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PRELIMINARY GEOLOGIC MAP OF THE ENTERPRISE QUADRANGLE, WASHINGTON AND IRON COUNTIES, UTAH

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INTRODUCTION

This map is the first to be released of 4 contiguous 1:24,000-scale geologic map sheets comprising the area known informally as the Bull Valley district of the eastern Bull Valley Mountains. The district contains abundant low-grade contact metasomatic and jaspillitic sediment-hosted iron deposits, and less abundant but higher-grade vein-iron deposits. All are associated with monzonitic hypabyssal magmatism of early Miocene age, including emplacement of the Big Mountain intrusion, which cores the Big Mountain structural and topographic dome in the southeast corner of the Enterprise quadrangle. Numerous iron mining claims in the district were patented in years past but intensive exploration, including diamond drilling, had ceased by about 1960 and no ore has ever been shipped from the district on a commercial basis.

Mineral resources of the eastern Bull Valley Mountains and vicinity include gold and silver in addition to iron. The Goldstrike district, about 18 km southwest of the Enterprise quadrangle, is currently an active gold producer; and until recently the Escalante mine, located a few km north of the quadrangle, was an important primary producer of silver. Ground water is doubtless the most significant non-mineral resource in the quadrangle, sustaining a flourishing agricultural industry in the southern Escalante Valley.

The structural and stratigraphic framework of southwest Utah, including the Bull Valley Mountains, is discussed in reports by Rowley and others (1979), Hintze (1986), Siders and Shubat (1986), Winkler and Shubat (1990), and Blank and others (1992), among others. Geophysical data have been presented by Blank and Kucks (1989) and Blank and Crowley (1990). Published geologic maps of the region include works by Hintze (1963) at 1:250,000-scale and Cook (1960) at a scale of approximately 1:130,000.

Geology shown on this map has been compiled from the early work of Blank (1959) at scale 1:20,000, with modifications and expanded coverage resulting from additional field work carried out by the author during 1989-1992 and subsequent photogeology at the U.S. Geological Survey offices in Denver. Photogeology is the main basis for delineation of unconsolidated Quaternary deposits, which up to this point have received only brief field examination. Volcanic rocks in the descriptive text are named according to the chemical classification of Le Bas and others (1986), except where no chemical data are yet available, in which case the rock name is tentative and followed by a query. Petrographic descriptions are from Blank (1959) and the published literature; more detailed data for many of the volcanic units that have regional distribution are contained in reports by Best and Grant (1987), Best and others (1987), and Scott and others (in prep.). Macroscopic rock color for units described in the present report have been assigned subjectively, without reference to the Rock Color Chart (Geological Society of America, Rock-Color Chart Committee, 1948); because of the wide range of colors typically exhibited from place to place by all but a few rock units, this attribute may be misleading if precisely specified. Isotopic dates, all from published literature, are reported with 2-sigma errors where multiple results (each with its own analytical error) have been published, and pre-1976 K-Ar dates have been recalculated in consideration of the revised constants of Steiger and Jager (1977), using the conversion tables of Dalrymple (1979).

DESCRIPTION OF MAP UNITS

SEDIMENTARY AND VOLCANIC UNITS

Qal **Alluvium (Holocene)**--Alluvium of active ephemeral and intermittent streams. Includes weakly incised (gullied) fillstrath terrace deposits of Meadow Creek (Holt Canyon) in northeastern part of quadrangle, and subordinate colluvium. Maximum thickness probably about 3 m

Qct **Colluvium and talus (Holocene)**--Colluvial and talus deposits, mapped where they conceal the lithology and structure of underlying bedrock. Unit has indefinite boundary with alluvium downslope (Qal) and locally with high-level pediment gravel (Qpg) upslope. Maximum thickness about 5 m

Qsy **Young flood-plain deposits of Shoal Creek (Holocene)**--Silt, sand, and gravel comprising natural levee and overbank deposits of modern flood plain of Shoal Creek. Includes subordinate overbank deposits from flooding of Spring Creek, a tributary debouching west of Enterprise. Unit boundary locally obscured by cultural modifications of landscape. Maximum thickness unknown, but possibly about 10 m

Qso **Old flood-plain deposits of Shoal Creek (Holocene)**--Silt, sand, and gravel comprising older flood-plain deposits of Shoal Creek, downstream from Enterprise in Escalante Valley. Unit delineated by photointerpretation, as flattish, northeast-widening surface that truncates flanking bahadas, displays vague northeast-trending flood-scour marks, and is incised on its west side to a depth of several meters by modern flood plain of Shoal Creek. Area of these deposits is possibly subject to inundation during extremely severe flooding of Shoal Creek. Maximum thickness unknown; probably at least 10 m

Qty **Young stream terrace deposits (Holocene and Pleistocene)**--Gravel, sand, and silt of relatively young aggradational stream terraces, 1-5 m above modern valley floor. Thickness several meters

Qfc **Coalesced-piedmont-fan (bahada) deposits (Holocene and Pleistocene)**--Generally coarse alluvium (gravel, sand, silt) of coalesced piedmont fans and aggraded floors of associated feeder drainages. Together with Meadow Creek fan (deposits distinguished as Qfm; see below), these fans form a bahada whose distal margin is truncated by Shoal Creek flood plain. Upslope contacts approximately located and in some places poorly located, especially where obscured by slopewash of basin-fill deposits (QTbf; see below). Maximum thickness possibly as much as 50 m at heads of fans

Qfm **Fan deposits of Meadow Creek (Holocene and Pleistocene)**--Generally coarse alluvium (gravel, sand, silt) of Meadow Creek (Holt Canyon) piedmont fan. Penecontemporaneous with deposits of coalesced piedmont fans (Qfc) but constructional surface somewhat higher than that of adjacent fans. Deposits of Meadow Creek unit readily distinguished by relative abundance of red-orange silt. Unit includes alluvium of minor flanking drainages and is correlative with young stream-terrace deposits (Qty) in Holt Canyon. Maximum thickness 50-60 m

Qls **Landslide deposits (Holocene and Pleistocene)**--Unsorted, angular debris of landslides and slumps. Maximum thickness 10-20 m

Qaf **Alluvial fan deposits (Holocene and Pleistocene)**--Alluvium of minor alluvial fans, and deposits of talus cones. Maximum thickness 5-10 m

Qlr **Loess and rubble deposits (Holocene and Pleistocene)**--Light-tan to dark-brown aeolian silt and soil, and coarse volcanic rubble locally mantling flattish high surfaces of Miocene and younger lava flows. Rubble is mainly non-transported flow-top debris, modified by weathering; aeolian deposits and dark soil fill primary surface irregularities. Mapped by photointerpretation. Maximum thickness several meters

Qlp **Loess and playa deposits (Holocene and Pleistocene)**--Aeolian silt, soil, little-transported volcanic rubble, and saline clay in closed depressions exclusively on surfaces of andesite of Black Hills (Qbh). Maximum thickness 5-10 m

Qto **Old stream terrace deposits (Holocene and Pleistocene)**--Gravel, sand, and silt of relatively old aggradational stream terraces, 5-15 m above modern valley floor. Thickness several meters

Qfo **Old piedmont-fan deposits (Holocene and Pleistocene)**--Alluvium of isolated fan remnants located between mouths of Twin Springs Creek and Cottonwood Creek, about one mile southeast of Enterprise. These remnants are 5-15 m above level of closest coalesced-piedmont-fan deposits (Qfc), and probably are penecontemporaneous with older stream terrace deposits (Qto). Maximum thickness about 10 m

Qpg **Pediment deposits (Pleistocene)**--High-level pediment gravel deposited on beveled basin fill and older rocks on southern and southwestern margins of Escalante Valley. Unit mapped only where associated with a well-identified pediment surface; merges with alluvium and talus and generally has indefinite boundaries. Best exhibited capping steep-faced bluffs on north side of Shoal Creek immediately west of Enterprise. Maximum thickness 5-10 m

Qbh **Andesite of Black Hills (Pleistocene?)**--Black, sparsely porphyritic two-pyroxene andesite lava. Characterized by presence of coarse (to 4-5 mm diameter), blocky phenocrysts of zoned plagioclase and more numerous but finer phenocrysts of hypersthene. Formerly designated *Black Hills basalt* (Blank, 1959); classified as andesite on basis of chemistry (Hausel and Nash, 1977). Well-preserved dendritic pattern of flow channels indicates that flows issued from vent at base of Ox Valley Peak, 10 km south-southwest of Enterprise. Maximum thickness about 200 m

Qenc **Basalt of Enterprise cinder cone (Pleistocene?)**--Basaltic tephra of little-dissected cinder cone centered 3.5 km southwest of Enterprise, on map margin. Dominantly black cinders, with subordinate red scoria and cinders; includes spatter lapilli, blocks, and bombs. Contains abundant fine-grained phenocrysts of olivine and augite; petrographically similar to basaltic lava of Enterprise and Gum Hill (QTen and Tgh; see below). Cinder cone postdates lavas immediately west of Enterprise but may be penecontemporaneous with youngest lava of Enterprise succession mapped in Hebron quadrangle, just west of long 113°45'W. Thickness 0-175 m (approximate topographic relief of cone)

QTen **Basalt of Enterprise (Pleistocene(?) and Pliocene)**--Dark-gray- to black-weathering olivine-augite basalt lava immediately south and west of Enterprise. First described and informally named by Blank (1959); geochemistry of sample from 4 km west of Enterprise reported by Hausel and Nash (1977). Phenocrysts consist almost exclusively of diopsidic augite and olivine, with the augite generally much more abundant. Plagioclase occurs as fine laths or prisms that approach phenocryst size. The groundmass contains olivine, clinopyroxene and finely dispersed Fe-Ti oxide, in addition to plagioclase and cryptocrystalline to glassy material. From the analyses reported by Hausel and Nash (1977), the rock plots as a trachybasalt but is very close to the trachybasalt-basalt line. Youngest flows of succession, northwest of Enterprise cinder cone, have youthful surface morphology. Age range based on similarity to dated lavas from nearby areas in southwestern Utah (Best and others, 1980). Number of discrete flows unknown; no interbeds have been found. Source vent probably in vicinity of Enterprise cone. Maximum thickness in Enterprise quadrangle about 100 m

QTbf **Basin-fill deposits (Pleistocene(?) and Pliocene)**--Light-gray to buff, poorly consolidated, gravel, sand, and silt deposited in structurally controlled topographic depression of Escalante basin by fluvial and sheetwash processes. Upper part contains abundant pedogenic caliche and is locally capped by pediment gravels or by basalt of Enterprise. Much of basal zone is rich in coarse basaltic clasts, which give it a darker aspect than the rock above. In places, particularly where unit directly overlies volcaniclastic rocks of Enterprise Reservoir (Ter), lower bound is not well located. Unit typically dips 5-10° basinward. Thickness probably exceeds 1 km in northeastern corner of map area, where unit is inferred to underlie piedmont fan deposits (Qfc, Qfm) and fill southwestern extremity of 3-km deep Newcastle graben (Pe and Cook, 1980).

Tgh **Basalt(?) of Gum Hill (Pliocene(?) and Miocene)**--Dark-gray- to black-weathering olivine-augite basaltic lava flows forming caprock of Gum Hill and other high prominences east-southeast of Enterprise. In previous work, unit was informally designated *Flattop Mountain basalt* (Blank, 1959) because of petrographic and structural similarities to caprock of Flattop Mountain, in Hebron quadrangle (Blank, in prep). Unit appears to be about the same age as basalt of Flat Top Mountain area but is distinguished here pending further work on correlations. Basalt on Flat Top Mountain has been dated by whole-rock K-Ar analysis (of specimen collected about 10 km west of Enterprise) at 7.7±0.2 Ma (Best and others, 1980). Basalt(?) of Gum Hill is also petrographically similar to basalt of Enterprise (QTen), which is structurally much less disturbed and appears to be much younger. Gum Hill unit includes basaltic lava flow and flow-breccia exposed in isolated outcrops at low elevations north of Gum Hill and between Spring Creek and Cottonwood Creek. Maximum thickness about 50 m

Ter **Volcaniclastic rocks of Enterprise Reservoir (Pliocene? and Miocene)**--Soft, predominantly pink to salmon-colored, largely volcaniclastic sandstone, siltstone, and mudstone; poorly to moderately consolidated volcanic pebble-cobble conglomerate of alluvial fan and fluvial origin; subordinate white and gray airfall ash in layers a few cm to tens of cm thick. Informally named for occurrences in vicinity of Enterprise Reservoir, 12-15 km west-southwest of Enterprise (*Reservoir formation* of Blank, 1959). In part temporally equivalent and lithologically similar to (though not contiguous with) Muddy Creek Formation of southern Nevada (see Cook, 1960b; Hintze, 1986). Near Enterprise Reservoir and Flat Top Mountain, in Hebron quadrangle, volcaniclastic sedimentary rocks of Enterprise Reservoir are intercalated with non-welded rhyolitic ash-flow tuff (sillar) and agglomerate, and are deformed and penetrated by rhyolite intrusives. Deposits mainly occupy broad, arcuate structural depression peripheral to south half of Flat Top Mountain rhyolite eruptive complex, which is centered about 9 km southwest of Enterprise (Blank, 1959; in prep.). Where unit is directly overlain by basin-fill deposits of Pleistocene(?) and Pliocene age, which have many similar lithologic characteristics, location of its upper boundary is uncertain. Maximum thickness in Enterprise quadrangle about 120 m, but much thicker near Enterprise Reservoir

Tsh **Rhyolite of Shinbone Creek (Pliocene(?) and Miocene)**--Light-tan, gray, and pink, biotite-bearing rhyolite to dacite lava exposed in limited area in vicinity of Shinbone Creek, about 6 km south of Enterprise at southern margin of quadrangle. Informally named *Shinbone rhyolite* and described by Blank (1959). Plots approximately on rhyolite-dacite boundary, using major-element analyses supplied by Columbia Iron Mining Company (see Blank, 1959). South of quadrangle boundary, in adjacent Central West quadrangle, unit is stratiform and highly vesicular; in Enterprise quadrangle, unit displays contorted flow layering, is relatively dense, and contains sparse, ovoidal, holocrystalline cognate inclusions. Phenocrysts are highly variable but on average comprise about 10% of rock volume and consist mainly of subequal amounts of quartz, plagioclase, and sanidine up to 4-5 mm in diameter. Fine-grained phenocrysts of biotite are present in subordinate amounts, along with minor oxyhornblende; minor accessories seen in thin section are Fe-Ti oxide, zircon, apatite, and sphene. Shinbone rhyolite mass is interpreted as exogenous volcanic dome of low relief, erupted during period of emplacement of volcaniclastic rocks of Enterprise Reservoir, and spreading laterally over surface as frothy lava. Northern periphery of dome probably is buried beneath younger volcaniclastic rocks of Enterprise Reservoir (Ter) and andesite of Black Hills (Qbh). Maximum exposed thickness about 150 m

Trc **Racer Canyon Tuff (Miocene)**--White to pale gray, moderately welded, moderately crystal-rich rhyolite to dacite, regional ash-flow tuff. Contains 15-30% felsic phenocrysts (quartz, sanidine, and plagioclase in amounts ranging from subequal, to predominantly quartz or plagioclase), a few percent mafic phenocrysts (chiefly fine flakes of biotite, with much less abundant oxyhornblende and accessory Fe-Ti oxide). Also contains abundant red, brown, and purple lithic clasts and cognate pumice. Name first informally used by Blank (1959) for tuff member exposed in Racer Canyon, 18 km southwest of Enterprise, and later formalized as a formation name by Rowley and others (1979). Classified as dacite, using major-element analysis supplied by Columbia Iron Mining Company (see Blank, 1959); as "rhyolitic" by Siders and others (1990) based on same classification scheme and unspecified analysis. Apparent discrepancies in nomenclature may indicate a real difference in rock type, reflecting compositional zoning within the sequence of ash-flows. Mean average radiometric age based on 3 K-Ar analyses of biotite from Racer Canyon Tuff from 1) near Gunlock and 2) 30 km S of Enterprise (Noble and McKee, 1972), and 3) the Mt. Escalante area 25 km northwest of Enterprise (Siders, 1990), is 19.6±1.8 Ma. A lead-alpha date of 19 Ma was obtained by Jaffe and others (1959) from zircon in Racer Canyon Tuff apparently collected near Kane Point, about 20 km east of Enterprise. Eruptive source probably in eastern part of Caliente caldera complex (Ekren and others, 1977; Rowley and Siders, 1988; Siders and others, 1990). Unit is similar in age and lithology to Hiko Tuff of Dolgoff (1963), which was derived from western part of Caliente complex (Rowley and others, 1990). Regional relations and detailed lithology of Racer Canyon Tuff have been discussed by Siders and others (1990).

At type locality in Racer Canyon, Racer Canyon Tuff consists of at least two compound cooling units and 2-3 m of intervening volcaniclastic sedimentary strata. Lower unit is typically more welded, somewhat darker, and contains more abundant biotite. Racer Canyon Tuff in Enterprise quadrangle is believed to be mainly correlative with lower of these two units, based on lithologic character of ash-flow tuff and on presence of several meters of overlying white to gray, well-bedded airfall tuff and water-lain volcaniclastic strata that are included with the map unit. Unit rests on andesite of Shoal Creek (Tsc; see below). Maximum thickness exposed in quadrangle is probably only about 50 m, but in type section and elsewhere in eastern Bull Valley Mountains and adjacent areas Racer Canyon Tuff attains thicknesses of as much as several hundred meters. Large thickness variations are attributable in part to topographic relief associated with pre-existing andesitic volcanic centers and monzonitic hypabyssal intrusions.

Tmr **Andesite(?) porphyry of Maple Ridge (Miocene)**--Dark-purple, less commonly red and brown, porphyritic andesite(?) lava and flow breccia characterized by abundant phenocrysts of coarse (up to one cm diameter), blocky, zoned plagioclase (20-25% of the rock volume). Smaller and less numerous phenocrysts consist mainly of biotite and oxyhornblende in subequal amounts (about 10% of volume); other minerals include minor augite and less common, deeply embayed quartz and altered olivine, in addition to accessory Fe-Ti oxide. Occurs only in extreme northwest corner of quadrangle, in North Hills, although is widespread in quadrangles to west and southwest. Informally named for occurrences on Maple Ridge, about 15 km southwest of Enterprise (Blank, 1959). Probably erupted from predominantly hornblende andesite stratovolcano complex in North Hills. Occupies similar stratigraphic position to that of dacite of Piñon Park Wash and may be facies of same flow or flows (see below). No chemical or isotopic data yet available. Maximum thickness in quadrangle is about 170 m, assuming subhorizontal attitudes, but this figure is highly uncertain.

Tpw **Dacite of Piñon Park Wash (Miocene)**--Red to gray and lavender, crystal-rich, porphyritic dacitic lava. First named and described by Siders (1985a), for occurrence as flow or flow-dome sequence in vicinity of Piñon Park Wash northwest of Enterprise (Piñon Point quadrangle). Consists of up to 50% phenocrysts, mainly coarse, blocky, zoned plagioclase, with subordinate fresh biotite, typically in thick books. Minor augite, Fe-Ti oxide, and quartz; traces of hornblende and sanidine, and accessory apatite and zircon are seen in thin section (Siders, 1985a). Classified as trachyandesite according to mean values of Na_2O, K_2O, and SiO_2 reported by Siders (1985a), but trachydacite, dacite, and andesite are all permissible classifications taking into account standard deviations. Modal composition is similar to that of Harmony Hills Tuff (Tqh; see below). Occurrence in Enterprise quadrangle restricted to a single roadcut about one mile north of Enterprise, and at this site field relations are obscure. Directly overlies hornblende andesite (andesite of Shoal Creek (Tsc); see below) in good exposures on north side of Shoal Creek about 3 miles west of Enterprise. Siders (1985a) reports K-Ar date of 21.7±3.3 Ma obtained from biotite. Maximum thickness in Enterprise quadrangle possibly only about 10 m; much thicker to west.

Tsc **Andesite of Shoal Creek (Miocene)**--Varicolored, two-pyroxene hornblende-andesitic lava, laharic breccia, and agglomerate of eruptive complex centered in North Hills area northwest of Enterprise. A small area of hydrothermally altered hornblende andesite occurs in a fault zone in the northwest corner of the Enterprise quadrangle, and numerous zones of hydrothermal alteration occur in andesitic rocks and associated volcaniclastic sedimentary rocks exposed in the adjacent Hebron quadrangle (Blank, in prep.). Fresh lava and mudflow facies are typically dark brown; agglomerate facies typically exhibits black, glassy, subrounded pyroclasts in a light- to dark-gray, ashy matrix. Abundant phenocrysts of black hornblende reaching lengths of up to one cm are characteristic, although in some occurrences the rock is uniformly fine grained. Phenocryst content ranges to about 40%, and averages about two-thirds plagioclase, one-third mafites. Mafic phenocrysts are mainly hornblende (25-30% of phenocrysts), augite (also 25-30%) and hypersthene (about 40-50%). Iron-titanium oxide is the most common accessory. Unit was informally named *Shoal Creek breccia* by Blank (1959), after rudely bedded laharic deposits that occur on either side of Shoal Creek about 10 km west of Enterprise. Correlative lava flows in Beryl Junction and Piñon Point quadrangles, immediately north and northwest, respectively, of the Enterprise quadrangle, were mapped as *andesite of Enterprise* by Siders (1985b, 1985a); chemical analysis reported by Siders (1985a, 1985b) indicates classification as basaltic andesite, with basaltic trachyandesite a permissible classification within analytic uncertainty. A K-Ar date of 24.2±1.2 Ma was obtained for hornblende from andesite of the Piñon Point quadrangle (Siders, 1985a), but the actual age may be less than 22 Ma, based on isotopic ages of two underlying ash-flow tuffs (upper cooling unit of Rencher Formation (Tr2) and Harmony Hills Tuff(Tqh)) in the Bull Valley Mountains southwest of Enterprise (Maple Ridge quadrangle). Maximum thickness in Enterprise quadrangle possibly as much as 200 m, judging from topographic relief and assuming subhorizontal attitudes in North Hills, but attitudes there are difficult to determine and base is not exposed.

Tr **Rencher Formation, undivided (Miocene)**--White, tan, brown, red, and purple, lightly to moderately welded, mostly deuterically altered, crystal-rich, andesite to dacite, regional ash-flow tuff and tuff-breccia. Exposed in south-central part of quadrangle. Phenocrysts comprise 25-40% of rock and consist of about two-thirds plagioclase and one-third mafites. The absence of quartz and sanidine in the phenocryst mode distinguish this unit from Harmony Hills Tuff (Tqh; see below). Mafites in order of decreasing abundance are biotite (about 20% of phenocrysts), hornblende (10%), and augite (5%); accessory minerals are abundant Fe-Ti oxide and apatite, and sparse zircon. Pyrogenic Fe-Ti oxide occurs both as discrete phenocrysts and as inclusions in other mafics; it comprises as much as several percent of fresh, unaltered Rencher vitrophyre in Moody Wash, 16 km south of Enterprise. Hematitic fine-grained Fe-Ti oxide is a ubiquitous product of vapor-phase alteration of the tuff and commonly imparts to highly altered rock a reddish coloration; fresher, glassy phases near the base and top are generally gray-greenish. Devitrified glass of groundmass is composed of microcrystalline to cryptocrystalline alkali (mainly potassium) feldspar and silica. The rock is classified as andesite to dacite, using analyses of Columbia Iron Mining Company as reported by Blank (1959). Its modal and chemical compositions are similar to those of hypabyssal quartz monzonite porphyry intrusions of the so-called *iron axis* of southwest Utah (Tobey, 1976; see description of intrusive units, below). Rencher ash flows are widespread in the eastern Bull Valley Mountains, northern Pine Valley Mountains, and Iron Springs district. The unit was named by Cook (1957, 1960) for exposures at Rencher Ranch (now Broken Arrow Ranch) in Grass Valley, about 8 km northeast of the town of Pine Valley and 25 km southeast of Enterprise. Rencher cooling units in the Pine Valley Mountains and Iron Springs district are approximately coeval with and mineralogically similar to, but not necessarily identical to, cooling units in the Bull Valley Mountains; it is now known that Rencher ash flows have more than one source (D.B. Hacker, in prep.). Two cooling units are locally distinguished in the Enterprise quadrangle. Both were erupted from a fissure-like vent on the crest of the Bull Valley-Big Mountain intrusive arch, a northeast-trending, largely buried ridge of quartz monzonite porphyry that is approximately co-linear with intrusions of the Iron Springs district. The northeast end of this arch is exposed at the southern margin of the Enterprise quadrangle (Big Mountain intrusion (Tqmb); see description of intrusive units, below). The ash-flow vent is located at the southwest end, 13-15 km south-southwest of Enterprise (Bull Valley intrusion).

Tr2, **Upper cooling unit**--Red to purple ash-flow tuff. A simple cooling unit, typically darker, denser, and more crystal-rich than the underlying cooling unit (Tr1; see description below) pervasively altered by vapor-phase processes. Contains sparse xenoliths, mostly less than 2-3 cm in diameter. Bulk of rock composed of eutaxitically foliated, subangular to subrounded cognate inclusions in a wide range of sizes but mostly less than 10 cm in diameter. Unit represents the culminating eruptions from the Bull Valley vent and generally is the only Rencher unit found on or north of the crest of the intrusive arch. Close to source vent (in Maple Ridge and Central West quadrangles), top of unit is a flow breccia, indicating late-stage viscous mobility. Base of unit appears gradational with underlying cooling unit through distance of several cm, but south and southwest of vent upper and lower units are separated by a largely hematitized layer of laminated airfall tuff. Locally the two units are virtually indistinguishable. Isotopic age of upper Rencher cooling unit is 21.65±0.3 Ma based on K-Ar analyses of biotite from Rencher at two locations (Rowley and others, 1989). This age is within range of ages reported for intrusions of the iron axis (see description of intrusive units, below). Maximum thickness of known upper unit in Enterprise quadrangle could be as much as 500-600 m.

Tr1, **Lower cooling unit**--composed mainly of white tuff breccia. Probably a simple cooling unit in Enterprise quadrangle but elsewhere is typically compound. The tuff breccia contains abundant angular lithic fragments of older sedimentary and extrusive volcanic rocks, quartz monzonite porphyry, and dense, blue-purple Rencher-like rock of probable intrusive origin. Map unit also contains numerous subangular to subrounded cognate inclusions; both these inclusions and their host have undergone varying degrees of deuteric (vapor-phase) alteration. Lower Rencher is known to occur at only two places in the Enterprise quadrangle: one about 6 km south of Rose Spring and the other about 0.6 km southwest of Twin Spring; both localities are 5-6 km southeast of Enterprise. Maximum thickness at these localities is possibly 10-15 m. South and east of the quadrangle the unit becomes much thicker, and several internal partial cooling breaks are recognized.

Quichapa Group (Miocene and Oligocene)--name informally used by J.H. Mackin (as reported by Cook, 1957) for a sequence of three regional ash-flow tuffs well exposed in Quichapa Canyon of Harmony Hills, 40 km east of Enterprise. Cook (1957) proposed group rank for the Quichapa but did not formalize names of the ash-flow tuffs. Mackin (1960) lowered the rank to formation and distinguished four ash-flow tuffs, or members, which he named the Harmony Hills Tuff (Tqh), Bauers Tuff (Tqcb), Swett Tuff (Tqcs), and Leach Canyon Tuff (Tql) (in descending order). Williams (1967) and Anderson and Rowley (1975) reinstated Quichapa to group status. The age initially assigned, Miocene, was extended to Oligocene as a result of isotopic dates for the Leach Canyon Formation (Tql). Field descriptions of Quichapa ash-flow tuff sections and documentations of regional correlations have been given by Cook (1965) and Williams (1967); Williams (1967) has also provided chemistry and detailed petrography. Quichapa ash-flows, like those of the underlying Isom Formation (Tis; see below), were mostly spread over surfaces of flattish regional topographic relief, punctuated in some places by andesitic stratovolcanoes.

Tqh **Harmony Hills Tuff (Miocene)**--Red to pink, moderately welded, crystal-rich trachyandesite to andesite ash-flow tuff. Contains 35-50% phenocrysts, which are predominantly plagioclase (60-70% of phenocrysts), with biotite (20-25%), quartz (several percent to as much as 10%), hornblende (4%), pigeonitic augite (2-4%; generally less abundant than hornblende), and sanidine (from trace amounts to as much as 2%). Iron-titanium oxide is the most common accessory; hypersthene, sphene, zircon, and apatite are present in trace amounts. The presence of quartz and sanidine in the phenocryst mode, as well as the relatively greater biotite to hornblende ratio, facilitate distinction from some units of Rencher Formation (Tru) which have very similar lithology. Cognate pumice is abundant, and commonly weathers out leaving oblate pocks that display strong eutaxitic foliation. The rock contains sparse red and purple lithic fragments generally not exceeding 2-3 cm in diameter. A dark gray or greenish, partly devitrified basal vitrophyre is locally observed. All occurrences of Harmony Hills Tuff in the Enterprise quadrangle are truncated by faults and/or an erosional unconformity, and thus complete sections are lacking; the maximum exposed thickness is only about 30 m. The tuff is widespread in southwestern Utah and adjacent parts of Nevada. In most places it is considered a simple cooling unit, but in the eastern Bull Valley Mountains two subunits can be distinguished (with intervening airfall tuff) and the cooling unit is compound. As yet no source has been unequivocally identified. Considerations of grain size, thickness, and compound structure, as well as mineralogical, chemical, and isotopic age affinity with monzonitic intrusions of the iron axis, led Blank (1959) to suggest a source in the Bull Valley-Big Mountain intrusive arch in the Bull Valley Mountains; an equally plausible source area may be the southern Escalante basin. The average isotopic age of the formation is 21.0±1.2 Ma, based on 4 K-Ar determinations on biotite and plagioclase by Armstrong (1970) and one on biotite by Noble and McKee (1972). However, the actual age is suspected to be at least 22 Ma, based on isotopic ages of plutons and ash-flow tuff (Rencher Fm.) that post-date Harmonly Hills Tuff in the Iron Springs district (Rowley and others, 1989).

Tqc **Andesite(?) of Little Creek (Miocene)**--varicolored, porphyritic-aphanitic to -vitrophyric, two-pyroxene andesitic lava flow, flow breccia, autobrecciated lava, agglomerate, and laharic breccia. This unit was informally named *Little Creek breccia* by Blank (1959) for occurrences in drainages above Little Creek, the local name for a minor (100-m-long) spring-fed tributary of Moody Creek one-half km downstream from the Moody Creek-Pilot Creek confluence and 15 km south-southwest of Enterprise. The andesite(?) lies stratigraphically between two regional ash-flow tuff sheets (Harmony Hills Tuff (Tqh) and Bauers Tuff (Tqcb; see below) of the Quichapa Group and is present at that horizon almost everywhere in the eastern Bull Valley Mountains. Because of its regional mappability and stratigraphic position, the map unit is accorded the rank of an informal formation of the Quichapa Group. The andesite(?) typically contains 30-40% phenocrysts, of which about two-thirds are plagioclase, and one-third augite and hypersthene (the latter somewhat less abundant); Fe-Ti oxide is abundant in the groundmass. Partial devitrification of groundmass glass has commonly produced prominent alternations of black vitric and red aphanitic layers, or in some cases, tabular zones of red devitrified spheroids that are bounded by sheet joints inherited from viscous flow. Chemical analyses of the rock are not yet available.

The age of the Little Creek unit is constrained by isotopic ages of the underlying and overyling ash-flow tuffs to be about 22.0-22.5 Ma. Little Creek andesites(?) were probably erupted from a stratovolcano centered in the vicinity of Copper Mountain, 17 km southwest of Enterprise, where the flows and agglomerates are believed to reach their maximum aggregate thickness (300-350 m) and have been subjected to the most intense hydrothermal alteration (the name *Copper Mountain* is an informal local designation deriving from the green coloration of altered andesites in that vicinity).

Condor Canyon Formation (Miocene)--Defined by Cook (1965) as a succession of 1-5 lithologically similar rhyolitic ash-flow tuff sheets stratigraphically between Harmony Hills Tuff (Tqh) and Leach Canyon Tuff (now Leach Canyon Formation (Tql); see below) in eastern Nevada and southwestern Utah. The designated type locality of the Formation is in Condor Canyon, along the Pioche branch of the Union Pacific Railroad, 5-8 km northeast of the town of Panaca, Nevada, and about 60 km northwest of Enterprise. Of the various sheets, two are much more widespread than the others and are the only two found in southwestern Utah. These are (in descending order) Bauers Tuff Member and Swett Tuff Member, both earlier named by Mackin (1960) for occurrences in the Iron Springs district. Both are rhyolitic to rhyodacitic in composition and were apparently erupted from sources in the Caliente caldera complex of eastern Nevada (Rowley and Siders, 1988; Rowley and others, 1990). The Condor Canyon Formation was included in the Quichapa Group by Williams (1967). With one exception, explained below, Bauers Tuff is believed to be the only member of the Condor Canyon Formation present in the eastern Bull Valley Mountains.

Tqcb **Bauers Tuff Member**--Red to reddish brown, light-blue-gray and purple, densely welded, crystal-poor rhyolite ash-flow tuff. Probably forms a simple cooling unit in Enterprise quadrangle; in Condor Canyon, the unit is compound. Characteristically exhibits extreme eutaxitic foliation of pumice lenticules, and strong sheet joints which mimic eutaxitic foliation but result from late-state viscous flow. The eutaxitic foliation is typically developed in a red lithoidal zone above a jet-black, several-meters-thick basal vitrophyre. Above the eutaxitic zone is a pale-blue-gray zone of vapor-phase alteration. Phenocrysts comprise 10-20% of the rock and consist mainly of sanidine and plagioclase in subequal amounts, with subordinate but generally conspicuous biotite, and accessory Fe-Ti oxide and sphene. Quartz is absent in the phenocryst mode. Lithic fragments are sparse to rare. The type section for the Bauers Tuff Member is Bauers Knoll (Mackin, 1960), 10 km west-northwest of Cedar City and about 48 km east-northeast of Enterprise. The average isotopic age of the unit is 22.7±2.1 Ma based on 2 K-Ar dates on biotite and sanidine obtained by Armstrong (1970), 4 K-Ar dates on plagioclase and whole rock by Fleck and others (1975), one date on biotite by Noble and McKee (1972), and one Ar-Ar date on sanidine by Best, Christiansen, and others (1989). Bauers Tuff Member attains a maximum exposed thickness of about 60 m in the Enterprise quadrangle. However, the tuff commonly is highly brecciated and has evidently been tectonically thinned, most likely as a result of low-angle gravity sliding from the Big Mountain area during growth of the Bull Valley-Big Mountain intrusive arch (see description of intrusive units, below)

Tqcs **Swett Tuff Member**--Rhyolite ash-flow tuff that superficially resembles Bauers Tuff Member (Tqcb), the principal distinction being that Swett Tuff Member lacks sanidine and has relatively more biotite in the phenocryst mode. Swett Tuff Member was named by Mackin (1960) for occurrences in the Swett Hills, 20 km west of Cedar City and about 37 km east-northeast of Enterprise. It is less extensive than Bauers tuff and has not previously been identified in the eastern Bull Valley Mountains, although it is known to be present at a locality 15 km northeast of Enterprise near Newcastle (Siders and others, 1990). In the Enterprise quadrangle, it has been tentatively identified in a limited, fault-bounded area on the north side of a low ridge of Little Creek andesitic breccia (Tqk) in Section 32, T37S, R16W, about 2.5 km northwest of the summit of Big Mountain. The rock in the fault slice weathers to a dark chocolate-brown, hackly surface, is highly welded, and relatively crystal-poor. Its phenocryst mode, as determined by the etched and stained thick-slab method using a binocular microscope (Williams, 1960), is similar to that given by Williams (1967). Phenocrysts comprise 10-15% of the rock; about 90% are plagioclase and 10% are biotite. Tuff of this locality was previously considered to be Baldhills Tuff Member of the Isom Formation (Blank, 1959; see description of Isom Formation (Tis), below.) The mean isotopic age of Swett Tuff Member is 23.7±2.1 Ma based on 6 K-Ar dates obtained for biotite, plagioclase, and glass by Armstrong (1970) from samples collected in eastern Nevada and the Iron Springs district. Maximum exposed thickness of the unit is probably only 10-20 m.

Tql **Leach Canyon Formation (Oligocene)**--Pale-cream to pink and gray, moderately welded, moderately crystal-rich rhyolite ash-flow tuff. Typically contains abundant red and reddish-brown lithic fragments, in places surrounded by a halo of bleached tuff. Cognate pumice is abundant but often inconspicuous. Locally a brownish-gray, partly devitrified basal vitrophyre is present. Phenocrysts comprise 10-20% of the rock and consist chiefly of plagioclase (generally the most abundant species), sanidine, and quartz (generally somewhat more abundant than sanidine), with fine-grained biotite a prominent accessory (3-6% of phenocrysts). The name *Leach Canyon* was first used by Mackin (1960) to designate a member of his Quichapa Formation (now Group), after exposures in Leach Canyon, about 18 km west-southwest of Cedar City and 40 km east-northeast of Enterprise. The unit was elevated to formation rank by Cook (1965), as Leach Canyon Tuff, and by Williams (1967) and Anderson and Rowley (1975) as Leach Canyon Formation.

In much of its regional distribution the Leach Canyon Formation consists of two compound flow units separated by a complete cooling break (Williams, 1967). The upper unit, characteristically less welded and more fragment-rich, was designated by Williams (1967) the Table Butte Member, after its occurrence at Table Butte in the southern Escalante Valley, and the lower unit was designated the Narrows Tuff Member, after its occurrence at White River Narrows in eastern Nevada. Petrographically the two members are virtually indistinguishable. Discrete members have not been recognized in the Enterprise quadrangle; according to Williams (1967), the Table Butte Member does not extend as far south as Enterprise, and so the Leach Canyon Formation in this area is probably represented by the Narrows Tuff. Isopach data suggest a probable source for Leach Canyon ash flows in the Caliente caldera complex (Williams, 1967). The average isotopic age of the Formation is 24.7±3.1 Ma, based on 3 K-Ar analyses of biotite, sanidine and plagioclase by Armstrong (1970); a fission-track date of 24.2±2.0 Ma was obtained on zircon by Kowallis and Best (1990). Like the other Quichapa formations, Leach Canyon tuff in the Enterprise quadrangle is tectonically disturbed (commonly highly pulverized), and no complete sections are known. The estimated maximum thickness is about 200 m.

Tis **Isom Formation (Oligocene)**--Originally defined by Mackin (1960) as consisting of two regional ash-flow tuff sheets which he named the Hole-in-the-Wall Tuff and Baldhills Tuff Members, and a basal, unnamed ash-flow tuff member "of the Leach Canyon type", apparently of local extent only. Mackin's type locality is just north of Isom Creek in the Iron Springs district, about 20 km northwest of Cedar City and 50 km northeast of Enterprise. By far the thickest member at the type locality is Baldhills Tuff, which consists of multiple cooling units and crops out throughout the Bald Hills, a low range extending north for about 10 km from Isom Creek. Hole-in-the-Wall tuff was named for exposures of the uppermost ash-flow cooling unit at the east end of a narrow notch cutting through the range. The Isom Formation was subsequently redefined by Anderson and Rowley (1975) to include a basal ash-flow tuff, the Blue Meadows Tuff Member, which is widely distributed on the Markagunt Plateau but not recorded elsewhere.

Hole-in-the-Wall and Baldhills Tuff Members have similar lithologic characteristics and are not readily distinguishable, even in the Bald Hills, except by stratigraphic position. Both are characterized by dark red-brown-purple coloration, high degree of welding, low phenocryst content, and the presence of drawn-out vesicles, incipient sheet joints, and other features associated with late-stage viscous flowage (rheomorphic-flow structures). Light-gray cognate pumice fiamme are moderately abundant. The pumice has been flattened by compaction and further deformed (stretched) by flowage; it readily weathers out to form irregular cavities. Typically the cooling units of these two members have well-developed black basal vitrophyres. Widespread in eastern Nevada and southwestern Utah, their thickness variations and zonal structures suggest a point source north of Modena in the southern Escalante Desert near the southeastern margin of the Indian Peak caldera complex of Nevada-Utah (Best and others, 1989).

Compositionally, the Isom ash-flow tuffs are trachytes or trachyandesites (Best and others, 1989). Mackin (1960) gives histograms of phenocryst content as follows: Hole-in-the-Wall Tuff Member, 2-3% phenocrysts (all plagioclase); Baldhills Tuff Member, 4-5% phenocrysts, which consist of plagioclase (90%) and biotite (10%). The histogram given for Baldhills is similar to that given for Swett Tuff Member (Tqcs) in the same report. However, the mode for Baldhills Tuff Member appears to be in error. Subsequent field mapping and petrographic studies of Isom by many workers, and the examination of Isom tuffs in the Bald Hills by the author, have failed to reveal any Isom unit with dominant plagioclase-biotite in the phenocryst mode. In the vicinity of the Indian Peak complex, both members of the Isom Formation consist of multiple cooling units of ash-flow tuff with sparse phenocrysts of plagioclase and subordinate clinopyroxene and Fe-Ti oxide (no biotite) (Best and others, 1989). Isom cooling units in the North Pahroc Range of eastern Nevada (Scott and others, 1992); in the Red Hills, west of Parowan, Utah (Judy, 1974; Maldonado and Williams, 1993); in the Iron Springs District (Mackin and Rowley, 1976); and in the western foothills of the Markagunt Plateau, north and northeast of Cedar City (Maldonado and Moore, 1993), also have phenocrysts of plagioclase and subordinate clinopyroxene and lack biotite. It appears that all Isom ash-flow cooling units contain plagioclase and have variable, but always subordinate, amounts of clinopyroxene and Fe-Ti oxide, but lack biotite.

An isotopic date of 25.7±0.5 Ma for Baldhills Tuff Member in the Iron Springs district was obtained by Armstrong (1970) and an identical date (±0.4 Ma) was obtained for Baldhills on the Markagunt Plateau by Fleck and others (1975) from K-Ar analysis of plagioclase.

As mapped in the Enterprise quadrangle, Isom Formation consists of the following: thin and discontinuous remnants of one or more ash-flow tuff sheets lithologically similar to those at the type locality; at least three andesitic lava flows, not all present at any one locality but generally stratigraphically underlying the ash-flow tuff; and as much as 35 m of associated thin-bedded volcaniclastic rocks and lacustrine limestone, which locally occur either at the base, or intercalated with ash-flow tuffs and lava, or at the top of the Isom Formation. In most places the map unit has been extensively faulted and brecciated, and its maximum total thickness is estimated to be only about 100 m, although the aggregate thickness of the various members is probably several times greater.

Representatives of all major rock types of the formation can be seen in excellent exposures at and near a roadcut on Utah Highway 18, in Sections 29 and 30, T37S, R16W. The roadcut exposes a massive ledge of dull brick-red to purple ash-flow tuff 7-10 m thick overlying a black vitrophyre 0.3-0.4 m thick, which is separated from the devitrified, lithoidal zone by about 1.5 m of soft white clayey material interpreted to be altered glass. Phenocrysts are sparse (less than 5% of the rock) and altered, and consist predominantly of plagioclase, with subordinate clinopyroxene (augite) and Fe-Ti oxides. The rock also contains sparse gray fiamme of altered, flattened pumice, incipient sheet joints marked by gray laminae of devitrification, and irregular cavities. This lithology is typical of occurrences of Isom ash-flow tuff in the eastern Bull Valley Mountains. Such tuffs were formerly correlated with Hole-in-the-Wall Tuff of the Bald Hills (Blank, 1959), but the correlation is now considered doubtful, and whether they are Hole-in-the-Wall or Baldhills cooling units is unresolved.

The basal vitrophyre at the roadcut is underlain by 30-35 m of white to cream-colored, thin-bedded tuffaceous sandstone, below which is a massive pyroxene-andesite(?) lava flow that in turn rests directly on gray limestone of the upper Claron Formation (Tcu; see below). Andesitic lava flows of the Isom package in the Enterprise quadrangle consist of the following (stratigraphic order unknown): (1) a red to black, crystal-rich plagioclase-augite flow or flows, best exposed in Cottonwood Wash near Cottonwood Spring, just south of the Highway 18 roadcut. This lava occurs in many places on the northern perimeter of Big Mountain and in the vicinity of Gum Hill, stratigraphically beneath Isom ash-flow tuff. Coarse, clear plagioclase and lustrous black glomeroporphyritic augite comprise more than 50% of the rock, which typically weathers in rough, platy slabs. The maximum thickness at any locality is about 50 m. (2) A gray and light-purple plagioclase-rich flow or flows found only at a few localities close to Gum Hill, and nowhere well exposed. This rock is characterized by abundant, relatively fine-grained (length mostly less than 5 mm), white plagioclase laths strongly lineated by flowage and set in an aphanitic groundmass. The phenocrysts comprise 30-50% of the rock and no mafic minerals are evidenced in hand specimen. The maximum thickness of the flow unit(s) is 10-15 m. (3) A bluish-gray, brown, and purple, essentially aphyric flow or flows characterized by numerous extremely elongate open vesicles and amygdules, and typically weathering to smooth-faced chips. This rock is well exposed on the southwest flank of Gum Hill, in Section 20, T37S, R16W. Typically the rock contains less than 1-2% phenocrysts, which consist almost entirely of fluidally aligned plagioclase, with rare crystals of altered pyroxene(?). In many places a vesicular flow of this type is the only representative of the Isom Formation present. Where Isom ash-flow tuff is also present, a vesicular lava has been found stratigraphically above the tuff in some places, below it in others. Stratigraphic relationships of tuff and vesicular lava are better revealed in adjacent areas than in the Enterprise quadrangle. For example, at a locality on the south flank of Moody Wash, 16 km south-southwest of Enterprise (Maple Ridge quadrangle), vesicular lava appears to pass gradationally upwards into Isom ash-flow tuff, which lacks a vitrophyre; near Central, about 18 km southeast of Enterprise (in the Central East quadrangle), vesicular lava is stratigraphically *above* Isom ash-flow tuff and consists of at least two flows, each red, lithoidal, and grading upwards to a scoriaceous flow-top breccia. The widespread distribution of thin sheets of vesicular flows closely associated in space and time with Isom ash-flow tuff suggests that they are in fact rheomorphic ash-flows of the Baldhills-Hole-in-the-Wall succession. However, their chemical and petrologic relation to Isom tuffs have not yet been established, and their mode of emplacement remains conjectural. The maximum thickness of this type of lava in any occurrence is about 40 m.

Tc **Claron Formation, undivided (Oligocene and Eocene)**--Generally upward-fining, chiefly fluvial and lacustrine, limestone, sandstone, siltstone, and conglomerate. Interpreted to be extensively modified and bioturbated by pedogenic processes (Mullett and others, 1988; Mullett, 1989). Locally subdivided into three informal members in the Enterprise quadrangle, based on dominant lithology. These are, in descending order, upper gray limestone (Tcu), middle red siltstone (Tcm), and basal conglomerate (Tcl) members. These correspond roughly to the 3-fold division of Tertiary sedimentary formations on the High Plateaus of southwest Utah early noted by Dutton (1880): upper white limestone and calcareous marl, pink calcareous sandstone, and basal pink conglomerate. Similarly a 3-fold division was recognized by Cook (1957, 1960) in the Pine Valley Mountains. The name *Claron* was first proposed by Leith and Harder (1908), and later adopted by Mackin (1947), for Paleogene sedimentary rocks exposed in the vicinity of Mt. Claron in the Iron Springs district. Five members have now been distinguished in that district (Mackin and others, 1976; Mackin and Rowley, 1976); at least the upper 4 members are probably correlative with the informally named *Pink Cliffs Wasatch* formation (Gregory, 1951) of the Colorado Plateau, which includes the pink limestone beds spectacularly exposed at Cedar Breaks and Bryce Canyon on the Markagunt and Paunsaugunt Plateaus. Claron has since been mapped over a broad region in southwest Utah and southeast Nevada. The upper and lower bounds of the formation are not firmly established, due to a lack of consensus on what should constitute those bounds, a paucity of diagnostic fossils, and probable time-transgressive character of depositional environments across the region (for example, basal Claron apparently youngs eastward; see Goldstrand, 1991). Problems of Claron lithology provenance and nomenclature have recently been reviewed by Taylor (in press). Claron sections in the Enterprise quadrangle are much faulted and probably nowhere complete. The maximum apparent thickness of the formation is about 300 m, at a ridge 2 km northwest of the summit of Big Mountain.

Tcu **upper member**--Predominantly gray or mottled pink and gray, massive and thick-bedded, ledge-forming, sparsely fossiliferous, fresh-water limestone. Micritic, coarse-clastic, and to a less extent, sparitic. Chiefly lacustrine; may include spring-fed and paludal deposits. Beds range from 20 cm to about 3 m thick and form strong ledges that weather to rough uneven surfaces, typically alternating with less resistant red siltstone and yellow-gray limy mudstone in a ledge-and-slope topography. Stromatolites, oncoids, and subplanar laminations are found in some carbonate beds as are fragmental shells and plant casts. Well-preserved but non-diagnostic gastropods have been collected from upper Claron in some areas but none from the Enterprise quadrangle. Regional distribution of the limestones testifies to the existence of a vast fresh-water lake during much of Upper Claron time. The depression occupied by this lake may be the earliest manifestation of regional extension in southwest Utah.

The upper Claron member has an estimated maximum thickness of about 70 m. Interbedded with gray, ledge-forming limestone strata within 20-25 m of the top is an apparently discontinuous bed, 0-20 m thick, of soft, crystal-rich ash-flow tuff (Tcuw) correlated with tuff of the Wah Wah Springs Formation of the Needles Range Group (see below). Gray limestone resting on this tuff typically is overlain by lighter gray and white, thinly laminated limestone beds, which in places are characterized by a fine undulating white and pink banding (algal mats?). The first appearance of volcanic or volcaniclastic sedimentary rocks stratigraphically above Wah Wah Springs tuff is here taken to mark the base of the overlying Isom Formation (Tis). The basal Isom lithology difffers from place to place, as noted above, and may consist of volcaniclastic sedimentary rock, or andesitic lava, or trachytic to trachyandesitic ash-flow tuff. No angular discordance between the Isom and Claron Formations is evident, nor are there indications of soil development or subaerial erosion; the contact probably represents a paraconformity. However, a few km southeast of the quadrangle, near the community of Central in the Central East quadrangle, the upper two members of the Claron Formation are missing and have presumably been removed by erosion (see description of lower member (Tcl), below).

To the north and northeast of the Enterprise quadrangle, volcaniclastic sedimentary rocks are interbedded with limestone beds *beneath* tuff of the Needles Range Group (for example, in member E of Claron in the Three Peaks quadrangle; see Mackin and Rowley, 1976); northeast of Iron Springs, volcaniclastic rocks, including tuffaceous sandstones, volcanic conglomerates, ash-flow tuffs and laharic breccias, comprise a pre-Needles Range package up to several hundred meters thick with only subordinate limestone (*Trs* formation of Maldonado and Williams, 1993; *Brian Head* formation of Maldonado and Moore, 1993). However, in the Enterprise quadrangle the oldest known volcanic or volcaniclastic bed is tuff correlated with the Wah Wah Springs Formation. A more restricted definition of the upper boundary of Claron (namely, at the base of Wah Wah Springs tuff) was applied by Hintze (1986) in the Gunlock and Motoqua quadrangles and by Anderson and Hintze (1991) in the Dodge Spring quadrangle, on the south flank of the Bull Valley Mountains south-southwest of Enterprise. A much *less* restricted definition is that of Willden and Adair (1986), who subdivided Claron into 7 members in the Goldstrike district (immediately north of the Motoqua quadrangle) as follows (in descending order): 7) upper limestone, 6) upper tuff (Isom), 5) middle limestone, 4) lower tuff (Needles Range), 3) lower limestone, 2) red beds, and 1) basal clastics. Their members 5-3 correspond to the upper Claron member of the Enterprise quadrangle.

Tcuw **Wah Wah Springs Tuff Bed**--Soft, pink, brown, or green, moderately welded, moderately crystal-rich, hornblende-biotite dacite ash-flow tuff. Previously mapped as Needles tuff, a marker bed within the Claron Formation (Blank, 1959); shown as dashed line within upper Claron member (Tcu) on present map. Correlated on the basis of lithology (including mineralogy) and regional distribution with Wah Wah Springs Formation of the Needles Range Group, but here a formally named bed within the (informal) upper member of the Claron Formation. Not accorded formation rank (that is, not marking the upper bound of Claron) in the Enterprise quadrangle because the tuff is thin and discontinuous, and limestone beds above and below the tuff are not readily distinguishable, that is, in the absence of the tuff as a marker horizon there is no unequivocal basis for delineating a formation contact within the limestone succession. Emplacement of the tuff was essentially an instantaneous event in a closed basin dominated by slow accumulation of carbonate ooze. Moreover, designation as a unit within, rather than above the Claron Formation agrees with previous usage for the Enterprise area (Blank, 1959) and with usage in a recent regional analysis (Taylor, in press). The thickness of the Wah Wah Springs Tuff Bed varies from 0 to about 15 or 20 m. Whether this variation is a function of a primary depositional feature, poor exposure, tectonic elimination by low-angle faulting, or subsequent erosion, is not known.

Megascopically the tuff shows strong eutaxitic foliation and rude platy partings. Exposures are generally poor, and typically occur in debris-mantled slopes between strong limestone ledges. The most continuous exposures occur near the common edge of Sections 29 and 32, R16W, T37S, southeast of Rose Spring. There the tuff appears to be a single simple cooling unit with a partially developed basal vitrophyre. Red lithic fragments up to several cm in diameter are sparsely distributed throughout and commonly have pale haloes of alteration. Altered pumice discoids up to about 10 cm in diameter are plentiful. In stained slabs the rock contains 15-20% phenocrysts, consisting of about 70% plagioclase, 20% hornblende, and 5% each of biotite and quartz. Sanidine and Fe-Ti oxide are found in trace amounts. A total crystal content of about 40%, including minor augite and no sanidine, was reported by Best and Grant (1989) from petrographic analyses. The rock is classified as dacite on the basis of chemical analyses of Best and others (1989).

Wah Wah Springs ash-flow tuff was first identified and named by Mackin (1960) for exposures just south of Wah Wah Springs on the east side of the Wah Wah Mountains, about 100 km north of Enterprise. At the type locality the tuff is the lower of two lithologically similar ash-flow sheets which he designated members of the Needles Range Formation, with type locality about 12 km to the west. Subsequently the formation was elevated to group rank and the Wah Wah Springs Member became a formation (Best and Grant, 1989). The tuffs of the Needles Range Group, including the Wah Wah Springs Formation, were erupted from the Indian Peak caldera complex (Best and Grant, 1989; Best and others, 1989), and Wah Wah Springs tuff in the Enterprise quadrangle and elsewhere in the eastern Bull Valley Mountains is a distal facies and the southernmost known occurrence of ash-flow sheets of that system. The average isotopic age of the tuff is 29.5±2.0 Ma based on 16 K-Ar determinations on biotite, hornblende, and glass reported by Best and Grant (1987). This mid-Oligocene unit serves as an excellent time marker for the Claron lacustrine sedimentary environment. Upper Claron limestone is about half as thick above the Wah Wah Springs Tuff Bed as below it. The time interval represented by the Claron above must be considerably less than 3.8 m.y., the difference in age of Wah Wah Springs Tuff and Baldhills Tuff (Isom Formation), since as much as 35 m of volcaniclastic sedimentary strata were deposited, and andesitic lava flows were emplaced, following Claron limestone deposition and preceding Isom ash-flows. Thus the time interval represented by pre-Wah Wah Springs limestone of the upper Claron member is probably no greater than 6-7 m.y., which suggests that the upper Claron member is entirely Oligocene.

Tcm **middle member**--predominantly soft red and maroon calcareous siltstone, sandstone, and mudstone, interbedded with subordinate mottled gray-purple-pink-yellow, more resistant, massive to thick bedded, cobble conglomerate and algal limestone. Conglomerate clasts commonly include abundant dark-gray limestone cobbles and are well rounded. Unit corresponds approximately to pink sandy (middle Claron) member of Pine Valley Mountains (Cook, 1959, 1960) and probably includes beds correlative with maroon mudstone (middle Claron) member of southern Bull Valley Mountains (Hintze, 1986). The unit may also be equivalent to at least part of the informal *red member* distinguished by Anderson and Rowley (1975) on the High Plateaus. The chiefly clastic middle member and the more coarsely clastic lower member of Claron in the Enterprise quadrangle probably reflect progressive erosional reduction of landforms related to the Sevier orogeny.

The thickness of the middle member is highly variable, from a few meters to about 50-75 m. To some extent the thickness variations may be due to stratigraphic pinchout against paleotopography, but they are probably mainly the result of low-angle faulting concomitant with the rise of the Big Mountain monzonite-cored dome (see description of intrusive units, below). No unconformity has been recognized at upper or lower bounds of or within the member, nor have any fossils been recovered that might help constrain its age.

Tcl **lower member**--predominantly yellow-orange to gray, massive, resistant polymictic pebble-cobble conglomerate, with subordinate thin layers and lenses of white to light gray and yellowish, coarse-grained, commonly gritty sandstone. Matrix-supported, with variable amounts of calcite, micrite, quartzose sand, and fine rock fragments. Clasts are mostly rounded to subrounded and consist largely of buff to brown quartzite, sandstone, chalcedony, and gray limestone. Much material has probably been recycled from coarse clastic beds of the underlying Tertiary(?)-Cretaceous(?) Grapevine Wash (Wiley, 1963) or Late Cretaceous Iron Springs Formations. Thickness ranges from zero to about 40 m. Mapped only due east of Gum Hill, in Section 21, R16W, T37S; elsewhere in the quadrangle the middle Claron member (Tcm) either rests directly on the Iron Springs Formation (Kis; see below) or has not been recognized as a mappable subdivision. As is the case with the middle member, absence of the basal conglomerate member can be attributed to stratigraphic pinchout (non-deposition), removal by erosion, or tectonic elimination. The unit is equivalent in part to the basal Claron conglomerate noted by Cook (1957, 1960) in the Pine Valley Mountains, although that unit (not mapped separately by Cook) is now considered to include Wiley's Grapevine Wash Formation (for example, at Gunlock; see Hintze, 1986).

The identification of partial, fault-bounded sections of conglomerate overlain by Claron middle member or underlain by Iron Springs Formation can be problematic, and it is possible that such conglomerates, here mapped as basal Claron member, include conglomerate of the Grapevine Wash Formation. The Grapevine Wash Formation consists of up to 610 m of coarse clastic rocks near its type locality in the Gunlock quadrangle, 30 km south of Enterprise, where it has been subdivided into a basal reddish brown pebble-cobble conglomerate member, a middle, brown and gray sandstone member with conglomerate lenses, and an upper red cobble conglomerate member (Hintze, 1986). These rocks are believed to represent a local fanglomerate derived from erosion of the Square Top Mountain thrust sheet and to be Late Cretaceous(?) to Paleocene(?) in age (Wiley, 1963; Hintze, 1986; Goldstrand, 1990). The formation is separated from yellowish-white sandstone and orange conglomerates of the overlying basal Claron conglomerate member in the southern Bull Valley Mountains (Gunlock and Motoqua quadrangles) by an angular discordance of 0° to 10° (Hintze, 1986). Massive red cobble conglomerate 2 km northeast of Central (and about 18 km southeast of Enterprise), is directly overlain with at most a few degrees of angular discordance by volcaniclastic strata of the Isom Formation (Tis). This conglomerate is tentatively assigned to the upper member of the Grapevine Wash Formation (Blank, unpub. data) on the basis of lithologic similarity. If the correlation is correct, then the distribution of the Grapevine Wash Formation may not be as restricted as has been assumed and it would not be surprising to find this unit in the Enterprise quadrangle.

Another possible correlative of the lower Claron conglomerate member in the Enterprise quadrangle is the Grand Castle formation (informal name, Goldstrand, 1991, 1992). The Grand Castle formation, like the Grapevine Wash Formation inferred to have been derived from erosion of Sevier thrust sheets but from those in the Wah Wah Mountains area, is exposed north and east of Cedar City, from Parowan Gap to the Table Cliff Plateau northeast of Bryce Canyon. It was considered by early workers (e.g., Thomas and Taylor, 1946; Gregory, 1950, 1951; Threet, 1963) to be the basal part of the Claron Formation. At its type locality a few km southeast of Parowan (and about 85 km east-northeast of Enterprise) the formation is 140 m thick and consists of a basal gray *beehive*-weathering conglomerate member, a middle white sandstone member, and an upper red, massive conglomerate member (Goldstrand, 1990). In its westernmost recognized occurrences the formation fines upwards into red calcareous siltstone, mudstone and limestone of the Claron Formation, abruptly at the type locality and gradationally at other places. The bulk lithology, provenance, and contact relations are analogous to those of the Grapevine Wash Formation, and it seems likely that these two formations are roughly correlative. Massive basal conglomerates of Claron in the Enterprise quadrangle may be penecontemporaneous, but derived from erosional reduction of the Bull Valley-Big Mountain flexure rather than from thrust sheets. Their age is undetermined except by analogy with the Grapevine Wash or Grand Castle formations. Palynomorphs in Grand Castle of the Table Cliffs Plateau suggest a lower Paleocene age (Goldstrand, 1990).

Kis **Iron Springs Formation (Late Cretaceous)**--Chiefly buff, rust-brown, white, and yellow-mustard-colored, chiefly thick-bedded to massive, fine to coarse-grained, commonly gritty sandstone, with subordinate lensoidal pebble-cobble conglomerate, red to red-orange siltstone, gray-green-maroon shale, and gray lenticular limestone. Includes thin black carbonaceous shale or coal, and near or at top, a massive buff to purple, iron-stained, silicified, very resistant quartzite and conglomerate that commonly weathers to huge boulders. Is friable to silica- or carbonate-cemented. Typically is strongly jointed, forms prominent but discontinuous ledges, and weathers to subrounded slabs. Well-exposed in roadcuts on Utah Highway 18 north of Big Mountain, and on track leading south from the highway to microwave facility on crest of Big Mountain. In places in the Bull Valley Mountains the map unit is variegated, with purple, red, and orange colors predominant; in general it coarsens upward, becoming increasingly conglomeratic. On the southern flank of the Bull Valley Mountains and Pine Valley Mountains, the basal part of the Upper Cretaceous section is a coarse conglomerate bed assigned to the Dakota Formation (Albian) of the Colorado Plateau (Bissell, 1952; Hintze, 1986), but this distinction has not been made in the Enterprise quadrangle and it is unknown whether Iron Springs as mapped includes Dakota equivalents. At a well-exposed contact in the Enterprise quadrangle, about one km southwest of the summit of Big Mountain, Iron Springs sandstones rest disconformably on limestone of the Jurassic Carmel Formation (Jc; see below) with no intervening conglomerate. At Gunlock, 30 km south of Enterprise and in the Gunlock quadrangle, Iron Springs conformably(?) overlies about 6 m of bentonite, which rests conformably(?) on Dakota conglomerate (Hintze, 1986; Fillmore, 1989); there the basal Dakota unconformity truncates Carmel with no apparent angular discordance. However, the unconformity cuts across progressively younger rocks moving eastward across the Colorado Plateau. Zircon from the bentonite yielded a date of 80±10 Ma (B.J. Kowallis; cited by Hintze, 1986), which provides a lower age limit for Iron Springs exclusive of possible Dakota equivalents. Identifiable fossils are rare and none has been collected from the Enterprise quadrangle. A probable age span of Cenomanian through Turonian has been suggested by R.A. Christopher (cited by Hintze, 1986) on the basis of pollen analysis. Near Gunlock the formation grades upwards into or intertongues with the conglomeratic Late Cretaceous(?)-Paleocene(?) Grapevine Wash Formation (Hintze, 1986; see above). Midway between Gunlock and Enterprise the angular discordance with overlying Claron Formation is about 15°, and it is as much as 30° at some places on the Bull Valley-Big Mountain arch (Blank, 1959; unpublished data). Claron-Iron Springs contacts in the Enterprise quadrangle commonly show extensive brecciation in the contact zone suggestive of low-angle normal faulting.

The Iron Springs Formation has been interpreted as a continental synorogenic unit derived from uplift and erosion of eastward- and southeastward-advancing thrust sheets (Fillmore, 1989). It was deposited by sheetfloods on alluvial fans, and by fluvial systems on braidplains, in the proximal reaches of a foreland basin (Johnson, 1984; Fillmore, 1989). First named by Mackin (1947), who subdivided the *Pinto sandstone* of Leith and Harder (1908) into Iron Springs (Late Cretaceous) and *Entrada* (Jurassic) Formations. The Iron Springs itself has subsequently been subdivided into 5 members at its type locality near The Three Peaks (Mackin and Rowley, 1976). Mackin's *Entrada* is now assigned to the upper part of the Carmel Formation (Cashion, 1967; see below). The Iron Springs was inferred to be a western facies of marine and intertonguing marine-continental clastic formations of the Colorado Plateau: these are, in descending order, the Kaiparowits, Wahweap, Straight Cliffs, Tropic, and Dakota Formations. The Plateau units have been mapped on the Hurricane front east of Cedar City (Averitt, 1962; Averitt and Threet, 1973, and on the east side of the Pine Valley Mountains (Cook, 1957, 1960). Recent studies by Goldstrand (1990, 1992) suggest that the Kaiparowits Formation (middle to upper Campanian at its type locality on the Kaiparowits Plateau; see Eaton, 1991) in fact overlies the Iron Springs Formation between Cedar Breaks and Cedar City, but limited palynological data indicate a pre-Campanian age for the "Kaiparowits" in this area (Nichols, in prep.), and thus the lithostratigraphic correlation with type Kaiparowits must be regarded as uncertain. Until this matter is resolved, it is possible that in the narrowest sense the Iron Springs is equivalent only to Tropic Formation through Straight Cliffs-Wah Weap. Iron Springs Formation has a maximum thickness in the Enterprise quadrangle estimated to be 450-600 m; close to the physiographic Colorado Plateau margin its thickness probably exceeds one kilometer.

Jc **Carmel Formation (Jurassic)**--Blue-gray to cream, buff, and white, massive to thick-bedded, thin bedded, and fissile, marine limestone, red and maroon siltstone, and gray to maroon and olive-green shale. As a whole sparsely fossiliferous; some beds contain abundant *pentacrinus* columnal segments. In the Enterprise quadrangle, exposed only on the west, south and east flanks of the Big Mountain monzonite-cored dome (see description of intrusive rocks, below). The monzonite intrusion is essentially concordant, roofed by the lower part of the Carmel. In less structurally disturbed areas of southwestern Utah, Carmel rests disconformably on the Temple Cap Formation or (eastern areas) on the Navajo Sandstone, the contact being the *J2* unconformity of Pipiringos and O'Sullivan (1972). The Temple Cap itself was formerly considered to be an upper member of the Navajo Sandstone (Gregory, 1950; Wright and Dickey, 1963) or, alternatively, the basal member of the Carmel Formation (Baker and others, 1936; Cook, 1957, 1960), but was elevated to formation rank by Peterson and Pipiringos (1979). It consists largely of incompetent gypsiferous red mudstones, siltstones, and sandstones, and is a locus of laccolithic monzonitic intrusion in both the eastern Bull Valley Mountains and the Iron Springs district.

The Carmel Formation of the San Rafael Group (Gilluly and Reeside, 1928) of the Colorado Plateau is a Middle Jurassic, generally eastward-thinning, shallow-marine and marine-marginal deposit representing both transgressive and regressive stages. It was named by Gilluly and Reeside (1928) and first described by Gregory, and Moore (1931), for exposures near Mt. Carmel Junction, nearly 100 km southeast of Enterprise. Stratigraphic work by Peterson and Pipiringos (1979) and Blakey and others (1983) has documented facies relationships of the formation from the plateaus to its westernmost exposures, which are in the Gunlock area. At the type locality the formation consists of 4 members: from youngest to oldest these are the Winsor Member, gypsiferous member, banded member, and limestone member (Cashion, 1967). The 4 members are mappable at 1:100,000-scale on the Colorado Plateau (for example, on the Kanab 30'x60' sheet; see Sable and Hereford, 1990). In the Gunlock and Motoqua 7 1/2' quadrangles, Hintze (1986) has mapped 3 members, which he correlated with the Upper and Lower Judd Hollow Members of Blakey and others (1983; see also Phoenix, 1963) and the Crystal Creek Member of Thompson and Stokes (1970). These are probably equivalent to the limestone and banded members of Cashion (Hintze, 1986; Rigby, 1986). Two and three members of the Carmel are recognized in the Antelope Range (Shubat and McIntosh, 1988; Shubat and Siders, 1988) and Iron Springs district (Mackin and others, 1976; Mackin and Rowley, 1976), respectively, northeast of Enterprise. They are, from youngest to oldest, banded member, Homestake Limestone Member, and basal siltstone member (Iron Springs district only). The basal siltstone of the Iron Springs district Carmel may be correlative with the Temple Cap Sandstone of the Colorado Plateau (Everett, 1968, Mackin, 1968; Mackin and others, 1976). Homestake Limestone Member, a local name given formal status by Leith and Harder (1908), was considered by them to be Carboniferous(?) but is now known to be Middle Jurassic and correlative with the limestone member of Cashion (1967); it is important as a host for replacement iron ores. The banded member was originally correlated by Mackin (1947, 1954) with the Entrada Formation of the Colorado Plateau as mapped by Gregory (1950), but later work by Wright and Dickey (1963) showed that Gregory's Entrada is equivalent to the upper-lower part of the Carmel section of the San Rafael swell region.

No subdivision of Carmel has been made in the Enterprise quadrangle, but the bulk if not all of the formation where exposed is lithologically similar to the Homestake Limestone Member of Iron Springs and is believed to be correlative with that member. The closest measured section, and probably one of the most complete in the eastern Bull Valley Mountains, is located at the junction of Moody and Pilot Creeks about 15 km south-southwest of Enterprise, where the beds have been turned up on end by emplacement of monzonite (Blank, 1959). There, a thin (9 m), hornfelsized basal siltstone unit is overlain by about 96 m of "Homestake limestone" (predominantly limestone in the lower part, shale in the upper part), overlain by 23 m of red shale and covered section, and, at the top, 40 m of predominantly massive limestone (Blank's "Moody Wash limestone" member). These units probably include correlatives of all three units of the Iron Springs district. The red shale member crops out only locally in the Enterprise quadrangle and is generally the uppermost unit of the Carmel section; the Moody Wash limestone is typically absent. The shale was formerly mapped as "Entrada Formation" although it was recognized as probable Carmel (Blank, 1959). No fossils have been collected from the Carmel Formation during the present study. The maximum exposed thickness of the formation in the Enterprise quadrangle is estimated to be about 90 m.

INTRUSIVE UNITS

Trd **Rhyolite dike (Pliocene(?) and Miocene)**--Light blue-gray aphyric rhyolite dike, typical of numerous rhyolite dikes of similar age in eastern Bull Valley Mountains but only dike known to occur in Enterprise quadrangle. Transects sedimentary strata of Claron Formation near confluence of Spring Creek and Shinbone Creek at eastern margin of Black Hills, about 5 1/2 km south of Enterprise. Near-vertical; thickness 2-5 m. Age uncertain, but likely coeval with magmatic activity of Flat Top Mountain complex, a late Miocene to early Pliocene rhyolitic eruptive center 8-9 km to the west.

Tqmb **Big Mountain intrusion (Miocene)**--Tan to light gray, weakly resistant quartz monzonite porphyry. Typically weathers to smooth, grussy slopes. Consists of about 50% phenocrysts, which in a typical specimen are plagioclase (65% of total phenocrysts), biotite (18%), hornblende (12%), and augite (5%). Plots approximately on quartz monzonite-granite line of QAP classification of IUGS (Streckeisen, 1973; see Blank, 1959, for analyses). The groundmass is microcrystalline to very fine grained phaneritic xenomorphric granular, and consists of potash feldspar and quartz in nearly eutectic proportions (about 2:1). Potash feldspar includes both sanidine and orthoclase. Iron-titanium oxides and apatite are common accessories; hypersthene and pigeonite occur rarely. Much of the rock has undergone deuteric alteration, with the formation of secondary minerals including chlorite (pennine), phlogopite(?), sericite, and calcite. Mineralogically and chemically the monzonite is nearly identical to rock of its consanguinous extrusive equivalent, the Rencher Formation.

The Big Mountain intrusion is exposed only at the extreme southern margin of the Enterprise quadrangle about 1 1/4 km south of the summit of Big Mountain, an exhumed structural dome. However, the intrusion is much more extensively exposed on the adjacent quadrangle to the south (Central West). It is inferred on the basis of aeromagnetic and drilling data (Columbia Iron Mining Company, unpublished data), to core the Big Mountain dome and to be contiguous in the subsurface with two monzonitic bodies exposed to the southwest, the Hardscrabble Hollow and Bull Valley intrusions (Blank, 1959). These three intrusions are aligned with three closely related and penecontemporaneous intrusions of the Iron Springs district along a southwest-trending, southeast-vergent Sevier compressional structure (Mackin, 1947, 1960); together they delineate the so-called *iron axis* of southwest Utah (Tobey, 1976). In its broad sense the iron axis includes all early Miocene hypabyssal granitoid intrusions in a belt that extends from the western High Plateaus to the Nevada border. Most are concordant, and iron-rich. Several, including those of Iron Springs, Big Mountain, and Bull Valley, have produced contact-metasomatic iron deposits in Carmel limestone of their confining roofs. The genetic relationship of iron ores of the Iron Springs district to monzonitic intrusive bodies in the district has been documented in the classic field studies of Mackin (1947, 1954, 1968), and subsequently explored from a petrological and geochemical point of view by Barker (in press); an analogous relationship in the Bull Valley district has been investigated by Wells (1938), Bullock (1970), and Tobey (1976), among others.

No rock suitable for dating has been collected from monzonite in the Enterprise quadrangle. Iron-axis intrusions have yielded K-Ar dates of 20 to 22 Ma (Armstrong, 1970), which spans the age of the Rencher Formation (see above).

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MAP SYMBOLS

Contact - queried where location uncertain

Fault - high-angle, dashed where approximately located, dotted where concealed, queried where location uncertain. Ball and bar on downthrown side where relative offset is known. Probably includes some faults with little or no offset, and some low-angle faults; may include faults with strike-slip component

Fault - low-angle; teeth on upper plate

Slickensides or mullion, showing bearing and plunge; absence of fault symbol indicates rock is pervasively brecciated and measurement was not made on a discrete fault plane

Slickensides or mullion, subhorizontal; double-barbed line indicates bearing

25

Strike and dip of bedding in layered rocks, including layered ash-flow tuff units

Contorted bedding, showing generalized direction of dip

Horizontal bedding

Strike and dip of eutaxitic foliation in ash-flow tuff

Anticline, showing approximate crestline (surface trace of axial plane) and direction of plunge, where known

Sheet joint related to flowage, showing strike and dip

Sheet joint, vertical

Zone of hydrothermal alteration

CORRELATION of MAP UNITS