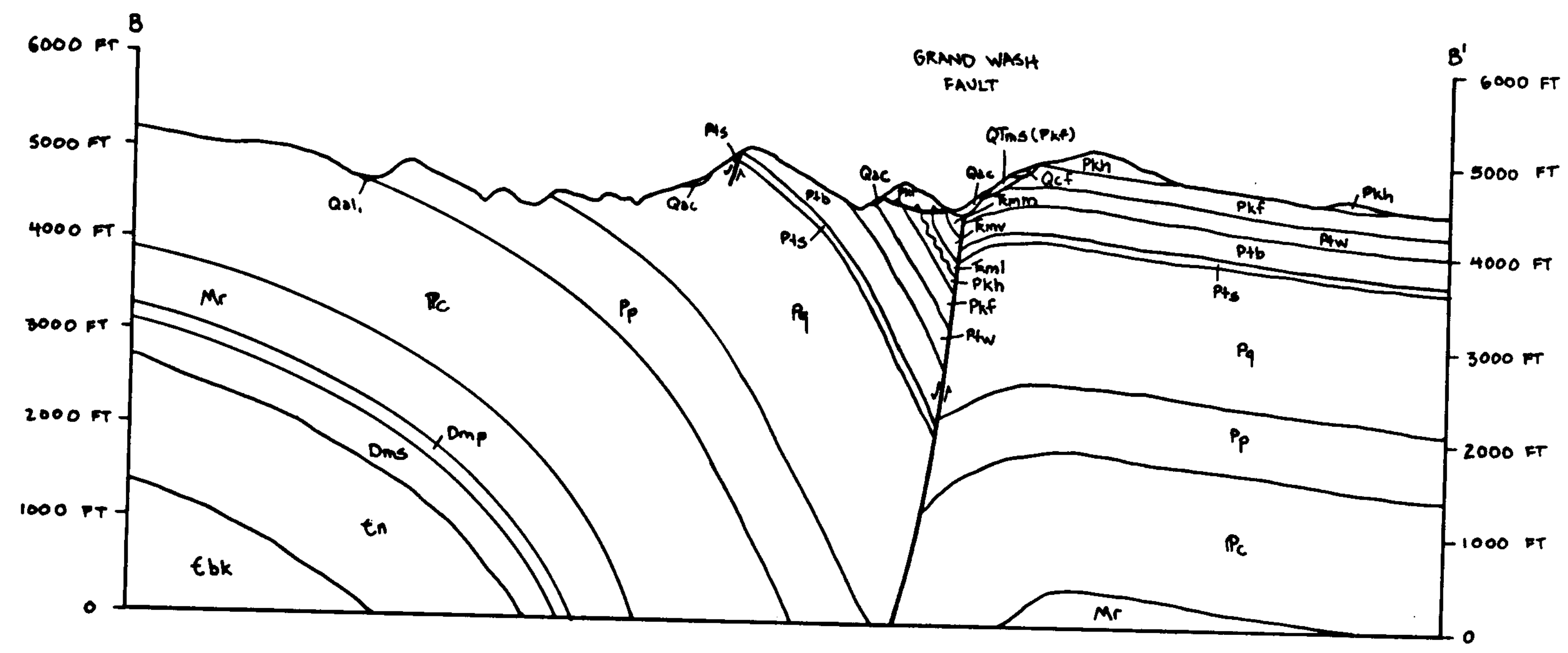


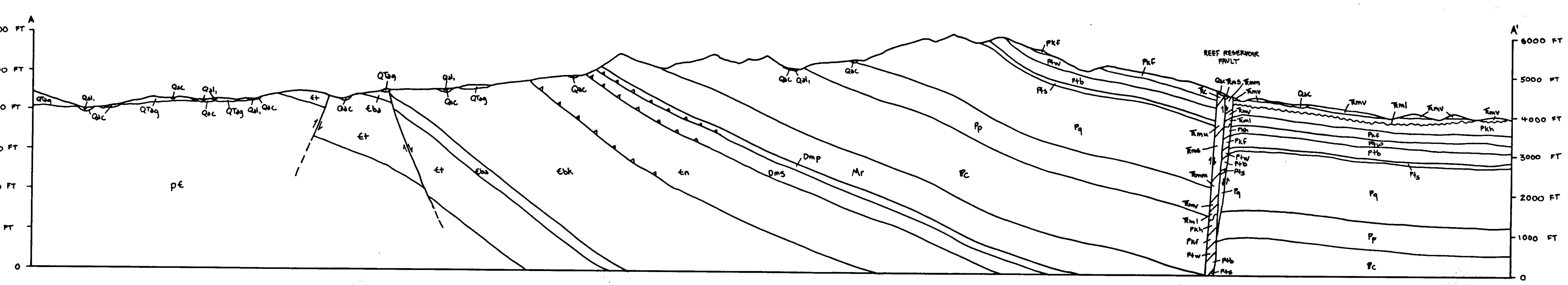
CORRELATION OF MAP UNITS

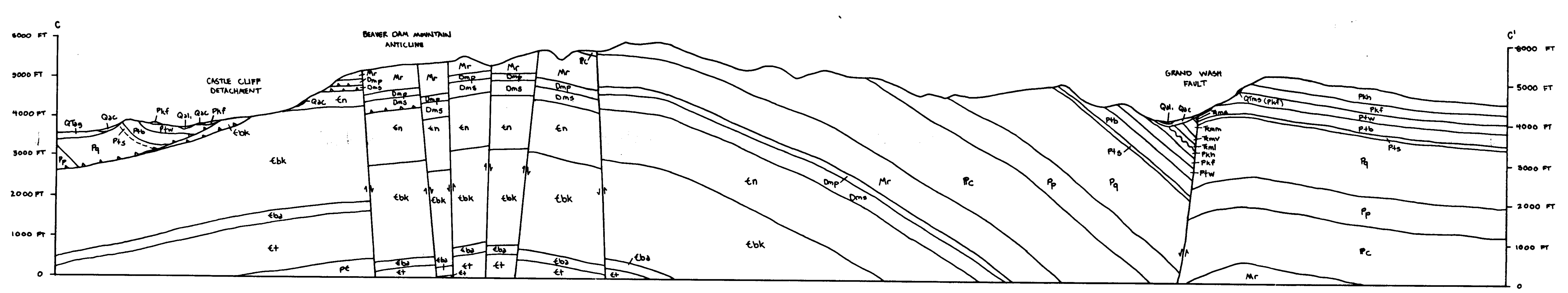


MAP SYMBOLS









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