INTERIM GEOLOGIC MAP OF THE CEDAR CITY 30' x 60' QUADRANGLE, IRON AND WASHINGTON COUNTIES, UTAH

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This open-file report will be superceded by an improved geologic map following completion of reviews.

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DESCRIPTION OF MAP UNITS

QTs Quaternary and Tertiary basin-fill sediments, undivided—Cross sections only; for included units see correlation chart and descriptions.

Qf Artificial-fill deposits—Man-made deposits of artificial fill, mostly mine dumps in the Iron Springs mining district and construction fill for dams and highways.

Qal Alluvium—Youngest alluvium and colluvium in channels, floodplains, and adjacent low terraces of rivers and major streams; sand, silt, and clay with lenses of gravel; maximum thickness about 20 feet (6 m).

Qat_1 Younger stream-terrace deposits—Sand and gravel that form dissected surfaces as much as 15 feet (5 m) above the level of adjacent modern streams; maximum thickness about 10 feet (3 m).

Qat_2 Older stream-terrace deposits—Sand and gravel that form well dissected surfaces 15 to 30 feet (5 to 10 m) above the level of adjacent modern streams; maximum thickness about 10 feet (3 m).

Qaf_1 Young alluvial-fan deposits—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans; includes alluvium and colluvium in upper stream courses; surface is modern and generally undissected; maximum thickness at least 30 feet (10 m).

Qaf_2 Middle alluvial-fan deposits—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans; surface is moderately dissected by modern streams; maximum thickness at least 50 feet (15 m).

$QTaf_3$ Old alluvial-fan deposits—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on alluvial fans; surface is well dissected by modern and older streams; maximum thickness at least 100 feet (30 m).

Qap_1 Young piedmont-slope alluvium—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on coalesced proximal alluvial fans and pediments; surface is modern and generally undissected; maximum thickness at least 30 feet (10 m).

Qap_2 Middle piedmont-slope alluvium—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on coalesced proximal alluvial fans and pediments; surface is moderately dissected by modern streams; maximum thickness at least 50 feet (15 m).

$QTap_3$ Old piedmont-slope alluvium—Poorly to moderately sorted silt, sand, and gravel deposited by streams, sheetwash, debris flows, and flash floods on coalesced proximal alluvial fans and pediments; surface is well dissected by modern and older streams; where mapped northeast of Table Butte in the Escalante Desert, unit ranges from above to below the level of the Lake Bonneville shoreline and contains overlying sand and gravel that may represent a crows-foot delta or bars of a mixed shoreline and lagoonal environment; above the level of the shoreline it has been locally eroded by floods; maximum thickness at least 100 feet (30 m).

Qp Playa deposits—Laminated clay, silt, and fine-grained sand deposited in intermittent lakes (playas); locally contains salt efflorescences; maximum thickness about 30 feet (10 m).

Qmtc Talus and colluvium—Poorly sorted, mostly angular gravel, sand, and silt deposited by rockfall, creep, sheetwash, debris flow, and streams along scarps and hillsides; mostly mapped where conceals underlying bedrock; maximum thickness about 30 feet (10 m).

Qms Landslide deposits—Unsorted, mostly angular, unstratified rock debris moved by gravity from nearby bedrock cliffs; maximum thickness about 100 feet (30 m).

Qed Windblown sand in dunes—Well sorted sand in mostly northeast-oriented parabolic dunes and in local transverse dunes as much as 15 feet (5 m) high; partly vegetated; maximum thickness about 30 feet (10 m).

Qes Windblown sand in vegetated sheets that lack dune form; maximum thickness about 10 feet (3 m).

Qea Mixed eolian and alluvial deposits—Sand, silt, and clay in deflation basins and lag material from underlying reworked alluvium; includes playa deposits in small seasonal ponds in the basins; maximum thickness about 10 feet (3 m).

Qeo Older windblown sand—Well-sorted sand in vegetated degraded dunes and ridges that are generally oriented northeast with forms modified by sheetwash; maximum thickness about 15 feet (5 m).

Qlae Mixed lacustrine, inflow/outflow channel, alluvial, and eolian deposits—Mostly tan, brown, and red, locally laminated clay, silt, and sand likely deposited in Escalante Bay of late Pleistocene Lake Bonneville, in a Pleistocene or Pliocene(?) lake in Cedar Valley, in large channels draining into and out of these lakes, and as Pleistocene and Holocene windblown sand and silt; includes swamp and delta deposits as well as fine-grained alluvial and eolian deposits that intertongue with and overlie the lacustrine deposits; Cedar Valley was filled by a lake with a shoreline likely of well over 5,500 feet (1,675 m) elevation that overtopped the valley thresholds and spilled northwest into Lake Bonneville through Mud Springs Canyon (Rowley, 1975, 1976; Rowley and Threet, 1976) and Iron Springs gap (Thomas and Taylor, 1946; Mackin and others, 1976); the possibility of Lake Bonneville shorelines above 5,090 feet (1,551 m) in Escalante Bay in the map area (T. 32-34 S., R. 13-15 W.) was discounted by Dennis (1946), Crittenden (1963), Currey (1982), Currey and others (1983), and Grant and others (1990) but is shown here on the basis of some faint shorelines suggested by Gilbert (1890) and Anderson and Bucknam (1979) and on the basis of beach, offshore-bar(?) spit, and deltaic deposits (Qls) at about 5,120 feet (1,560 m) north and northeast of Table Butte (Vice and others, 2004); the shoreline is projected elsewhere in the map area at this elevation, partly on the basis of the elevation above which alluvial-fan morphologies are clear on 1:40,000-scale aerial photos and below which a series of “discontinuous curved lines” are visible (noted by Anderson and Bucknam, 1979, p. 421, which they interpreted as lacustrine bars), spits and shorelines of greater than 5,090 feet and as high as 5,120 feet

have been mapped between Milford and Lund, Utah, just north of the mapped area, by Dennis (1946), Crittenden (1963), Rowley (1978), Anderson and Bucknam (1979), and Currey (1982); global positioning system recordings by G.S. Vice and D.J. Maxwell (unpub. data, 2004) have verified the elevations of some of these shoreline features; maximum thickness of the deposits at least 30 feet (10 m).

Qls Lacustrine and deltaic sand and gravel—Shoreline, deltaic, and lagoonal deposits of Escalante Bay of Lake Bonneville, consisting of sand, silt, clay, and subordinate rounded and subrounded pebble gravel; the pebbles are less than 1.5 inches (3 cm) long and consist of chert, vein quartz, Paleozoic and Tertiary (Eocene and Oligocene Claron Formation) limestone, and distinctive but minor (about 5 percent) basaltic scoria; although most of the rounding of the pebbles could represent second generation (Claron Formation) gravel rounded by early Tertiary to modern streams, the rounding of the scoria and some of the other lithologies is inferred to result from wave action and longshore drift along Lake Bonneville (Vice and others, 2004); deposits locally cap ridges interpreted as beach bars and offshore bars and spits, some noted by Anderson and Bucknam (1979) in the north Table Butte area; map unit forms a bed less than 1 foot (0.3 m) thick exposed at an elevation of about 5,120 feet (1,560 m) west of Table Butte but elsewhere forms scattered pebbles at, below, and locally above this elevation; unit includes deposits that appear as ridges that splay westward along the lower part of a large inflow channel northeast of Table Butte (from Iron Springs gap) that are inferred to be deposited as flood-induced stream or debris-flow channels, perhaps in a crows-foot delta environment, whose intervening flood-plain deposits have been eroded away by wind.

Qan Andesite of Black Hills—Resistant, black andesite lava flows containing various percentages of phenocrysts as large as 0.2 inches (5 mm) of plagioclase and smaller pyroxene; mapped by Blank (1959, 1993) southwest of Enterprise; a sample submitted by H.R. Blank for the Utah Geological Survey recently yielded an Ar/Ar age of about 400,000 years (Peters, 2002); thickness about 650 feet (200 m).

Qb Basalt—Resistant, dark-gray and black, crystal-poor (olivine and pyroxene phenocrysts) olivine basalt lava flows and cinder cones; includes basalt straddling the Hurricane fault scarp, one sample 3 miles (5 km) north-northeast of Kanarraville and the other 4.2 miles (7 km) northeast of Kanarraville, both with K-Ar ages (Anderson and Mehnert, 1977) of 1.1 Ma; also includes the basalt of Enterprise, with a prominent (575 feet, or 175 m, high) cinder cone mapped by Blank (1959, 1993), a sample of which was submitted by H.R. Blank to the Utah Geological Survey and recently yielded an Ar/Ar age of about 1.1 Ma (Peters, 2002); includes the basalt of the south Red Hills (Rowley and Threet, 1976), which was dated by Anderson and Mehnert (1979) and Best and others (1980) at 1.3 Ma; maximum thickness of lava flows about 300 feet (100 m).

Ts Basin-fill sedimentary rocks—Poorly to moderately consolidated, tan, gray, and light-red, tuffaceous sandstone and subordinate mudstone,

siltstone, and conglomerate deposited in basins of various ages (Pliocene to at least 19 Ma) and origins; most basins related to the basin-range episode of extension in the area; some basins formed as the last subsidence of the Caliente caldera complex and as sags from ash-flow eruptions postdating the caldera complex, such as after deposition of local tuffs Thr and Twr that are intertongued with the sediments; the youngest parts of the sequence have been called the Muddy Creek Formation (Cook, 1957, 1960; Hintze and others, 1994); includes the volcaniclastic rocks of Enterprise Reservoir (Blank, 1993); north of Hebron, a north-striking graben includes a high amount of airfall tuff; the oldest parts of the sequence resulted from erosion of rapidly emplaced intrusions of the Iron Axis, and might better be mapped as Tpr but are included because they cannot be distinguished from the Ts sequence; these oldest parts, exposed in the east and south Harmony Mountains, North Hills, and Markagunt Plateau, contain clasts that include large boulders of a distinctive latitic porphyry ("Kolob latite" of Averitt, 1962) interpreted by Averitt (1962, 1967) to be intrusions and alluvium derived from it, and by Anderson and Mehnert (1979) and Biek (2002a) to be derived from the Pine Valley Mountains; maximum thickness of Ts at least 2,000 feet (600 m).

Tvc Tertiary volcanic units and Claron Formation, undivided—Cross section only; for included units see correlation chart and descriptions; shown only where well logs could not distinguish between Tertiary sedimentary and volcanic units.

Tv Tertiary volcanic units, undivided—Cross section only; for included units see correlation chart and descriptions.

Trdy Young rhyolite and dacite lava flows—Small centers of resistant, crystal-poor, high-silica rhyolite and dacite volcanic domes and lava flows with K-Ar ages of about 8.5 to 5 Ma; includes the rhyolite of Shinbone Creek south of Enterprise (5.0 Ma; Blank, 1959, 1993; McKee and others, 1997), the rhyolite of Pilot Peak southwest of Enterprise (6.1 Ma; Blank, 1959; Peters, 2002), and the dacite of Bullion Canyon and rhyolite of Silver Peak northeast of Newcastle (8.5 and 8.4 Ma respectively; Shubat and Siders, 1988; Siders and others, 1990); maximum thickness of each unit 425 to 575 feet (130 to 175 m).

Tb Basalt—Resistant, dark-gray and black, aphanitic to crystal-poor lava flows and local cinder cones of mostly olivine basalt that erupted in different parts of the mapped area from about 20 Ma to about 6 Ma and, along with Quaternary basalts, are synchronous with basin-range extension (Christiansen and Lipman, 1972; Rowley and Dixon, 2001); isotopic ages were reported for the basalt of Gum Hill east of Enterprise (Ar/Ar age of 5.7 Ma; Cornell and others, 2001), a flow on Flat Top Mountain 6 miles (10 km) west of Enterprise (K-Ar age of 7.7 Ma; Best and others, 1980; Blank, 1993), flows in the south Black Mountains (K-Ar ages of 9.9 to 9.0 Ma; Anderson and Mehnert, 1979), a flow south of Modena (K-Ar age of 10.8 Ma; Best and others, 1980), and a flow about 15 miles (24 km) west-northwest of Enterprise (K-Ar age of 11.7 Ma; Siders, 1991) that is similar in age to basalts just west of the mapped

area that yielded new Ar/Ar ages of 12.29 and 12.06 Ma (Table 1) that may be younger than indicated because of excess Ar; maximum thickness of lava flows about 300 feet (100 m).

Trdm Middle rhyolite and dacite lava flows—Mostly resistant, generally gray and tan, thick and widespread sequences of crystal-poor, high-silica rhyolite and dacite volcanic domes and lava flows that erupted from different centers in the west part of the mapped area, with K-Ar ages of about 15 to 10 Ma; locally includes ash-flow tuff, tuff breccia, and other pyroclastic beds; includes the rhyolite of Beryl Junction in the northeast Bull Valley Mountains (10.8 Ma; Siders, 1985a, b), the dacite of the Hogback north and northeast of Lower Enterprise Reservoir (12.0-11.4 Ma; Blank, 1959, 1993; McKee and others, 1997; R.E. Anderson, unpublished data, 2000), the rhyolite of Little Pine Creek north of Lower Enterprise Reservoir and south of where Nephi Draw enters Shoal Creek (12.0 Ma; Blank, 1959; McKee and others, 1997), the rhyolite of Pinon Point that covers much of the north Bull Valley Mountains north of Shoal Creek (12.8 Ma; Siders, 1985a, 1991), the rhyolite lava-flow member of the Steamboat Mountain Formation in the northwest part of the mapped area (13 to 10 Ma; Best, 1987; Williams, 1997), and the rhyolite of Cow Hollow north and northeast of Lower Enterprise Reservoir (15.3 to 14.3 Ma; Blank, 1959; McKee and others, 1997); maximum thickness of each unit 400 to 1,400 feet (120 to 400 m).

Thr Tuff of Honeycomb Rock—Soft, generally gray, unwelded, crystal-poor (about 2 percent sanidine), high-silica rhyolite ash-flow tuff intertongued within Ts and mapped west of Enterprise; well exposed at Honeycomb Rock Campground adjacent to Upper Enterprise Reservoir; has same mineralogy, age, and inferred magma chamber as the rhyolite of Little Pine Creek; source probably a small caldera or vent beneath South Flat Top Mountain, where a gravity low was shown by Blank and Kuchs (1989) and where Ts is thickest; a sample submitted by H.R. Blank for the Utah Geological Survey recently yielded an Ar/Ar age of about 11.8 Ma (Peters, 2002); another Ar/Ar age is 11.91 Ma (Table 1) for a sample collected just west of the mapped area; thickness about 500 feet (150 m).

Tvn Volcaniclastic rocks of Newcastle Reservoir—Moderately resistant, tan, brown, and gray, pebble to boulder conglomerate and subordinate mudflow breccia and sandstone filling an east-striking, mostly buried graben that extends from the northeast Bull Valley Mountains (Siders, 1985b) to the Newcastle area (Siders and others, 1990); the host for silver ore at the Escalante silver mine, where adularia from the main silver vein yielded an age of 11.6 Ma (Siders, 1985b); maximum thickness at least 1,000 feet (300 m).

To Ox Valley Tuff—Moderately resistant, gray and red, poorly to densely welded, crystal-poor, high-silica rhyolite ash-flow tuff exposed as outflow in the Bull Valley Mountains and likely derived from the east part of the Caliente caldera complex in and just west of the mapped area (Rowley and others, 1995); two new Ar/Ar ages on To and another age on a lava flow that rests on To (Table 1) suggest an age of about 13.5

Ma (Rowley and others, 1995; Snee and Rowley, 2000); maximum thickness about 50 feet (15 m).

Twr Tuff of White Rocks—Soft to moderately resistant, white, light-gray, tan, and light-yellow, unwelded, crystal-poor (1 to 5 percent sanidine, traces to 2 percent quartz, local traces of plagioclase), high-silica rhyolite ash-flow tuff and minor tuffaceous sandstone forming an intracaldera sequence within the Pine Park caldera (Siders, 1991) of the Caliente caldera complex; Pine Park caldera poorly exposed but well constrained by gravity data (Blank and Kucksm 1989; Cook and others, 1989; Bankey and others, 1998); upper part intertongued within Ts and well exposed near White Rocks, at the west edge of the mapped area, where it was apparently dated at 16.0 Ma by Siders (1991); thickness about 600 feet (200 m) in the mapped area and at least 1,000 feet (300 m; base not exposed) northeast of Pine Park Campground, Utah, just west of the map area.

Thc Tuff of Horse Canyon—Soft to moderately resistant, tan, light-yellow, and light-gray, unwelded to poorly welded, crystal-poor, high-silica rhyolite ash-flow tuff best exposed as outflow tuffs of many mineralogies in the upper Horse Canyon/Indian Draw/Wide Canyon area in the southwest part of the map area, where it was mapped as the upper member of the Racer Canyon Tuff by Siders (1991); includes intertongued, moderately resistant, tan tuffaceous sandstone; petrography indicates that the unit is correlative with rocks on North Flat Top Mountain mapped by Blank (1959) as the upper member of the Racer Canyon Tuff; tuffs likely derived from various calderas of the Caliente caldera complex; Ar/Ar age of 17.40 Ma (Table 1; Snee and Rowley, 2000), which shows some Ar loss so its age could be slightly younger, was determined from a tuff just above Tr that contains 5 percent quartz, 5 percent sanidine, and 2 percent plagioclase and was called the tuff of Dow Mountain by Snee and Rowley (2000) and considered to be derived from the north-central part of the Caliente caldera complex in the southern Dow Mountain quadrangle, Nevada; maximum thickness about 500 feet (150 m).

Tr Racer Canyon Tuff—Resistant, tan, gray, and pink, poorly to moderately welded, low-silica rhyolite ash-flow tuff; where exposed in the mapped area, is outflow tuff from the east part of the Caliente caldera complex (Rowley and others, 1995), which reaches into the west part of the mapped area, as the Pine Park caldera (Siders, 1991), whose upper part is interpreted to be filled with Twr and Ts; in the Horse Canyon area, upper outflow tuffs of the unit contain pumice blocks as large as 2 feet (0.6 m) and large abundant phenocrysts, suggestive of proximity to its source; probable age of Racer Canyon Tuff about 18.7 Ma (Rowley and others, 1995) based partly on two ages in Table 1; about 12 outflow cooling units well exposed south of Upper Enterprise Reservoir collectively total at least 1,500 feet (450 m), its maximum thickness in the area.

Tpr Sedimentary rocks of Page Ranch—Mostly soft, tan conglomerate, sandstone, and mudflow breccia derived from erosion of rapidly intruded quartz monzonite plutons of the Iron Axis, which is a northeast-

trending belt of plutons extending through and southwest of the Iron Springs mining district; unit mapped locally but may be correlative with lower parts of Ts, as in the east Harmony Mountains; maximum thickness about 200 feet (60 m).

Ta Andesite lava flows—Moderately resistant, red and brown, mostly crystal-poor andesitic lava flow, flow breccia, and mudflow breccia erupted from widely scattered stratovolcanoes or other local vents over a poorly known time span of 24(?) to about 21 Ma; occurs at several stratigraphic positions in this age range, including (1) thin lava flows that underlie gravity slides (Tgb) shed north from Tis and now located south (Hacker, 1998) of Iron Mountain, and mudflows that overlie Tgb shed east from Tii and now located east of Iron Mountain; (2) the andesite of Maple Ridge (Blank, 1959, 1993), which underlies Tr and contains abundant large phenocrysts of plagioclase, pyroxene, and biotite; (3) an andesitic volcanic mudflow breccia within the Tqc and also between Tqh and Tqc in the Antelope Range (Shubat and Siders, 1988) that thickens southward in the Enterprise area, where it is called the andesite of Little Creek (Blank, 1993); and (4) the andesite of Enterprise in the north Bull Valley Mountains, north of Shoal Creek, that has a K-Ar age of 24.2 Ma (Siders, 1985a, b, 1991) but apparently locally correlates with the andesite of Shoal Creek in the northeast Bull Valley Mountains that is demonstrably younger because it is underlain by Tre (with K-Ar ages of 21.8 to 21.5 Ma; see Blank, 1993) and also because apparently correlative hornblende andesite lava flows in the northwest part of the mapped area appear to both underlie and overlie Tqc (Best, 1987); maximum thickness of individual sequences about 1,600 feet (500 m).

Trdo Old rhyolite and dacite lava flows—Mostly resistant, generally gray, red, brown, and tan, locally thick, largely crystal-poor low-silica rhyolite and crystal-rich dacite volcanic domes and lava flows erupted from different vents about 22 to 20 Ma; includes the rhyolite flow member of the Blawn Formation in the northwest part of the map area (20.9 to 19.7 Ma; Best, 1987), the dacite of Spanish George Spring in the northwest part of the mapped area (Best, 1987), and the lithologically similar and thus perhaps correlative dacite of Pinon Park Wash in the north Bull Valley Mountains (21.7 Ma; Siders, 1985a, 1991); thickness of individual units as much as 1,600 feet (500 m).

Tpv Pine Valley Latite—Resistant, gray, pink, and black, flow-foliated, crystal-rich, dacitic and trachydacitic lava flows erupted from a vent area at Rencher Peak and derived from the Pine Valley laccolith just south of the mapped area (Cook, 1957; Hacker, 1998); this laccolith is the largest and second youngest pluton of the Iron Axis; Tpv has Ar/Ar ages of 20.44 to 20.42 Ma (Table 1), similar to the reported age of 20.5 Ma for the Pine Valley laccolith (Hacker and others, 1996) on the basis of Ar/Ar ages given in Table 1; maximum thickness in the mapped area about 1,100 feet (335 m), thickening southward.

Tcv Volcanic rocks of Comanche Canyon—Moderately resistant, red and pink, crystal-rich dacitic lava flows and poorly to moderately welded ash-flow tuff derived from the Stoddard Mountain intrusion (Tis) and resting on

gravity slides and fanglomerate also derived from Tis; the tuff is derived from a small caldera about 1 mile (1.6 km) in diameter on the east side of Tis; the tuff, whether inside or outside the caldera, contains distinctive clasts of red Kis; Tcv has Ar/Ar ages of 22.72 and 21.78 Ma (Table 1), the older of which is here rejected and the younger of which is consistent with other pluton ages and is similar to that of Tis; maximum thickness about 160 feet (50 m).

Tre Rencher Formation—Moderately resistant, white, tan, red, and purple, poorly to moderately welded, crystal-rich, dacite ash-flow tuff and tuff breccia; derived from the Bull Valley intrusion (Blank, 1959; Hacker, 1998; Hacker and others, 2002) south of the map area and just south of the Big Mountain intrusion (Blank, 1993;), whose north part underlies concordantly arched Jct and Kis on Big Mountain, 4 miles (6 km) southeast of Enterprise; Tre rests on gravity-slide masses that resulted from partial unroofing of the Bull Valley intrusion; Tre has K/Ar ages of 21.8 and 21.5 Ma (McKee and others, 1997) and Ar/Ar ages of 21.8 and 21.5 Ma (Cornell and others, 2001); thickness about 1,600 feet (500 m).

Tpa Rocks of Paradise—Resistant to moderately resistant, gray, pink, and red, crystal-rich dacitic lava flows and poorly to moderately welded ash-flow tuff derived from the Pinto Peak intrusion (Tip) and tilted westward by emplacement of Tis (Hacker, 1998; Hacker and others, 2002); has Ar/Ar ages of 21.97, 21.62, and 21.75 Ma (Table 1); sample 91-669 in the table was recalculated from a preliminary age of 21.93 Ma reported on Tre by Hacker and others (1996); maximum thickness about 600 feet (180 m).

Tgb Gravity-slide breccia—Moderately resistant, mostly pink and gray, tectonic breccia resulting from gravity slides (huge landslides) of various ages, made up of sedimentary (Kis, Tc, Tpv) and volcanic (Tn, Ti, Tql, Tqc, Tqh, Tpa, Tre) rocks shed off the roofs of rapidly rising quartz monzonite porphyry laccoliths and stocks (Tis, Tii, Tip, and several others outside the map area) of the Iron Axis (Cook, 1957; Mackin, 1960; Blank, 1959, 1993; Blank and Mackin, 1967; Blank and others, 1992; Hacker, 1998; Hacker and others, 2002); maximum thickness in the mapped area about 250 feet (75 m).

Tiq Intrusions of quartz monzonite porphyry—Mostly resistant, gray and pink, crystal-rich, shallow (most emplaced within about 1.2 miles, or 2 km, of the surface), quartz monzonite laccoliths and concordant stocks that rose at about 22 to 20 Ma above the roof of an inferred large batholith (Rowley and others, 1998; Rowley, 1998) of the same material; the shallow plutons define a northeast-trending belt known as the Iron Axis, extending from the Mineral Mountain pluton in the southwest Bull Valley Mountains to at least the Iron Peak laccolith (20.2 Ma, youngest in the Iron Axis; Fleck and others, 1975) in the Markagunt Plateau east of Paragonah, northeast of the map area; the northeast-trending line of plutons is partly controlled by the northeast-striking, southeast-verging Sevier-age (Late Cretaceous to early Tertiary) Iron Springs Gap thrust fault stratigraphically located within Jct or between Jct and Jn, and that emplaced Jct over Kis (Mackin and others, 1976); the Iron Springs Gap thrust controlled emplacement of the shallow plutons by providing an

access upward through the thick Jn; many of the plutons of the Iron Axis produced large hematite ore deposits, from replacement of the Homestake Limestone Member of the Carmel Formation, and from small magnetite veins; three plutons (The Three Peaks, Granite Mountain, and Iron Mountain intrusions) in the central part of the Iron Axis, making up the Iron Springs mining district, were extensively mined to become the largest iron-producing district in the West (Mackin, 1947, 1954, 1960, 1968; Blank and Mackin, 1967; Mackin and others, 1976; Mackin and Rowley, 1976; Rowley and Barker, 1978; Barker, 1995); these three plutons, along with others exposed in the map area, are mapped individually because each differed slightly in age and evolved differently, although most are characterized by partial deroofing and by gravity sliding and were immediately followed by volcanic eruptions (Mackin, 1960; Blank and Mackin, 1967; Hacker, 1998; Hacker and others, 2002); some quartz monzonite, perhaps part of the underlying batholith, is exposed or encountered in drill holes (see cross section A-A') as far west as the central Escalante Desert (Grant and Proctor, 1988; Williams, 1967); most plutons had several lithologic phases (thin outer peripheral-shell phase, selvage-joint phase, and interior phase) whose mapping elucidated that the iron solutions were derived from deuteric breakdown of ferromagnesian minerals in the selvage-joint phase (Mackin, 1947, 1954, 1960, 1968; Mackin and Ingerson, 1960; Mackin and others, 1976; Mackin and Rowley, 1976; Rowley and Barker, 1978; Barker, 1995); mapped as Tiq where not part of the named intrusions.

Tit The Three Peaks laccolith—The northern intrusion in the Iron Springs district, with the least structural relief and smallest ore bodies; a drill hole searching for petroleum was spudded in Kis west of the exposed intrusion, passed entirely through (2,586 feet, or 788 m) the intrusion and into a floor of Jct and Jn, demonstrating that the intrusion is a laccolith (Van Kooten, 1988); Ar/Ar age is 21.76 Ma (Table 1), but its relative age with respect to the other intrusions is unknown.

Tig Granite Mountain intrusion—The central intrusion of the Iron Springs district, younger than Tii and Tis because its southern extension, buried beneath Neck of the Desert, bowed and arched the Swett Hills and Eightmile Hills, which are capped by deposits of Tgb and Tcv that were derived respectively from Tii and Tis; K-Ar age is 21.5 Ma (Armstrong, 1970).

Tis Stoddard Mountain intrusion—A barren intrusion just south of the district that was intruded stratigraphically higher (into Kis) than the intrusions in the Iron Springs district (which are against Jct), had high structural relief, and erupted ash-flow tuff and lava flows (Tcv) from vents on the southwest and east margins of the body; Tis has a new Ar/Ar age of 21.86 Ma (Table 1), similar to the likely age of Tcv.

Tii Iron Mountain intrusion—The southern intrusion of the Iron Springs district, surrounded by the largest ore bodies; gravity slides were shed south and southeast as far as 5 miles (8 km) from the exposed intrusion; these slides underlie Tcv on top of the Swett Hills.

Tip Pinto Peak intrusion—A small barren intrusion southwest of Tis that shed gravity slides and erupted Tpa, which has Ar/Ar ages of 21.97 to 21.62 Ma (Table 1).

Tq Quichapa Group—Regional ash-flow sheets (Mackin, 1960; Williams, 1967; Anderson and Rowley, 1975), locally lumped where too thin to show separately; unit also includes Isom Formation in the Page Ranch quadrangle, which here is too thin to show separately.

Tqh Harmony Hills Tuff—Resistant, gray and tan, crystal-rich, moderately welded, dacitic ash-flow tuff; source unknown but isopachs are centered on Bull Valley, suggesting that it was derived from the east Bull Valley Mountains, perhaps from an early, much more voluminous eruptive phase of the Bull Valley intrusion (Blank, 1959; Williams, 1967; Rowley and others, 1995); consistent with this interpretation is the fact that the lithology and age of the tuff are nearly identical to the eruptive products of the plutons of the Iron Axis; has an Ar/Ar age of 22.0 Ma (Cornell and others, 2001); maximum thickness about 400 feet (120 m).

Tqc Condor Canyon Formation—Resistant, brown, gray, and purple, crystal-poor, densely welded, dacitic to trachydacitic ash-flow tuff of two eruptive sequences, the Bauers Tuff Member and the underlying Swett Tuff Member, both derived from the northwest part (Clover Creek caldera) of the Caliente caldera complex (Rowley and others, 1995); Ar/Ar ages of the Bauers Member are 22.8 Ma (Best and others, 1989a; Rowley and others, 1994b), and an Ar/Ar age of the Swett is 23.87 Ma (Table 1) but its age may be slightly younger than this on the basis of ages on Tql; maximum thickness about 400 feet (120 m).

Tql Leach Canyon Formation—Moderately resistant, tan and gray, crystal-poor, poorly welded, low-silica rhyolite ash-flow tuff whose source is unknown but probably is the Caliente caldera complex because isopachs show that it thickens toward the complex (Williams, 1967); the Ar/Ar age of the formation is about 23.8 Ma (Best and others, 1993); maximum thickness about 750 feet (230 m).

Thv Horse Valley Formation—Soft, gray and pink, dacitic lava flows and volcanic mudflow breccia made up of angular clasts of crystal-poor dacitic rock of a probable stratovolcano complex that thickens drastically to the north (Anderson and Rowley, 1975; Rowley, 1978); about 22 to 19 Ma (Fleck and others, 1975); maximum thickness in the area about 150 feet (50 m).

Tmd Mount Dutton Formation—Mostly soft, brown and dark-gray, volcanic mudflow breccia made up of angular clasts of crystal-poor andesitic rock (Anderson and Rowley, 1975); these stratovolcano deposits are exposed in the northeast part of the map area and thicken drastically to the north and northeast, forming much of the south Marysvale volcanic field (Rowley and others, 2002), where they are dated at 26-21 Ma (Fleck and others, 1975); maximum thickness in the area about 1,000 feet (300 m).

Tl Latitic lava flows—Resistant, reddish-brown, crystal-poor latite lava flows and flow breccia that are widespread north of Modena, and quartz latite flows in the north Bull Valley Mountains (Best, 1987; Siders, 1985a);

unit has K-Ar ages of 22.8 and 21.9 Ma (Best, 1987); maximum thickness about 1,000 feet (300 m).

Tm Markagunt Megabreccia—Moderately resistant, brown and gray, gravity-slide breccia derived mostly from the Isom Formation (Ti) and Leach Canyon Formation (Tql) in the Markagunt Plateau (Anderson, 1993), exposed in one area along Interstate highway I-15 three miles north of Cedar City (Maldonado and others, 1997, plate 1); age is bracketed outside the map area by its position between the underlying Tql (23.8 Ma) and an overlying local tuff (22.8 Ma; Hatfield and others, 2000; Moore and others, 2004); thickness about 50 feet (15 m).

Tin Isom Formation and Needles Range Group, undivided—Regional ash-flow sheets lumped where too thin to show separately; generally primarily Isom Formation.

Ti Isom Formation—Resistant, brown and reddish-brown, crystal-poor, densely welded, trachydacitic ash-flow tuff derived perhaps from the Indian Peak caldera complex (Best and others, 1989a, b), whose south margin is in the northwest part of the map area; age appears to be about 27 Ma, on the basis of many Ar/Ar and K-Ar ages (Best and others, 1989b; Rowley and others, 1994a); includes flows of Mud Springs in the northeast part of the map area; maximum thickness of intracaldera (?) tuff at the north edge of the mapped area is 2,600 feet (800 m), but most outflow tuff is no more than 500 feet (150 m) thick.

Tn Needles Range Group—Resistant, gray, tan, and light-purple, crystal-rich, moderately welded, dacite ash-flow tuff; locally includes associated lava flows and airfall tuff; derived from the Indian Peak caldera complex (Best and others, 1989a, b); ash-flow units in the northwest part of the map area probably belong to the Lund Formation (28 Ma), whereas those in the Iron Springs mining district belong to the Wah Wah Springs Formation (30 Ma); maximum thickness about 800 feet (240 m).

Tc Claron Formation—Soft to resistant, mostly red, white, gray, and pink, lacustrine and fluvial limestone, calcrete, sandstone, siltstone, mudstone, and conglomerate; maximum thickness about 1,700 feet (500 m).

K Cretaceous units—Cross section only; for included units see correlation chart and descriptions.

Kis Iron Springs Formation—Mostly soft, generally gray and tan shale, mudstone, sandstone, and minor limestone and conglomerate of mostly continental origin; the clastic material was derived from erosion of Paleozoic strata exposed in Sevier thrust sheets to the west, including the Blue Mountain thrust (Goldstrand, 1994); in the Iron Springs district includes at the base the thin (as much as 100 feet, 30 m) Marshall Creek Breccia, a sedimentary breccia of fanglomerate or mudflow origin that reflects local tectonism (Mackin, 1947, 1954); exact age and correlation with other Upper Cretaceous units in the Markagunt Plateau poorly constrained (Goldstrand, 1994; Eaton and others, 2001; Moore and others, 2004); as much as 3,000 feet (1,000 m) thick, thinning eastward.

Ks Straight Cliffs Formation—Consists of an upper soft, gray, yellow-gray, and light-brown mudstone with minor sandstone and conglomerate, of mostly continental origin and about 750 feet (230 m) thick; a middle soft

carbonaceous mudstone and coal, of brackish marine and continental origin and about 350 feet (110 m) thick; and a lower resistant, gray sandstone with subordinate limestone and mudstone, of mostly marginal marine origin and about 500 feet (150 m) thick (Eaton and others, 2001); mapped in the Markagunt Plateau, and partly correlative with the Iron Springs Formation (Kis) to the west (Goldstrand, 1994; Eaton and others, 2001).

Kd Dakota Formation—Consists of an upper, moderately resistant, tan sandstone and gray shale, mudstone, and coal, of marginal marine origin and about 400 feet (120 m) thick; and an underlying, soft to moderately resistant, gray mudstone, minor tan sandstone, and basal conglomerate, of continental origin and about 650 feet (200 m) thick (Eaton and others, 2001); includes at its top the soft gray marine Tropic Shale, from 0 to 100 feet (30 m) thick (Eaton and others, 2001); unit commonly landslid.

Jcn Carmel and Temple Cap Formations and Navajo Sandstone, undivided—Cross section only.

Jct Carmel and Temple Cap Formations, undivided—In the Iron Springs district, the Carmel consists of an upper, moderately resistant, gray and maroon, well-bedded shale, siltstone, and sandstone (the banded member of Mackin and others, 1976) of probable marine origin, as much as 250 feet (75 m) thick, underlain by resistant, gray, massive marine limestone of the Homestake Limestone Member (the host for the hematite ore bodies), as much as 270 feet (80 m) thick; in the Hurricane Cliffs at the east edge of the map area, Averitt and Threet (1973) showed that the Carmel is represented by mostly marine units: (1) an upper soft, gray and reddish-brown, well-bedded mudstone and sandstone (Winsor Member; Biek, 2002b) as much as 320 feet (100 m) thick; underlain by (2) moderately resistant, gray gypsum and limestone (Paria River Member; Biek, 2002b) as much as 140 feet (40 m) thick; (3) soft, reddish-brown, well-bedded siltstone, sandstone, mudstone, and gypsum (the banded member at Iron Springs; Crystal Creek Member; Biek, 2002b) as much as 200 feet (60 m) thick; and (4) a basal resistant, gray thin-bedded limestone (Co-op Creek Limestone Member; Biek, 2002b) as much as 600 feet (170 m) thick (Averitt and Threet, 1973); the Temple Cap Formation in the mining district consists of moderately resistant, gray siltstone and sandstone (called the basal siltstone member of the Carmel Formation by Mackin, 1947, and Mackin and others, 1976) of probable coastal marine origin, as much as 50 feet (15 m) thick, in concordant intrusive contact with some of the quartz monzonite plutons; in the Hurricane Cliffs, the Temple Cap was correlated by Everett (1968) and others with the basal 40 to 50 feet (12 to 15 m) of the Carmel of Averitt (1962, p. 19-20) and just south of the map area is mapped as the Sinawa Member of the Temple Cap Formation (10 feet, 3 m, thick; Biek, 2002b).

Jn Navajo Sandstone—Resistant, orange and red, spectacularly cross-bedded sandstone formed as sand dunes; locally includes the Shurtz sandstone tongue (Averitt, 1962); maximum thickness about 2,000 feet (600 m).

JTR Kayenta, Moenave, Chinle, and Moenkopi Formations, undivided—Cross sections only.

Jk Kayenta Formation—Soft to moderately resistant, reddish-brown, gray, and orange, mostly fluvial and eolian mudstone, siltstone, and sandstone with a maximum thickness of about 1,300 feet (400 m).

Jm Moenave Formation—Continental units made up of the upper Springdale Sandstone Member of resistant red and purple-brown sandstone as much as 110 feet (35 m) thick, the middle Whitmore Point Member of purple-brown mudstone and claystone about 100 feet (30 m) thick, and the basal Dinosaur Canyon Member of soft reddish-brown sandstone, siltstone, and mudstone as much as 300 feet (90 m) thick.

TRc Chinle Formation—Continental rocks made up of the upper Petrified Forest Member, of soft reddish-brown and light-red mudstone and siltstone at least 360 feet (110 m) thick (Biek, 2002b) and commonly landslid; and the lower Shinarump Conglomerate Member of resistant gray conglomeratic sandstone at least 60 feet (20 m) thick (Averitt and Threet, 1973).

TRm Moenkopi Formation—Made up of three marine members, the Shnabkaib Member, the Virgin Limestone Member, and the Timpoweap Member, interbedded with three continental members, the upper, middle, and lower red members. From top to bottom, the upper red member is made up of soft siltstone and mudstone about 250 feet (75 m) thick (Biek, 2002b); the Shnabkaib Member is interbedded soft, gray and red siltstone and mudstone about 450 feet (140 m) thick (Biek, 2002b); the middle red member is soft reddish-brown mudstone and siltstone about 550 feet (170 m) thick (Biek, 2002b); the resistant Virgin Limestone Member is gray limestone about 200 feet (60 m) thick (Biek, 2002b); the lower red member is soft siltstone and mudstone as much as 280 feet (85 m) thick (Biek, 2002b); and the basal Timpoweap Member is resistant gray limestone about 100 feet (30 m) thick (Averitt and Threet, 1973); basal parts of the Moenkopi locally include several tens of feet of the Triassic Rock Canyon Conglomerate Member and, in turn, of the Kaibab Formation (Averitt, 1967).

Pk Kaibab Formation—Consists of two members along the edge of the Hurricane Cliffs in the south part of the map area: the Harrisburg Member of soft and resistant, gray limestone and dolomite about 100 feet (30 m) thick (Biek, 2002b); and the underlying Fossil Mountain Member of resistant, light-gray, fossiliferous limestone about 200 to 250 feet (60-75 m) thick.

Pz Paleozoic rocks, undivided—Cross section only; used only where well logs did not distinguish included units.

PlP Permian and Pennsylvanian rocks, undivided—Cross section only; various units identified in well logs.

M Mississippian rocks, undivided—Cross section only; identified in well logs.

DC Devonian through Cambrian rocks, undivided—Cross section only; various units identified in well logs.

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