GEOLOGIC MAP OF THE EAST OF GROTTO HILLS QUADRANGLE, CALIFORNIA

by Jane E. Nielson

INTRODUCTION

The East of Grotto Hills 1:24,000-scale quadrangle of California lies west of the Colorado River about 30 km southwest of Searchlight, Nevada (figs. 1, 2), near the boundary between the northern and southern parts of the Basin and Range Province. The quadrangle includes the eastern margin of Lanfair Valley, the southernmost part of the Castle Mountains, and part of the northwest Piute Range. The generally north-trending Piute Range aligns with the Piute and Dead Mountains of California and the Newberry and Eldorado Mountains and McCullough Range of Nevada (fig. 1). The southern part of the Piute Range adjoins Homer Mountain (Spencer and Turner, 1985) near Civil War-era Fort Piute (fig. 2). Adjacent 1:24,000-scale quadrangles include Castle Peaks, Homer Mountain, and Signal Hill, Calif.; also Hart Peak, Tenmile Well, and West of Juniper Mine, Calif. and Nev. (fig. 2).

The mapped area contains Tertiary (Miocene) volcanic and sedimentary rocks, interbedded with and overlain by Tertiary and Quaternary surficial deposits. Miocene intrusions mark conduits that served as feeders for the Miocene volcanic rocks, which also contain late magma pulses that cut the volcanic section. Upper Miocene conglomerate deposits interfinger with the uppermost volcanic flows. Canyons and intermontane valleys contain dissected Quaternary alluvial-fan deposits, mantled by active alluvial-fan deposits and detritus of active drainages. The alluvial materials were derived largely from Early Proterozoic granite and gneiss complexes, intruded by Mesozoic granite, dominate the heads of Lanfair Valley drainages in the New York Mountains and Mid Hills (fig. 1; Jennings, 1961). Similar rocks also underlie Tertiary deposits in the Castle Peaks, Castle Mountains, and eastern Piute Range (figs. 1, 2).

Regional geologic mapping by Hewett (1956) and Bingler and Bonham (1973) included parts of the map area. New geologic mapping in the area was undertaken by U.S. Geological Survey (USGS) between 1983 and 1991; summaries of Castle Mountains and Piute Range stratigraphy have been published from this work by Nielson and others (1987, 1993), and Nielson and Nakata (1993).

GEOLOGIC SETTING

The volcanic rocks of the Castle Mountains and Piute Range were erupted onto a basement complex of mostly Early Proterozoic age (Wooden and others, 1986), which is not exposed in the East of Grotto Hills quadrangle. Intrusive relations between Early Proterozoic gneiss and less foliated Early Proterozoic granite crop out within the Castle Peaks, Hart Peak, Homer Mountain, West of Juniper Mine, and Tenmile Well quadrangles (fig. 2). Deformed to undeformed granite, probably of Mesozoic age, intrudes the Early Proterozoic complex within the Homer Mountain, West of Juniper Mine, and Signal Hill quadrangles (Miller and others, 1986; Spencer and Turner, 1985).

Extensional faulting of Miocene age produced the main structural elements exposed within the East of Grotto Hills quadrangle. High-angle normal faults with north and northeast strikes, also due to Miocene extension, are the main structures in the area. No low-angle normal (detachment) faults crop out in the Castle Mountains or Piute Range, although detachment faults are exposed to the west in the Kingston Range (Reynolds, 1993) and to the east in the Black Mountains of Arizona (Faulds and others, 1990; Faulds, 1993)(fig. 1). The relation of exposed high-angle faults, either to hypothetical Miocene low-angle normal faults at depth or to regional strike-slip faults, such as the Las Vegas Valley shear zone, remains unclear (Faulds and others, 1990).

TERTIARY AND QUATERNARY ROCKS

Lower, Middle, and Upper Miocene Deposits

Tertiary rocks in the East of Grotto Hills quadrangle are middle and upper Miocene, mafic-to-silicic, volcanic flows, tuff, and breccia and interbedded volcaniclastic and epiclastic sedimentary rocks. Basal Miocene rocks have not been observed in the quadrangle. Regionally, the base of the Miocene section is locally-derived arkosic sandstone and conglomerate of

Tertiary age (Oligocene? and Miocene), observed in the Castle Peaks, Homer Mountain, West of Juniper Mine, and Tenmile Well quadrangles (fig. 2). The oldest volcanic rock unit of local origin is a basaltic andesite flow in the southernmost part of the Piute Range (Homer Mountain quadrangle), dated at 19.8±0.5 Ma (Nielson and Nakata, 1993; Nielson and Turner, 1998).The oldest regional Miocene volcanic unit is the sanidine-rich, sphene-bearing Peach Springs Tuff of Young and Brennan (1974), a widespread ash-flow tuff dated at 18.5±0.2 Ma (Nielson and others, 1990; Nielson and Turner, 1998). The closest outcrops of Peach Springs Tuff to the map area are in the West of Juniper Mine and Hart Peak quadrangles (fig. 2).

The East of Grotto Hills quadrangle contain middle Miocene volcanic rocks that were erupted in the Castle Mountains and the Piute Range. Volcanic units in both the Castle Mountains and Piute Range include basaltic, andesitic, and rhyolitic rocks, but the Castle Mountains contain a higher proportion of silicic rocks and also a greater abundance of alkalic compositions compared to rocks of the Piute Range (rock compositions are listed in Nielson and Turner, 1998).

Volcanic rocks of the Castle Mountains are represented by thin outcrops of rhyolitic tuff and breccia (Tr), basalt flows (Tb), and interbedded rhyolite tuff and breccia and basalt flows (Tbts) in the northern and western parts of the map area. The light-colored rhyolite units were erupted from rhyolite domes in the Hart Peak quadrangle to the north of the map area (fig. 2). Rhyolite units in the Castle Mountains have ages between 12.8 and 16.3 Ma (Turner and Glazner, 1990; Capps and Moore, 1991). Outcrops of welded tuff in the southeastern part of the quadrangle, also shown as unit Tr, could have had a source in either the Castle Mountains or the Woods Mountains at the west side of Lanfair Valley (fig. 1; McCurry, 1988).

The far eastern part of the East of Grotto Hills quadrangle is composed largely of Piute Range volcanic rocks, a sequence of dark-colored middle and upper Miocene flows and breccia, which overlap light-colored Castle Mountains units in the northwestern part of the map area, and in the Hart Peak quadrangle (fig. 2). The Piute Range rocks are mostly short, stubby andesite, trachyandesite, basalt, trachybasalt, and basaltic andesite flows and flow breccia (Tb, Ta), interbedded tuff (Tpr) and gravel, representing channel-fill deposits (Tg). Abundant porphyritic or aphyric andesitic and basaltic dikes occur throughout unit Ta in the Piute Range. A unit of thin trachyandesite flows and breccia, lithologically similar intrusions, and interbedded sedimentary rocks (Tats) is exposed in cliffs in the northeastern part of the quadrangle. Dacitic flows and domes (Td) and domes (Tid) are scattered throughout the more mafic units. Ages that vary from 19.8 to 8 Ma were determined on basaltic and andesitic flows at localities throughout the Piute Range (Nielson and Nakata, 1993). In the East of Grotto Hills quadrangle, samples of basalt and trachyandesite yielded ages of 13.3 to 10.7 Ma.

Tertiary and Quaternary Surficial Deposits

Deposits of middle and upper Miocene gravel (Tg) unconformably overlie the volcanic rocks of the Castle Mountains. Clasts in the conglomerate include Early Proterozoic gneiss and granite, Paleozoic limestone and marble, Mesozoic granite, and varying—generally minor—proportions of volcanic rocks. Conglomerate units of Pliocene and Quaternary age conformably overlie the upper Miocene rocks in the Hart Peak quadrangle (Nielson, 1995).

Lacustrine deposits (QTp) in the East of Grotto Hills quadrangle extend south into the Signal Hill quadrangle, where they conformably overlie Miocene volcanic rocks, but also crop out in buttress unconformity against fault scarps composed of Miocene lava. The unit of lacustrine deposits is deeply dissected into badlands topography by the locally-developed drainage of Piute Gorge (fig. 2), and is capped by alluvium that bears a soil horizon with a thick petrocalcic layer. The thickness of the petrocalcic layer suggests that the soil developed between early and late Pleistocene (Katzenstein and others, 1995). Other playa deposits overlie Piute Range volcanic rocks within the West of Juniper Mine quadrangle; these playa units contain zones of siliceous tufa deposited by hot springs. Some of the tufa outcrops contain fossil bison, yielding a Rancholabrean (late Pleistocene) land mammal age (R.E. Reynolds, oral commun., 1987).

Several generations of unsorted alluvial-fan and stream-channel deposits are found in the quadrangle, mantling mountain slopes and washes and blanketing the intervening valleys. Older fan deposits (Qoa) are highly dissected; the surfaces are stripped of soil and expose calcified zones. Fan and stream deposits of intermediate age (Qia_{1a}, Qia_{1b}) have thick, poorly defined soil profiles. Stream deposits of intermediate age (Qia_{2a}, Qia_{2b}) have bar-and-swale surfaces.

STRUCTURE

Miocene rocks in the East of Grotto Hills quadrangle mostly dip 15° or less, either to the west or east. Low radial dips occur locally where lava flows overlapped older domical silicic flows, which formed topographic mounds. Miocene faults are difficult to identify within sequences of monotonously similar-appearing lava and breccia that make up the southwestern part of the Piute Range in the map area. Near Fort Piute, in the Homer Mountain and Signal Hill quadrangles to the south, flows and breccia of the Miocene section dip gently eastward and these units are repeated by well-exposed northwest-striking and west-dipping normal faults. Thus, faults in the quadrangle that have north and northeast strikes also probably dip steeply; the dip directions could be either to the west or east, however, and the displacements are unknown.

Elsewhere in the Castle Mountains and Piute Range, faults with northern strikes have observable displacements of tens of meters at most. In the eastern part of the Piute Range (Homer Mountain, West of Juniper Mine, and Tenmile Well quadrangles), however, the contact of basal units—arkosic sedimentary deposits or the Peach Springs Tuff (Nielson and Turner, 1998)—on Early Proterozoic augen gneiss is as much as 300 m lower than the basal contact in the central part of the Castle Mountains (Hart Peak quadrangle). The difference in elevation of the basal nonconformity indicates at least a 300 m fault offset of the basal Tertiary rocks in less than a 4 km horizontal distance, therefore. Gravity measurements (Mariano and others, 1986) show a steep gravity gradient that strikes parallel to the west side of the Piute Range in the eastern part of the East of Grotto Hills quadrangle, suggesting the presence of buried or cryptic range-parallel faults with substantial offset.

INTERPRETATION

The volcanic rocks of the Castle Mountains and Piute Range were erupted in adjacent faultbounded volcano-tectonic depressions (Nielson and Turner, 1998). The basin-bounding faults are not well expressed, but one of the mapped north-northeast-striking Piute Range faults in the East of Grotto Hills quadrangle could belong to the group of faults that offset the basal contact of Tertiary deposits on Early Proterozoic rocks by 300 m. Such faults probably represent the western boundary of a volcano-tectonic half-graben in which Piute Range lavas accumulated at the same time that rhyolite ejecta were erupted and intrusive domes emplaced in the Castle Mountains volcano-tectonic depression to the west (Nielson and Turner, 1998).

Volcanism continued in the Piute Range until about 8 Ma, more than 4 m.y. after the rhyolitic eruptions in the Castle Mountains had ended (at about 12.8 Ma), and this activity apparently filled the eastern volcano-tectonic depression. To the north and west in the Castle Mountains, Miocene gravel (Tg) and younger fanglomerate deposits conformably overlie the rhyolite units, and these deposits apparently filled the western depression. The predominant pre-Tertiary sources of all the surficial units, including channel-gravel deposits within and above the Miocene volcanic sequences, show that the map area has continuously received detritus eroded from uplands composed of Early Proterozoic gneiss and granite, and Mesozoic granite, similar to the dominant sources for both Holocene and active channel fills in Lanfair Valley.

Depositional and structural relations in the East of Grotto Hills quadrangle and adjacent quadrangles support a history of continued faulting episodes in the late Tertiary and early Quaternary. The linear boundary of the range is most likely controlled by faults parallel to basin-bounding faults that defined the volcano-tectonic depression of the Piute Range in early and middle Miocene time. Thick playa deposits at the western boundary of the Piute Range indicate formation of a buttress that ponded drainages at the east side of Lanfair Valley after volcanism ended in the late Tertiary, probably due to continued movement on faults. Other evidence of continued faulting in the region include:

1) Superimposed drainages that cross the Piute Range to the north and south of the East of Grotto Hills quadrangle (Piute Gorge on the Signal Hill quadrangle; unnamed canyon west of Old Homestead Road on the Tenmile Well and Hart Peak quadrangles, fig. 2).

The Piute Gorge drainage cuts a soil horizon that probably developed no earlier than early Pleistocene (Katzenstein and others, 1995), which suggests faulting and relative offset of valleys and mountain ranges after late Tertiary time.

2) Miocene gravel deposits in the Castle Mountains and Piute Range commonly contain clasts of Paleozoic limestone, and Mesozoic granite of the Teutonia batholith, which were derived from sources in and near the Mescal Range to the northwest and the southeastern New York Mountains to the southwest. Drainages from those sources presently are either obstructed by topographic barriers or flow in an inappropriate direction for transportation of such clast types to the present site of deposits. The earliest time that the topographic barriers could have formed is the late Miocene (Nielson, 1995; Miller, 1995; Nielson and Turner, 1998). Formation of the topographic barriers provided wide exposure of basement rocks, from which detritus continues to be shed into the drainage systems of Lanfair Valley.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qts

Talus and scree (Holocene)—Regolith of basalt talus, cobbles, and boulders. Single outcrop mapped only in southeast corner of quadrangle on steep slope where underlying stratigraphic and structural relations are obscured. Thickness as much as 5 m

Qya

Younger alluvium (Holocene)—Clay, sand, pebbly sand, and gravel. Matrix is clay-rich and clasts are mostly subangular to subrounded volcanic rocks close to mountain fronts and in canyons. Elsewhere, matrix is predominantly sand, and clasts are about equal proportions of granite, gneiss, and volcanic rocks. Forms in active stream channels and flanking bar-and-swale zones. Estimated thickness less than 2 m

Qau **Older, intermediate, and younger alluvium, undivided (Holocene and Pleistocene?)**—Deposits present in areas of low, finely dissected ridges made of older matrix-supported gravel deposits (Qoa), flanked by planar terraces (Qia_{1b}), and thin active channels (Qya) and overbank flood deposits with bar and swale morphology (Qia_{2b}). Shown in broad alluvial valleys where component units cannot be mapped separately

Intermediate alluvium (Holocene and Pleistocene?)—Slightly lithified to lithified sand, pebbly sand, gravel, and cobbles. Divided into:

Unit 2—Consists of:

Qia_{2b} **Younger deposits (Holocene)**—Overbank deposits with sandy matrix having bar-and-swale morphology, mostly found in broad alluvial valleys. Bar-and-swale morphology includes network of thin pebbly to cobble-rich stream-channel deposits with weak surface imbrication. Clasts consist of granite, gneiss, and volcanic rocks in about equal proportions. Grades laterally into active stream deposits (Qya) or low terraces underlain by unit Qia_{1b} deposits. Exposed thickness 0 to 2 m

Qia_{2a} **Older deposits (Holocene and Pleistocene?)**—Debris-flow and distributary alluvial-fan and braided-channel deposits, which have bar-and-swale morphology. Chiefly volcanic-clast boulder conglomerate of well-sorted sand, as well as granitic and gneissic rocks derived from reworking of older alluvium. Imbrication of surface clasts strong in bars and swales; pavement development is weak. Found on lower slopes of Piute Range. Surfaces and boulder trains are black due to high content of dark volcanic lava: basalt, andesite, and basaltic andesite; some clasts may acquire part of their varnish after deposition. Surfaces are dissected, standing 1 m or more above younger surfaces underlain by unit Qia_{1b}. Exposed thickness 0 to 2 m

Unit 1—Consists of:

Qia_{1b}

Younger deposits (Holocene)—Reddish, predominantly unsorted sand and pebbles. Horizons of clast-supported pebble- and cobble-size, angular to subangular gravel that consists of about equal amounts of granite, gneiss, and volcanic clasts. Soil well developed locally, at least 50 cm thick; sandy in upper 10 cm but clay-rich and vesicular below 20 cm, with patchy calcareous zones. Forms terraces 2 to 4 m above active washes (Qya); deposits overlap and, in places, partly bury dissected ridges of older alluvium (Qoa). Terraces in the broad valleys merge laterally into deposits of unit Qia_{2b}. Surfaces have no preserved bar-and-swale morphology; surface pavements appear poorly developed and unvarnished. The lack of development may be due in part to destruction of surface by range cattle, and lack of varnish may reflect the high proportion of granitic materials. Exposed thickness 0 to 3 m

Qia_{1a}

Older deposits (Holocene and Pleistocene?)—Inactive deposits of reworked talus, scree, and older alluvial fans (Qoa) on lower slopes of Piute Range. Surfaces smoother and lighter colored than those of adjacent and surrounding deposits of unit Qia_{2a}, indicating erosion of surfaces. Surfaces are 1 m or more above channel-margin terraces underlain by unit Qia_{1b}. Exposed thickness 0 to 3 m

Qoa

Older alluvium (Pleistocene)—Clast- or matrix-supported gravel deposits. Consists of clay-rich matrix, coarse sand grains with calcium carbonate septa, and cobbles of angular to subangular granite or gneiss; local concentrations of volcanic rock types common. Pebbly zones and large boulders are not common. Soils thin or absent in most places. Surfaces light-colored due to litter of fragments from exhumed petrocalcic horizon at shallow depth (10-

to 12-cm maximum depth), as shown by concentrations of small pebbles around ant hills. Forms steep-sided spurs at mountain fronts and wide alluvial ridges 5 to 6 m above active stream channels (Qya). Surfaces display no depositional morphology; local concentrations of clasts interpreted as lag deposits. Exposed thickness 0 to 5 m

QTp **Playa and lacustrine deposits (Pleistocene? to Miocene)—**Buff, dark-tan, and reddish-brown, horizontally bedded, soft claystone, siltstone, sandstone, and pebbly sandstone with gypsum and calcite beds, capped by soil horizon with thick petrocalcic layer. Contains dispersed pebbles of basaltic scoria, massive basalt, and andesite. Basaltic flows intersected beneath playa strata in a water well located south of the quadrangle and west of any outcrops has been interpreted as Quaternary lava interbedded with playa sediments (Environmental Solutions, 1989) but may be the top of a downfaulted Miocene section. Deeply dissected deposits: about 60 m thick in East of Grotto Hills quadrangle. In Signal Hill quadrangle at western end of Piute Gorge (fig. 1), 80-m thickness exposed in buttress unconformity with faulted basaltic and andesitic volcanic rocks that have low dips to the west

VOLCANIC AND SEDIMENTARY ROCKS

Tg **Gravel deposits (Miocene)—**Conglomerate and interbedded sandstone and siltstone. Consists of immature coarse- to medium-grained crystal-lithic sand matrix containing subangular to rounded clasts. Matrix crystals are predominantly biotite and feldspar, with rarer pyroxene grains. Clasts are generally granite, gneiss, massive quartz, and gray Paleozoic limestone containing stringers of brown chert. Proportions of volcanic and sedimentary clasts are generally small. Overlies or locally interbedded with middle and upper Miocene rhyolite tuff and flows (Tr), and basalt flows

(Tb). Exposed thickness 0 to 5 m

Tbts **Basalt flows, rhyolite tuff, and sedimentary rocks (Miocene)**—Air-fall tuff, tuff breccia, flows, and ash-flow tuff, interbedded with thin basaltic flows and dikes, and local conglomerate. Mapped where silicic tuff and breccia ejecta (Tts) and basalt flows (Tb) are indistinguishable. Generally forms gentler slopes than either tuff (Tts) or basalt (Tb). Thickness 10 to 150 m

Tb **Basalt flows (Miocene)**—Vesicular and scoriaceous, porphyritic, fine-grained to glassy flows and flow breccia; dominantly composed of basalt and basaltic andesite, with local andesite, trachyandesite, and rare rhyolite flows. Commonly brecciated; includes local interbeds of cinder and scoria. Flows are dark gray to black, locally reddened by oxidation. Unit contains about 15 percent phenocrysts: basalt mostly contains felted plagioclase feldspar, pyroxene, and sparse (commonly altered) olivine; basaltic andesite may contain only plagioclase phenocrysts or include sparse pyroxene. Dispersed andesite and trachyandesite flows and breccia are plagioclase-rich, and contain hornblende and biotite phenocrysts. Age on rhyolite flow at location 10 (fig. 2, map) is 13.3±0.3 Ma (biotite); on basalt at location 6 is 12.2±0.3 Ma (fig. 2, map) (Nielson and Nakata, 1993). Rock compositions in Nielson and Turner (1998, table 2). In northern part of map area, overlies or interbedded with rhyolite (Tr), layered tuff (Tts), and gravel (Tg). In eastern and southern parts, either interbedded with gravel (Tg) or overlies and interbedded with andesite flows (Ta). Forms steep cliffs or steep-sided ridges. Thickness in northern part of map area, 3 to 50 m; in eastern part, as much as 250 m

Tats **Andesitic flows and intrusions, silicic tuff, and sedimentary rocks**

(Miocene)—Blue-gray and light-gray plagioclase-pyroxene and plagioclase-pyroxene hornblende flows and breccia, and local intrusions of same composition. Flows interbedded with thin air-fall and ash-flow tuffs, reworked tuffaceous sedimentary rocks, and stream-channel conglomerate. Widespread fanglomerate lenses separate individual flows, whereas conglomerate is limited to channels incised into underlying flows. Locally, flows also filled stream channels. Conglomerate clasts include Paleozoic limestone, gneiss (locally garnetiferous), granite, and minor volcanic rock types. Interbedded with gravel (Tg) or underlies basalt flows (Tb). Forms moderately steep slopes interrupted by short cliffs where flows crop out. Thickness 0 to 375 m

Ta **Andesitic flows, breccia, and sedimentary rocks (Miocene)—**Dark- to light-gray andesite, trachyandesite, and dacite flows and flow breccia. Andesite and trachyandesite flows have fine-grained matrix with approximately 10 percent phenocrysts, mostly of plagioclase (grain size as much as 3 mm across), less common pyroxene (average 0.2 mm across), and rarer olivine. Flow bases commonly brecciated. Flows and breccia form two distinct intervals; in the East of Grotto Hills quadrangle only the upper interval crops out. Composed mostly of flows and intrusions with fine-grained matrix and sparse phenocrysts. Dips gently west in quadrangle, but to the east, gently east-dipping flows are displaced by near-vertical faults. Some andesitic flows drape over thick dacitic or rhyolitic flows and plunge gently north or south. A trachyandesite flow at location 8 yielded age of 12.7±0.8 Ma (fig. 2, map). Other samples from northern part of the Piute Range (fig. 2) were dated at 12.4±1.4 Ma (trachyandesite, location 9), 10.4±0.7 Ma (trachybasalt breccia, location 12); and 8.0±0.6 Ma (dacite flow, location 13). Flows interbedded with stream-channel conglomerate, fanglomerate, sandstone, and siltstone and, locally with monolithologic megabreccia of Proterozoic augen gneiss. Conglomerate clasts include Paleozoic limestone, gneiss (locally garnetiferous), granite, and minor volcanic rock types. East of quadrangle, overlies Proterozoic augen gneiss, arkosic sedimentary rocks, or lenses of the Peach Springs Tuff of Young and Brennan (1974). In quadrangle, interbedded with tuff of the Piute Range (Tpr), and mixed unit of andesitic flows, tuff, and sedimentary rocks (Tats). Underlies basalt flows (Tb). Forms steep cliffs with 50 to 350 m of relief: relief may be equivalent to range of exposed thickness, but this does not account for the possibility of unexposed paleotopographic variations or fault repetition of indistinguishable flows

Td

Dacite flows and intrusions (Miocene)—Light gray biotite and hornblende-biotite dacite flows interleaved with intrusive domes, which have marginal breccia zones. Predominantly biotite-bearing porphyritic rocks. Steep-sided domes enclosed by andesite flows (Ta). Thickness 5 to 100 m

Tr

Rhyolite tuff and flows (Miocene)—Rhyolite ejecta, including air-fall and ash-flow tuff (welded and unwelded), volcaniclastic tuff breccia, and pumice breccia. Mostly forms isolated outcrops in northwestern part of quadrangle. Outcrops near west margin of Piute Range, southeastern part of map area, are ash-flow tuff of unknown source. Interbedded with basalt flows and breccia (Tb), underlies gravel (Tg), or is mixed with basalt and sedimentary rocks (Tbts). Thickness 0 to 50 m

Tts

Tuff, volcanic breccia, and sedimentary rocks (Miocene)—Well-bedded silicic air-fall tuff and tuff breccia, pumice breccia, ash-flow tuff and flow breccia, and minor volcaniclastic sedimentary rocks, tuffaceous rocks, and volcanic conglomerate. Thin air-fall tuff beds contain angular pumice fragments as much as 3 cm across; related to dacitic domes on east flank of Piute Range. Sedimentary parts of unit consist of lenses of siltstone; fine- to medium-grained sandstone; and pebble to cobble conglomerate, predominantly of volcanic clasts but also containing granite and gneiss pebbles and cobbles. Interbedded with andesite and basalt flows (Ta, Tb) at east margin of quadrangle. Forms steep slopes between cliffs. Thickness 250 m

Tpr **Tuff of the Piute Range (Miocene)**—White biotite tuff of pebble-size biotite-bearing pumice in biotite-rich matrix of rhyolite ash. Contains rare, large (30 cm across), lithic and pumice clasts; poorly sorted. Where reworked, unit displays normal grading and crossbedding. Biotite-rich tuffaceous sandstone typically forms upper part of unit. Locally, clasts of augen gneiss, dacite, and andesite blocks are present; blocks commonly underlain by soft-sediment sag features. Exposed on steep slopes or cliffs; overlain and underlain by trachyandesite flows and breccia (Ta). Thickness 3 to 10 m

INTRUSIVE ROCKS

Tid **Dacitic intrusions (Miocene)—**Light-gray hornblende-biotite dacite and biotite rhyodacite domes, dikes, and associated intrusive breccia, enclosed within resistant andesite flows, intrusions, and breccia (Ta). Mapped where intrusions can be distinguished from surrounding flow rocks. Forms elongate or oval zones with gentle slopes. Width of exposed intrusions, 10 to 500 m

REFERENCES CITED

Bingler, E.C., and Bonham, H.F., 1973, Reconnaissance geologic map of the McCullough Range and adjacent areas, Clark County, Nevada: Nevada Bureau of Mines and Geology Map 45, scale 1:125,000.

Capps, R.C., and Moore, J.A., 1991, Geologic setting of mid-Miocene gold deposits in the Castle Mountains, San Bernardino County, California and Clark County, Nevada, *in* Raines, G.L., Lisle, R.E., Shafer, R.W., and Wilkinson, W.H., eds., Geology and ore deposits of the Great Basin: Geological Society of Nevada, Symposium Proceedings, v. 2, p. 1195–1219.

Environmental Solutions, 1989, Castle Mountains Project: evaluation of potential effects on Lanfair Valley Aquifer and Piute Spring: Irvine, Calif., Report to U.S. Bureau of Land Management, 55 p.

Faulds, J.E., 1993, Miocene stratigraphy of the central Black Mountains, northwestern Ariz.: variations across a major accommodation zone, *in* Sherrod, D.R., and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona, and Nevada: U.S. Geological Survey Bulletin 2053, p. 37–43.

Faulds, J.E., Geissman, J.W., and Mawer, C.K., 1990, Structural development of a major extensional accommodation zone in the Basin and Range province, northwestern Arizona and southern Nevada: implications for kinematic models of continental extension, *in* Wernicke, B.W., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Geological Society of America Memoir 176, p. 37–76.

Hewett, D.F., 1956, Geology and mineral resources of the Ivanpah quadrangle, California and Nevada: U.S. Geological Survey Professional Paper 275, 172 p.

Jennings, C.W., compiler, 1961, Kingman sheet, Geologic atlas of California: California Division of Mines and Geology, scale 1:250,000.

Katzenstein, Y.A., Kendrick, K., and Knott, J.R., 1995, A preliminary assessment of calcic soil development at Piute Gorge, Fort Piute Wilderness, California, *in* Reynolds, R.E., and

Reynolds, Jennifer, eds., Ancient surfaces of the east Mojave Desert: San Bernardino County Museum Association Quarterly, v. 42 no. 3, p. 125-126,

Mariano, John, Helferty, M.G., and Gage, T.B., 1986, Bouguer and isostatic residual gravity maps of the Colorado River region, including the Kingman, Needles, Salton Sea, and El Centro quadrangles: U.S. Geological Survey Open-File Report 86–347, 7 sheets, scale 1:250,000.

McCurry, Michael, 1988, Geology and petrology of the Woods Mountains volcanic center, southeastern California: implications for the genesis of peralkaline rhyolite ash flow tuffs: Journal of Geophysical Research, v. 93, no. B12, p. 14,385–14,855.

Miller, D.M., 1995, Tectonic implications of a middle Miocene paleovalley, northeastern New York Mountains, California, *in* Reynolds, R.E., and Reynolds, Jennifer, eds., Ancient surfaces of the east Mojave Desert: San Bernardino County Museum Association Quarterly, v. 42 no. 3, p. 155–159.

Miller, D.M., Frisken, J.G., Jachens, R.C., and Gese, D.D., 1986, Mineral resources of the Castle Peaks Wilderness Study Area, San Bernardino County, California: U.S. Geological Survey Bulletin 1713–A, 17 p.

Nielson, J.E., 1995, Cenozoic geologic framework and evidence for late Cenozoic uplift of the Castle Mountains, Castle Peaks, and Piute Range, California, *in* Reynolds, R.E., and Reynolds, Jennifer, eds., Ancient surfaces of the east Mojave Desert: San Bernardino County Museum Association Quarterly, v. 42 no. 3, p. 149–153.

Nielson, J.E., Frisken, J.G., Jachens, R.C., and McDonnell, J.R., Jr., 1987, Mineral resources of the Fort Piute Wilderness Study Area, San Bernardino County, California: U.S. Geological Survey Bulletin 1713–C, 12 p.

Nielson, J.E., Lux, D.R., Dalrymple, G.B., and Glazner, A.F., 1990, Age of the Peach Springs Tuff, southeastern California and western Arizona: Journal of Geophysical Research, v. 95, no. B1, p. 571–580.

Nielson, J.E., and Nakata, J.K., 1993, Tertiary stratigraphy and structure of the Piute Range, Calif. and Nev., *in* Sherrod, D.R., and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona, and Nevada: U.S. Geological Survey Bulletin 2053, p. 51–53.

Nielson, J.E., and Turner, R.D., in press, Geologic map of the Hart Peak quadrangle, California and Nevada: U.S. Geological Survey Open File Report OF–XXXX, scale, 1:24,000.

Nielson, J.E., Turner, R.D., and Glazner, A.F., 1993, Tertiary stratigraphy and structure of the Castle Mountains and Castle Peaks, Calif. and Nev., *in* Sherrod, D.R., and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona, and Nevada: U.S. Geological Survey Bulletin 2053, p. 45–49.

Reynolds, R.E., 1993, Erosion, deposition, and detachment: the Halloran Hills area, Calif., *in* Sherrod, D.R., and Nielson, J.E., eds., Tertiary stratigraphy of highly extended terranes, California, Arizona, and Nevada: U.S. Geological Survey Bulletin 2053, p. 21–24.

Spencer, J.E., and Turner, R.D., 1985, Geologic map of Homer Mountain and the southern Piute Range, southeastern California: U.S. Geological Survey Miscellaneous Field Studies Map MF-1709, scale 1:24,000.

Turner, R.D., and Glazner, A.F., 1990, Miocene volcanism, folding, and faulting in the Castle Mountains, southern Nevada and eastern California, *in* Wernicke, B.P., ed., Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Geological Society of America Memoir 176, p. 23–35.

Wooden, Joe, Miller, Dave, and Elliot, Geoff, 1986, Early Proterozoic geology of the northern New York Mountains, southeastern California [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 5, p. 424.

Young, R.A., and Brennan, W.J., 1974, Peach Springs Tuff: its bearing on structural evolution of the Colorado Plateau and development of Cenozoic drainage in Mohave County, Arizona: Geological Society of America Bulletin, v. 85, no. 1, p. 83–90.

FIGURE CAPTIONS

Figure 1. Index map showing location of East of Grotto Hills quadrangle (box) and selected regional features.

Figure 2. Generalized geology and 7.5-minute quadrangles that cover area of the Castle Peaks, Castle Mountains, and Piute Range, California and Nevada. Numbers indicate locations of dated samples (see map and Description of Map Units).

Map credit: Mapping by J.E. Nielson, 1983–92; C.A. Ardito, 1983; and Jay S. Noller, 1984–85.