CASTLE MOUNTAINS
GEOLOGY AND GOLD MINERALIZATION

SAN BERNARDINO COUNTY, CALIFORNIA
AND CLARK COUNTY, NEVADA

by

Richard C. Capps
Department of Geology
University of Georgia
Athens, Georgia 30602

and

John A. Moore
Viceroy Precious Metals
9555 Las Vegas Boulevard South, Suite 109
Las Vegas, Nevada 89123

Air photo of the southern Castle Mountains.

Photo by Thomas L. Nimsic, American Au Ag Associates.

ABSTRACT

The Castle Mountains, about 60 miles south of Las Vegas, Nevada, consist mostly of a Miocene, calc-alkaline rhyolite dome field that hosts major gold deposits. A Proterozoic metamorphic and plutonic basement is overlain by minor Paleozoic limestone. These are in turn overlain by Miocene sedimentary rocks and the regionally extensive, 18.5-Ma Peach Springs Tuff. Most outcrop consists of the dominantly rhyolitic Castle Mountains volcanic sequence, which was emplaced in three complex intrusive-extrusive episodes between 18.5 and 14 Ma. Trachyandesite and basalt with lesser rhyolitic tuff erupted during the first episode (<18.5 to 15.2 Ma, rocks of Jacks Well). Rhyolitic flow-dome complexes and surge deposits of the rocks of Linder Peak formed during the second at about 15 Ma. Numerous rhyolitic plugs, lavas, tuffs, and lesser trachyandesite and basalt were emplaced during the third episode between 15 and 14 Ma (rocks of Hart Peak). Youngest volcanic rocks are 14- to 13-Ma trachyandesites of the Piute Range volcanic rocks, which are extensive in the eastern Castle Mountains and the adjacent Piute Range.

Structures of the Castle Mountains indicate four episodes of deformation. Proterozoic rocks show a strong crystalloblastic foliation that generally strikes northwest and dips moderately northeast. A probable Mesozoic northeast-striking fault displaces the Proterozoic rocks and a small outcrop of Paleozoic limestone. North-northeast-striking faults, fractures, hypabyssal dikes, and quartz-calcite veins indicate west-northwest extension between about 18.5 and 14 Ma. Subordinate Miocene northwest-striking structures may predate the Miocene northeast-striking structures. Faulting and fracturing occurred throughout the evolution of the Castle Mountains but ended by 14 Ma. Peach Springs Tuff and the rocks of Jacks Well are variably tilted west. Westward tilting of the rocks of Linder Peak and younger rocks is minor.

INTRODUCTION

The north-northeast-striking Castle Mountains lie astride the Nevada-California border about 60 miles south of Las Vegas. The southwestern end of the range is in northern Lanfair Valley, California and the northeastern end extends into Piute Valley, Nevada. The 10 by 2 to 3 mile range intersects the northern end of the Piute Range and parallels the larger New York Mountains, which lie to the northwest.

The Castle Mountains rise about 1,000 feet above Lanfair Valley (4,500 feet). Volcanic plugs and domes form prominent peaks, notably Hart Peak (5,543 feet) in the northern part of the range, and a peak locally and informally known as “Linder Peak” (5,581 feet) in the central part. We also refer to two informal physiographic features of the southern Castle Mountains: “Egg Hill,” named for an oval-shaped rhyolite plug, and “Northwest Rim,” a northeast-trending set of ridges on the western side of the range.

The Castle Mountains are located near the western margin of the Colorado River Extensional Corridor, a major regional tectonic feature (Spencer, 1985; Weber and Smith, 1987; Reynolds, 1988; Spencer and Reynolds, 1989; Wells and Hillhouse, 1989; Smith and others, 1990). The volcanotectonic evolution of the Castle Mountains and accompanying synvolcanic gold mineralization are related to the formation of the Colorado River Extensional Corridor. Major gold deposits were discovered in the Castle Mountains by Harold Linder, consulting geologist, in 1986. Viceroy Precious Metals, operators of the Castle Mountains Mine, announced premine (1990) combined reserves of over 38 million short tons of ore in six deposits totalling about two million ounces of gold in the ground (Capps and Moore, 1991). In 1992, production began on a single open pit to mine the Jumbo South and Lesley Ann deposits.

REGIONAL GEOLOGIC SETTING

The Castle Mountains are in the eastern Mojave Desert within the southern Basin and Range province. They are a little-extended range that lies between the highly extended Colorado River trough to the east (Spencer, 1985; Weber and Smith, 1987; Reynolds, 1988; Spencer and Reynolds, 1989; Wells and Hillhouse, 1989, Smith and others, 1990) and a relatively unextended area to the west (Burchfiel and Davis, 1977). Stratigraphic sequences in the Castle Mountains, the New York Mountains to the west, the Piute Range to the east, and Hackberry Mountain to the south are similar (see plate); Hewett, 1956; Burchfiel and Davis, 1977; Miller and others, 1986; Nielson and others, 1987). Each range contains a Proterozoic metamorphic-plutonic basement and prominent Miocene volcanic and sedimentary rocks. Paleozoic and Mesozoic sedimentary rocks occur in the New York Mountains, and there is one small outcrop of Paleozoic limestone in the Castle Mountains. Mesozoic granitoids intrude the older rocks in all but the Castle Mountains. Proterozoic rocks in the New York Mountains are 1.7 Ga (Wooden and others, 1986).

Compositions of Miocene volcanic rocks vary between ranges. The Castle Mountains are mostly rhyolite with subordinate mafic and intermediate rocks. Volcanic rocks in the Piute Range are mostly intermediate to mafic; mafic rocks dominate the upper part of the section (Nielson and others, 1987). Mafic and silicic rocks are equally abundant in the New York Mountains (Miller and others, 1986; Miller and Wooden, 1993). Volcanic rocks at Hackberry Mountain are rhyolite, and intermediate rocks (Hewett, 1956; Capps and Moore, 1991; Capps, 1993b, 1996).

PREVIOUS WORK

This investigation is the first comprehensive study of the Castle Mountains. Regional geologic studies include those of Hewett (1956; Ivanpah Quadrangle), Longwell and others (1965; Clark County, Nevada), and Bingler and Bonham (1973; McCullough Range and adjacent areas). Local studies include those of Medall (1964) of the northwestern Castle Mountains and Turner (1985) and Turner and Glazner (1990) of the northeastern Castle Mountains. Nielson and Nakata (1993) and Nielson and others (1993) compared stratigraphy of the Castle Mountains, New York Mountains, and Piute Range. Mineralization in the Castle Mountains has been described comprehensively by Capps and Moore (1991), and Capps (1996). Specific aspects of the mineralization have been described by Ausburn (1991), Potts and Cline (1992), Williams (1992), Mitchell (1994), and Crowe and others, (1996). The results of detailed geologic, petrographic, geochronologic, structural, and geochemical investigations by Viceroy Gold Corporation are summarized by Linder (1988, 1989a, 1989b), Capps and Moore (1991), and Capps (1993a, 1993b). Capps (1996) discussed petrogenesis and volcanotectonic evolution of the Castle Mountains and vicinity.

Geologic mapping (1987-1994) for this study progressed at several scales. The northern and central Castle Mountains were mapped at 1:12,000. About 13 square miles surrounding the Hart mining district in the southern Castle Mountains were mapped at 1:2,400. The Jumbo South - Lesley Ann (JSLA) pit was mapped to the 4,380-foot bench or 4,400-foot elevation at 1:600. Subsurface stratigraphic correlations and structural interpretations were supported by over 1,500 core and rotary drill holes.

STRATIGRAPHY

PROTEROZOIC ROCKS

Proterozoic rocks crop out along the eastern flank of the Castle Mountains and in the eastern New York Mountains. Proterozoic granitoid rocks are encountered at depths of 1,440 feet beneath the Jumbo South deposit and 1,200 feet beneath the Hart Tunnel deposit in the southern Castle Mountains. Rock types include strongly and poorly foliated gneiss (**Xgl**, **Xgc**), pegmatite and alaskite (**Xp**), amphibolite (**Xa**), leucocratic granitoids (**Xgr**), and minor, massive, white and very light-gray lenses of quartz.

METAMORPHIC ROCKS

Gneiss (**Xgl**, **Xgc**) forms light-gray and light-greenish-gray, subdued outcrops. Poorly foliated gneiss is most abundant in the northeast but also occurs in the east-central Castle Mountains. Contacts between gneissic rocks conform to the generally northwest but locally variable strike of the compositional foliation.

General rock types include quartzofeldspathic gneiss, amphibolite, biotite gneiss, granitic gneiss, migmatite, mica schist, and relatively rare quartz-rich rocks. Medium-greenish-gray, medium-brown, and medium-pinkish-gray quartz-potassium feldspar-muscovite-biotite gneiss is most common. Identified minerals include sericite, chlorite, almandine garnet, plagioclase, magnetite, hornblende, alkali feldspar, quartz, biotite, apatite, zircon, rutile, epidote, sphene, and allanite. The different rock types are commonly finely interlayered on scales of millimeters to meters. Schistosity paralleling compositional foliation is a distinctive characteristic. Augen gneiss containing ovoid potassium feldspar megacrysts occurs locally within granitic gneiss (**Xgc**). Minor specular hematite is associated with quartz lenses.

Leucocratic, coarsely crystalline pegmatite and alaskite (**Xp**) are common as small ellipsoidal pods and sills. Migmatitic textures are common in some outcrops. Minor pods are entirely composed of very coarse light-pink or light-green alkali feldspar. Quartz is locally abundant, and plagioclase, magnetite, muscovite, tourmaline, hornblende, and sphene are accessory minerals.

Dark-green, greenish-gray, and very dark-gray coarse-grained amphibolite (**Xa**) forms discontinuous bodies less than 100 feet long and variable in width that follow compositional foliation in surrounding gneiss. Amphibolite may be more common in contact zones between well-foliated (**Xgl**) and poorly foliated (**Xgc**) gneiss, or between pegmatite segregates (**Xp**) and surrounding gneiss. Quartz zones are common. Accessory minerals are plagioclase, biotite, chlorite, garnet, magnetite, and sphene.

Metamorphic mineral assemblages indicate middle to upper amphibolite grade. Retrograde greenschist metamorphism is common locally.

Pre-Miocene metamorphosed chloritic mylonite and cataclasite occur locally as discontinuous lenses. Some mylonitic zones follow compositional gneissic layering and contain minerals typical of upper amphibolite facies (sillimanite and K-feldspar). Other, lower grade tectonized zones contain secondary calcite and quartz and are moderately to weakly hematitic.

GRANITE (Xgr)

Medium- to coarse-grained, light-pinkish-gray to light-brown, leucocratic granite forms most of the basement in the area between the northwest Castle Mountains and eastern New York Mountains. The rock consists mostly of potassium feldspar with interstitial quartz. Thin zones of micaceous and rare opaque minerals impart a crude foliation. Biotite and garnet are more abundant near contacts with Proterozoic gneiss.

PALEOZOIC LIMESTONE (Pzl)

Light- to medium-gray and light-reddish-gray limestone containing light-gray chert nodules crops out in a 200- by 20-foot area (N125,680, E117,550). The limestone is probably in fault contact with Proterozoic gneiss along the eastern contact, which is mostly covered, and the western contact with gneiss is a fault. The limestone is a fine-grained micrite containing rare, pale-white echinoderm (?) fragments 0.5 to 1.5 mm diameter, concentrically laminated algal balls, oncolites, and other partially preserved finely laminated zones of possible algal origin. Rare, darker colored zones about 1.5 cm in diameter may be intraclasts. Coarse sparry zones occur locally. The fossils suggest a Early Cambrian to Middle Devonian age. The limestone probably originated in low-energy marine to restricted marine conditions (Rodney Watkins, private report to Viceroy Corp., 1990). It probably correlates with one of several Paleozoic carbonate units in the New York Mountains (Burchfiel and Davis, 1977).

TERTIARY ROCKS

PREVOLCANIC SEDIMENTARY ROCKS (Tc)

Poorly sorted conglomerate, coarse sandstone, and breccia up to 15 feet thick crop out discontinuously at the base of the Tertiary sequence in the northern Castle Mountains and are cut by drill holes in the southern Castle Mountains. Conglomerate contains subrounded to angular clasts of Proterozoic granitoid, pegmatite, and biotite gneiss up to 10 cm in diameter in a coarse sand matrix.

PEACH SPRINGS TUFF (Tps)

The Miocene Peach Springs Tuff (Young and Brennan, 1974), a regionally extensive rhyolite ash-flow tuff, is the oldest Tertiary volcanic rock in the Castle Mountains. It crops out discontinuously around the eastern and northeastern Castle Mountains and the adjacent eastern New York Mountains, where it rests upon Proterozoic rocks. The largest outcrop, about 1 mile east of Linder Peak in the east-central Castle Mountains, forms moderate to steep slopes and 3 to 6 foot high ledges. The Peach Springs Tuff is typically less than 33 feet thick, but it is 90 and 85 feet thick in two drill holes in the southern Castle Mountains.

The tuff is light pinkish gray, moderately welded, devitrified, and variably vitric-crystal to crystal-vitric. It contains flattened pumice as much as 15- by 1-cm and fragments of Proterozoic metamorphic rocks and Tertiary volcanic rocks. The rock contains 10 to 15% phenocrysts of sanidine, oligoclase, quartz, biotite, hornblende, ilmenite, and magnetite, and traces of zircon, apatite, and sphene. Some sanidine is strongly chatoyant. The groundmass is micrographophyric. Faint rims of iron oxide outline some shards.

^{40}Ar/^{39}Ar ages of the Peach Springs Tuff include 18.46 ± 0.02 Ma (single crystal isochron on sanidine; C171, table 1, fig. 2), 18.79 ± 0.04 Ma (single crystal on sanidine from the same outcrop; Nielson and Nakata, 1993), and 18.35 ± 0.06 Ma (^{40}Ar/^{39}Ar single crystal isochron on sanidine for tuff from the Hackberry Mountains; Capps, 1996; Capps and others, 1996). These are consistent with the 18.5 ± 0.2 Ma age suggested by Nielson and others (1990) but contrast with K-Ar ages of 22.3 ± 0.7 Ma on biotite and 21.8 ± 0.7 Ma on sanidine also from sample C171 (table 1; Linder, 1988). The difference probably indicates xenocryst contamination in the K-Ar separates (Nielson and others, 1988, 1990, 1993).

The Peach Springs Tuff is widely distributed in southern Nevada, southern California, and Arizona (Miller and others, 1986; Nielson and others, 1987, 1990; Miller and Wooden, 1993). Buesch (1993) interpreted a source near Kingman, Arizona.

CASTLE MOUNTAINS VOLCANIC SEQUENCE (CMV)

The calc-alkaline Castle Mountains volcanic sequence (CMV, Capps and Moore, 1991) consists of rhyolitic domes, flows, and tuff and lesser andesitic, latitic, and basaltic lava. The CMV includes all volcanic rocks above the Peach Springs Tuff and below Piute Range volcanic rocks. These rocks were derived dominantly if not entirely from sources within the Castle Mountains. We divide the CMV into three informal units on the basis of stratigraphic relations, composition, and isotopic ages (tables 1 and 2; fig. 2):

Rocks of Hart Peak (Th) — 15 to 14 Ma

- Trachyandesite and trachydacite — Intrusions and minor flows.
- Rhyolite — Highly porphyritic rhyolite flows, plugs, and welded ash-flow tuff; pyroclastic-surge tuff; and volcaniclastic rock.
- Basalt — Porphyritic to aphyric basalt and trachyandesite.

Rocks of Linder Peak (Tl) — ~ 15 Ma

- Rhyolite flow-dome complexes, abundant pyroclastic-surge tuff and volcaniclastic rock.

Rocks of Jacks Well (Tj) — < 18.5 to 15.2 Ma

- Trachyandesite and basalt flows, minor rhyolite ash-flow tuff and locally abundant lahar and sedimentary rock.

Most K-Ar ages are older than ^{40}Ar/^{39}Ar ages for the same rocks. Reconnaissance studies suggest significant xenocrystic contamination by older rocks (Matt Heizler, New Mexico Geochronological Research Laboratory, Socorro, personal commun.)

Thickness of the CMV is highly variable and difficult to determine because of stratigraphic discontinuity and local unconformities. It is typically less than 900 feet thick, except in the southern Castle Mountains where it is more than 1,500 feet thick. Composite maximum thickness is probably more than 3,000 feet but no one section is this thick. Rhyolite and minor welded tuff form ridges and cliffs whereas the more easily eroded basalt, intermediate rock, and poorly welded tuff form valleys and hummocky terrain. Basalt crops out along the perimeter of the range.

Rocks of Jacks Well

The rocks of Jacks Well occur throughout the Castle Mountains; the most complete stratigraphic section is near the type section, Jacks Well in the northern Castle Mountains. These rocks are typically about 200 feet thick along the northeast-striking axis of the Castle Mountains and thin toward its borders. Jacks Well rocks overlie Peach Springs Tuff or Proterozoic rocks, but are locally absent. Jacks Well rocks are absent about 2 miles north of a prominent ridge locally and informally known as “Razorback Butte,” where Proterozoic rocks are overlain by Hart Peak rocks, and about 1.2 miles west-northwest of Hart Peak. They are younger than 18.5 Ma, the age of Peach Springs Tuff. Isotopic ages include 15.20 ± 0.03 Ma (^{40}Ar/^{39}Ar isochron age on sanidine; C303 of Tjw, table 1), 16.8 ± 0.5 Ma (K-Ar, biotite, sample C303; table 1), and 16.5 ± 0.5 Ma (C304, K-Ar, biotite, Tja, table 1). Jacks Well rocks are weakly to strongly propylitically altered (Capps, 1996).

Rock types include epiclastic rocks, alluvial fan deposits, channel gravel, sandstone, and finely laminated mudstone and claystone (**Tjs**), basalt (**Tjb**) and trachyandesite flows (**Tja**) and tuff (**Tjat**), debris flows, lahar and mudflows (**Tjc**), and thin, discontinuous rhyolite ash-flow tuff (**Tjt** and **Tjw**). Ten volcanic and volcaniclastic beds make up the Jacks Well type section, which is up to 490 feet thick. In order from oldest to youngest, the beds are (1) porphyritic basalt flows (**Tjb**), (2) a thin poorly welded lithic ash-flow tuff (**Tjt**), (3) porphyritic basalt flows (**Tjb**), (4) debris flows, epiclastic rocks, and mudflows (**Tjc**), (5) highly porphyritic trachyandesite flows (**Tja**), (6) debris flows, epiclastic rocks, and mudflows (**Tjc**), (7) arkose and channel gravel (**Tjs**), (8) two thin crystal-rich nonwelded ash-flow tuffs separated by minor sediment (**Tjt**), (9) arkose, channel gravels, mudstone, and claystone (**Tjs**), and (10) a moderately welded rhyolite ash-flow tuff (**Tjw**).

Table 1. K/Ar and Ar/Ar ages from the Castle Mountains.

Map	Sample	Latitude(N)[4]	Longitude(W)[4]	Material	Host Rock	% K[6]	$^{40}Ar_{rad}$	Age (Ma)	Unit/Ore Deposit
1	C171[5,8]	35° 17' 54"	115° 04' 23"	Sanidine	Rhyolite tuff			18.46 ± 0.02[8](IS)	Peach Springs
1	C171[5]	35° 17' 54"	115° 04' 23"	Biotite	Rhyolite tuff	6.752	0.0105	22.3 ± 0.7[1,3]	Peach Springs
1	C171[5]	35° 17' 54"	115° 04' 23"	Sanidine	Rhyolite tuff	5.063	0.007705	21.8 ± 0.7[1,3]	Peach Springs
2	C304	35° 21' 31"	115° 03' 05"	Biotite	Trachyandesite	6.116	0.007038	16.5 ± 0.5[1,7]	Jacks Well
3	C303	35° 21' 26"	115° 03' 29"	Sanidine	Rhyolite tuff			15.20 ± 0.03[8,10](IS)	Jacks Well
3	C303[5]	35° 21' 26"	115° 03' 29"	Biotite	Rhyolite tuff	7.540	0.008798	16.8 ± 0.5[1,7]	Jacks Well
4	LM-95-5	35° 21' 51"	115° 03' 32"	Sanidine	Lithic tuff			15.1 ± 0.03[8,10,11]	Linder Peak
5	LM-95-4	35° 21' 51"	115° 03' 32"	Sanidine	Lithic tuff			14.95 ± 0.4[8,10]	Linder Peak
6	C313	35° 18' 45"	115° 05' 12"	WR	Rhyolite dome	1.903	0.002182	16.5 ± 0.7[1,7]	Linder Peak
7	C306[5]	35° 22' 06"	115° 04' 34"	WR	Rhyolite dome	3.303	0.003738	16.3 ± 0.6[1,7]	Linder Peak
8	C391	35° 21' 57"	115° 04' 03"	Sanidine	Rhyolite dome	5.363	0.005771	15.5 ± 0.5[1,7]	Linder Peak
9	C309	35° 18' 03"	115° 05' 36"	WR	Rhyolite dome	3.700	0.004003	15.5 ± 0.6[1]	Linder Peak
10	C301	35° 21' 25"	115° 04' 42"	WR	Rhyolite dome	3.531	0.003676	15.0 ± 0.6[1]	Linder Peak
11	EGG	35° 16' 55"	115° 05' 42"	WR	Rhyolite dome	4.538	0.004692	14.9 ± 0.4[2,7]	Linder Peak
12	C308	35° 15' 11"	115° 05' 42"	WR	Trachyandesite	1.883	0.002019	15.4 ± 0.7[1]	Hart Peak
13	C181[5]	35° 16' 07"	115° 08' 00"	WR	Basalt	0.635	0.000667	15.1 ± 1.1[1]	Hart Peak
14	C307	35° 12' 59"	115° 06' 48"	WR	Basalt	2.420	0.002523	15.0 ± 0.6[1,7]	Hart Peak
15	C302[5]	35° 22' 19"	115° 04' 07"	WR	Trachyandesite	2.339	0.002244	13.8 ± 0.6[1,7]	Hart Peak
16	C248[5]	35° 20' 29"	115° 04' 48"	Biotite	Rhyolite dike	6.293	0.007031	16.0 ± 0.5[1,7]	Hart Peak
17	LM-95-3	35° 20' 40"	115° 05' 17"	Sanidine	Rhyolite flow			14.80 ± 0.10[8,12]	Hart Peak
18	C389	35° 20' 57"	115° 06' 10"	Sanidine	Rhyolite flow			14.71 ± 0.02[8](IS)	Hart Peak
18	C389	35° 20' 57"	115° 06' 10"	Biotite	Rhyolite flow	6.526	0.007385	16.3 ± 0.5[1,7]	Hart Peak
19	C170	35° 16' 15"	115° 05' 19"	Biotite	Rhyolite dike	7.350	0.008120	15.9 ± 0.5[1,7]	Hart Peak
20	C388[5]	35° 13' 53"	115° 06' 27"	Biotite	Trachydacite	6.520	0.006930	15.3 ± 0.5[1,7]	Hart Peak
21	C457	35° 22' 07"	115° 04' 16"	Sanidine	Rhyolite tuff			14.69 ± 0.02[8,10](IS)	Hart Peak
22	LM-95-1	35° 17' 05"	115° 05' 58"	Biotite	Trachyandesite			14.89 ± 0.03[8,13](IS)	Hart Peak
23	LM-95-2	35° 17' 08"	115° 05' 53"	Biotite	Trachyandesite			15.19 ± 0.03[8,14](IS)	Hart Peak
24	AND.1	35° 17' 05"	115° 05' 28"	Biotite	Trachyandesite	7.021	0.007360	15.1 ± 0.4[2,7]	Hart Peak
25	C177[5]	35° 17' 25"	115° 05' 17"	Biotite	Trachyandesite	6.868	0.006939	14.5 ± 0.5[1,7]	Hart Peak
26	C314	35° 22' 11"	115° 03' 46"	WR	Diorite sill	0.152	0.000138	13.0 ± 1.3[1,7]	Diorite
27	C168	35° 16' 20"	115° 05' 00"	WR	Trachyandesite	2.345	0.002257	13.8 ± 0.6[1,3]	Piute Range
28	C169[5]	35° 16' 26"	115° 04' 33"	WR	Trachyandesite	1.728	0.001561	13.0 ± 0.6[1,3]	Piute Range
29	DDH12:5	35° 16' 53"	115° 06' 12"	Adularia	Tuff breccia			14.74 ± 0.24[8,15]	Jumbo South
29	DDH12:5	35° 16' 53"	115° 06' 12"	Adularia	Tuff breccia	4.116	0.004500	15.7 ± 0.6[1,7]	Jumbo South
30	J.S.	35° 16' 54"	115° 06' 12"	I-S	Tuff breccia	6.882	0.007132	14.9 ± 0.3[2,3]	Jumbo South
31	C250	35° 18' 22"	115° 06' 29"	I	Rhyolite breccia	3.570	0.003692	14.9 ± 0.5[2,7]	Northwest Rim
32	C256	35° 17' 17"	115° 05' 54"	I	Heterolithic tuff	4.529	0.004652	14.7 ± 0.3[2,7]	Oro Belle
33	DDH10: 912-917'	35° 16' 46"	115° 06' 04"	I	Rhyolite breccia	5.050	0.004980	14.17 ± 0.3[2,7]	Lesley Ann
34	C421	35° 19' 44"	115° 02' 34"		Heterolithic tuff	3.564	0.003639	14.7 ± 0.5[1]	Razorback Butte
35	C305[9]	35° 19' 51"	115° 02' 46"	Adularia	Quartz-adularia			13.19 ± 0.03 (IS)[9]	Stray Cow Well

[1] Analysis by Geochron Labs, Cambridge, Mass. [2] Analysis by University of Arizona Isotope Geochemistry Lab. [3] Date reported by Linder, 1989a. [4] Sample locations, see plate. [5] See table 2. [6] Mean of analyses. [7] Date reported by Capps and Moore, 1991. [8] Ar/Ar analysis by Dr. Matt Heizler, New Mexico Geochronological Research Laboratory, Socorro. [9] Ar/Ar analysis by Chris Henry, Nevada Bureau of Mines and Geology, Reno. [10] Date reported by Capps (1996). [11] Apparent age determined on a single sanidine crystal. [12] Mean age of 10 single crystal analyses. [13] $^{40}Ar/^{36}Ar_i$ trapped values less than air. [14] Fine-grained bulk sample. [15] Fine-grained aggregate in all runs. WR = Whole-rock analysis. I-S = Illite-sericite, <0.1 µm size. I = Fine illitic clay, <0.1 µm size. IS= Ar/Ar isochron age.

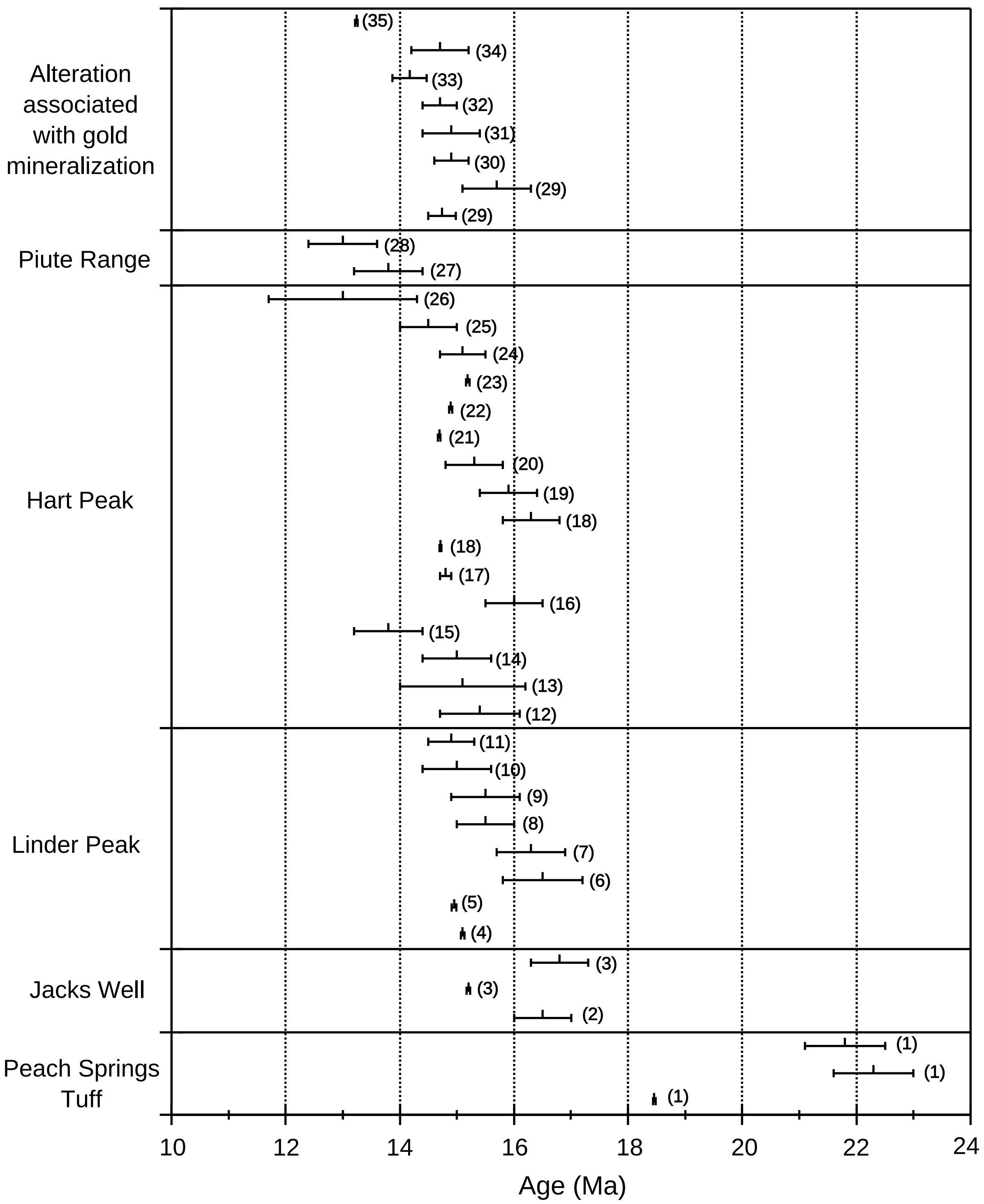

Figure 2. Isotopic age chart. Numbers in parentheses refer to sample locations on the plate and in table 1.

South and southeast of the JSLA pit the Jacks Well section is more than 900 feet thick. The stratigraphic section is consistent with that of the northern Castle Mountains but the 15.2-Ma rhyolite ash-flow tuff (**Tjw**) that caps the section is missing and trachyandesite flows are much thicker. The thick trachyandesite sequence may have accumulated in a post-Peach Springs Tuff and pre-Jacks Well graben.

Basalt and basaltic-andesite flows (Tjb). Dark-gray, medium-reddish-brown, and medium-brownish-gray, moderately to highly porphyritic, vesicular, amygdaloidal, and locally scoriaceous trachybasalt flows and scoriaceous agglomerate, 0 to 200 feet thick, are interbedded with Jacks Well trachyandesites, lahars, and volcaniclastic rocks. Propylitically altered basalt is dark greenish gray, medium greenish brown, and medium brown.

Phenocrysts include as much as 20% plagioclase, clinopyroxene, olivine, magnetite, and ilmenite. Sieve-textured plagioclase up to 1.1 mm occurs with augite and opaque minerals in cumulophyric inclusions. Smaller, euhedral plagioclase phenocrysts are more abundant than sieve-textured plagioclase. The felty groundmass consists of interlocking 0.3-mm-long plagioclase laths. Euhedral opaque minerals and alteration minerals occupy interstices and vesicles.

Andesitic lithic tuff breccia (Tjat). Light- and medium-gray, light-yellowish-brown, and medium-reddish-brown poorly welded, discontinuous, andesitic, lithic-vitric tuff breccia, lapilli tuff, and vitric-lithic tuff are interbedded with Jacks Well sedimentary rocks. Tuff-breccia beds, 0 to 60 feet thick, typically occur at the base and top of andesite flows. Propylitically altered rocks are medium greenish gray. Angular clasts of Proterozoic metamorphic rocks and Jacks Well intermediate and mafic rocks in the tuff-breccias average about 2.5 cm in diameter.

Poorly welded rhyolite tuff (Tjt). At least three, light-gray, light-pinkish-gray, and very light-brown, porphyritic, poorly welded, vitric-crystal and vitric rhyolite ash-flow tuffs, < 20 feet thick, are interbedded in the Jacks Well rocks. Locally, a nonwelded base contains abundant fragments of andesite flows and Proterozoic metamorphic rocks. Small, light-brown, rounded fragments may be fine-grained soft sedimentary rocks incorporated into the ash flows. Phenocrysts (<5 %, <0.3 mm) of biotite, sanidine, smoky quartz, and minor sphene give the tuffs a salt-and-pepper appearance.

Epiclastic rocks, debris flows, lahars, mudflows, and minor andesitic flow rock (Tjc). These rocks are mottled medium and dark reddish brown and dark gray and are 0 to 200 feet thick. They include poorly indurated alluvial fan and channel conglomerate, coarse sand and mudflow deposits, and nonsorted poorly bedded lahars and debris flows. Clasts of mostly Proterozoic metamorphic rocks, Jacks Well intermediate and mafic flows, and minor Peach Springs Tuff range in size from coarse sand to angular boulders more than 4 feet across. Beds are matrix to clast supported and have a fine, hematitic matrix. Clasts in the bedded conglomerates are well-rounded, and normally graded beds 1 to 3 feet thick are common.

Trachyandesite and minor basalt flows (Tja). Mottled dark-gray and medium- to dark-reddish-brown, highly porphyritic trachyandesite and minor dark-gray interbedded basalt flows are 0 to more than 900 feet thick. Propylitically altered trachyandesite is greenish gray. Trachyandesite flows are typically dense and massive but have common basal and flow-top breccias, minor, dark-greenish-gray, hydrated basal vitrophyre, and intraflow vesicular and breccia zones. Thin soil horizons separate many flows.

Phenocrysts in the trachyandesite include 30 to 40% plagioclase, quartz, biotite, pyroxene, hornblende, magnetite, and ilmenite and trace amounts of apatite and zircon. Mafic blebs occur in some flows. Distinctive oligoclase phenocrysts are up to 2 cm in diameter.

Arkose, mudstone, claystone, and gravel (Tjs). Very fine- to coarse-grained, cross-bedded, normally graded volcaniclastic arkose, mudstone, claystone, and lenticular channel gravel are 0 to 300 feet thick. These epiclastic rocks are most commonly light and medium pinkish brown but are light to medium greenish gray in areas of propylitic alteration. Clasts are Tertiary volcanic and Proterozoic metamorphic rocks. Clasts of abraded feldspar crystals up to 2 cm and rounded fragments of previously deposited fine-grained sediments occur locally. Light-gray, lenticular, and discontinuous beds within these generally darker sedimentary rocks are thin, fine-grained rhyolitic tuffs and reworked tuffs.

Lateral variation in thickness, texture, and contact relationships suggests several coeval depositional and erosional environments. The sedimentary rocks generally are more mature up-section and distally. In the upper Jacks Well, sedimentary rocks grade from coarse-grained beds in the east-central Castle Mountains to channel gravel and fluvial sandstone north along strike, and to finely laminated mudstone and claystone at the northern end of the range. The coarse-grained, normally graded beds resemble modern alluvial fan deposits, and the fine-grained sedimentary rocks are similar to playa muds. Lenses and discrete grains of pyrite within fine-grained Jacks Well sedimentary rocks suggest quiet-water reducing conditions during deposition.

Phenocryst-rich welded rhyolite ash-flow tuff (Tjw). Light-gray and light-brown incipiently to weakly welded and indurated, locally vitric, vitric-crystal, and vitric-lithic rhyolite ash-flow tuff is 0 to 100 feet thick. Lithic fragments are Tertiary mafic volcanic rocks, Proterozoic metamorphic rocks, and rounded light-brown poorly consolidated fine-grained sedimentary rocks averaging less than 1 cm in diameter. The tuff contains, in order of abundance, up to 10% phenocrysts of sanidine (0.8 to 2 mm), biotite, euhedral smoky quartz, and sphene (up to 1.5 mm). Zircon and opaque minerals occur in trace amounts.

Rocks of Linder Peak

The rocks of Linder Peak consist of rhyolitic hypabyssal intrusions, domes, flows, autoclastic breccias, blocky pumice flows, block-and-ash flows, lithic tuff, and volcaniclastic rocks (fig. 3). These rocks overlie and intrude the older volcanic and volcaniclastic rocks, make up most of the central Castle Mountains, and are the principal hosts of gold mineralization. Linder Peak is a prominent rhyolite dome that intrudes cogenetic pyroclastic-surge tuff and earlier flow rock (fig. 3A).

Field relationships indicate several periods of dome growth and coeval pyroclastic deposition. Domes and flows are divided into phenocryst-poor (**Tl**), phenocryst-rich (**Tlp**), and late (**Tll**) types. Most phenocryst-rich rhyolites intrude phenocryst-poor Linder Peak rhyolites. Early Linder Peak domes are northeast-elongate, whereas later domes are more cylindrical.

Tuff, breccia, and volcaniclastic rocks form deposits several hundred feet thick adjacent to vent areas and coalescing domes (fig. 4) and thin toward the margin of the range. A drill hole at the Jumbo South deposit cut more than 650 feet of volcaniclastic rocks and hydrothermal breccias. Locally, younger rhyolite intrusions dome the clastic rocks. Buttress and angular unconformities, intraformational and collapse breccias, and major intraformational slumps are common but are not shown on the plate.

Precise Ar-Ar ages of sanidine separates from early surge tuffs are 15.1 ± 0.03 (LM-95-5) and 14.95 ± 0.4 (LM-95-4; table 1). Conventional K-Ar ages on whole rock and sanidine separates from Linder Peak rhyolite range from 16.5 ± 0.7 (C313) to 14.9 ± 0.4 Ma (EGG, table 1). A reconnaissance survey of phenocryst phases in Hart Peak rhyolite (Matt Heizler, New Mexico Geochronological Research Laboratory, Socorro, personal commun.), probably cogenetic with Linder Peak rhyolite (Capps, 1996), finds some xenocrystic material with 33 Ma single crystal ages. Therefore, the older Linder Peak K-Ar ages may represent contamination by older material. Given the common hydrothermal alteration of Linder Peak rhyolites, the whole-rock dates should be interpreted cautiously. The whole-rock K-Ar age of 14.9 ± 0.4 Ma from mineralized rock near Egg Hill (EGG, table 1) probably indicates the time of mineralization.

Phenocryst-poor (Tl), phenocryst-rich (Tlp), and late phenocryst-poor (Tll) rhyolite. Hypabyssal intrusions, domes, and flows of phenocryst-poor (1 to 3% but up to 8%) and phenocryst-rich (8 to 15% but up to 25%) rhyolite are mostly light-pinkish-gray and mottled light-gray and medium-gray. The rocks are generally devitrified, dense, and flow-foliated; vitrophyre, which is mostly hydrated, breccia, and vesicular zones occur at margins and help to identify intrusive and extrusive contacts.

Phenocrysts consist of subequal sanidine and quartz, oligoclase, biotite, minor hornblende, magnetite, ilmenite, and trace fayalite, zircon, and sphene. Bipyramidal smoky quartz is more typical of phenocryst-rich rhyolite, and oligoclase is more abundant in phenocryst-poor rhyolite. Intermediate to mafic, commonly vesicular and probably magmatic inclusions, 0.5 cm to 10 cm in diameter, occur in most flows and intrusions but are more abundant in the phenocryst-rich facies (fig. 3B)

Rhyolite autoclastic breccia, dome-related block and ash flows, and blocky pumice flows (Tlbx). Coarse, monolithologic breccia contains angular clasts of phenocryst-rich and phenocryst-poor rhyolite up to 3 feet in diameter. Deposits are up to 65 feet thick, mostly clast-supported, and light-gray to light greenish gray. Breccia within domes is generally devitrified whereas breccia within tuff is incipiently welded, clast supported, and vitric.

Rhyolite pyroclastic-surge tuffs and breccias and volcaniclastic rocks (Tlt):

Cognate-lithic dominant (Tltc),
Accidental-lithic dominant (Tlta),
Leached-clast-bearing vent breccia (Tltl).

Generally poorly welded and poorly consolidated rhyolite tuff, breccia, and associated volcaniclastic rocks are 200 to 600 feet thick within the range and thin toward the margins. Lithic tuff breccia, pumiceous vitric tuff, and vitric-lithic tuff derived from rhyolite domes are the most abundant rock types. The rocks are light gray, light pinkish gray, light yellowish brown, and light pinkish brown. A few thin beds are incipiently to moderately welded and have thin lenticular vitrophyres. The tuffs contain 1% to rarely 5% phenocrysts, less than 2 mm in diameter, of sanidine, smoky quartz, biotite, and traces of sphene, zircon, apatite, and opaque minerals.

Accidental-lithic tuffs are most voluminous and widely distributed and generally occur near the base of the tuff apron around each dome. Uppermost surge

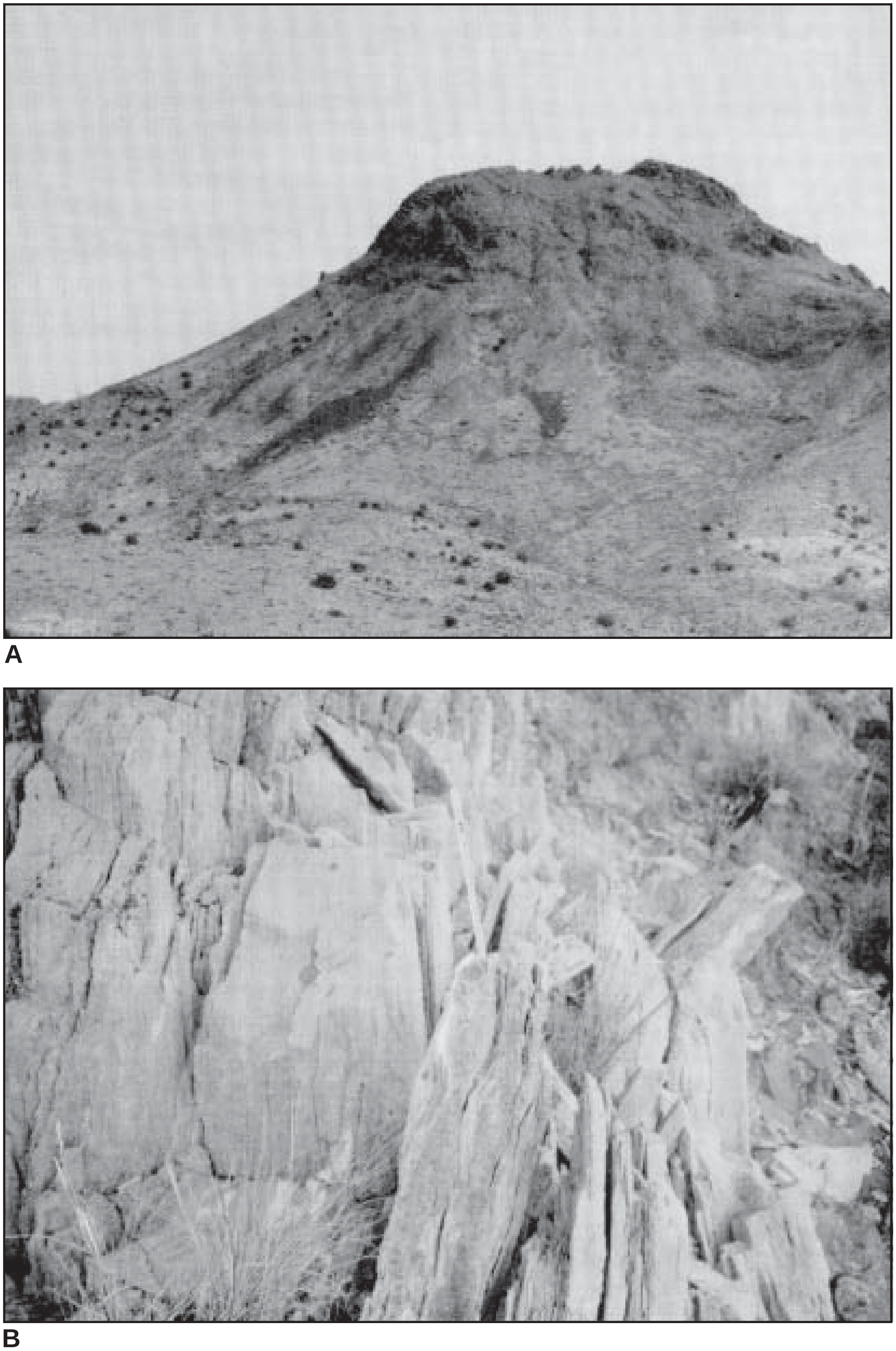

Figure 3. (A) View of the west side of Linder Peak, the highest point in the Castle Mountains and type locality for rhyolite of Linder Peak. The slope break near the top is the high-angle contact between a cylindrical rhyolite dome and a rhyolite pyroclastic-surge tuff. (B) Vertically flow foliated rhyolite of Linder Peak. Note mafic blebs in rhyolite. Pencil in center of photo for scale.

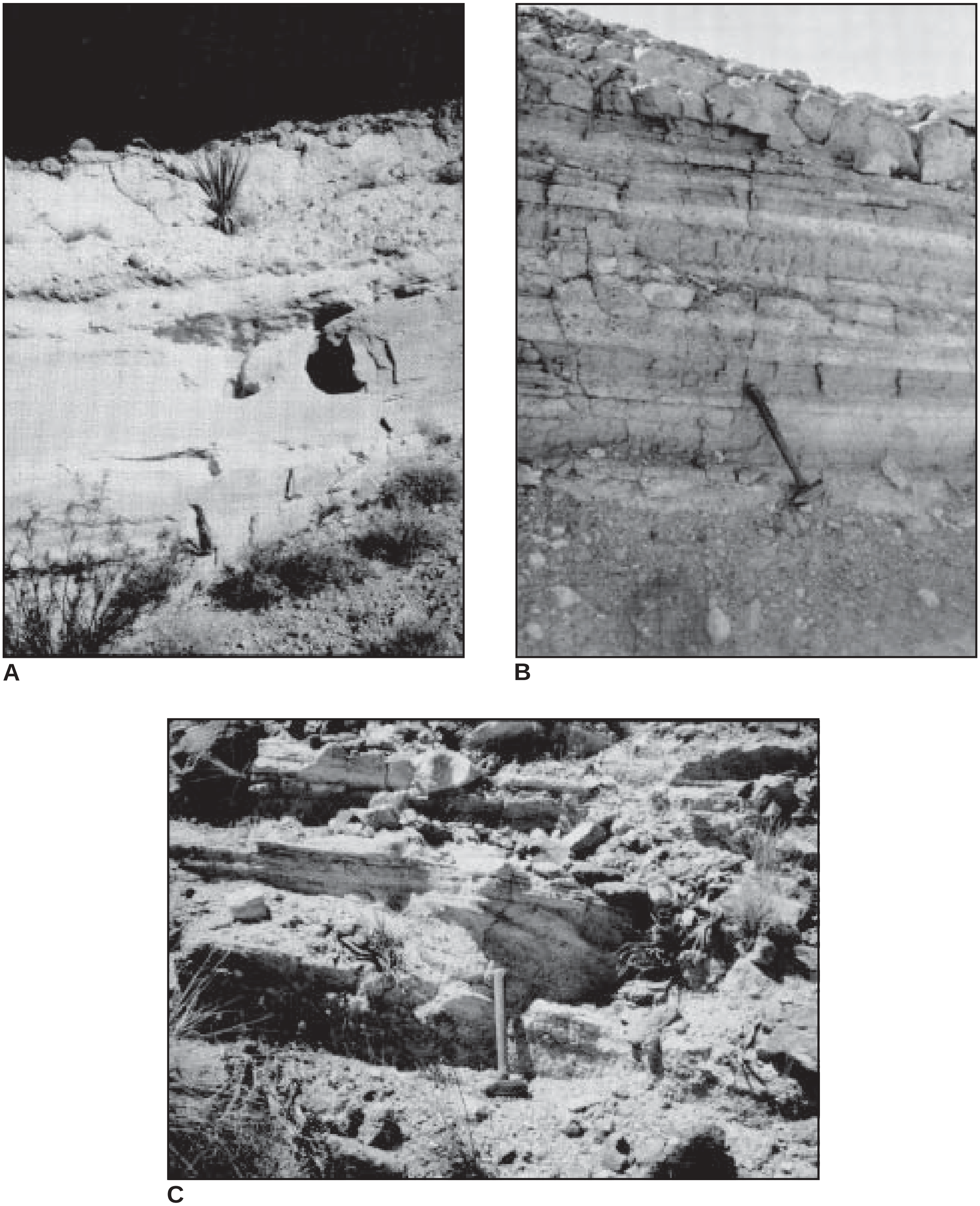

Figure 4. Linder Peak pyroclastic-surge sequences. (A) Fine-grained volcaniclastic rocks near the base of a surge sequence in the northern Castle Mountains (N135,170 E114,720) overlain by a blocky pumice bed and by thin, planar-bedded surge deposits. (B) Thick (1 to 12 inch) planar-bedded pyroclastic-surge tuffs (N133,800, E109,320). (C) Cross- and planar-bedded vitric pumiceous surge deposits in the northern Castle Mountains (N131,780, E107,590).

deposits and some individual beds are dominated by cognate-lithic fragments. The largest and most abundant clasts are phenocryst-poor rhyolite (**Tl**) up to about 20 feet in diameter, which are concentrated near the base of a surge sequence; other volcanic rocks and Proterozoic rocks are also present.

Pyroclastic-surge tuffs show planar or sandwave bedding or are massive (Wohletz and Sheridan, 1979). Massive deposits are most common within the central Castle Mountains and within vents. Ripples, cross-laminations, antidunes, chutes, cut-and-fills, and massive beds are common within sandwave deposits. Many planar beds are inversely graded.

Intensely altered and hydrothermally brecciated fragmental rocks are closely associated with the ore deposits. The JSLA pit is centered on a phreatomagmatic vent with phreatomagmatic- and phreatic-breccia containing strongly leached rhyolite clasts (**Tltl**) and accidental-lithic surge tuff (**Tlta**). The massive vent facies surge (**Tltl**) contains phenocryst-poor rhyolite (**Tl**) blocks up to several hundred feet long.

Rocks of Hart Peak

Rocks of Hart Peak occur throughout the Castle Mountains (see plate and fig. 5) and include basalt and trachyandesite (**Thb**), trachydacite-trachyandesite flows (**Tha**) and intrusions (**Tiha**), rhyolite flows (**Thr**) and intrusions (**Tihr**), rhyolite tuffs (**Tht, Thw**), and volcaniclastic rocks (**Thv**). Andesite flows are the most widely distributed; they are more than 490 feet thick about 2.4 miles northeast of Hart Peak. Trachyandesite and subordinate rhyolite are abundant in the southern Castle Mountains where they overlie and intrude altered, mineralized Linder Peak rocks.

Lower Hart Peak rocks are hydrothermally altered whereas upper parts are not. Sedimentary rocks in the lower part are silicified and argillized, and contain local ore-grade mineralization in the Northwest Rim area of the southern Castle Mountains. Hart Peak rhyolite and trachydacite-trachyandesite are unaltered throughout the Castle Mountains.

Volcaniclastic rocks (Thv). Light-brown and medium-brown, light-gray, and light-pinkish-brown volcaniclastic rocks up to 300 feet thick form broad aprons in the north-northeastern and south-southwestern Castle Mountains. These rocks consist of normally graded alluvial fan deposits, channel conglomerate, distal pyroclastic-surge tuffs, coarse- and medium-grained arkose with little tuffaceous component, and minor eolian sand. Conglomerate contains well-rounded, granule to boulder-sized clasts in a matrix of coarse and medium sand. Clasts are mostly Proterozoic rocks and Tertiary porphyritic basalt with lesser Paleozoic carbonate, Tertiary ash-flow tuff, fine-grained chalcedonic and coarse-grained milky vein quartz, and Tertiary rhyolite.

Poorly welded rhyolite tuff (Tht). Light-gray, light-pinkish-brown, and light-brown, lithic-vitric and vitric rhyolite pyroclastic-surge tuff, tuff-breccia, and minor associated volcaniclastic rocks are interbedded with basalt (**Thb**), volcaniclastic rocks (**Thv**), and rhyolite lava (**Thr**). The pyroclastic-surge tuffs are related to rhyolite intrusions at Hart Peak and in the west-central and southern Castle Mountains. Tuffs contain clasts of andesite and basalt (**Thb**) up to 8 feet across, rhyolite (**Thr**), older Castle Mountains volcanic rocks, and Proterozoic metamorphic rocks.

Basalt and trachyandesite (Thb). Dark-gray and medium- to dark-reddish-brown trachyandesite and basalt flows and scoriaceous andesitic agglomerate are interbedded with rhyolite pyroclastic-surge tuffs (**Tht**) and volcaniclastic rocks (**Thv**). The flows form steep slopes and cliffs. The andesites are sparsely to abundantly porphyritic. Phenocryst-poor flows from near Hart Peak contain less than 5% phenocrysts of pyroxene, opaque minerals, and olivine altering to iddingsite. Matrix consists of fine, intersertal plagioclase laths 0.3 mm long. Younger, phenocryst-poor, very dark-gray trachyandesite flows occur along the northwestern range front. Trachyandesite flows in the north-central Castle Mountains and the eastern New York Mountains contain abundant phenocrysts of plagioclase, up to 1 cm long, and hornblende; larger plagioclase phenocrysts are commonly sieve textured.

Welded rhyolite ash-flow tuff (Thw). A dark-gray, medium-brown, and medium-pinkish-gray vitric-lapilli and locally lithic rhyolite tuff is interbedded with andesite of Hart Peak (**Thb**) and volcaniclastic rocks (**Thv**) in the northwest Castle Mountains. It is 3 to 16 feet thick. The tuff contains 5 to 15% phenocrysts of feldspar, quartz, biotite, and hornblende. Vitric lapilli, up to 2.5 cm, impart a eutaxitic texture.

Rhyolite flows (Thr) and intrusions (Tihr). Medium- and dark-brown and locally mottled light-pinkish gray, light-pinkish brown, light-gray, and medium-gray porphyritic rhyolite flows (up to 130 feet thick) and hypabyssal intrusions form steep slopes and cliffs in the northwestern and southeastern Castle Mountains and in northeastern Lanfair Valley. Hart Peak is a prominent intrusion (fig. 6). Basal breccia and marginal vitrophyre are common. The rhyolites average about 20% phenocrysts, which average 3 to 4 mm in diameter, of plagioclase (mostly oligoclase), quartz, sanidine, biotite, hornblende, pyroxene, and fayalite. Hart Peak rhyolites are distinguished from Linder Peak rhyolites by a generally greater phenocryst content and size, especially mafic minerals, higher alkali/silica, and greater iron and magnesium contents (table 2). Devitrified Hart Peak rhyolites are much darker than Linder Peak rhyolites.

Trachydacite-trachyandesite flows and domes (Tha) and dikes and sills (Tiha). Light- and medium-gray, greenish-gray, and dark- and medium-brown trachydacite-trachyandesite forms dikes, sills and dome complexes with rhyolite (**Thr**). The trachydacite-trachyandesite is locally flow foliated, vesicular, or vitrophyric. All are abundantly porphyritic with up to 30% phenocrysts of plagioclase, hornblende, biotite, quartz, magnetite, ilmenite, and clino- and orthopyroxene. Fine-grained dioritic xenoliths up to 5 cm diameter and xenocrystic inclusions are common.

Boulder conglomerate (Tbc). Light-gray, unconsolidated and unsorted conglomerate crops out extensively in the western Castle Mountains, where it overlies Hart Peak rocks, and in the eastern Castle Mountains and western Piute Range, where it underlies PRV rocks. Similar conglomerate is abundant in the eastern New York Mountains (Miller and others, 1986). Conglomerate is at least 98 feet thick in the western Castle Mountains and 150 to 300 feet thick in a paleocanyon that is exposed in the JSLA pit; conglomerate there is capped by up to 25 feet of arkose (**Ta**). Well-rounded clasts averaging 1 foot but ranging up to 10 feet in diameter reside in a matrix of medium to coarse sand. Clasts consist of regional Precambrian, Mesozoic, and Tertiary rock units; CMV clasts are present only in reworked upper portions of conglomerate in the southern Castle Mountains.

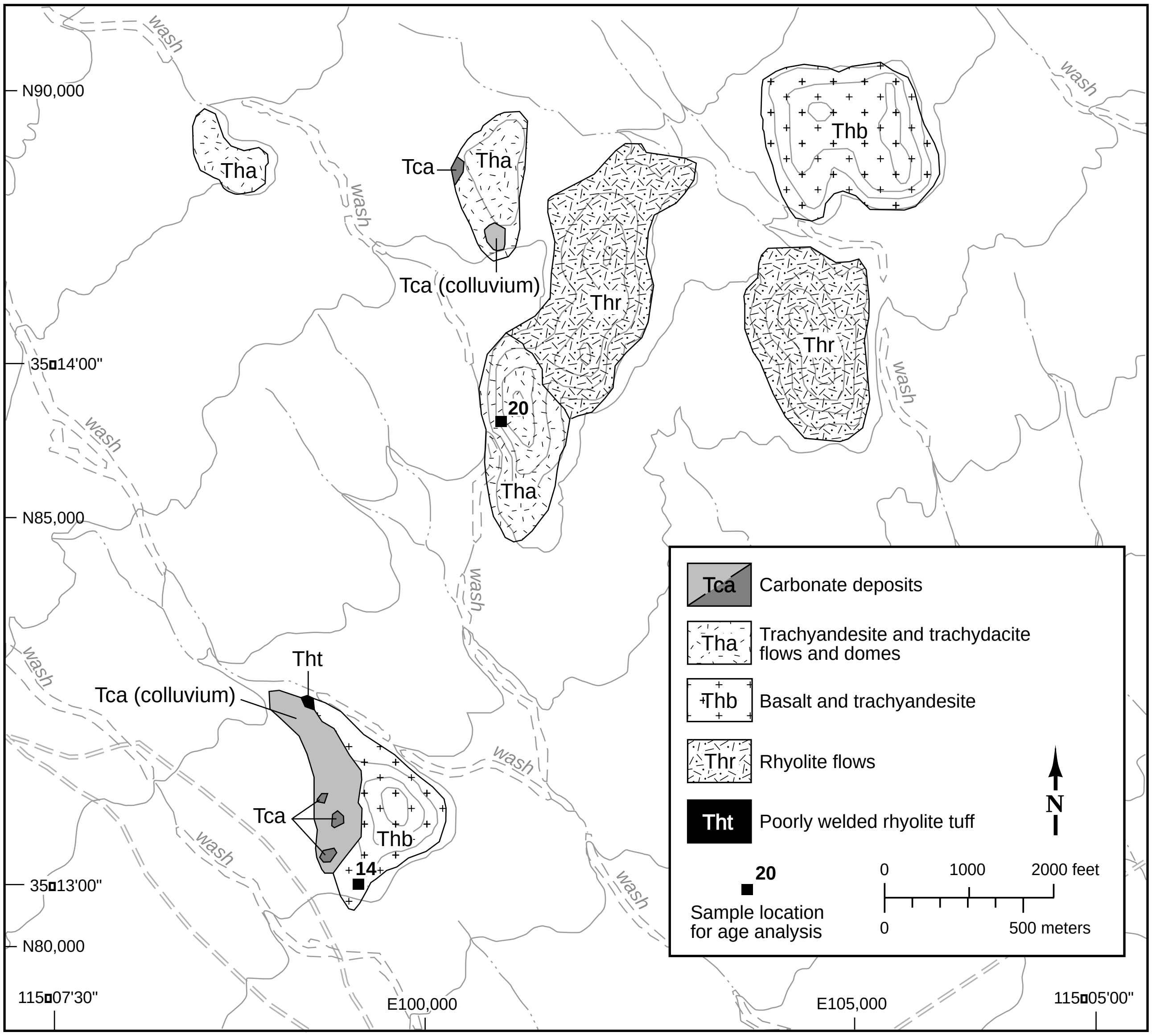

Figure 5. Geologic map of isolated outcrops in Lanfair Valley contiguous with the plate.

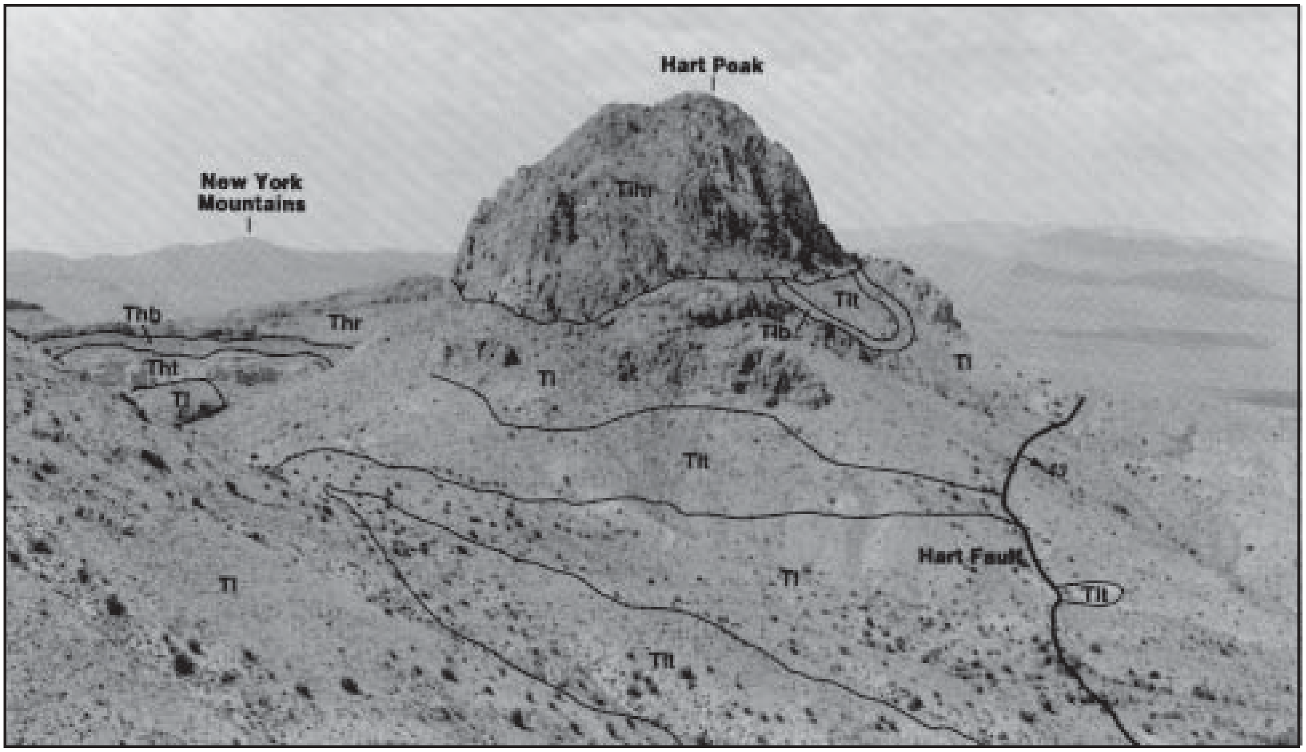

Figure 6. View of the southeast face of Hart Peak showing the trace of the Hart fault.

Table 2. Selected geochemical[1] data from the volcanic rocks of the Castle Mountains (CM) and the Piute Range (PR).

Location	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM	PR
Unit	Tps	Tjw	Tjb	Tja	Tl	Thb	Thb	Thr	Tha	Tiha	Tpa
Sample	C171[2]	C303[2]	C450	C451	C306[2]	C181[2]	C302[2]	C248[2]	C388[2]	C177[2]	C169[2]
SiO_2(ICP)[3]	74.21	77.9	51.85	58.99	77.66	47.2	55.26	71.57	66.35	64.38	54
TiO_2(ICP)	0.26	0.24	1.25	0.92	0.08	1.28	1.67	0.28	0.43	0.64	1.37
Al_2O_3(ICP)	13.86	10.93	17.01	16.73	12.56	16.7	16.65	13.48	14.72	15.57	16.41
Fe_2O_3(ICP)	1.13	1.52	7.23	5.88	0.73	3.76	2.24	0.98	0.98	1.65	1.66
FeO(T)[4]	0.04	0.1	0.36	0.57	0.22	4.8	4.49	0.67	1.23	1.8	5.21
MnO(ICP)	0.05	0.04	0.08	0.05	0.04	0.14	0.12	0.04	0.07	0.07	0.12
MgO(ICP)	0.26	0.33	3.43	1.63	0.08	6.1	3.9	0.43	0.64	1.34	5.79
CaO(ICP)	0.65	0.37	6.65	4.89	0.53	10.7	6.33	1.14	2.09	3.19	7.32
Na_2O(ICP)	3.94	3.05	4.81	4.6	4.06	3.41	4.33	3.73	4.02	4.31	3.98
K_2O(ICP)	6.14	4.77	2.54	3.77	4.59	1.7	2.91	5.42	5.04	4.62	2.43
P_2O_5(ICP)	0.12	0.17	1.31	0.73	<0.01	0.29	0.46	0.1	0.24	0.24	0.4
LOI	0.89	0.78	4.32	1.71	0.58	1.87	0.24	2.84	3.79	2.3	0.26
Total	101.6	100.2	100.8	100.5	101.1	97.9	98.6	100.7	99.6	100.1	99.0
Selected normative minerals											
Quartz	25.65	40.32	0	5.48	34.73	0	0	25.74	19.43	12.79	0
Corundum	0	0.48	0	0	0	0	0	0	0	0	0
Orthoclase	36.01	28.19	15.66	22.66	27.13	10.5	17.2	32.03	31.09	27.92	14.57
Albite	33.09	25.81	42.13	5.48	34.4	17.8	36.64	31.56	35.51	37.29	34.16
Anorthite	1.98	0.73	18.07	14.11	2.49	26.3	17.4	4.03	7.55	9.71	20.02
Nepheline	0	0	0.17	0	0	6.68	0	0	0	0	0
Diopside	0.39	0	6.14	4.8	0.12	22.1	9.16	0.91	1.35	4.25	11.46
Hypersthene	0	2.53	0	7.93	1.28	0	11.91	2.3	2.48	5.66	9.91
Olivine	0	0	10.88	0	0	11.9	0.57	0	0	0	4.23

[1] Weight percent analyses by Chemex Labs, Inc.
[2] See table 1, K/Ar and Ar/Ar ages from the Castle Mountains
[3] ICP - Inductively coupled plasma emission spectrometry
[4] T - Titration

PIUTE RANGE VOLCANIC ROCKS (PRV)

The mostly intermediate to mafic volcanic rocks of the PRV crop out extensively in the Piute Range and in a few, small areas in the Castle Mountains. PRV rocks are flat-lying to gently west-dipping and unconformably overlie more steeply tilted CMV, including altered Linder Peak rocks near Razorback Butte. PRV rocks include trachyandesite flows (**Tpa**), agglomerate (**Tpag**), lahars (**Tpl**), and subordinate dacitic domes (**Tpd**), rhyolitic tuff (**Tpt**), and volcanigenic sedimentary rock (**Tpvs**).

The PRV are less than about 14 Ma (table 1). Two whole-rock K-Ar ages are 13.8 ± 0.6 Ma on a clast in a trachyandesite agglomerate and 13.0 ± 0.6 Ma on a nearby trachyandesite flow, both at the base of the section in the southern Castle Mountains.

Rhyolite tuff (Tpt)

Light-gray, biotite-rich, rhyolite air-fall tuff, 0 to 20 feet thick, is interbedded with lahars, mudflows, and debris flows in the east-central Castle Mountains and near the JSLA pit. Tuff in both areas was deposited within paleocanyons. Tuff in the southeastern Castle Mountains overlies boulder conglomerate (**Tbc**) and underlies PRV andesite.

Lahars, debris flows, mudflows, and epiclastic rocks (Tpl)

Light-brown and light-gray lahars, debris flows, mudflows, and related epiclastic rocks, up to 200 feet thick, are common in the eastern Castle Mountains and western Piute Range. Clasts, <1 to 30 feet across, are of CMV, PRV, and Proterozoic metamorphic rocks. Deposits are mostly massive, but epiclastic rocks are cross bedded and normally graded. Lahars are commonly reversely graded.

At least 40 lahars and debris flows, along with thin biotite-sanidine rhyolite tuffs (**Tpt**), overlie boulder conglomerate (**Tbc**) and ore in the JSLA pit. These are divided into Egg Hill lower debris flows (**Tpel**), Egg Hill upper debris flows (**Tpeu**), lower lahars (**Tpll**), and upper lahars (**Tplu**) on the pit map; debris flows are most abundant in the lower part. Central and lower parts of lahars are generally non-sorted and contain boulders in a silt to fine sand matrix whereas upper parts are fine-grained. Clasts include Linder Peak rhyolite (**Tl** and **Tlp**) and hydrothermal breccia (**Tib**) in all deposits and Hart Peak trachydacite-trachyandesite (**Tha**) in lower lahars and upper debris flows. Southwest dips and channel and bedform orientations suggest lahars were derived from the northeast. Debris flows dip shallowly west off a topographic paleo-high on Egg Hill to the east.

Volcaniclastic rocks (Tpvs)

Light-gray, poorly indurated, finely bedded, biotitic, tuffaceous sedimentary rocks are interbedded with lahars and andesite along the eastern side of the Castle Mountains.

Dacite (Tpd)

A medium-brown flow-foliated porphyritic dacite underlies PRV andesite in the northeastern Castle Mountains. The dacite contains 3 to 5% phenocrysts of feldspar, quartz, and biotite.

Trachyandesite flows (Tpa) and agglomerate and volcanic breccia (Tpag)

Dark-and medium-gray and medium-reddish-brown, flow-foliated andesite flows, agglomerate, and volcanic breccia are the most abundant rocks in the Piute Range. Flows have dense interiors and vesicular to scoriaceous tops and bottoms. Andesite contains 1 to 15% phenocrysts of plagioclase, augite, hypersthene, amphibole, and olivine.

TERTIARY INTRUSIVE ROCKS

RHYOLITE DIKES (Tir, Tipr)

Fine-grained, phenocryst-poor (**Tir**) and phenocryst-rich (**Tipr**) rhyolite dikes, probably related to Linder Peak rhyolite, occur throughout the Castle Mountains but are most abundant in the northeastern Castle Mountains. Quartz-adularia veins locally cut the dikes. The phenocryst-poor dikes contain up to 8% phenocrysts of quartz, oligoclase, sanidine, biotite, hornblende, fayalite, magnetite, ilmenite, and trace zircon. The phenocryst-rich dikes contain greater than 8% of the same assemblage.

PYROCLASTIC DIKES AND SILLS (Tip)

Possible pyroclastic dikes and minor sills, 1 to 3 feet wide, cut Linder Peak rocks throughout the Castle Mountains. Clasts, less than 5 inches long, are Proterozoic metamorphic rocks and minor CMV rocks. Moderately sorted and oriented clasts suggest fluidization.

A possible pyroclastic sill and baked zone occurs along the upper contact of the large diorite sill in the north-central Castle Mountains. The pyroclastic sill contains clasts and fiamme of porphyritic rhyolite, with 2% phenocrysts of sanidine and smoky quartz, and minor clasts of Proterozoic metamorphic rocks, andesite, chert, and sandstone.

ANDESITE DIKES AND PLUGS (Tia)

Fine-grained, unaltered andesite dikes and plugs occur throughout the Castle Mountains. The dikes are probably related to late Hart Peak or PRV volcanism.

DIORITE SILLS AND DIKES (Tid)

Dark-gray, medium-gray, and dark-brown, coarse- and medium-grained diorite dikes and sills occur in the north-central and northeastern Castle Mountains. The diorites locally intrude low-angle normal faults. The large sill in the northern Castle Mountains has a whole-rock K-Ar age of 13.0 ± 1.3 Ma (table 1, C314). The diorite is probably related to late Hart Peak volcanism on the basis of chemistry (Capps, 1996).

TERTIARY ROCKS ASSOCIATED WITH AREAS OF MINERALIZATION AND ALTERATION

QUARTZ VEINS (Tqz)

Finely banded veins of quartz ± iron oxides, calcite, sericite, pyrite, clay minerals, and adularia occur throughout the Castle Mountains. Veins are common in the southern Castle Mountains where they occupy N25°-35°E-striking fractures and cavities formed by hydrothermal leaching within Linder Peak rhyolite. Quartz-after-calcite is common. Adjacent wall rock is commonly silicified and contains thin seams of clay and hydromica.

HYDROTHERMAL BRECCIA

Early hydrothermal breccia (Tib1),

Late hydrothermal breccia (Tib2)

Dikes, sills, pipes and small irregular bodies of silicified breccia and microbreccia are associated with gold mineralization. Most bodies are less than 1 foot wide, but dikes up to 800 feet long and 100 feet wide occur in the Jumbo South deposit (pit map, see plate). Intrusive breccia typically grades into mosaic fractured rock. Clasts include a wide range of Linder Peak rocks, as well as Jacks Well and Proterozoic rocks and quartz-calcite veins. Early breccia (**Tib1**) is distinguished by greater silicification, rounding, and sorting of clasts than in late breccia (**Tib2**).

TERTIARY AND QUATERNARY DEPOSITS

CARBONATE DEPOSITS (Tca)

Light-gray Tertiary limestone, < 30 feet thick, caps boulder conglomerate in Lanfair Valley and the valley between the Castle and New York Mountains, and overlies Hart Peak basalt in Lanfair Valley. The limestone is dense to porous and contains coarse to medium quartz sand and light-gray chert nodules about 8 cm in diameter. Rodney Watkins (private report to Viceroy Gold Corp., 1990) found filamentous algae, replacement by chert, and sparry replacement zones.

UNCONSOLIDATED DEPOSITS

Late Tertiary and Quaternary deposits include unconsolidated and calichified pediment and elevated terrace sediments and colluvium (**QTs**) that underlie dissected terraces 6 feet or more above modern drainages, unconsolidated older stream sediments and flood deposits (**Qso**) of gravel-poor sand and sandy gravel in flood plains elevated 1 to 6 feet above the modern channels, and undifferentiated stream channel deposits (**Qs**) of sand and gravel in modern channels or on low-lying terraces adjacent to these channels.

STRUCTURAL GEOLOGY

Field relationships suggest four episodes of deformation in the Castle Mountains: (1) Proterozoic deformation, (2) Mesozoic deformation, (3) cryptic Miocene northwest-striking faulting, and (4) Miocene dilation associated with growth faults and hypabyssal dike emplacement. The Miocene dilation culminated in Miocene faulting and fracturing. Early dike formation, faulting, and fracturing were probably contemporaneous.

PROTEROZOIC DEFORMATION

Proterozoic deformation that accompanied amphibolite-grade metamorphism produced a well-developed, northwest-striking, northeast-dipping crystalloblastic foliation defined by compositional banding and mineral orientation in gneiss and granite. Compositional banding at many scales is obvious in the gneiss but is evident in granite only in thin section. Biotite, muscovite, and amphibole typically define the foliation in both rock types; lineation is lacking. The foliation may indicate northeast-southwest contraction.

The age of the foliation is unknown. Proterozoic rocks in the New York Mountains are 1.7 Ga (Wooden and others, 1986), but Proterozoic granite there discordantly intrudes the gneiss. Some deformation probably occurred during intrusion.

MESOZOIC(?) DEFORMATION

A broad, northeast-striking, northwest-dipping, possibly Mesozoic shear zone cuts the small outcrop of Paleozoic limestone and Proterozoic gneiss but not Tertiary rocks in the northern Castle Mountains. Cataclasite in the hanging wall contains thin boudins of carbonate, up to 3 feet long, with their long axes parallel to the shear zone. Rounded fragments of gneiss about 20 cm in diameter occur with the carbonate fragments in the otherwise fine-grained mylonite. Thin-section analysis of an oriented sample of gneiss from the shear zone suggests, additionally, northeast-striking ductile deformation. This shear zone may be related to complex Mesozoic structures in the New York Mountains (Burchfiel and Davis, 1977; Miller and Wooden, 1993).

MIOCENE EXTENSION

DIKES

North-northeast-striking dikes and normal faults express mid-Tertiary extension in the Castle Mountains. Dikes, related fractures, and quartz veins formed throughout CMV activity strike north-northeast and are either vertical or dip steeply eastward. The steep dip indicates relatively modest tilting of the range after dike emplacement.

All dikes show a change in strike across a cryptic northwest-striking discontinuity in the central Castle Mountains. For example, the thick Hart Peak dike (**Tiha**) that crosses eastern Egg Hill changes strike before ending in the central Castle Mountains.

FAULTS AND FRACTURES

Low to high angle normal faults and possibly oblique-slip faults, mostly with less than a few feet displacement, occur throughout the range, especially in the northern and northeastern part. Two larger faults and a major fracture zone are described here.

The Hart fault extends from east of Linder Peak for 4.5 miles to the northern Castle Mountains (fig. 6). It disappears beneath Quaternary sediments on its northern end and beneath post-faulting PRV rocks on its southern end. The fault dips steeply to gently eastward and is down on the east. The fault is mostly in CMV rocks, but Proterozoic rocks form the footwall in the east-central Castle Mountains.

The Razorback fault can be traced for at least 2 miles through the northeastern Castle Mountains and may extend another 2.7 miles to the north. At Razorback Butte the fault drops intensely deformed Linder Peak rocks east of the fault down against Proterozoic rocks and lower CMV rocks. The fault surface strikes about N40°E and dips 60° southeast. Intensely deformed Linder Peak pyroclastic-surge tuffs at Razorback Butte generally strike parallel to the Razorback fault and dip 23° to 90° southeastward. Beds adjacent to the fault are locally overturned. Because primary dip on the surge beds is uncertain, the amount of tilting is also uncertain.

A poorly exposed Northwest Rim fracture zone extends about 6 miles along the western Castle Mountains from the Northwest Rim. The zone strikes N30°-40°E and dips steeply southeast in the Northwest Rim but changes to a more northerly strike where it crosses a cryptic northwest-striking discontinuity in the central Castle Mountains. The fracture zone is intruded by Hart Peak rhyolites at and near Hart Peak. Gentle northwest dips, up to 12°, in Hart Peak epiclastic rocks along the zone are probably primary.

Peach Springs Tuff and the rocks of Jacks Well are variably tilted west. Westward tilting of the rocks of Linder Peak and younger rocks is minor. Therefore, total extension is likely minor. Faulting and fracturing were largely completed by 14 Ma when the generally flat-lying PRV rocks were extruded. Several geologists have interpreted the outcrop pattern of Miocene volcanic rocks surrounding Proterozoic metamorphic rocks in the northeast Castle Mountains to be a northeast-striking, doubly plunging asymmetrical anticline (Hewett, 1956; Spencer, 1985; Turner, 1985; Turner and Glazner, 1990, Ausburn, 1991). Our mapping indicates that this apparent antiform probably results from Miocene normal faulting.

POORLY DEFINED OLDER STRUCTURES

Poorly defined, northwest-striking discontinuities and photo lineaments locally disrupt the more prominent north-northeast trends. These may represent older Miocene structures that influenced younger Miocene faulting and intrusions. Linder Peak and Hart Peak dikes and quartz veins commonly change strike across the lineaments. Discontinuous northwest-striking fractures, faults, and chalcedonic quartz veins of unknown but apparently small displacement within Linder Peak rocks occur along the lineaments. The Peach Springs Tuff commonly strikes northwest and dips to the southwest, consistent with tilting along northwest-striking, northeast-dipping normal faults. Overlying rocks do not show these attitudes. Some northwest-striking faults may have been active following deposition of the Peach Springs Tuff and before CMV deposition.

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