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GEOLOGIC MAP AND DIGITAL DATABASE OF THE COUGAR BUTTES 7.5′ QUADRANGLE, SAN BERNARDINO COUNTY, CALIFORNIA

Version 1.0

SUMMARY PAMPHLET:

LATE CENOZOIC DEPOSITS OF THE COUGAR BUTTES 7.5′ QUADRANGLE, SAN BERNARDINO COUNTY, CALIFORNIA

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Open-File Report 00-175, The Geologic Map and Digital Database of the Cougar Buttes 7.5' Quadrangle, San Bernardino County, California, and this summary pamphlet have been approved for release and publication by the Director of the U.S. Geological Survey. The geologic map, digital database, and summary pamphlet have been subjected to rigorous review and are a substantially complete representation of the current state of knowledge concerning the geology of the quadrangle, although the USGS reserves the right to revise the data pursuant to further analysis and review. This Open-File Report is released on the condition that neither the USGS nor the United States Government may be held responsible for any damages resulting from its authorized or unauthorized use.

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INTRODUCTION

The Southern California Areal Mapping Project (SCAMP) of Geologic Division has undertaken regional geologic mapping investigations in the Lucerne Valley area co-sponsored by the Mojave Water Agency and the San Bernardino National Forest. These investigations span the Lucerne Valley basin from the San Bernardino Mountains front northward to the basin axis on the Mojave Desert floor, and from the Rabbit Lake basin east to the Old Woman Springs area. Quadrangles mapped include the Cougar Buttes 7.5' quadrangle, the Lucerne Valley 7.5' quadrangle (Matti and others, in preparation b), the Fawnskin 7.5' quadrangle (Miller and others, 1998), and the Big Bear City 7.5' quadrangle (Matti and others, in preparation a). The Cougar Buttes quadrangle has been mapped previously at scales of 1:62,500 (Dibblee, 1964) and 1:24,000 (Shreve, 1958, 1968; Sadler, 1982a).

In line with the goals of the National Cooperative Geologic Mapping Program (NCGMP), our mapping of the Cougar Buttes quadrangle has been directed toward generating a multipurpose digital geologic map database. Guided by the mapping of previous investigators, we have focused on improving our understanding and representation of late Pliocene and Quaternary deposits. In cooperation with the Water Resources Division of the U.S. Geological Survey, we have used our mapping in the Cougar Buttes and Lucerne Valley quadrangles together with well log data to construct cross-sections of the Lucerne Valley basin (R.E. Powell, unpublished data, 1996-1998) and to develop a hydrogeologic framework for the basin. Currently, our mapping in these two quadrangles also is being used as a base for studying soils on various Quaternary landscape surfaces on the San Bernardino piedmont (Eppes and others, 1998). In the Cougar Buttes quadrangle, we have endeavored to represent the surficial geology in a way that provides a base suitable for ecosystem assessment, an effort that has entailed differentiating surficial veneers on piedmont and pediment surfaces and distinguishing the various substrates found beneath these veneers.

Geologic setting

The Cougar Buttes 7.5′ quadrangle is located along the southern margin of the western Mojave Desert province (fig. 1). The quadrangle straddles the east half of Lucerne Valley between the north piedmont of the San Bernardino Mountains and the Cougar Buttes inselberg. Structurally and geomorphically, Lucerne Valley is a closed desert basin that is flanked to the south by the San Bernardino Mountains and ringed to the north by highlands in the Mojave Desert, including the Granite Mountains, Sidewinder Mountain, Stoddard Ridge, the Ord Mountains, and Cougar Buttes. The basin has evolved in conjunction with uplift of the San Bernardino Mountains and with displacement on right-lateral faults of the Mojave Desert. Climatic fluctuations and tectonism have led to an evolving landscape and have generated a wide variety of Quaternary surficial deposits associated with various landforms in and around Lucerne Valley (Powell and Matti, 1998a,b).

Geomorphically, Lucerne Valley is a bolson with a central playa fed by alluvial fans emanating from the surrounding bedrock mountain ranges. Intervening between the principal fans are broad piedmont slopes covered by thin veneers of Pleistocene and Holocene deposits. These veneers, including slopewash and alluvium, mantle pediments beveled across tilted Pliocene and early Pleistocene sedimentary strata onto underlying igneous and metamorphic rocks. These surfaces are most prominent on Cougar Buttes, a granite inselberg encircled by a pediment apron, but are present on the piedmonts of all the ranges around Lucerne Valley, including the San Bernardino Mountains. Inselbergs on the north piedmont of the San Bernardino Mountains include the bedrock ridge on the east margin of the Cougar Buttes quadrangle south of State Highway 247 and the bedrock ridge just southeast of the town of Lucerne Valley in the Lucerne Valley quadrangle. Moreover, parts of the range-front itself just south of the Cougar Buttes quadrangle appear to rise at the upper margin of a piedmont erosion surface that is rather like a pediment.

Structurally, the Lucerne Valley basin originated as part of broad trough that developed coincident with uplift of the San Bernardino Mountains during late Pliocene and Quaternary time. The trough extends eastward through Fry and Johnson valleys and westward to the San Andreas fault near Cajon Pass, where it accumulated deposits of the late Pliocene upper Crowder Formation (Phelan Peak deposits of Meisling and Weldon, 1989) and the Pleistocene Harold Formation and Shoemaker Gravel (Dibblee, 1967a; Foster, 1982; Meisling and Weldon, 1982, 1989). The trough formed as a downwarp in the basement that accompanied the

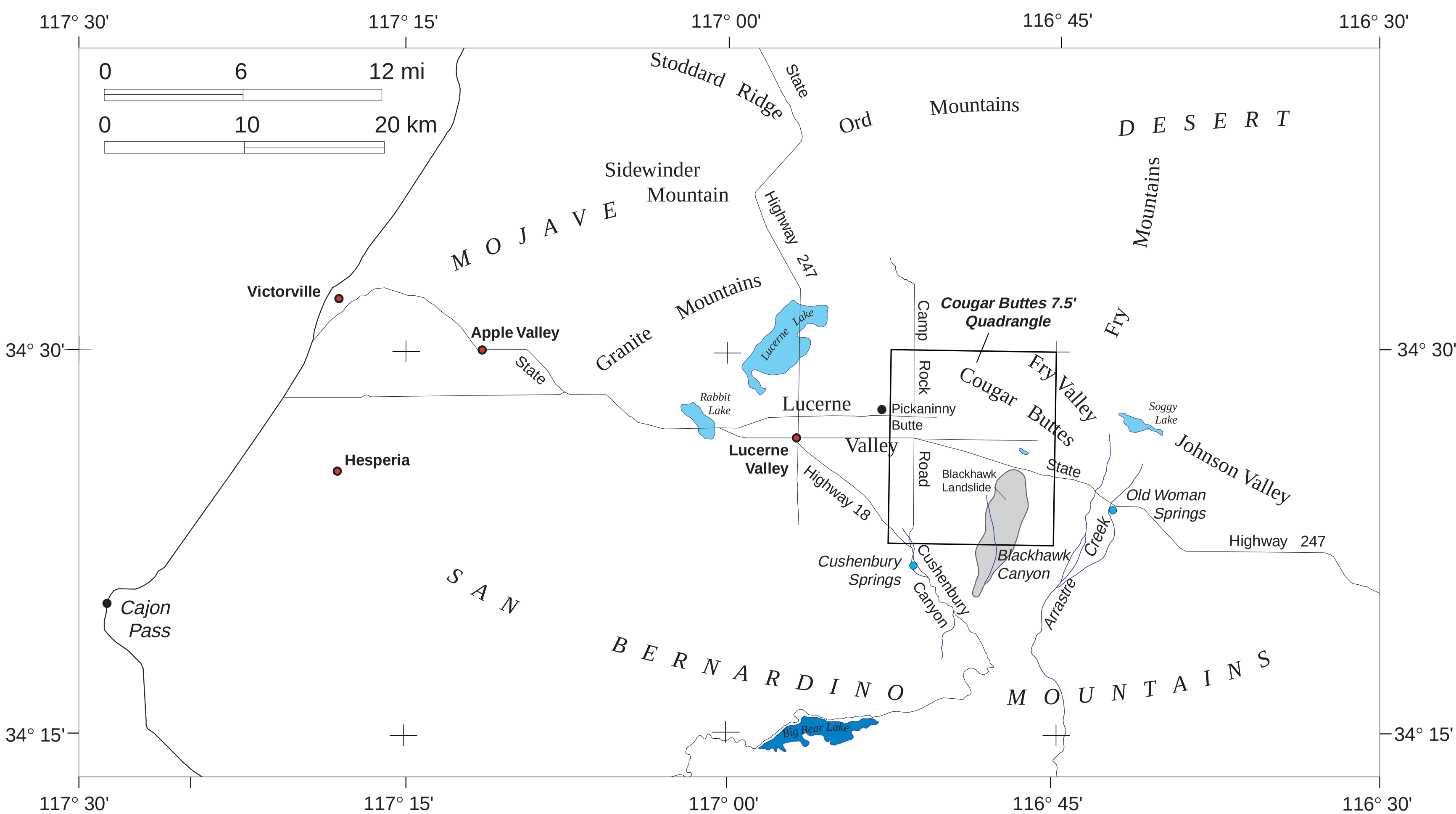

Figure 1. Index map for Cougar Buttes 7.5' quadrangle and vicinity

uplift of the San Bernardino Mountains. As it grew, the trough received sediment from the rising mountain range to the south and the highlands in the Mojave Desert block to the north. The development of the trough represents a major paleogeographic change from the Miocene, when fluvial systems transported sediment southwestward from highlands in the Mojave Desert across the future location of the San Bernardino Mountains (Foster, 1980; Meisling and Weldon, 1982, 1989; Sadler, 1982c). The trough is segmented where it is transected by various right-lateral faults of the Mojave Desert province, including the Helendale and Old Woman Springs faults. Faults of this system control the position of the modern bolson in Lucerne Valley.

Mapping approach

Late Cenozoic deposits in the Lucerne Valley area have accumulated in a basin that developed along the boundary between the Transverse Ranges and Mojave Desert provinces. The basin has evolved in response to tectonism associated both with uplift of the San Bernardino Mountains and with movement on the right-lateral fault system of the Mojave Desert province. Deformation and climate variation have both had roles in forming the landscape and creating depositional environments. Interpretation of the geomorphologic and sedimentary records and representation of them on a geologic map present a number of scientific and cartographic challenges. In this pamphlet, we outline our approach to meeting these challenges and summarize our findings to date on the stratigraphic relations among, and the geomorphic settings of, late Cenozoic deposits in the Cougar Buttes quadrangle. This initial version of the map, pieced together from field observation and interpretation of aerial photographs, presents a working model that needs to be refined, improved, and corrected by further field work.

TERTIARY ROCKS

Erosion surface

During the Miocene, a widespread regional erosion surface developed on the bedrock of the Mojave Desert (Oberlander, 1972, 1974), although this surface may represent multiple cycles of weathering and erosion, perhaps extending as far back in time as the Cretaceous (Vaughan, 1922; Dibblee, 1967a; Meisling and Weldon, 1982, 1989). Granitic rocks were deeply weathered beneath the erosion surface; metamorphic rocks were not as deeply weathered and uphold some of the inselbergs in and around the Cougar Buttes quadrangle. As described by Oberlander (1972), the weathering profile from the surface down consisted of (1) argillaceous red soil (argillic red B-horizon), (2) uniformly saprolitic granitic rocks (~ 40 ft thick), (3) saprolitic granitic rocks with corestones of less altered granitic rock, and (4) jointed granitic rock. Near Old Woman Springs just east of the Cougar Buttes quadrangle, Oberlander describes a complete profile beneath Miocene basalt. In the Cougar Buttes quadrangle, however, we have observed saprolitic granitic rocks and reddened arkosic sandstone beneath basalt, but no argillic B-horizon. The erosion surface was broadly planar, especially where developed on granitoid rocks.

As the crust was flexed with the growth of the San Bernardino Mountains, the Miocene erosion surface was deformed. Where downwarped, the surface lies buried beneath younger basinal deposits; where upwarped it has undergone erosion in the highlands that surround the basins and played a role in the development of Quaternary pediments. Nearly all of the lithologic logs for wells that penetrate basement in Lucerne Valley describe an interval of 20-40 ft of decomposed granite between sedimentary basin-filling deposits and basement rocks. Moreover, the basement rocks are typically described as fractured granite passing downward into fresh, solid granite. We infer that the interval of “decomposed” and “fractured” granite represents the weathered profile of the Miocene erosion surface and that the surface is widely preserved beneath the basin. In the bedrock highlands around the Lucerne Valley basin, subsequent erosion has stripped and dissected the upwarped parts of the erosion surface, thereby exposing the layered sequence of its horizons. In the northeast corner of the Cougar Buttes quadrangle, and at other places in surrounding quadrangles, the top of the uniformly saprolitic granitic rock is preserved as a remarkably planar surface beneath Pliocene alluvial strata.

We have mapped the saprolitic horizon on granitic rocks in the Cougar Buttes quadrangle, distinguishing two units according to whether it is developed on the monzogranite of

Cougar Buttes ($QTsp_{cb}$) or on mixed plutonic rocks ($QTsp_{mp}$). Erosion of the saprolite horizon began in the Miocene prior to extrusion of some of the basalt flows on Cougar Buttes and continued after their extrusion. Stripping of this relatively soft, readily eroded grussy saprolite horizon was apparently a factor in the development of rock pediments and inselbergs during the Quaternary. We have designated the age as Quaternary(?) and Tertiary because some saprolite may have formed during subsurface weathering in the development of Quaternary pediments.

Basal arkose (Ta)

A thin reddish arkose that crops out on the east flank of Cougar Buttes beneath Miocene basalt probably represents sediment derived from stripping of the Miocene weathering profile. This basal residual arkose is deposited on saprolitic granitic rock, lacks basalt clasts, and is unconformably overlapped by basalt. In wells that penetrate to basement in the Lucerne Valley basin, this basal arkosic unit may be present, but if so it is indistinguishable within the recorded lithologic descriptions from underlying decomposed granite (saprolite) or overlying Pliocene arkosic sand.

Miocene basalt (Tb)

On Cougar Buttes east of Lucerne Valley, along the east boundary of the quadrangle, late Miocene basalt flows overlap a thin reddish arkose onto saprolitic granitic basement rock. These flows are near-vent and, on Negro Butte, are spatially associated with a set of high-angle normal(?) faults. The basaltic volcanism and associated faulting both are consistent with crustal flexing. Olivine basalt flows are widely distributed in the western Mojave Desert and eastern Transverse Ranges, where they range in age roughly from 6 to 23 Ma (Oberlander, 1972; F.K. Miller, in Woodburne, 1975, p. 83; Neville and Chambers, 1982; Carter and others, 1987; J.K. Nakata, in Howard and others, in press). In the San Bernardino Mountains, basalt flows in this age interval interfinger with arkosic sandstone of the Santa Ana Formation (Sadler, 1982c; Strathouse, 1982) and on Cougar Buttes in the northeast corner of the Cougar Buttes quadrangle basalt is interlayered with unnamed arkosic sandstone. Basalt is described in the lithologic log for one of the wells in Lucerne Valley near Pickaninny Butte.

TERTIARY AND QUATERNARY DEPOSITS

Tilted and folded Pliocene and early Pleistocene strata that crop out around the southern margin of the Lucerne Valley basin historically have been included within formations known as the Old Woman Sandstone (Shreve, 1958, 1968; Richmond, 1960; Dibblee, 1964; and Sadler, 1982a,b,c) and the Cushenbury Springs Formation (Shreve, 1968). Our mapping for this study, however, has revealed that these two stratigraphic units do not adequately represent the facies variations, local geologic complexities, or unconformities that we have recognized throughout the greater Lucerne Valley region; hence, we do not use the name "Old Woman Sandstone" in this map and we restrict our usage of the name “Cushenbury Springs.”

The latest Tertiary and earliest Quaternary deposits in the Cougar Buttes quadrangle represent only part of the regional stratigraphic framework that we have developed for the Lucerne Valley basin for this interval of time. For the basin as a whole, we have recognized lacustrine deposits and alluvial lithofacies derived from at least six distinct bedrock terranes. In the Cougar Buttes quadrangle, we have mapped the lacustrine unit, an alluvial unit derived from carbonate rocks in the San Bernardino Mountains, and sand and gravel units derived from Cougar Buttes and from the Fry Mountains. We infer subsurface stratigraphic relations for Pliocene and Pleistocene strata in the basin by integrating our field observations with lithologic descriptions from water-well logs.

Strata of Blackhawk Canyon

These strata, predominantly sandstone and conglomerate, are exposed just south of the Cougar Buttes quadrangle along the San Bernardino Mountains range-front and the top of the piedmont between the Blackhawk Canyon area to the east and the Furnace Canyon area to the west. The strata of Blackhawk Canyon consist of beds of medium- to coarse-grained reddish arkosic sandstone with scattered pebbles and cobbles of vesicular basalt alternating with beds of light buff to gray conglomeratic sandstone with pebbles to boulders of quartzite, lineated granitic gneiss, amphibolite, granite, basalt, and rare limestone. The unit is characterized by fluvial cross-bedding and channels. The cross-bedding and clast assemblage show that the unit was derived from the east-southeast from the bedrock terrane in and east of Arrastre Canyon. Along the base of the range front east of Cushenbury Canyon, we have observed that this unit passes up-section into finer-grained sand and silt, but have not observed any interbedded clay. These strata contain clasts of Miocene olivine basalt and are overlain unconformably by late Pliocene lacustrine strata.

In the Cougar Buttes quadrangle, occurrences of the strata of Blackhawk Canyon are confined to gravitationally displaces masses ($QTbr_{bc}$, $Qmols_{bc}$, $Qols_{bc}$). In these masses, the sandstone and conglomerate contain their characteristic clast assemblages and typically appear coherent, but the prominent bedding features exhibited by in situ strata are generally obscured, disrupted, and discontinuous.

Late Pliocene and early Pleistocene(?) deposits

In the latest Pliocene, a lake was situated on what is now the upper piedmont and lower range-front of the San Bernardino Mountains. In the Cougar Buttes quadrangle, these lacustrine deposits (Tl) are exposed along the southern boundary of the quadrangle and in the core of the piedmont anticline that extends eastward from Camp Rock Road. To the south in the Big Bear City 7.5′ quadrangle, lacustrine strata crop out on the uppermost piedmont and as high as a few hundred feet up the range front between Cushenbury and Blackhawk Canyons. To the west in the Lucerne Valley 7.5′ quadrangle, lacustrine strata crop out around the inselberg ridge southeast of the town of Lucerne Valley between State Highway 18 and Meridian Road. The lacustrine strata have yielded late Pliocene vertebrate fossils at two localities: (1) outcrops along the southern boundary of the Cougar Buttes quadrangle just east of State Highway 18 and (2) outcrops west of Highway 18 at the north end of the inselberg southeast of the town of Lucerne Valley (May and Repenning, 1982; Sadler, 1982a,b,c; Matti and others, in preparation b).

In exposures in the Cougar Buttes and Big Bear City quadrangles, conglomerate, conglomeratic sandstone, and sandstone rich in clasts of carbonate rocks interfinger with and overlie the late Pliocene lacustrine strata. These deposits are derived from Paleozoic carbonate rocks that make up the adjacent range front to the south and were included in the Cushenbury Springs Formation of Shreve (1968). As defined by Shreve, however, this formation also includes multiple generations of Pleistocene landslide breccia deposits (including the Blackhawk landslide) and alluvial fan deposits. Shreve included rocks ranging in age from late Pliocene to as young as the middle or late Pleistocene Blackhawk landslide breccia in the unit. Subsequent studies, including our mapping, have shown that it is useful to represent these younger parts of the Cushenbury Springs Formation of Shreve as different units. Hence, we restrict our usage of the name to limestone-clast conglomerate exposures along the lower range-front and upper piedmont, which we refer to as the conglomerate of Cushenbury Springs (QTc).

Well logs from commercially drilled water wells and USGS monitoring wells on the San Bernardino Mountains piedmont reveal widespread fine-grained silty and clayey deposits that contain abundant brown clay variously described as “sticky,” “hard,” or as having high plasticity. We interpret these fine-grained sediments as lacustrine. Within the uncertainty inherent in the well-log descriptions, however, it is likely that the fine-grained interval includes distal alluvial plain deposits intermingled with the lacustrine strata. We correlate the fine-grained strata encountered in well logs beneath the upper piedmont with exposures of late Pliocene lacustrine beds. Using well logs, we have traced the clay-rich lithofacies in the subsurface down-piedmont, where it emerges at the surface as Qmol.

Logs from water wells drilled into the piedmont also show that sand and gravel facies similar to the conglomerate of Cushenbury Springs prograde basinward above fine-grained lacustrine facies. This progradation accompanied uplift and northward encroachment of the San Bernardino Mountains. As a result of the regional uplift and tilting, the Lucerne Valley lake basin has migrated northward.

Along the south boundary of the Cougar Buttes quadrangle, sheets of carbonate breccia ($QTbr_c$) have been detached from carbonate bedrock in the San Bernardino Mountains and gravitationally displaced northward over lacustrine deposits. South of the quadrangle, these masses are interpreted as being interlayered with QTc (Shreve, 1968; Matti and others, in preparation a). Carried along beneath the carbonate breccia sheets are smaller masses of displaced granitic rock breccia ($QTbr_g$) and displaced strata of Blackhawk Canyon ($QTbr_{bc}$). We interpret the contact between the carbonate breccia and these other rocks as a thrust fault displaced by gravitational processes. Similar, younger masses of breccia constitute the rock avalanche deposits of the Silver Reef landslide breccia ($Qmols_c$, $Qmols_{cc}$, $Qmols_{bc}$) of Shreve (1968) and the Blackhawk landslide breccia ($Qmols_c$, $Qmols_g$, $Qmols_{bc}$).

Sandstone and conglomerate in the northeast part of the quadrangle overlie saprolitic granitic rocks and basalt. These alluvial sediments consist of arkosic sandstone (QTs_2) with basalt granules derived from a source such as that exposed on Cougar Buttes, and conglomeratic sandstone (QTs_1) with a clast assemblage derived from a source such as that exposed in the Fry Mountains to the northeast. The two units represent interfingering lithofacies.

QUATERNARY DEPOSITS

For Quaternary surficial deposits, we have distinguished units indicative of diverse sedimentary environments, including alluvial wash (w), alluvial fan (f), debris flow alluvial fan (df), alluvial fan sand skirt (fs), alluvial fan feeder channel or wash (fw), alluvial axial valley (a), slope wash and alluvium (s), colluvial (c), eolian (e), lacustrine (l), playa (p), and landslide (ls) deposits. We distinguish slope wash from colluvium, using the former to represent deposits transported primarily by a combination of rain splash, overland flow, and channelized flow on broad, gentle piedmont slopes and the latter to represent debris aprons transported by mass wasting assisted by water flow on more local, steeper slopes. Slope wash and alluvial deposits consist predominantly of material derived from bedrock scarps immediately upslope from the deposits or reworked from underlying strata. Alluvial fan deposits, on the other hand, consist of debris transported to piedmont slopes by way of drainage basins from more distant parts of the source highlands. Where deposits of differing origin are exposed in areas too small to distinguish at 1:24,000, we combine them in mixed units, such as alluvial and slope wash deposits (as), colluvial and eolian deposits (ce), and alluvial fan and eolian deposits (fe).

We have mapped differing assemblages of these various Quaternary deposits in different geomorphic settings in and around the Cougar Buttes quadrangle. We distinguish three principal geomorphic settings: (1) the San Bernardino Mountains piedmont, (2) the slopes that flank bedrock inselbergs around Lucerne Valley (including some inselbergs that rise from the San Bernardino Mountains piedmont), and (3) the valley floor. As an important step in understanding the evolution of the Lucerne Valley basin, we have endeavored to correlate units deposited in these different geomorphic settings.

We have established a relative temporal sequence of the Quaternary deposits based largely on observed stratigraphic relations, augmented by first-order observations on soil development and maturity of erosional morphology. Within the overall sequence, we recognize broad categories of deposits. We classify loose to poorly consolidated sediment deposited late in the sequence as young Quaternary deposits (Qy). We classify consolidated deposits as old (for example, Qof), moderately old (for example, Qmof), or very old (for example, Qvof) depending on stratigraphic position, position on piedmont slopes, degree of cementation, degree of soil development, and degree of incision. Numerical subscripts (for example, $Qvof_1$, $Qvof_2$, etc.) are used where more than one unit of a given age interval and depositional type occur. Our observations in mapping Qy deposits are consistent with criteria that have been established for Holocene and perhaps latest Pleistocene deposits (Bull, 1991). Similarly, our observations in mapping old, older, and very old deposits are consistent with criteria that have been established for Pleistocene deposits. A key step toward understanding the geologic evolution of the region, however, lies in accurately assigning various parts of the relative temporal sequence to epochs and epochal subdivisions. In the absence of any geochronologic control and pending the results of a soils investigation now in progress (Eppes and others, 1998), the ages that we assign to various surficial deposits in the quadrangle are tentative and subject to change as more quantitative data become available.

At least three factors complicate interpretation of Quaternary deposits in the Cougar Buttes quadrangle and vicinity. First, many of the fan deposits on the San Bernardino Mountains piedmont consist almost exclusively of carbonate clasts and the criteria for calibrating soil development are not as well established for carbonate-clast dominated fans as they are for granite-clast dominated fans. Second, deformation of Quaternary fans on the piedmont introduces a degree of uncertainty into our stratigraphic interpretation. These two factors are currently being studied (Eppes and others, 1998).

Third, the surfaces of virtually all of the older deposits have been partially or completely stripped and reworked and are largely obscured by a veneer of Qy deposits. As a consequence of the extreme thinness of many of these deposits, the stratigraphic record of the geologic history is compressed, discontinuous, and difficult to map beneath successively younger parts of the record. To deal with this factor, we have constructed the map so as to represent not only the Qy units that we actually observe over most of the land surface, but also successively older units that we observe at point localities such as incised washes, roadcuts, trenches, and pits and that we infer to be present over broader areas. We use alphanumeric subscripts (for example, $Qyso_{s1}$, $Qyso_{s2}$, etc.) to differentiate various substrate units beneath a particular younger surficial unit.

Pediment deposits

During one or more intervals in the early Pleistocene, late Pliocene and early Pleistocene(?) strata were folded, tilted, and beveled by pediments. These erosion surfaces formed along the San Bernardino Mountains range front, around piedmont inselbergs, and across emergent anticlines on the upper piedmont. The surfaces are mantled with veneers of largely unsorted debris that was reworked from coarse strata of the eroding Pliocene section and from local basement rocks, then was transported down-slope by slope wash and (or) alluvial processes. Planation of the the pediments is likely to have been accomplished by a combination of processes, including weathering, rain splash, overland flow, rill wash, and channelized flow (see discussion in Cook and Warren, 1973, p. 188-215; Dohrenwend, 1994). Because the geologic record is compressed into a stack of thin deposits, all but the youngest of which are largely covered by younger deposits, mapping on pediments presents daunting challenges, including (1) working out the number and sequence of events, (2) mapping the distribution of deposits related to the various events, and (3) cartographically representing the sequence of buried deposits.

Very old pediment deposits. The oldest deposits that veneer pediments in the Lucerne Valley area consist of unsorted slope wash debris (Qvos) that was reworked from coarse strata of the eroding Pliocene section and from local basement rocks, then was transported down-slope by a combination of colluvial and alluvial processes, and subsequently was cemented with calcrete. We propose this unit by grouping, somewhat speculatively, widely separated exposures in and around the Cougar Buttes quadrangle. We have observed or inferred that well cemented deposits included in this unit unconformably overlap older deposits. In the northeast corner of the Cougar Buttes quadrangle, unsorted cemented debris unconformably overlies Pliocene and (or) Pleistocene sandstone and conglomerate (QTs_1, QTs_2). In the piedmont anticlines in the southern part of the quadrangle, unsorted cemented debris unconformably overlies Pliocene and (or) Pleistocene sandstone and conglomerate (QTc) and Pliocene lacustrine strata (Tl). In the Lucerne Valley quadrangle at the north end of the inselberg ridge just southeast of the town of Lucerne Valley, unsorted cemented debris unconformably overlies Pliocene and Pleistocene(?) alluvial and lacustrine strata. On the slopes flanking the Cougar Buttes inselberg, we assign unsorted and well cemented pebbly arkosic sandstone to Qvos on the basis of similarity to the degree of calcification to outcrops where relations are better exposed. Well logs from the south flank of Cougar Buttes indicate that this deposit is underlain in part by brown-clay-bearing strata.

Deposits assigned to this unit are pervasively cemented with chalky, hard calcrete and laced with abundant subhorizontal veinlets of laminar calcrete. Although much of the calcrete is pedogenic, some of it may have other origins related to the flow and evaporation of surface or ground water in carbonate-rich sediments (see Gile and others, 1966; Lattman, 1973; Machette, 1985; McFadden and Tinsley, 1985). The cemented debris aprons on the pediments were later eroded to form flatirons on slopes flanking the Mojave Desert inselbergs and the San Bernardino Mountains. In the Lucerne Valley quadrangle at the north end of the inselberg ridge northeast of the town of the Lucerne Valley and in the east-central Old Woman Springs quadrangle, these flatirons form prominent hogbacks in the landscape. In the Cougar Buttes quadrangle, however, the flatirons for the most part are buried beneath younger deposits. On the slopes flanking Cougar Buttes, we recognize the distribution of buried flatirons of calcrete by the distribution of abundant calcrete fragments in the Holocene veneer and by muted morphology.

These very old sediments were deposited as a slope wash apron on pediments that cut across Pliocene and early Pleistocene(?) alluvial and lacustrine deposits into the readily eroded saprolitic granite that had developed previously beneath the Miocene erosion surface (Powell and Matti, 1998a,b). Further saprolitic weathering of the granitic basement may have occurred beneath these deposits (see, for example, Bull, 1991, p. 135-147, 158-161; Dohrenwend, 1994, p. 343-344). The stratigraphic position and the degree of carbonate cementation of these deposits are consistent with an early or early middle Pleistocene age.

Moderately old pediment deposits. The buried cemented deposits on the slopes flanking the Cougar Buttes inselberg are overlain by reddened to strongly reddened arkosic sand with clay coatings on grains, interpreted as an argillic B-horizon. In mapping very thin pediment deposits on which soils have not been studied it can be difficult to establish how many reddened argillic B-horizons are present and the relation between the argillic horizon(s) and underlying strongly cemented deposits. We do, however, have enough evidence to outline the general framework. First, reddened soil appears to be or to have been present over broad surfaces on slopes flanking all inselbergs in the Lucerne Valley area. We have observed it beneath younger alluvium and slope wash at enough localities to support this conclusion. Second, in the Lucerne Valley quadrangle at the north end of the inselberg ridge just south of the town of Lucerne Valley and in the vicinity of State Highway 247 in the Old Woman Springs quadrangle just east of the Cougar Buttes quadrangle, very old deposits rise above the geomorphic surface on which the reddened soil was developed. In the Cougar Buttes quadrangle, the veneer of loose Holocene sediment contains domains characterized by abundant angular fragments of calcrete surrounded by domains characterized by abundant reddish-orange feldspar grains. Where we are able to see beneath these domains, we find cemented pebbly sand and reddened argillic B-horizon, respectively. From these relations, we infer that the reddened soil developed on the surface of sediment deposited on an erosional surface that exhibited minor relief in the form of flatirons of cemented very old deposits.

High on the slopes flanking Cougar Buttes, a reddened to strongly reddened pedogenic argillic B-horizon grades down into an underlying Bk- or K-horizon. This calcic horizon is pervasively cemented with white calcium carbonate, but not to the extent of appearing chalky-cemented and without the subhorizontal veinlets of laminar calcrete characteristic of the very old deposits. This soil profile, largely buried, is exposed in the walls of at least one wash at the base of the granite bluffs of Cougar Buttes (T. 4 N., R. 2 E., SW 1/4 NE1/4 sec. 6) and at the east boundary of the quadrangle where the soil profile is developed on arkosic sediment that has filled deeply weathered joints in granitic basement (T. 4 N., R. 2 E., NW 1/4 NW 1/4 sec. 11). A nearly identical profile is exposed in the Big Bear City quadrangle just south of the Cougar Buttes quadrangle at the base of a granite inselberg just east of State Highway 18 (T. 3 N., R. 1 E., SE 1/4 SE 1/4 sec. 2). The soil profile is developed on a unit of arkosic sand that was deposited as alluvium or slope wash (Qmos) and is mappable in the Cougar Buttes quadrangle only at the first of the above-mentioned localities.

At localites lower on the slopes around Cougar Buttes and other inselbergs in the Lucerne Valley area, similar arkosic deposits with a reddened to strongly reddened pedogenic B-horizon overlie hard, chalky-cemented deposits with subhorizontal veinlets of laminar calcrete (for example, T. 4 N., R. 1 E., SE 1/4 SE 1/4 SE 1/4 sec. 1; T. 4 N., R. 2 E., SE 1/4 SE 1/4 SE 1/4 sec. 34). Although the simplest interpretation of this sequence is that it represents a B-K soil profile, the abruptness of the contact between the B-horizon and the K-horizon suggests that the cemented deposits have a history of carbonate accumulation that preceded the development of the B-horizon. It seems likely that these strongly cemented deposits in part represent the K-horizon of a truncated very old soil profile. It is this very old unit that locally projects above the surface on which the moderately old B-horizon developed. We speculate that the arkosic sand unit (Qmos) tapered down-pediment above an unconformity that pinches out the older more strongly cemented pediment veneer (Qvos). The approximate location of this pinch-out is shown on the geologic map as the upper of two buried (dotted) contacts surrounding bedrock inselbergs. Upslope from this boundary, the substrate for Holocene slope wash ($Qyso_{s1}$) is Qmopb/Qmos/granitic rocks; downslope from the boundary the substrate for Holocene slope wash ($Qyso_{s2}$) is Qmopb/Qvos. Thin units with stratigraphic relations and pedogenic features identical to those that we have mapped as Qvos and Qmos in the Lucerne Valley area are widespread in the Mojave Desert (Sharp, 1984).

These moderately old sediments were deposited as an apron of alluvium and slope wash on pediments that cut into the cemented apron of very old Quaternary slope wash (Qvos) as well as further into the Pliocene and early Pleistocene alluvial and lacustrine deposits and weathered granite basement that underlie Qvos (Powell and Matti, 1998a,b). The deposition of arkosic sand of Qmos on a surface planed onto granitic basement and as fill in joints eroded out below that surface indicates that Qmos represents a unit that aggraded following an interval of planation and degradation during which inselberg scarps were eroded back from their positions during Qvo time. The stratigraphic position and the degree of carbonate cementation of these deposits are consistent with a middle or early late Pleistocene age. We tentatively correlate Qmos on pediment slopes with Qmof on the San Bernardino Mountains piedmont.

Old pediment deposits. Cemented middle and (or) late Pleistocene alluvial and (or) slope wash deposits are poorly exposed beneath a thin veneer of younger deposits (Qyos) on the lower part of the piedmont slopes around the Cougar Buttes inselberg. These deposits are largely inferred from the presence of pavemented surface with scattered, varnished pebbles. This surface appears to have been continuous with the pavemented surfaces observed on old fan deposits low on the San Bernardino Mountains piedmont and on the old fan (Qof) that entered Lucerne Valley from the north (see later section on Old fan deposits).

Old and young pediment deposits. Consolidated Pleistocene deposits on inselberg-flanking slopes in the Lucerne Valley area are mantled by thin veneers of loose, young sediment with little or no soil development. These young deposits constitute the mappable units on the inselberg-flanking slopes, but because they are so thin, we are able to observe varied units in the substrate beneath the young deposits. The young deposits are derived at least in part as slope wash from underlying Pleistocene deposits. In an effort to represent the characteristics of the slope wash deposits and the paleogeology beneath the slope wash veneer, we have subdivided the Holocene slope wash veneer into several units based both on lithology and substrate. Where oxidized feldspar grains dominate the slope wash, it has an orange cast on color aerial photographs. At several widespread localities, we have found this slope wash to be underlain by the well developed Pleistocene B-horizon (Qmopb) and we suggest that the distribution of oxidized slope wash ($Qyso_{s1}$, $Qyso_{s2}$, $Qyso_{s3}$) serves as a rough proxy for the widespread distribution of a soil profile developed on a middle(?) Pleistocene surface.

Where abundant calcrete fragments give the Holocene slope wash a white color on aerial photographs, we have observed that the slope wash is a veneer on cemented older deposits. We divide white slope wash into subunits according to whether we observe or infer that the substrate consists of early and (or) middle Pleistocene deposits ($Qysw_{s1}$) or middle or late(?) Pleistocene deposits ($Qysw_{s2}$).

A mixed unit that appears to be continuous with the oxidized feldspar slope wash unit consists of sand and pebbly sand with reworked and admixed windblown sand (Qyse). Middle Holocene slope wash and eolian components may make up the entire unit or they may represent a surficial reworking of latest Pleistocene or early Holocene alluvial or colluvial deposits that accumulated on the relict delta-top platform.

In the east-central part of the quadrangle, we distinguish slope wash (Qys_s) that we infer to overlie QTs_1. We base this inference on exposures in the Old Woman Springs quadrangle just east of Cougar Buttes quadrangle, where Holocene slope wash overlies arkosic sandstone capped by a very well-developed pedogenic calcrete horizon.

On slopes flanking inselbergs, alluvial deposits equivalent to the fan system on the San Bernardino Mountains piedmont occur in small alluvial fans, alluvial channels, and as sheetwash (Qyas). Where these Holocene fan deposits (Qyf, Qyas) radiate from channels incised into older surfaces mantled by veneers of loose Holocene slope wash, they spread a thin veneer of alluvium and sheetwash over the older slope wash deposits.

Alluvial fan and wash deposits

During the Pleistocene, at least three generations of alluvial fans were deposited on the north piedmont of the San Bernardino Mountains. The oldest of these generations of fan deposits are exposed high on the piedmont and ensuing generations are exposed successively down piedmont. Based on their stratigraphic position, cementation, soil profile development, and degree of deformation and incision, we classify these oldest fan deposits as very old, moderately old, and old.

One of the challenges of mapping on the north piedmont of the San Bernardino Mountains in the Lucerne Valley area has been to reconcile our surficial mapping with the lithologic descriptions contained in well logs. Poor exposure on the lower piedmont and the lack of geochronological dates hinder our efforts to correlate between surficial Pleistocene alluvial fan deposits and the subsurface strata that we infer from the well logs. Our observations to date reveal that alluvial fan deposits accumulated along an evolving and northward-migrating range-front between the late Pliocene, when a lake basin environment existed along the present-day mountain front, and the Holocene development of the modern playa basin in Lucerne Valley. During the Pleistocene, alluvial fans shed from the rising and northward-advancing San Bernardino Mountains interfingered with and prograded over fine-grained basinal lacustrine and alluvial plain deposits. The northward tilting of the piedmont was punctuated by at least two intervals during which erosion surfaces were planed across the emerging piedmont. These erosion surfaces appear to have formed synchronously with the formation of pediments described above and the fan deposits that accumulated on these surface appear to be time equivalent to the alluvial and slope wash deposits that accumulated on the pediments.

Very old fan deposits. The oldest alluvial fan deposits (Qvof$_1$, Qvodf, Qvof$_2$) crop out on the upper piedmont along the base of the San Bernardino Mountains (see also Miller, 1987; Miller and others, 1998; Matti and others, in preparation a,b). In the Cougar Buttes quadrangle, these fan deposits, while strongly folded and deeply incised, are spatially associated with the canyons from which they were derived and form a relict bajada that dives beneath younger sediments to the north down the piedmont. The oldest fan deposits originating from Cushenbury Canyon consist of assemblages of mixed clasts derived from granitic, metamorphic, and carbonate rocks. These fan deposits, exposed at the southern boundary of the quadrangle just east of State Highway 18, have been eroded into smoothly rounded ridges and the surface is littered with fragments of calcrete. Deposits derived from canyons east of Cushenbury Canyon are characterized by fluvial and debris flow deposits that consist chiefly of gray carbonate rocks with scattered clasts of basalt and granitic rocks. Carbonate-clast fans are very well cemented, resistant, and weather to form ledgy outcrops. Clasts are strongly pitted and etched. We classify these oldest fan deposits as very old and consider it likely that they are early and (or) middle Pleistocene in age.

In the south-central part of the Cougar Buttes quadrangle, the very old fan sequence splayed out across an erosion surface beveled onto folded and tilted late Pliocene fluvial and lacustrine strata that underlie the upper piedmont. Down piedmont, the base of successively younger units of the very old fan sequence rest atop the unconformity. In some places, a chalky cemented debris mantle (Qvos) intervenes between the very old fan deposits and tilted late Pliocene lacustrine beds. Deformation was ongoing along the piedmont while these very old fans were being deposited: earlier parts of the fan systems are folded, whereas later parts are deposited at the mouths of channels that have been incised into the folded strata.

Moderately old fan deposits. The second generation of alluvial fan deposits crops out along the middle reach of the San Bernardino Mountains piedmont. These fans debouch from feeder channels that are incised into the very old fan deposits and we classify them as older fan deposits (Qmof). On the mixed-clast Cushenbury fan in the Cougar Buttes quadrangle, a surficial veneer of loose orangish-brown Holocene slope wash (Qyso$_{s3}$) caps well cemented fan deposits of this generation. A reddened B-horizon that we observed beneath the slope wash veneer at one locality along the west boundary of the quadrangle probably was widespread on this unit, but appears to have been largely stripped. On carbonate-clast fan deposits east of the Cushenbury fan, well cemented fan deposits are capped by a veneer of grayer Holocene slope wash and alluvium with no evidence of a reddened B-horizon having been present.

Well logs describing the subsurface beneath the lower piedmont show that progradation of sand and gravel deposits into and over clayey deposits continued upsection and northward from the areas of exposed late Pliocene strata. We interpret these logs as indicating that a lake basin persisted in Lucerne Valley and that fan-delta systems developed where drainages from the major canyons in the San Bernardino Mountains debouched into the lake. We correlate the very old fan deposits with deeper parts of this subsurface section and the older fan deposits with shallower parts. One such fan-delta, located along the west boundary of the Cougar Buttes quadrangle down-slope from the mouth of Cushenbury Canyon, interfingers with basinal lacustrine deposits in the subsurface north of State Highway 247. Lacustrine strata that constitute the youngest part of these basinal deposits (Qmol) are exposed in Lucerne Valley. A soil developed on abandoned surfaces of these deposits above the lake level.

Old fan deposits. We tentatively include three groups of deposits in this category, each of which is being or needs to be further studied to ascertain its age. All of the deposits we assign to this age appear to be thin and to represent younger episodes of Pleistocene alluvial fan deposition than do the very old and older deposits. First, we include fan deposits derived from the north that are exposed in the northwest corner of the quadrangle. These deposits exhibit a well developed desert pavement of strongly varnished gneissic and metavolcanic pebbles. These old fan deposits (Qof) are thin and appear to be graded to an old, probably late Pleistocene lake level at approximately 2,865 ft (in the Lucerne Valley 7.5′ quadrangle) characterized by gravelly strand line and offshore bar deposits (see section on lacustrine and playa deposits, below).

Second, we include in Qof fan deposits that radiate from small drainages incised into older and very old carbonate-clast fan deposits in the south-central part of the quadrangle. The Pleistocene surfaces of these fans, mantled by loose, younger deposits, are currently being studied to develop criteria for establish age in soil profiles developed on carbonate-clast fans (Eppes and others, 1998).

Finally, we include alluvial and (or) slope wash deposits (Qyos) that are widespread but poorly exposed on the lower piedmont beneath a thin, discontinuous veneer of younger deposits. At the snout of the Cushenbury fan north of State Highway 247, these deposits constitute a sequence of layers: (1) a pavement of scattered, varnished pebbles and small cobbles underlain by (2) a pedogenic Av horizon of vesicular, calcareous silt, in turn underlain by (3) a hardpan of poorly sorted and unbedded debris that is pervasively and firmly cemented with scattered, irregular domains of hard calcrete. Compared to older units, the cementation is not as hard and lacks the subhorizontal veinlets of laminar calcrete. In pits and roadbeds around the small playa near the east margin of the quadrangle south of State Highway 247, the old part of Qyos exhibits a soil profile that appears to be polygenetic (M.C. Eppes and L.D. McFadden, 1999, oral communication). From top down, the profile consists of the following horizons: (1) a pavement of scattered, varnished pebbles and small cobbles underlain by (2) an Av horizon of vesicular, calcareous silt, in turn underlain by (3) a hard, strongly reddened argillic B-horizon that contains abundant 1- to 4-cm nodules of white calcite, underlain by (4) loose, reddened pebbly sand. Some pebbles in the pavement exhibit partial rinds of cemented sandy matrix, indicating that they have been recycled from older sedimentary deposits on the piedmont. We suspect that the layers in this unit represent a composite assemblage that has developed over an interval of time that may be as long as late middle Pleistocene to early Holocene age. The pavement is probably a Pleistocene feature that was lifted by the influx of Holocene eolian silt (McFadden and others, 1987) and the presence of carbonate in the argillic B-horizon has been shown elsewhere to indicate that carbonate has been reintroduced into the B-horizon, from which it had previously been completely leached (McFadden, 1982; McFadden and Tinsley, 1985; Bull, 1991, p. 73, 107-112).

On aerial photographs, we map the sparsely pavemented surface discontinuously around the Lucerne Valley basin across the lower piedmont piedmont of the San Bernardino Mountains and across the lower part of the slope that flanks the Cougar Buttes inselberg. In the northwest corner of the quadrangle, where this sparsely pebbled surface merges with the fan system that enters Lucerne Valley, surface is lighter than and somewhat younger than the dark surface of Qof.

The bottom of Qyos is not exposed, but it pinches out to the north onto older lacustrine deposits (Qmol). Well logs indicate that Qyos is thin (< 20 ft) and that the underlying strata give way southward from clay-rich lacustrine deposits to sand- and gravel-bearing fluvio-lacustrine deposits. An interpretation that is consistent with our findings is that the subsurface strata represent deltaic deposits that formed where sediment supplied by major drainage systems such as Cushenbury Canyon encountered lake-level. The older part of Qyos as we observe it at the surface consists of old alluvial and (or) slope wash deposits that spread across the delta as lake level dropped. When the lake receded, the delta-top platform remained as a topographic bench and a colluvial debris mantle of reworked pebbly sand spread down the delta front onto the lake-bottom clay-rich deposits. Where we observe that a thin veneer of Holocene alluvium or sheetwash overlies old fan deposits (Qof), we represent it on the map as Qyos. This unit appears to overlap the subsurface transition from fan-delta deposits into lake-bottom deposits (Qmol). We approximate this transition as a buried contact by showing deposits ($Qyos_{s1}$) higher on the slope that overlie fluvio-lacustrine deltaic strata and deposits ($Qyos_{s2}$) lower on the slope that overlie Qmol. Sand dunes (Qye) are constructed on both Qmol and Qof surfaces.

The bench formed by the hypothesized delta-top platform has created a local base level for younger deposits. Young fan deposits (Qyf) and older colluvial or alluvial deposits (Qyse) aggraded onto this bench. As defined by the accumulation of these younger deposits at the local base level, the transition from fan to delta appears to have occurred at about 3,100 ft in present-day elevation on the Cushenbury fan-delta on San Bernardino Mountains piedmont. Traced east around the end of the basin, then back to the west and north around Cougar Buttes, the present-day elevation of this bench drops steadily to about 2,960 ft. If this feature did form at the level where alluvial fans entered a lake, then it approximates a line that was horizontal at the time the lake existed. This paleo-horizontal marker indicates northward tilting of about 100 ft across the part of Lucerne Valley that lies within the Cougar Buttes quadrangle.

Young fan deposits. Holocene alluvial fan (Qyf) and feeder wash deposits ($Qyfw_1$, etc.) on the north piedmont of San Bernardino Mountains grew progressively northward down the piedmont across a landscape inherited from the Pleistocene. Fans telescope basinward from oldest fans proximal to the range-front to youngest fans on the lower piedmont. The abandoned surfaces of these fans are characterized by soils with Av horizons of loess-like, vesicular light brown calcareous silt overlying a Cox horizon. The looseness and color of sediment on these fan surfaces are consistent with middle and (or) late Holocene soil-profile characteristics (Bull, 1991, p. 54, 68, 75, 86; Eppes and others, 1998). The Holocene fans buttress against geomorphic features inherited from the Pleistocene, including the Blackhawk landslide, folds in older units on the piedmont, and a topographic bench that we infer to have formed as a delta-top platform.

The youngest deposits in the Cougar Buttes quadrangle occur in washes incised into all older units (Qw, Qyw, Qya) and graded to base level playa deposits (Qp, Qyp) in Lucerne Valley and Fry and Johnson valleys. Geomorphic surfaces of these deposits are characterized by active and recently active sediment accumulation and show little or no soil-profile development.

Lacustrine and playa deposits

Quaternary lacustrine deposits exposed on the lowermost piedmont in the Cougar Buttes quadrangle extend westward into the adjoining Lucerne Valley quadrangle. The deposits include brown clay, silty clay, and clayey silt with irregular domains of grayish calcareous clay. These deposits appear to be overlain by cemented Pleistocene alluvial and (or) slope wash deposits and are likely to be middle Pleistocene in age or older—although we cannot rule out an early late Pleistocene age. Using logs from wells drilled into the San Bernardino Mountains piedmont, we have documented a subsurface stratigraphic link between these lacustrine exposures low on the piedmont and exposures of late Pliocene lacustrine deposits higher on the piedmont. We infer that the clay- and silt-rich deposits represent a diachronous lacustrine lithofacies.

In the Lucerne Valley quadrangle just west of the Cougar Buttes quadrangle, the bottom of Lucerne Valley is partially rimmed by a discontinuous arcuate array of beach and offshore bar gravel deposits (Matti and others, in preparation b). Similar deposits are typical of shorelines of late Pleistocene lakes throughout the Mojave Desert and Great Basin (see, for example, Gilbert, 1890; Clark and Lajoie, 1974; Weldon, 1982; Meek, 1989; Benson and others, 1990).

Colluvial deposits.

Colluvial deposits occur in and around the Cougar Buttes quadrangle as varnished debris aprons on recessive slopes below resistant cap rocks and as varnished lag gravel deposits. Around basalt-capped buttes on Cougar Buttes, colluvial aprons of basalt debris blanket slopes on more readily eroded granite, saprolite, and sedimentary rocks that underlie the basalt. On hogbacks developed in tilted strata on the San Bernardino Mountains piedmont, colluvial aprons of limestone debris from resistant conglomerate beds blanket slopes on underlying clay beds. On very old slope debris deposits (Qvos) and on conglomeratic sandstone deposits (QTs_1), colluvial deposits consist of lag gravel with varnished pebbles and cobbles. Debris aprons typically are dissected and partially eroded, leaving resistant flatirons of relict colluvium on slopes eroded into less resistant substrate. These deposits are interpreted tentatively as late Pleistocene based on the model that such aprons aggrade under pluvial climatic conditions and are incised and eroded during arid interglacial climatic intervals (Gerson, 1982; Bull, 1991, p. 157; Howard and Selby, 1994, p. 152-157). The older colluvial deposits (Qoc_1) may, however, correspond with a middle Pleistocene pluvial climatic interval that preceded the last major interglacial between 130 and 115 Ka.

Eolian deposits

In the Cougar Buttes quadrangle, we recognize a variety of eolian deposits. Around the valley bottom, windblown sand (Qye) occurs as relict dunes and coppices that were deposited on old lacustrine deposits (Qmol), on pavemented surface of old alluvial fan deposits (Qof), and on pavemented surface of young(?) and old slope deposits (Qyos). Sand in these deposits is unconsolidated and pale yellow on natural surfaces and firm to indurated and slightly reddened where exposed in roadcuts. These dunes are clearly younger than the sparsely pebbled pavement surface of Qyos and older than young wash (Qyw) and fan (Qyf_4) deposits. If, as we think, the pavemented surface is in part latest Pleistocene or Holocene in age, then the dunes are also young (latest Pleistocene to middle Holocene). This conclusion is consistent with the age range of dated sand dunes and ramps elsewhere in the Mojave Desert (Tchakerian, 1990).

Upslope from the mappable dune deposits, windblown sand occurs as a major component of a unit of mixed eolian alluvial or colluvial origin (Qyse). From the mapped distributions of Qye and Qyse, we suggest that there has been an evolving interaction between alluvial and windblown deposits: distal alluvial sandskirts have been reworked into dunes by the wind and dunes, in turn, have been reworked by younger alluvial events.

Eolian reworking of distal younger alluvial deposits is also evident higher on the San Bernardino Mountains piedmont where young alluvial fan deposits (Qyf_3) butted against Pleistocene landscape features. For example, the prominent distal sandskirts associated with the young alluvial fans that spilled out acoss the Blackhawk and Silver Reef landslide deposits have been extensively reworked by the wind. Similar, but less well developed, deposits are present where young fan deposits have butted against the Pleistocene piedmont anticline in the south-central part of the quadrangle.

Loess-like eolian silt is present in Holocene and Pleistocene(?) Av horizons that mantle most of the surficial units in the quadrangle.

Landslide deposits

The Cougar Buttes quadrangle encompasses parts of the Pleistocene Blackhawk and Silver Reef landslides (Woodford and Harriss, 1928; Shreve, 1958, 1968, 1987). Both of these deposits are giant rock avalanches that were shed catastrophically from the frontal escarpment of the San Bernardino Mountains just south of the quadrangle. Each of these landslide breccia deposits preserves a layered relict tectonic stratigraphy inherited from its source terrane on the mountain front. Breccia derived from metamorphosed Paleozoic limestone makes up most of the landslide deposits and overlies breccia masses derived from Pliocene strata. In the Blackhawk landslide crushed Pliocene sedimentary rocks were derived from the Blackhawk Canyon strata, whereas in the Silver Reef landslide they were derived from the Blackhawk Canyon strata and the limestone conglomerate of Cushenbury Springs. In the Blackhawk landslide, breccia derived from Cretaceous granitic rocks is observed at a few localities beneath the carbonate-clast breccia. The base of the carbonate-rock breccia represents a range front thrust fault that has been displaced and disrupted as part of the landslide masses. Freshwater gastropod and pelecypod shells recovered from pond deposits on the surface of the Blackhawk landslide have yielded an age of 17,400 ±550 yr (Stout, 1977). This date provides a minimum age for the Blackhawk landslide, but the degree of cementation of the surface of the landslide may indicate a much older age. Moreover, the presence of incised colluvial aprons on the flanks of the landslides indicate that the age of the slide predates Qoc_2 and may post-date Qoc_1. In the Cougar Buttes quadrangle, the Blackhawk landslide is the source for small Qyf fans, whereas the Silver Reef landslide is the source for small Qof fans as well as Qyf fans. Just south of the quadrangle both landslides are overlapped by Qyf fan deposits. Both landslide deposits appear to have overridden the land surface on which very old and moderately old pediment and fan deposits have accumulated and probably have overridden those deposits as well, although we lack direct observation of that sequencing relation. Swales in the surfaces of both landslides are filled with loose colluvium characterized by carbonate-clast pavements underlain by 4- to 8-cm thick Av horizons of vesicular, loess-like calcareous silt. As noted by Shreve (1968), the morphology of the Silver Reef landslide appears to be older than that of the Blackhawk. Based on these observations, it is plausible that the Blackhawk landslide is late Pleistocene in age and that the Silver Reef landslide was emplaced earlier in the late Pleistocene or in the middle Pleistocene.

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