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Surficial Geologic Map of the Amboy 30′ x 60′ Quadrangle, San Bernardino County, California

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View from Granite pass to the southern Granite Mountains pediments and inset surficial deposits.

Pamphlet to accompany

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Introduction

The surficial geologic map of the Amboy 30' x 60' quadrangle presents characteristics of surficial materials for an area of approximately 5,000 km^2 in the eastern Mojave Desert of southern California. This map consists of new surficial mapping conducted between 2000 and 2007, as well as compilations from previous surficial mapping. Surficial geologic units are mapped and described based on depositional process and age categories that reflect the mode of deposition, pedogenic effects following deposition, and, where appropriate, the lithologic nature of the material.

Many physical properties were noted and measured during the geologic mapping. This information was used to classify surficial deposits and to understand their ecological importance. We focus on physical properties that drive hydrologic, biologic, and physical processes such as particle-size distribution (PSD) and bulk density. The database contains point data representing locations of samples for both laboratory determined physical properties and semiquantitative field-based information in the database. We include the locations of all field observations and note the type of information collected in the field to help assist in assessing the quality of the mapping.

The publication is separated into three parts: documentation, spatial data, and printable map graphics of the database. Documentation includes this pamphlet, which provides a discussion of the surficial geology and units and the map. Spatial data are distributed as ArcGIS Geodatabase in Microsoft Access format and are accompanied by a readme file, which describes the database contents, and FGDC metadata for the spatial map information. Map graphics files are distributed as Postscript and Adobe Portable Document Format (PDF) files that provide a view of the spatial database at the mapped scale.

Mapping Methods

This map represents primarily new mapping at a scale of 1:100,000 using standard field methods and interpretation of remote sensing images, including aerial photography and Landsat 7 imagery. Field methods included examining the geomorphology, landscape position, surface features, and soil development. Locations of field observations were typically recorded with GPS to an accuracy of ±5 to 10 m.

Unit Label Explanation

Surficial geologic map units are defined by depositional process (alluvial, eolian, mass wasting) and relative age (old, intermediate, young, and active). Numeric age ranges or dates are provided where known. The first two characters of a map unit label typically represent the age of the deposit. For example, the characters “Qy” in Qya represent the age—Quaternary young. The third, and occasionally fourth, character denotes the depositional process. For example, the character “a” in Qya represents an alluvial depositional environment. Modifiers are commonly placed at the end of the unit label to denote mixed processes, age subsets, or compositional characteristics. The order of preference for placing these modifiers in the map unit label is depositional process, age, then composition modifier. These modifiers for mixed depositional processes are typically used in mixed eolian and alluvial environments and are ordered to place the character of the dominant process first. For example, unit Qyae would denote Quaternary young deposits of mixed alluvial and eolian processes with alluvial processes dominant over eolian processes. The age modifier (character “o”) is reserved for deposits that are recognized locally to be an older subset of a mapped unit, commonly unit Qya. Therefore, unit Qyao would represent an older subset of unit Qya and its younger subsets. Similarly the age modifier “y” denotes deposits that only consist of the younger deposits in a map unit or do not contain deposits of a map unit with an “o” identifier that can be mapped at map scale. The compositional modifier is used for deposits that are derived from grus. These deposits have different soil development characteristics but similar depositional processes and inferred ages as their associated units. Because of the disparity in soil development characteristics, they are mapped separately. For example, unit Qyag represents a Quaternary young alluvial deposit derived from grus.

Composite Map Symbols

Surficial geologic units commonly exist as thin (<2 m) veneers over older units. In areas where this relation is common, the unit labels are shown on the map separated by a slash (/). The younger, or overlying, unit is indicated first. Thus, Qya/Qoa indicates an area where a veneer of young alluvial fan deposits (Qya) overlies old alluvial fan deposits (Qoa), and Qya/fpg indicates an area where a veneer of young alluvial fan deposits (Qya) overlies felsic grussy granite (fpg).

The lateral extent of individual deposits is commonly so small that each deposit cannot be shown individually at map scale. Areas made up of deposits too small to show individually (representing more than 20 percent of the area) are indicated by deposits separated by a plus sign (+), with the most common deposit listed first. Thus, Qya+Qia indicates an area with both Qya and Qia deposits and associated surfaces, and unit Qya is more common than Qia; other deposits in the area compose less than 20 percent.

Conventions for Erosional Environments

Erosional environments such as mountains, areas underlain by bedrock, and pediments are widespread and represent generally thin surficial sediment distributed irregularly among rock exposures. Materials in mountains are largely formed in place by weathering of bedrock but may be transported short distances by mass-wasting and fluvial processes. We designate such materials as "hillslope materials," regardless of transport mechanism. Thicker, areally consistent, and mappable hillslope sediment is distinguished as colluvium and landslide deposits. Pediments are classified into three categories based on degree of dissection. Both pediments and hillslope deposits are indicated in the map unit label with underlying bedrock type. Bedrock is divided into ten units based on chemical composition and weathering characteristics.

Pediment surfaces are gently sloping erosional surfaces; where distinguished, substrate materials are included after the hyphen (-) in the unit label. Examples of pediments may be found in the Granite Mountains, the Fenner Hills, and the Old Woman Mountains.

Data Stations

Point data in the database indicate locations of field observations made during the duration of fieldwork for this report (1999–2007). Many more observations were made prior to that time but are not included due to lack of detailed location information (GPS) and nonuniform descriptions.

At some locations, quantitative data on landscape parameters, surface characteristics, and sediment texture were collected. These data are separated into broad categories, most of which were used to determine the surficial deposit type and to describe the material properties of the deposit. We provide a Boolean field indicating whether this additional information was collected at a given location. The data types collected and the database fields indicating the presence of this information follow:

Landscape surface characteristics—Surface information was quantified to improve GIS analyses and calibrate remote sensing data.

- Surface clast size—estimates of maximum, mean, and minimum clast distribution
- Surface clast lithology—estimates of dominant and subordinate clast lithology
- Surface microtopography—estimates of amplitude and frequency of microtopography
- Dominant plant species and relative cover—estimates of average size and size range (height, width, spacing) of dominant perennial species; estimates of ground cover for annual vegetation
- Lichen cover
- Influence of eolian sand
- Degree of mammal burrowing

Soil texture sample—Texture (particle size distribution) samples at three depths (0 to 1, 1 to 5, and 5 to 10 cm) were collected to capture deposit texture and upper pedogenic soil development primarily for Holocene deposits. Most samples were taken from the principal alluvial fan surfaces of interest, Qya, because those fans occupy much of the landscape, they are highly variable and difficult to characterize other ways, and they are the most biologically active part of the landscape. Particle size analysis (PSA) was determined for 10 size fractions using sieve and hydrometer laboratory techniques. In many PSA sample locations, bulk density and field-moisture-content samples were also taken. Bulk density was determined by weighing the amount of sediment from a core driven 10 cm into the soil. Moisture content is determined by subtracting the dry weight from the field weight of the bulk density sample.

Photographs—Digital photographs were taken (1) to characterize the surface for quantifying remote sensing data and (2) to illustrate notable features. Photographs for remote sensing purposes are typically vertical ground photos at two zoom levels and contain color and size scale, as well as location information. Other photographs are typically landscape style images at varying zoom levels.

Chronology sample—Sediment samples taken for chronology studies include ^{14}C, luminescence, tephrochronology, and fossils.

Physiographic and Geologic Setting

The Amboy 30' x 60' (1:100,000 scale) quadrangle occupies 5,000 km^2 in the eastern Mojave Desert of southern California (fig. 1). The area encompasses several mountain ranges including the Providence, Granite, Marble, Bristol, Piute, and Clipper Mountains (fig. 2). Piedmonts are prevalent on the landscape between the two major drainages in the area, Kelso Wash and Fenner wash, each of which lead to closed basins (Soda and Bristol Lakes, respectively). The Colorado River lies approximately 35 km east of the map area but only drains a small portion of the northeastern map area. The Devils Playground, Kelso Dunes, and Amboy Crater are notable features in the map area, both as public attractions and significant landmarks.

Elevations in the map area range from 180 m to 2,182 m. The climate is arid to semiarid. Although the area lies within the indefinite transition between Mojave (winter precipitation) and Sonoran (winter and summer monsoon precipitation) climatic regimes, the majority of rainfall apparently occurs in the winter months (Hereford and others, 2003).

The Amboy quadrangle is partially in the Eastern California Shear Zone, spanning the transition from the tectonically active Mojave Desert Block and the inactive Eastern Mojave Desert Block of Dokka and Travis (1990), with the approximately west quarter of the map area within the Mojave Desert Block. The Mojave Desert Block is expressed by northwest-striking, right-lateral, strike-slip faults active in the late Cenozoic that accommodated varied amounts of motion related to the Pacific-North American transform boundary along the greater San Andreas Fault System (Dokka and Travis, 1990).

The southwestern map area is traversed by the Bristol-Danby Trough, a structural depression trending west-northwest (Miller and others, 1982). Gravity modeling shows that the deepest portion of the trough is centered on Bristol Lake (Jachens and Howard, 1992). Surficial deposits and topography match the gravity lows of the Danby and Cadiz Basins, where playas occupy the valley axis. The Bristol-Danby Trough is an ambiguous feature, because it seems to bisect the northwest-striking faults of the Eastern California Shear Zone. This suggests that the Bristol-Danby Trough is a major crustal structure (Miller and others, 1982).

Several previous works (Bassett and Kupfer, 1964; Bishop, 1963; Howard and others, 1997; Loyd, 1988; Miller, 1993; Miller and others, 1982, 1991) have summarized the pre-Quaternary geologic history of the map area. Deposition and metamorphism of Proterozoic rocks was followed by erosion and deposition of Cambrian through Permian miogeoclinal sediments. Jurassic and Cretaceous plutons intruded into magmatic arcs and were interrupted by folding and faulting. Crustal deformation likely occurred prior to Late Cretaceous plutonism, although timing of Cordilleran thrusting is ambiguous. Following erosion and deposition, a volcanic sequence was deposited in the Tertiary (largely Miocene) that consists of basalt through rhyolite; most but not all basalt is near the base of the section, except the upper Peach Springs Tuff. Volcanism was followed by detachment, causing tilting and rotation of all deposits during extension. Clastic sedimentation occurred throughout the Tertiary as well, evidenced by thick sequences of alluvial material and small outcrops of late Miocene-Pliocene lacustrine deposits interbedded in alluvial deposits north of the town of Amboy.

Previous Quaternary Studies

Previous surficial geologic mapping (McDonald, 1994; McDonald and others, 1995, 2003) is primarily along the southwestern Providence Mountains. This work developed detailed alluvial and eolian chronosequences for the western Providence Mountains, incorporating the effects of dust and lithology into the variability of the soil sequence. Eolian sands in the alluvial deposits allowed for thermoluminescence dating of the alluvial deposits, which helped refine timing on the chronosequence.

Numerous authors have also worked on the timing and sand provenance of the Kelso Dunes and the associated Devils Playground eolian system (Clarke, 1994; Lancaster, 1995; Ramsey and others, 1999; Sharp, 1966). Sharp (1966) performed the first detailed studies of Kelso Dunes and developed a model in which the dunes were derived from sands transported by the Mojave River, including minor inputs from local alluvial fans, following deposition as the Mojave River exits Afton Canyon and loses carrying capacity. This model has largely been validated but with varied interpretations concerning the abundance of local sources from fans of the Providence Mountains and Kelso Wash (Lancaster, 1995; Ramsey and others, 1999). Sand in the Kelso Dunes eolian system dates as early as 17 ka (Clarke, 1994), and Lancaster (1995) established a chronology of five dune activation events: 25–6.8 ka, 12.5–3.5 ka, 3–1.5 ka, 0.8–0.4 ka, and 0.25–0.15 ka. The Kelso Dunes are active on a minor scale at present.

Studies of Quaternary climate change have recently focused on the relations of lacustrine and eolian deposits to elucidate wet and dry climates, respectively. Tchakerian and Lancaster (2002) associated the histories of Pleistocene Lake Manix and eolian systems through the Mojave River and have hypothesized that many of the eolian pulses are tied to fluctuating lake levels, which are driven by climatic change. In cool, wet periods, sediments accumulate in lake basins and on hillslopes and piedmonts. During dry periods, very low lake levels and reduced vegetation cover allow lake sediments to be desiccated, as well as potentially allowing hillslope and piedmont materials to be mobilized by eolian processes. This climatic relation is complex but provides a reasonable process-response model for eolian activity in the region.

Surficial Deposits

Surficial deposits are mapped based on the depositional or erosional process, and relative age classifications are based on characteristic soil development, geomorphic relations, and surface characteristics. These techniques have been developed by numerous authors in semi-arid and arid regions and are largely based on the work of Bull (1991). These surficial geologic units, termed geomorphic surfaces or soil-geomorphic surfaces, are the product of erosion, sedimentation, and soil development. The rates and magnitudes of these processes are functions of five main factors: climate, biologic activity, topography, parent (or initial) material, and time (Birkeland, 1999). Therefore, geomorphic surfaces with similar characteristics can be interpreted to have been deposited under grossly similar conditions and to have experienced similar postdeposition alterations. Depositional processes (overland flow, eolian transport, mass wasting) largely control the nature of the original deposit, which was governed by physical processes involving some aspect of topography. In many cases, particularly in tectonically inactive areas, climate is considered to be the dominant factor through time, and similar soils developed in deposits created by the same inferred depositional process can be adequately considered contemporaneous; although variations, particularly from lithologic, biologic, and climatic variations with elevation, can render deposits of the same age to have different soil-geomorphic characteristics.

In and largely north of the map area, numerous researchers have conducted detailed studies that led to the development of several groups of soil units or soil chronosequences for the eastern Mojave Desert (Bedford, 2003; McDonald, 1994; Menges and others, 2001; Reheis and others, 1989; Wells and others, 1990; Yount and others, 1994). These chronosequences tended to have similar soil unit characteristics, leading to the assumption that a regionally extensive chronosequence can be developed. In the absence of age control, early chronosequences in the southwestern United States were typically based on a relative time scale or a time scale based on few numeric ages. Geochronologic information at many of these sites showed that regional correlations of soils in these chronosequences can be conducted successfully (Menges and others, 2001; Wells and others, 1990). The ability to map similar soils from basin to basin in a broad area and correlate them to similar factors affecting the landscape allows us to make inferences about broad climatological, vegetative, and tectonic histories both across a broad area and through time. Menges and others (2001) provide a useful discussion and correlation of map units used throughout California and Nevada.

We present a set of geomorphic surface descriptions that fit largely into the studies by other authors working in the eastern Mojave Desert, but we have tailored ours to adequately represent units mappable at a regional scale (1:100,000). We describe geologic deposits that undergo pedogenesis and surface modifications, which is a departure from the geomorphic surface concept. We describe deposits by depositional process (lacustrine, eolian, fluvial, alluvial) and then further subdivide them by age as elucidated by pedogenic characteristics. Subdivisions in general are based on geologic breaks (periods of deposition), as well as physical properties important for describing hydrologic and biologic differences.

Landscape History

Quaternary Faulting and Tectonic Geomorphology

Several strike-slip faults that are known to have ruptured during the Quaternary are located in the Amboy quadrangle. From east to west and oldest to youngest, they are the Bristol-Granite Mountains, south Bristol Mountains, Broadwell Lake, and Ludlow Faults (Howard and Miller, 1992). Each fault strikes northwest and is dextral (fig. 3). The permissible translation on each, from west to east, is 0 to 10, 6.5, 6, and >6 km based on offset marker lithologies (Howard and Miller, 1992). Each fault, where well exposed, exhibits several subparallel strands.

The Bristol-Granite Mountains (BGM) Fault appears to cut middle to early Pleistocene unit Qoa in the Marble Mountains (fig. 3*A*), although relations are ambiguous due to the thin unit Qoa deposits lying on Miocene and older rock. The scarps in this setting might represent inherited topography from scarps expressed in the older rocks, tectonic scarps formed after unit Qoa was deposited, or both. Unit Qia, including its oldest subdivision that is mappable regionally (Qia3 of Yount and others, 1994), is not visibly cut by the fault. The fault last ruptured adjacent to the Marble Mountains in the middle Pleistocene or earlier. Subtle geomorphic evidence for Late Quaternary faulting exists in the pass between the Bristol and Granite Mountains in the form of lineaments that may represent scarps as young as late Pleistocene, many of which show apparent exhumation of pediments along the trend of faults typical of the region. The BGM Fault cuts Pleistocene materials to the north of the Amboy quadrangle (Brady, 1992), in the northern end of the Bristol Mountains (fig. 3*B*). Air photography analysis and field reconnaissance show that surfaces of probable late or latest Pleistocene age (unit Qia1 of Bedford, 2003; Yount and others, 1994) are cut by faults.

The South Bristol Mountains Fault cuts Quaternary materials in several places where it flanks the southwest side of the range (fig. 3*C*); farther northwest, it lies within the bedrock of the range and probably cuts colluvial deposits, but unambiguous relations are rare. The fault cuts older Qia deposits (mapped as Qiao, and correlates to unit Qia3 of Yount and others, 1994) but not the younger deposits of unit Qia (Qia2 of Yount and others, 1994, not mapped separately in this publication), which suggests it last ruptured during the middle or late Pleistocene. The 4.83 Ma Lawlor Tuff was identified by tephrochronology by A.M. Sarna-Wojcicki (written commun., 2003) from a sample taken at the base of a lake sequence interbedded with fan gravels 3.5 km north of the town of Amboy (unit Qha/pc). A maximum age of middle Pleistocene is provided by the tilting of these gravel and lake sediments, which dip south probably as a result of deformation associated with dextral faulting on the South Bristol Mountains Fault.

The Broadwell Lake Fault was first identified on the basis of satellite imagery (Ford and others, 1989). It is most evident where it cuts Miocene volcanic rocks in the Lava Hills and forms broad breccia and gouge zones in granitic rocks (fig. 3*D*). In the Lava Hills, the fault cuts unit Qoa surfaces that are too small to show at map scale. Northwest of the Lava Hills, unit Qiao is warped adjacent to the fault and younger unit Qia deposits are not cut by the fault. The fault apparently last ruptured during the middle or late Pleistocene.

The Ludlow Fault lies in the southwest corner of the Amboy quadrangle (fig. 3*E*). The fault cuts older deposits (Qiao) but not younger deposits of unit Qia (Howard and Miller, 1992).

Two previously unmapped faults are recognized in aerial photographs in the northwestern portion of the map area, although access to the locations was not permitted. The first fault parallels the Bristol-Granite Mountains Fault (that strikes northwest-southeast), while the second has an east-west strike.

The Hidden Valley Fault parallels the Bristol-Granite Mountains Fault and is present ~4 km to the southwest of the BGM Fault (fig. 3). The fault is observed in aerial photography and cuts deposits mapped as units Qiag and Qia, as well as bedrock units, and has apparent right-lateral offset of Qiag deposits of approximately 300 m. The fault is likely a major splay of the BGM Fault as it emerges from the highlands between the northern Bristol Mountains and Granite Mountains. The fault was not visited on the ground, and there is no clear faulting of Holocene deposits from aerial photography, limiting a minimum age of rupture to late Pleistocene. Understanding the partitioning of slip across the BGM Fault and the Hidden Valley Fault, particularly through time, may reveal important dynamics of the northern part of the eastern California Shear Zone.

The Lava Hills Fault is a newly identified northwest-striking fault zone that consists of several splays that cut units Qoa and Qiao in several places along the southwest margin of the Lava Hills. The fault dips steeply to moderately northeast and forms wide breccia and gouge zones in Miocene volcanic rocks and Mesozoic granitoids. It is probably the determinant of the linear southwest margin of the Lava Hills, although in most places the fault strand that bounds the bedrock of the Lava Hills is buried by late Pleistocene and Holocene alluvial deposits.

A prominent scarp cutting Qia deposits exists within the northern Bristol Mountains and lies west of the Amboy quadrangle. The scarp strikes nearly east-west and shows several geomorphic indicators for north-side-up offset and also for probable sinistral offset. It appears to extend east into the Amboy quadrangle, where relations are not as clear on aerial photographs because most exposure is within granitic rocks. The location is remote and we have not investigated it in the field. The questioned fault, identified as the Broadwell Mesa Fault in figure 3, is mapped along a series of east-trending linear zones that appear to correspond to decomposed rock, possibly representing fault gouge. Facies of granitic rock jog in a sinistral sense along this zone, supporting an interpretation that this late Pleistocene fault is left-lateral and is broadly related to the Cady Fault to the west.

Subtle evidence for Quaternary faulting is found on the northwest side of the Granite Mountains (fig. 3*F*). Preliminary fieldwork suggests that surfaces of unit Qia may be cut and deformed by northwest-striking faults. Along the west side of the low hills northwest of the Granite Mountains, consistently northwest-striking benches and ramps are visible in unit Qia. Apparent folding and gouging of unit Qia deposits are also observed. While benches and ramps may be inherited features from older deformation, the presence of gouge and folds infers deformation after unit Qia was deposited. Faulting may be as young as earliest Holocene based on possible offset of Qyao deposits in the wash emanating from the northwestern Granite Mountains, but the geomorphic pattern may be a result of complex incision patterns and, as such, should be considered tentative.

Linear mountains are prominent in the western part of the Amboy quadrangle but not elsewhere in the map area and coincide with locations of Quaternary dextral faults. The linear mountains exhibit asymmetrical topography, with low-gradient, deeply embayed piedmonts on the northeast and steep mountain fronts with narrow canyons and little embayment on the southwest. This asymmetry is probably the result of the interplay of two features: (1) a long, overall, gently sloping gradient from the high Granite and Providence Mountains on the north to Bristol and Cadiz Lakes on the south and (2) northwest-trending linear mountains athwart this gradient that disrupt southward transport of sediment. Each feature is probably tectonically controlled; the long gradient is possibly caused by broad folding of the upper crust (Howard and Miller, 1992), and the linear mountains reveal a down-to-the-southwest component of slip on the primarily dextral faults.

Further evidence for youthful tectonics is evident in Qoag deposits of the northern Marble Mountains. These deposits consist of sediment derived from felsic plutonic rocks of the Granite Mountains to the north yet are presently deposited on felsic volcanic rocks that form a bowl-shaped basin almost entirely around the deposits. Presently there is no physiographic connection of the deposits to their source area. This suggests that the drainage system at the time of deposition consisted of Granite Mountains watersheds that drained across the Marble Mountains, rather than around them. This configuration is also supported by older Tertiary sediments that locally dip towards the northern Marble Mountains.

Nonlinear mountain patterns, broad pediments and pediment-controlled piedmonts, and deep embayment of mountain fronts in the northeastern part of the quadrangle testify to lack of pronounced recent tectonic influence on those landforms. Large, integrated drainages, such as Fenner wash, also suggest that tectonics has not been a factor in drainage basin evolution in the eastern parts of the quadrangle.

Quaternary Volcanism

Quaternary volcanic rocks crop out in the southwestern portion of the map area. The most notable is Amboy Crater, a series of basaltic cinder and lava flow deposits capped by a 75-m-tall, breached cinder cone (Parker, 1963). Six periods of eruption are identified by Parker (1963) and have loosely been attributed to very short eruption periods, on the order of decades (Glazner and others, 1991). The rocks at Amboy Crater appear to have been deposited on playa deposits of Bristol Lake (Bassett and Kupfer, 1964) and were, in turn, shallowly buried on south and east margins by younger playa deposits (Parker, 1963).

Basaltic rocks crop out at in the southwestern Lava Hills at Dish Hill (Miller, 1993) which is a feature labeled hill 532 on 1:100,000-scale topographic maps and Dish Hill on 1:24,000-scale maps. Dish Hill shows characteristic morphology of a breached cone.

Quantitative numeric ages for the volcanic deposits in the map area are sparse, and most workers have attributed the age as Quaternary through stratigraphic relations with surficial units, with the exception of Dish Hill, which is dated at 1.9 and 2.1 Ma (Miller, 1993). Amboy Crater has recently been dated at 79±5 ka with cosmogenic ^{36}Cl methods (Phillips, 2003). Previous to cosmogenic dating at Amboy Crater, estimates of weathering rates on the volcanic rocks have been used to infer dates that are as young as mid-Holocene (Parker, 1963) and range to late Pleistocene (Glazner and others, 1991). Basaltic deposits having similar weathering characteristics in the eastern Mojave Desert have a broad range of numeric ages ranging from 60 ka to nearly 6.5 Ma (Turrin and others, 1985). Therefore, ages based solely on weathering characteristics should be considered as tentative. The absence of extensive burial of lake sediments and the absence of shoreline deposits associated with Bristol Lake suggests that Amboy Crater postdates the last glacial period, when it is inferred that the Bristol Lake Basin contained a large lake (Parker, 1963). The new numeric dates from Phillips (2003), mapping for this report, reconnaissance work of other authors (Bassett and Kupfer, 1964), and drill logs in Bristol Lake (Bassett and others, 1959) show no evidence that a large lake existed in the Bristol Lake Basin in the late Pleistocene.

Eolian History

A fairly large eolian system exists east of Fenner wash, from the Ship Mountains north to the central Piute Mountains near the town of Fenner. The source of sand for this system is Fenner wash and not Bristol Lake playa. There is no evidence for active or Holocene eolian sediments west of Fenner wash, but active, modern, mid-Holocene deposits are present immediately east of Fenner wash. Currently, the local wind regime is eastward, and the degree of eolian activity decreases to the east away from the wash based on qualitative assessments of fine-grained sediments in soil profiles and surface expressions of eolian features such as coppice mounds. The eolian deposits are increasingly younger to the south, as illustrated by fine-grained, sand-dominated, mixed eolian-alluvial deposits near the town of Fenner that lack surface expressions of modern eolian processes. Southward, the eolian processes and materials begin to dominate the system, gradually becoming more active along the wash margin near the towns of Essex and Danby.

The southward transition from older to younger eolian sediments may reflect the sediment-carrying capacity of Fenner wash for size fractions capable of being entrained by wind or may reflect fluvial responses to base-level change of the larger Fenner wash/Bristol Lake system.

New Age Data in Fenner Wash and Bristol Lake

We collected five samples for optically stimulated luminescence (OSL) analysis and two samples for ^{14}C analysis along Fenner wash in order to constrain ages of groundwater discharge (GWD) deposits in the Bristol Lake area. The stratigraphic relations of these deposits allow us to better understand the paleohydrology and landscape dynamics.

Luminescence samples were collected under opaque cloth in tubes inserted horizontally into vertical excavations of the deposits. Luminescence analysis was performed by Shannon Mahan in the U.S. Geological Survey Luminescence Lab in Denver, CO. Locations of samples are shown in figure 4*A*, and the preliminary data from the analysis is presented in table 1.

Near the town of Essex (fig. 4*A*), two luminescence samples (B02AM-393, B02AM-394) were collected in Fenner wash. Inset relations suggest that valley-filling Qia (Qia1 of Bedford, 2003) deposits occupy the broad center of Fenner Valley. Along the 1–1.5-m-deep incision along the modern drainage, Qyao (Qya4 deposits of Bedford, 2003) deposits were deposited within the incised channel of Fenner wash. The age of the Qia deposit allows a determination of the maximum age of incision, and the age of the Qyao deposit gives the minimum age of incision and the age of valley back-filling. We collected one sample from each of these deposits in a location with adjacent deposits (fig. 4*B*). IRSL ages (table 1) for these samples suggest that the inset Qyao deposit (sample B02AM-393) is older than the Qia deposit (sample B02AM-394). However, the OSL age on the Qia deposit yields an older age than the IRSL age on the same sample and that one is consistent with stratigraphic and inset relations. We attribute this inconsistency to the differences in textures used for luminescence analysis (silt for IRSL and fine sand for OSL). The Qia deposit contains a large amount of illuvial fines, as well as possible incorporation of eolian material. Because silt is more likely to be illuviated down into the soil profile, the samples may have been diluted with younger silt fractions that skewed the IRSL results.

Two luminescence samples (B02AM-391A, B02AM-391B) were collected from a vertical section of GWD deposits near the town of Chambless (fig. 4*A*). These deposits are described in the section Groundwater Discharge Deposits in Bristol Lake Basin. Figure 4*C* shows a sketch of the deposits and locations of samples. The age data in table 1 are stratigraphically consistent and suggest that the stratigraphic section was formed relatively swiftly, probably within 500 years.

One luminescence sample (M05SM-28) was collected to the south of Cadiz, along the Atchison Topeka and Santa Fe (ATSF) Railroad, in deposits similar to those near Chambless (fig. 4*A*). Deposits at this site also show similar ages (although with different luminescence techniques) as those near Chambless. Preliminary ^{14}C dates from snails at the ATSF Railroad site are younger than OSL dates for the same deposits. Two samples revealed ^{14}C ages of 11,720±60 and 12,110±140 in calendar years for *Fossaria* and *Pupillid* snails, respectively (Vicki Pedone, written commun., 2005).

There are two possible explanations for dissimilarities between OSL and ^{14}C dates. The first is simply that the two methods do not agree, or there may be calibration uncertainty. The second explanation is that the two methods are correct but are capturing two different stages of deposit formation. The ^{14}C data may represent a period of time with significant groundwater discharge and potentially large areas of open water, consistent with a climax in discharge. The carbonate-rich deposits in which luminescence samples were collected likely indicate a drying phase of discharge caused by lowered discharge and (or) increased aridity resulting in water evaporation and precipitation of carbonates. Thus our data may suggest that the peak, or final, period of large, open-water, marsh environments may have persisted until approximately 11–12 kya, followed by drying and carbonate-platform formation around 10 kya.

Bristol Lake and Bristol Playa History

There has been speculation about the presence of large lakes occupying the basins associated with the Bristol-Danby Trough. Bassett and Kupfer (1964) cite the need for through-going drainage from the Mojave River and Death Valley areas to the Colorado River. Evidence for large lakes in the basins during the late Miocene to Pliocene is largely from tilted lakebed deposits containing the 4.83 Ma Lawlor Tuff. This system of lakes may have also been connected with lakes occupying the Barstow Basin (Robert Reynolds, personal commun., 2002). Fossils from Cadiz Basin suggest a lake in the early history of that basin, but there are no dates from that stratigraphic interval (Bassett and others, 1959).

There is little evidence for large lakes in the Bristol Lake Basin in the Quaternary (Brown and Rosen, 1995; Rosen, 1991). Alluvial deposits of a variety of Quaternary ages show no known shoreline features preserved on piedmonts, and

Table 1. Feldspar infrared stimulated luminescence (IRSL) and quartz blue-light optically stimulated luminescence (OSL) ages and analytical data for Fenner Wash and Bristol Lake area.

[---, no data]

Sample No. (additional information)	Unit label[1]	Sample depth (cm)	Moisture content (%)[2]	IRSL dose rate (10^{-3} Gy/yr)	Equivalent dose (Gy)	IRSL age[3] (yr)	No. of samples	OSL dose rate (10^{-3} Gy/yr)	Equivalent dose (Gy)	OSL age (yr)	Best age estimate (yr)
B02AM-391A (below carbonate ledge)	Qyg	25	20±1.5	4.77±0.05	45.1±0.45 53.2±0.53	9,456±260 11,134±09	29	3.48 ± 0.05	35.1±1.07	10,074±530[4]	10,000
B02AM-391B (base below nodules)	Qyg	45–50	20±1.5	4.90±0.06	50.2±0.78 53.0±0.92	10,239±415 10,819±468	---	---	---	---	10,500
B02AM-393 (minimum age on incision)	Qyao (Qya4)	25–30	10±1.5	5.82±0.05	61.8±0.56 64.8±0.71	10,619± 55 11,120±303	---	---	---	---	10,800
B02AM-394 (reddened, older soil)	Qia (Qia1)	40	10±1.5	5.47±0.05	29.0±1.45 41.7±0.46	5,296±538 7,623±212	29	4.26±0.04	51.4±1.59	12,052±768[4]	12,000
M05AM-28 (below carbonate ledge)	Qyg	25	20±1.5	4.47±0.08	---	---	24	3.26±0.07	30.5±0.92	9,365±673[5]	9,400

[1]Unit labels in parentheses show correlative unit labels in Bedford, 2003.
[2]Field moistures at 1%; ages based on 10% (sands) to 20% (silts) moisture content through time as an average between field and saturation moisture values.
[3]Silt fraction (4–11 μ) for IRSL as multiple aliquot additive dose technique (MAAD).
[4]Lab used fine sand grains (125-105 μ) for blue-light OSL as single aliquot regeneration (SAR) technique.
[5]Lab used fine sand grains (105-90-105 μ) for blue-light OSL as single aliquot regeneration (SAR) technique.

cores from the Bristol Lake and Cadiz Basins consist of large amounts of salt and gypsum (Bassett and others, 1959), which are more consistent with ephemeral playa environments or short-lived shallow lakes.

Groundwater Discharge Deposits in Bristol Lake Basin

Extensive groundwater discharge events in the Bristol Lake Basin are shown by deposits east and south of the town of Chambless (fig. 4*C*). There are two types of deposits in outcrop and each represents a different period and inferred magnitude of groundwater discharge.

Surface expressions of older and more extensive groundwater discharge deposits consist of a mixed assemblage of platforms of calcium carbonate deposits and incipient pavements above fine-grained sand and silt with calcium-carbonate clast coatings. The platform deposits consist of white to cream-colored, moderately indurated to well-indurated calcium carbonate with popcorn-like textured calcium carbonate nodules. late Pleistocene mammalian fossils are present within the upper platform deposits. The carbonate platform deposits are 35 to 50 cm topographically and stratigraphically below deposits that are capped by a weak soil and incipient pavement. These deposits consist of a very weak pavement of gravel clasts that can be correlated to a provenance of the upper portions of Fenner Valley. Below the layer of surface clasts is a 3-cm-think, weak A_V horizon that is consistent with soils developed on Qyao deposits. Excavation and hand cores below the A_V horizon reveal mixed sand and silt deposits, including various amounts of calcium carbonate coatings and nodules, and basal (?) fine-grained silty sand (fig. 4*C*).

Excavations and geomorphic relations show that the platform deposits are intercalated with the sandy deposits. The basal silty sand deposits resemble fine-grained lacustrine or groundwater discharge deposits, but samples analyzed for paleobotanical content from the core lacked ostracodes and consists primarily of root fragments, root casts and molds, and calcareous rhizoliths (Richard Forester, written commun., 2003). Correlative deposits approximately 4 km to the south near the town of Cadiz contain ostracode species, as well as micrite and ostracode oxygen and carbon isotopic ratios consistent with wetland environments and deposits (Pedone and Rivera, 2003). Two preliminary luminescence dates from the fine-grained section near Chambless suggest that the deposits were formed around 9.5 to 11 ka (see New Age Data in Fenner Wash and Bristol Lake).

The older deposits near Chambless are interpreted to be formed in wetland environments containing mixtures of small, open-water pools and marshes similar to deposits and paleoenvironments termed “wet meadows” and described in southern Nevada by Quade and others (1995). Further interpretations can be made on the paleoenvironments for the two types of older deposits near Chambless. We suggest that the carbonate platform deposits may have formed through precipitation of carbonate as patches of open water dried. Small patches of vegetation may have persisted, as evidenced by root molds and casts, but the majority of vegetation may have been retarded due to a hardpan of carbonate-rich sediments. The thicker and finer grained deposits that presently are capped by weak soils and incipient pavements may have persisted as wet areas, which would have accumulated fine-grained deposits, and provided ideal environments for vegetation. These wetter areas may correlate to the “phreatophyte flat” of Quade and others (1995). As groundwater levels dropped, presumably at the end of the Younger Dryas, precipitation of minor carbonates may have deposited as carbonate coatings in the upper portions of the deposits. In southern Nevada, similar stratigraphic sections and relations are typically capped by organic-rich “black mat” deposits (Quade and others, 1998), but no black mat deposits were observed at the site near Chambless. At the Chambless site, black mat deposits may have never formed or may have been subsequently eroded. Organic-rich deposits are observed capping similar stratigraphy near the town of Cadiz (Pedone and Rivera, 2003) and may be black mat deposits.

Younger calcium carbonate deposits also present near Chambless appear as a broad, flat platform of massive to punky calcium carbonate disseminated in mid-Holocene alluvial surfaces of unit Qya. The calcium carbonate is present in the older Holocene deposits (unit Qya3 of Bedford, 2003) but are absent in the youngest deposits (units Qya1 and Qya2 of Bedford, 2003). The carbonates are present on top of, as well as throughout, the soil profile, suggesting that the carbonates were deposited after deposition of the alluvial unit, perhaps as percolation through the deposits. The abundance of calcium carbonate within the alluvial fan units decreases to the east, as well as decreases with increased stratigraphic depth in the up-fan direction (fig. 4). These deposits are interpreted as being the result of a rise in groundwater levels at or above the ground level in the lower Bristol Lake Basin following the deposition of the alluvial fan deposits. Percolation through or wetting of the deposits was likely followed by evaporation, which deposited calcium carbonate in the alluvial soil. Timing of the groundwater rise can only be constrained, because it is unlikely to have occurred during the mid-Holocene altithermal and must have occurred following significant soil development. Therefore, the groundwater rise appears to have occurred sometime after the mid-Holocene altithermal to allow minor soil development (A_V and weak B horizons) and before the younger suite of inset Holocene alluvial units were deposited. Ages of the younger alluvial deposits in the area are unknown, but regionally they range from 100 to 2,000 years old (Bedford, 2003; McDonald, 1994).

The deposits near the town of Chambless have obvious affinities to spring and wetland deposits in southern Nevada and, thus, may be interpreted in the same paleoenvironmental and paleoclimatic manner. The IRSL dates presented here are on the order of 500 to 1,000 years younger than most of the similar deposits in southern Nevada, which range from 11.8 to 6.3 ^{14}C ka and cluster at about 10 ^{14}C ka (Quade and others, 1998), which is roughly 9.5 ka in calendar years. Quade and others (2003) report that desiccation of black mat and other spring deposits in southern Nevada occurred between 9.5 and 7 ka ^{14}C, which is roughly 9 to 6 ka calendar years. If our preliminary IRSL date of 9.5 to 10.5 ka is accurate and interpreted as a result of initial drying of the wetland deposits, then it seems apparent that the wetlands at Chambless were active at an earlier time than those in southern Nevada. If the Younger-Dryas climatic shift is responsible for the increased regional moisture levels, then one would expect the carbonate caps in southern (Chambless) deposits to form (dry out) before the northern deposits as aridity returned to more northern latitudes in a time-transgressive manner.

Evolution of Fenner Wash and Adjacent Piedmonts

Alluvial fan and wash deposits along Fenner wash reveal dynamics of late Quaternary erosion and deposition (fig. 5). Late Pleistocene deposits (Qia) grade gently down to the center of Fenner Valley, which is occupied by Fenner wash. Late Pleistocene deposits mimic the present topography of the basin and extend to the valley center, which suggests that the base level of the valley was approximately that of the central valley through much of the Pleistocene. Near the town of Essex, a suite of late Pleistocene alluvial deposits with a minor eolian component (Qia) correlates to unit Qia1 of Bedford (2003), which is most likely a younger, latest Pleistocene deposit. The present wash bottom is incised approximately 2 m below this surface and has relatively limited lateral extent along a few primary wash systems such as Black Canyon, Woods, and Watson Washes. South of Essex, these washes merge into Fenner wash. The oldest deposit in the incised Fenner wash is a late Pleistocene to early Holocene alluvial deposit (Qyao), which suggests that between latest Qia depositional time and Qyao depositional time, a fairly large base-level change occurred to cause incision followed by backfilling of the incised channel. The timing of incision is prior to 10 ka and may have been in response to rapid cooling and increased moisture at the onset of the Younger Dryas. However there is some ambiguity to the start of incision due to unclear IRSL ages on the latest Pleistocene deposits. The soil development of the deposit suggests that it would be a youngest Qia deposit, which would likely be much older than 12 ka. One interpretation is that the IRSL samples were contaminated by young sand and silt during pedogenesis or bioturbation. Another interpretation is that the 12 ka blue OSL age is correct and that the IRSL age is incorrect due to contamination of silt. In this case, the deposit would likely be an older unit of type Qyao, and the incision happened very rapidly, between 12–10.8 ka. A deposit of unit Qyao near the town of Essex contains a moderate amount of fine-grained material and provided a preliminary IRSL age of 10.8 ka (see New Age Data in Fenner Wash and Bristol Lake). The similarity of the timing of deposition in the incised Fenner wash and groundwater deposition at the terminus of Fenner wash in Bristol Lake suggests that the blockage of the mouth of Fenner wash by wetlands and phreatophyte flats is responsible for deposition in the valley. Wetlands and phreatophyte flats effectively block sediment transport (Quade and others, 1995) and, in effect, would have acted to raise the effective base level of Fenner wash by as much as 50 to 60 m (the difference between the modern elevation of Bristol Lake and the highest elevation of groundwater discharge deposits). The younger deposits (Qyw, Qaw, Qyv, and Qav) of Fenner wash are not dramatically incised into the Qyao deposits, suggesting that base level has not changed dramatically following deposition of Qyao. These younger deposits are combinations of stream-channel, bar, and overbank deposits; the fine-grained components are often reworked into eolian deposits in the wash and on the east flank of the wash along the Piute and Old Woman Mountains. These eolian deposits have moved down Fenner wash along the eastern piedmont in a time-transgressive manner, but it is unknown if this occurred in a continuous or stepwise manner. The periods of Holocene eolian activity in and flanking Fenner wash can possibly be correlated to regional eolian sand ramp and dune activity and logically be linked to periods of aridity. Mid-Holocene eolian sand ramp deposits are known and dated at the Big Maria Mountains at 6 to 8 ka, at Soldier Mountain at 6.7 ka (Rendell and Sheffer, 1996), and at Kelso Dunes between 10 to 4 ka (Clarke, 1994; Lancaster and Tchakerian, 2003) and could correlate to the eolian materials incorporated into mid-Holocene alluvial sediments along the western Piute Mountains piedmont near the town of Fenner. Late Holocene deposits are also dated regionally at the west Cronese Basin between 2 to 1 ka, at Old Dad Mountain between 3 to 2.5 ka (Rendell and Sheffer, 1996), and at Kelso Dunes around 1.5 ka and between 0.8 to 0.5 ka (Clarke, 1994; Lancaster and Tchakerian, 2003). All of these deposits, and their associated dates, may correlate with wash deposits inset in Fenner wash and younger to active eolian and mixed alluvial deposits along the southeast flank of Fenner wash.

In summary, there appears to be little evidence that pulses of fan aggradation, which may be climatically linked, and eolian activity, inherently climatically linked, had significant effect on the geometry of the Fenner Basin. Base level fluctuations at the terminus of Fenner wash, caused by raised groundwater levels and significant vegetative activity in wetland and phreatophyte flat environments, are likely responsible for the incision and subsequent backfilling of sediments along the axial Fenner wash system.

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DESCRIPTION OF MAP UNITS

[Soil A_V and B horizon descriptions are from Birkeland and others (1991). Carbonate stage morphology follows Giles and others (1966), modified by Machette (1985)]

SURFICIAL DEPOSITS

ANTHROPOGENIC DEPOSITS

ml **Made land**—Material moved for construction purposes and agricultural disturbance sufficiently extensive to make landforms and deposits difficult to identify

ALLUVIAL DEPOSITS

Qaa **Active alluvial fan deposit (Holocene)**—Alluvial fan deposits characterized by surfaces and channels that actively receive or have received sediments within the last few years or decades. Composed of unconsolidated, poorly sorted gravel and sand in channels, fine sands and silts in overbank deposits. Deposit consists of active channel and young terrace or bar deposits. The annually active channel surfaces are a small part of the unit and form discrete channels that are commonly smooth. Terrace deposits with rough microtopography; strongly developed bar and swale throughout much of the extent of fan; less pronounced microtopography in distal fan. No soil development in active channels and little or no soil development, which may be expressed as accumulations of silt in the upper horizon, in terrace deposits. Surfaces active on a decadal scale form terraces 10 to 60 cm above active channels. Deposits inset into most of older alluvial deposits. Surfaces commonly lack annual and perennial vegetation on surfaces active on annual to decadal scale and are moderately to heavily inhabited with annual and perennial vegetation on surfaces or channels active on decadal to centennial scale. Perennial vegetation commonly consists of creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*). Surfaces are prone to flooding and sheet flow during intense or long-lasting precipitation events. Active channels inferred to be less than 10 to 20 years or less based on flooding frequency, terrace and bar deposits ranging from 20 to 100 years based on flooding frequency from air photography at different times, and 19th and 20th century tracks and trails buried by these deposits. Subdivided where predominantly grus

Qaag **Active alluvial deposit composed of grus**—Alluvial fan composed predominately of clasts from granitic source that weathers to grus. Surface undulates with smoother microtopography than unit Qaa; depths of channel incision is smaller; typically 10 to 40 cm separates active surfaces from centennial active surfaces

Qya **Young alluvial fan deposit (Holocene and latest Pleistocene)**—Alluvial fan deposits characterized by surfaces that are abandoned or receive flood materials on a centennial to millennial basis. Moderately to poorly sorted, loose to slightly compact sand and sandy gravel. Coarser-grained especially near nongranitic mountain fronts where boulders and cobbles are common. No or very weak desert pavement. Incipient to weak varnish on clasts. Soil development consists of 1-to-3-cm-thick, incipient to weak fine sand and silt

A_v, occasional reddening of subsurface (cambic B) horizons, and stage I calcic development. Microtopography ranges from 20 to 60 cm in much of fan and consists of moderate to faint remnants of bar and swale topography. Moderately to sparsely inhabited with creosote bush and smaller shrubs, typically white bursage. Can contain abundant patches of cryptobiotic soil crusts. Surfaces typically 0.3 to 1.5 m above active channels. This unit may contain any of the following subunits

Qyay **Younger young alluvial fan deposit (Holocene)**—Mapped as areas that lack deposits of unit Qyao

Qyad **Young alluvial fan composed of debris-flow deposits (Holocene and latest Pleistocene)**—Young alluvial deposits dominated by debris flows of bouldery, matrix-supported material. Bar and swale microtopography is distinct on the order of 0.5 to 1 m high. Mapped only where determined from field study; deposits are much more widespread than shown. Common along west side of Providence Mountains

Qyaf **Young alluvial fan composed of fine-grained deposits (Holocene and latest Pleistocene)**—Alluvial deposits dominated by fine-grained sediments in the extreme distal portions of fans or where wash deposits build fans onto playas, such as the terminus of Fenner wash. Commonly very subdued microtopography, very sparsely or unvegetated and mixed with eolian deposits

Qyao **Older young alluvial fan deposit (Holocene and latest Pleistocene)**—Alluvial deposits characterized by 1 to 5 m^2 patches of weakly to moderately developed pavements with weak varnish on clasts that develop varnish. Soil development consists of 1 to 4 cm thick A_v horizon, weak cambic to B_{tw} horizon, and stage I to II calcic horizon. Deposits inset into older (Qia) deposits and typically are incised by younger deposits (younger Qya and Qaa). Dated at about 10 ka by OSL in Fenner wash near the town of Fenner (Shannon Mahan, written commun., 2003; see discussion) and lie on groundwater discharge deposits dated at 13 ka by luminescence methods (Shannon Mahan, written commun., 2000; see discussion) in lower Kelso Wash just north of the map area. Mapped only where determined from field study; deposits are much more widespread than shown

Qyag **Young alluvial fan deposit composed of grus (Holocene and latest Pleistocene)**—Alluvial fan deposits made up of clasts from granitic source that weathers to grus. Surface undulating and smooth with smaller magnitudes of channel dissection. Soil development is weak with sandy incipient to weak sand and silt A_v, poorly developed cambic horizons, and stage I to I+ calcic horizons. Surfaces typically 20 to 50 cm above active channels. Very common downslope of Cretaceous granite outcrops.

Qyaog **Older young alluvial fan deposit composed of grus (Holocene and latest Pleistocene)**—Older young alluvial deposits made up of clasts from granitic source that weathers to grus and characterized by weakly developed pavements that generally lack varnish. Soil development is weaker than Qyao, particularly as weak sandy A_v horizons. Mapped only where determined from field study (mostly in the northwestern Granite Mountains); deposits are much more widespread than shown

Qia **Intermediate alluvial fan deposit (late to middle Pleistocene)**—Poorly sorted, sandy gravel alluvial fan deposits characterized by surfaces abandoned for tens of thousands of years. Compact. Characterized by moderately developed to well-developed desert pavement with moderate to strong varnish on clasts and flat smooth surface that is partly incised by narrow channels. Well-developed platy 4 to 10 cm thick A_v horizon composed of silt, very fine sand, and clay. Moderate to strongly developed B_t horizon and Stage I+ to III+ calcic horizon. Pavement, varnish, and A_v horizon subdued to absent at high altitudes (above approximately 1,100 m); B_t horizon typically thicker at high altitude; calcic horizon is thin. Very sparsely vegetated on flat surfaces with creosote bush, white bursage, and Mojave yucca (*Yucca schidigera*), more densely vegetated along rounded transitions to incised areas. Moderately vegetated at high altitude with Mojave yucca, blackbrush (*Coleogyne ramosissima*), and Joshua tree (*Yucca brevifolia*)

Qiad **Intermediate alluvial fan composed of debris-flow deposits (late to middle Pleistocene)—**Alluvial fan made up predominately of debris-flow deposits of bouldery, matrix-supported material. Mapped only where determined from field study

Qiag **Intermediate alluvial fan deposit composed of grus (late to middle Pleistocene)**—Alluvial fan made up of clasts from granitic source that weathers to grus; surface commonly is poorly developed with weak to no pavement and A_v horizon; B_t horizon is well developed; calcic horizon ranges from stage II to III+ and may be 2 to 3 m below the surface

Qiao **Older intermediate alluvial fan deposit (late to middle Pleistocene)**—Older intermediate alluvial deposits. Surface expression of two main types: degraded pavement including exposure of the A_v below disaggregated pavement clasts or in the presence of a moderately developed intact pavement; B_{tk} horizons thinner than for younger Qia deposits to nearly absent. Both types have extreme rounding of incised edges. Stage II+ to IV- calcic horizon. Moderately vegetated with similar assemblages as unit Qia but may be more dense. Mapped only where determined from field study; deposits are more widespread than shown

Qiaog **Older intermediate alluvial fan deposit composed of grus (late to middle Pleistocene)**—Older intermediate deposits made up of clasts from granitic sources that weather to grus; degraded weak pavements having moderate- to well-developed A_v horizon and well-developed B_t horizon with stage III calcic development. Mapped only where determined from field study

Qoa **Old alluvial fan deposit (middle to early Pleistocene)**—Alluvial fan deposits characterized by degraded remnants of abandoned surfaces forming bouldery ridges, or ballenas, after Peterson (1981). Poorly sorted sand and gravel, compact to well cemented. Commonly forms pale-colored ballenas above active washes in upper parts of alluvial fans near mountain fronts or rounded, deeply dissected terrain with little or no remnant depositional geomorphology; extends a few meters to tens of meters higher than surrounding surfaces. Most upper soil horizons stripped off by erosion but commonly superimposed with younger deposits on the petrocalcic horizon. In places may have remnant varnished pavement clasts at the surface, including disaggregated pieces of calcic horizon and a very thin or absent B_t horizon suggesting the surface once had pavement characteristics that have since degraded. Stage IV and greater calcic horizons 2 to 6 m thick. Moderately vegetated. The 0.74 Ma Bishop Tuff is deposited in lower part of the unit in the western Providence Mountains (McDonald and others, 1995) and is the only age control in the map area

Qoad **Old alluvial fan composed of debris flow deposits (middle to early Pleistocene)**—Old alluvial deposits dominated by debris flows of bouldery, matrix-supported material. Mapped only where determined from field study; deposits are much more widespread than shown

Qoag **Old alluvial fan deposit composed of grus (middle to early Pleistocene)**—Old alluvial fan made up of clasts from granitic source that weather to grus; surface commonly modified by overland flow and lacks A_v horizon; B_t horizon rarely remains. Contains pronounced stage III+ to IV+ calcic horizon. Typically deeply incised and rounded with moderate vegetation

QToa **Extremely old alluvial fan deposit (early Pleistocene to Pliocene)**—Alluvial fan deposits characterized by complete lack of original landform and general lack of soil horizons at the surface. Poorly sorted compact bouldery gravel and sand. Forms deeply dissected terrain with little or no remnant depositional geomorphology. Deposits generally did not form in present topography, as indicated by source directions or clast composition. Younger, superimposed, soil horizons locally developed and may have several sets of paleosols exposed in wash-cut profiles. Moderately to well vegetated. Between Lava Hills and Bristol Mountains, commonly contains thick calcic horizons and is distinguished from unit Qoa by generally deeper dissection and presence of abundant exotic rhyolite clasts

WASH DEPOSITS

Qaw **Active wash deposit (Holocene)**—Alluvial wash deposits characterized by surfaces and channels actively receiving sediments within the last few decades. Similar in character to unit Qaa but generally better sorted and bedded and deposited in larger, more frequently flowing integrated drainages. Composed of loose moderately to poorly sorted sand and gravel, moderately to poorly bedded. No soil development in active channels and little or no soil development, which may be expressed as accumulations of silt in the upper horizon, in terrace deposits. Commonly lacks vegetation on active channel surfaces and moderately vegetated on decadal- to centennial-scale surfaces with creosote bush, commonly cheesebush (*Hymenoclea salsola*), and smoke tree (*Psorothamnus spinosus*) at low altitudes. Surfaces are prone to flooding and sheet flow during intense or long-lasting precipitation events. Mapped mainly where ephemeral stream flow is channelized; distributed stream flow generally mapped as active alluvial fan deposit (Qaa) or valley-axis deposits (Qav). Major washes include Fenner Valley, Kelso Valley, and Orange Blossom Wash

Qawg **Active wash deposit composed of grus (Holocene)**—Wash deposits made up of clasts from granitic source materials that weather to grus. Typically moderately sorted to well-sorted sand and gravel with decreased magnitude of inset relations

Qyw **Young wash deposit (Holocene and latest Pleistocene)**—Largely inactive alluvial wash deposits in terraces above active wash surfaces. Composed of loose, moderately to poorly sorted, sand, gravel, cobbles and boulders commonly in close proximity to bedrock outcrops. Poorly to moderately bedded with common alternating beds of coarse-grained wash and fine-grained overbank sediments. Soil development typically consists of 1- to 3-cm-thick, incipient to weak, fine sand and silt A_v, weak to moderate B_w to weak B_t horizons, and stage I calcic development. Microtopography ranges from 10 to 50 cm. Moderately vegetated, commonly with cheesebush and smoke tree at low elevations, creosote bush and white bursage at higher elevations. Generally forms terraces flanking active washes, approximately 50 to 100 cm above active wash. Smaller alluvial wash tracts of similar age and characteristics generally mapped as alluvial fan deposit (Qya), particularly where distributed across alluvial fans rather than in confined axial channel, but designation somewhat arbitrary

Qywg **Young wash deposit composed of grus (Holocene and latest Pleistocene)**—Wash deposits made up of clasts from granitic source that weathers to grus. Soils more immature than Qyw; pavements and moderately developed A_v horizon rare. Surface undulating and smooth with decreased magnitude of channel dissection compared to unit Qyw

Qiw **Intermediate wash deposit (late to middle Pleistocene)**—Inactive remnant alluvial wash sediments generally forming high terraces along edges of major washes. Moderately sorted to well-sorted, well-bedded sand and gravel. Soil development similar to that for unit Qia. Sparsely vegetated. Smaller alluvial-wash tracts generally designated alluvial fan deposit (Qia)

EOLIAN DEPOSITS

Qae **Active eolian sand deposit (Holocene)**—Eolian sand deposits that are active and subject to migration. Composed of loose, moderately sorted to well-sorted sand. Generally lack vegetation but may be inhabited by grasses such as galleta (*Hilaria rigida*) or ricegrass (*Oryzopsis hymenoides*). Most active eolian sand deposits lie within Devils Playground from south of Soda Lake to Kelso Dunes, where they are derived from Mojave River flood materials. Deposits also lie on lee side of large wash systems such as Fenner wash where fine-grained wash materials are mobilized

Qaed **Active eolian sand dune deposit (Holocene)**—Dune deposits, commonly steep and well bedded, with corresponding steep slip faces

Qye **Young eolian sand deposit (Holocene and latest Pleistocene)**—Eolian sand deposits that are generally inactive. Loose, well-sorted to moderately well sorted, moderately to weakly bedded, fine to medium grained sand. Sparsely vegetated, typically with perennial or annual grasses and, less commonly, with shrubs. Little or no soil development. Dated in Kelso Dunes area as general pulses of eolian sand deposition from 8 to 10, 3.5 to 3.7, and 0.5 to 1.5 ka (Clarke, 1994; Lancaster, 1995). Subdivided into sand dune, sand ramp, and sand sheet deposits

Qyed **Young eolian sand dune deposit (Holocene and latest Pleistocene)**—Dune deposits. Commonly steep and well bedded, with corresponding steep slip faces

Qyer **Young eolian sand ramp deposit (Holocene and latest Pleistocene)**—Ramp deposits generally on inclined surface over bedrock. Weak to moderately bedded. May be well-sorted to poorly sorted based on mixing with colluvial materials from upper slopes

Qyes **Young eolian sand sheet deposit (Holocene and latest Pleistocene)**—Well-sorted to moderately sorted sand-sheet deposits generally forming subhorizontal surface over unconsolidated deposits

Qie **Intermediate eolian sand deposit (late to middle Pleistocene)**—Eolian sand sediments that are generally inactive, characterized by one or more B_t horizons and calcic horizons. Surface very flat and moderately compact. Sparsely vegetated

MIXED EOLIAN AND ALLUVIAL DEPOSITS

Qyea **Young mixed eolian sand and alluvial deposit (Holocene and latest Pleistocene)**—Eolian and alluvial sediments that are thoroughly mixed, with eolian processes dominant. Deposit predominately loose, mixed sand with sparse gravel in interfingering, layered, or thoroughly mixed beds. Little or no soil development. Forms broad, flat surfaces with alluvial channels muted or invisible. Sparsely vegetated, generally with grasses dominant and commonly no creosote bush

Qyae **Young mixed alluvial and eolian sand deposit (Holocene and latest Pleistocene)**—Alluvial and eolian sediments that are thoroughly mixed, with alluvial processes dominant. Loose, gravelly sand with vague to well-defined, thin bedding. Little or no soil development. Forms flatter surfaces than alluvial systems lacking significant eolian sand, because eolian sand additions mute topography. Sparsely vegetated with grasses and shrubs, generally supporting creosote bush communities. Contacts with deposits of Qyea and Qya are gradational

Qiea **Intermediate mixed eolian sand and alluvial deposit (late to middle Pleistocene)**—Eolian sand and alluvial deposits that are thoroughly mixed, with eolian processes dominant. Exhibits inconsistently developed surface pavement and B_t and calcic horizons. Forms moderately compact, very flat surfaces with sparse vegetation. Contacts with deposits of units Qia and Qiae or Qiea gradational over tens to hundreds of meters

Qiae **Intermediate mixed alluvial and eolian sand deposit (late to middle Pleistocene)**—Alluvial and eolian sand sediments that are thoroughly mixed, with alluvial processes dominant. Gravelly sand with vague to well-defined, thin bedding. Exhibits inconsistently developed surface pavement and B_t and calcic horizons. Forms moderately compact, flat surfaces with sparse vegetation. Contacts with units Qia and Qiae or Qiea gradational over tens to hundreds of meters

PLAYA DEPOSITS

Qyp **Young playa deposit (Holocene and late Pleistocene)**—Playa deposits that are rarely flooded. Composed of moderately sorted to well-sorted silt and clay, commonly compact. Generally flat to very gently undulating and lacks vegetation. In Bristol Lake, age determinations are difficult due to disturbance and diversion of flow from mineral mining operations; deposit may be mostly active

Qypf **Young playa fringe deposit (Holocene and latest Pleistocene)**—Playa fringe deposits of complexly mixed eolian, lacustrine, playa, alluvial, and groundwater discharge origins. Forms low-gradient surface that is moderately well vegetated by grasses with sparse creosote bush

AXIAL VALLEY DEPOSITS

Qav **Active valley-axis deposit (Holocene)**—Fine-grained deposits in valley axes characterized by anastomosing washes, diffuse interfluves, and complexly interfingering wash and eolian sediments. Composed of loose, moderately to poorly sorted, fine gravel, sand, silt, and clay. Active channels typically lack vegetation; older terraces commonly inhabited by moderately dense vegetation such as creosote bush, white bursage, cheesebush, smoke tree, and annual grasses. Areas with increased eolian activity may be inhabited by perennial plants such as desert trumpet (*Eriogonum inflatum*), grasses such as galleta, and annuals such as skeleton weed (*Eriogonum deflexum*). Contacts with active wash and fan deposits commonly gradational and somewhat arbitrary. Surfaces are prone to flooding and sheet flow during intense or long-lasting precipitation events

Qyv **Young valley-axis deposit (Holocene and latest Pleistocene)**—Fine-grained deposits in largely inactive valley-axis locations characterized by anastomosing washes, gentle interfluves, and complexly interfingering eolian sediments. Composed of loose, moderately to poorly sorted, sand, silt, and clay. Soil development similar to unit Qya. Moderately vegetated with creosote bush communities, eolian-related grasses such as galleta, and desert trumpet in eolian-rich environments

Qyvo **Older young valley-axis deposit (Holocene and latest Pleistocene)**—Older valley-axis deposits characterized by moderately developed B_t and A_v horizons. Deposits located locally under parts of Kelso Dunes, as observed by the authors of this report and Yeend and others (1984)

GROUNDWATER DISCHARGE DEPOSITS

Qyg **Young groundwater discharge deposit (Holocene and latest Pleistocene)**—Silt and fine sand in zones of former groundwater discharge. Commonly forms light-colored, flat areas or dissected badlands. Loose to compact silt, fine sand, and calcium carbonate materials. Commonly exhibits capping, massive to punky, popcorn-like calcium carbonate in upper exposures above fine sand and silt with diffuse calcium carbonate throughout. Soil development similar to unit Qya, but horizons may be shallower in places due to effects of calcium carbonate and fine-grained materials. Soil development commonly more pronounced than in finer-grained unit Qya deposits and less developed in more massive carbonate exposures. Amount of vegetation depends on extent of calcium carbonate but is generally sparse. Dated at 9.5 to 10 ka near the town of Chambless (Shannon Mahan, written commun., 2003; see discussion), wetland deposits in lower Kelso Wash dated at 13 to 14 ka by IRSL (Shannon Mahan, written commun., 2000)

EROSIONAL SURFACES AND RELATED HILLSLOPE DEPOSITS

Hillslope environment is characterized by patchy distribution of bare rock, thin deposits weathered from rock, and materials transported short distances by gravity and carried by water. Identified with appended substrate rock type (following hyphen in unit symbol). Divided into hillslope and mass-wasting colluvial deposits

HILLSLOPE DEPOSITS

Qha **Abundant hillslope deposits (Holocene and Pleistocene)**—Hillslope materials such as colluvium, talus, weathering products, and landslide deposits; disaggregated cover more abundant than rock exposure. Generally less than 2 m thick or patchy distribution with small fraction of area covered by deposits thicker than 2 m

Qhs **Sparse hillslope deposits (Holocene and Pleistocene)**—Hillslope materials such as colluvium, talus, weathering products, and landslide deposits; disaggregated cover less abundant than rock exposure. Generally less than 2 m thick and patchy distribution

MASS-WASTING COLLUVIAL DEPOSITS

Qmc **Mass-movement colluvial deposits, undivided (Holocene and Pleistocene)**—Colluvial materials thicker than 2 m covering a wide area; age undetermined. Rocky and poorly sorted. Soil development ranges from weak to strongly developed B_t and calcic horizons. Locally subdivided by age

Qymc **Young mass-movement colluvial deposits (Holocene)**—Colluvial materials thicker than 2 m and covering a wide area. Rocky and poorly sorted. Little pedogenic soil development

Qimc **Intermediate mass-movement colluvial deposits (Pleistocene)**—Colluvial materials thicker than 2 m and covering a wide area. Rocky and poorly sorted; strongly developed B_t horizon; generally strongly varnished. Local development of Stage II to III pedogenic calcic horizon

PEDIMENT SURFACES

Gently sloping erosional surfaces in various stages of erosion and burial. Generally forms in grussy granite (fpg) and partly consolidated (pc) materials. Divided into three general classes by surface characteristics and shown on the map by a dash and the underlying substrate type (Qpv-fpg for a veneered pediment on grus-weathering felsic plutonic rocks)

Qpv **Veneered pediment**—Fairly smooth veneer of sediment commonly alluvial in nature, generally less than 2 m thick on the pediment surface; soil development variable depending on the age of sediment. Mapped where bedrock is exposed in small knolls, road cuts, or washes. Thicker deposits on pediments south of Granite Mountains mapped as Qiag+Qpv, showing thin Qiag deposited on the pediment surface

Qpi **Incised pediment**—Incised pediment with most of the surface expressed as flat surfaces of bare rock with patchy cover of veneer and one to several-meters-deep channels cut into rock that transport eroded sediment through the pediment

Qpd **Deeply dissected pediment**—Deeply dissected pediment identified by similar heights of isolated bedrock pinnacles and tors 3 m to tens of meters high; may be as much as 1 km^2 in areal extent in the southern Granite Mountains. Area between pinnacles may be covered with sediment or nearly bare rock

VOLCANIC ROCKS

Volcanic flows, cinder cones, and other deposits emplaced during the Quaternary are distinguished because they interfinger with surficial sediments and affect surface processes

Qmv **Mafic volcanic rocks (Quaternary)**—Ejecta and lava flows of mafic volcanic rocks; chiefly basaltic rocks at Amboy Crater. Consists mainly of cinder cones with subordinate lava flows (Parker, 1963). Dated at 79 ka at Amboy Crater (Phillips, 2003)

QTmv **Mafic volcanic rocks (Quaternary to Tertiary)**—Ejecta and lava flows of mafic volcanic rocks. Age unknown

SUBSTRATE MATERIALS (PRE-QUATERNARY)

Shallowly buried rock and partly consolidated materials that lie under surficial deposits and under pediment and hillslope veneers. Ages range from Pliocene to early Proterozoic. Mapped units labeled with overlying hillslope deposit type (Qha-mv) and color. Subdivided into categories based on weathering and erosional products

pc **Partly consolidated deposits and rocks**—Moderately to weakly consolidated sedimentary deposits locally include volcanic rocks or highly altered rocks. May form badland topography. Weathered materials include common silt and clay. Typically Tertiary in age. North of the town of Amboy contains the 4.83 Ma Lawlor Tuff (A.M. Sarna-Wojcicki, written commun., 2003) interbedded with lacustrine sediments and alluvial fan gravels. General unit may be mapped as QToa by some authors in parts of the map

mv **Mafic volcanic rocks**—Volcanic rocks less than about 68 percent SiO_2, such as dacite, andesite, and basalt. Includes flows and ejecta. Weathered materials include common clay. Alluvial fans with mafic volcanic source commonly very bouldery

fv **Felsic volcanic rocks**—Volcanic rocks greater than about 68 percent SiO_2, such as rhyolite, rhyodacite, and felsite. Includes flows and ejecta. Weathered materials include quartz, feldspar, and clay

mp **Mafic plutonic rocks**—Plutonic rocks less than about 68 percent SiO_2, such as gabbro, diorite, monzodiorite, syenite, and alkalic rocks. Weathered materials chiefly feldspar, amphiboles, and micas

fp **Felsic plutonic rocks**—Plutonic rocks greater than about 68 percent SiO_2, such as granite and granodiorite

fpg **Felsic plutonic rocks that weather to produce grus**—Mostly Cretaceous in age. Weathered materials chiefly quartz, feldspar, and micas

sl **Siliciclastic rocks**—Silicic sedimentary and metamorphic rocks, such as sandstone, quartzite, shale, and siltstone. Weathered materials commonly quartz, silt, and clay

mr **Metamorphic rocks**—Metamorphic rocks of complexly mixed lithology, such as gneiss, migmatite, and structurally mixed rocks. Weathered materials variable

ca **Carbonate rocks**—Carbonate-mineral rocks such as marble, dolomite, and limestone. Weathered materials include common silt

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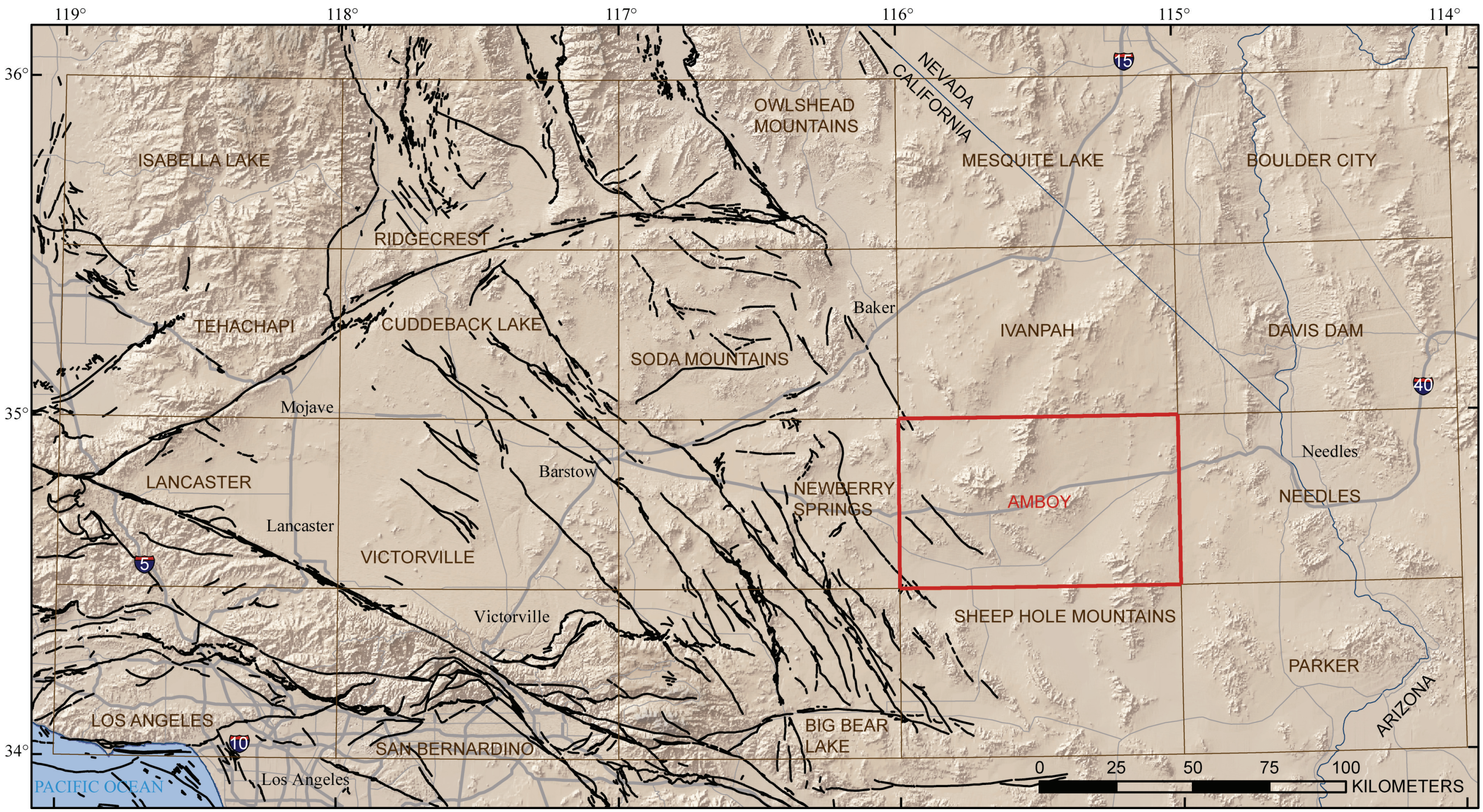

Figure 1. Shaded-relief image showing the location of the Amboy 30' x 60' quadrangle (red), surrounding quadrangles (brown), and Quaternary faults (heavy black lines) in southern California (Bryant, 2005).

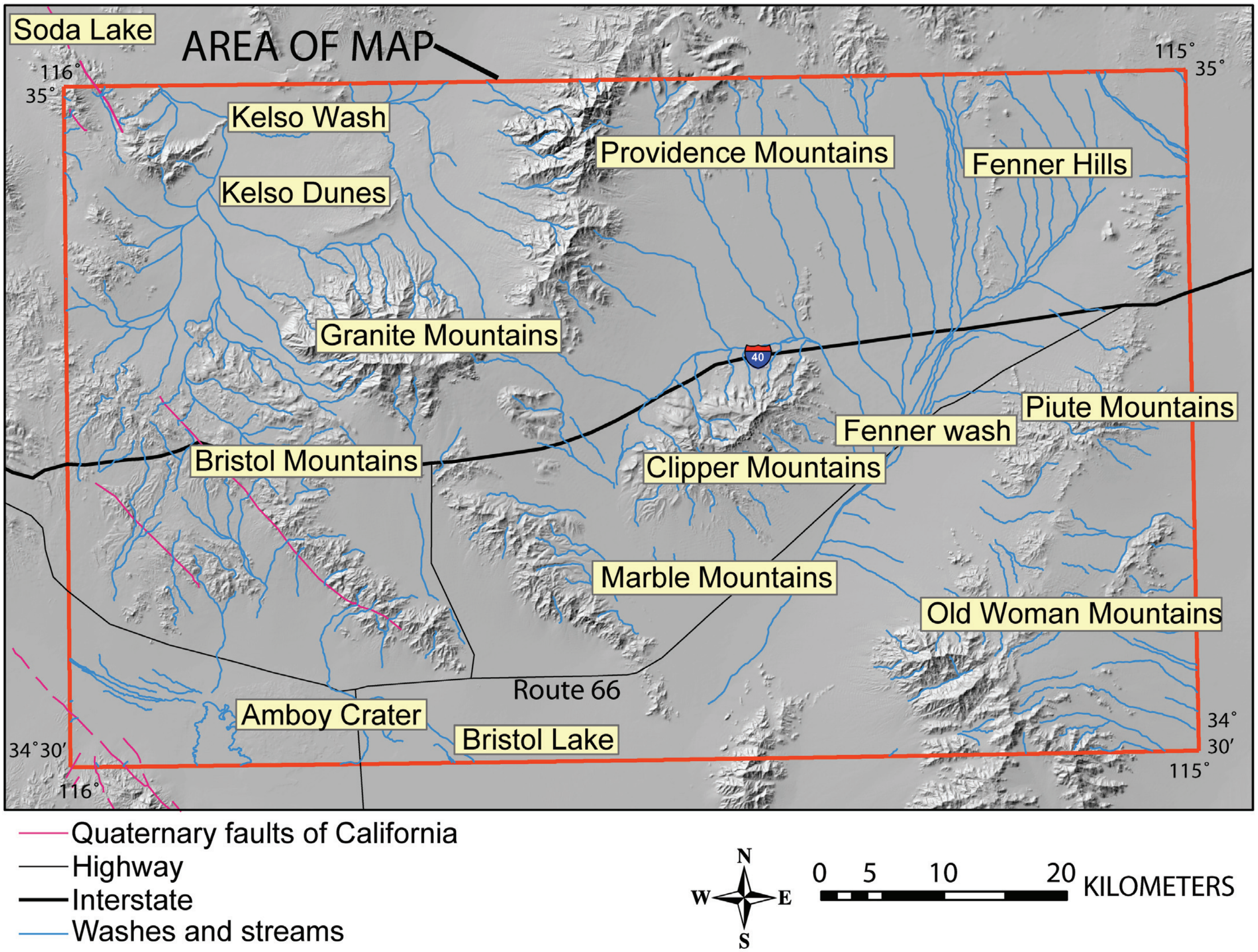

Figure 2. Shaded-relief image of the Amboy 30′ x 60′ quadrangle noting prominent physiographic features.

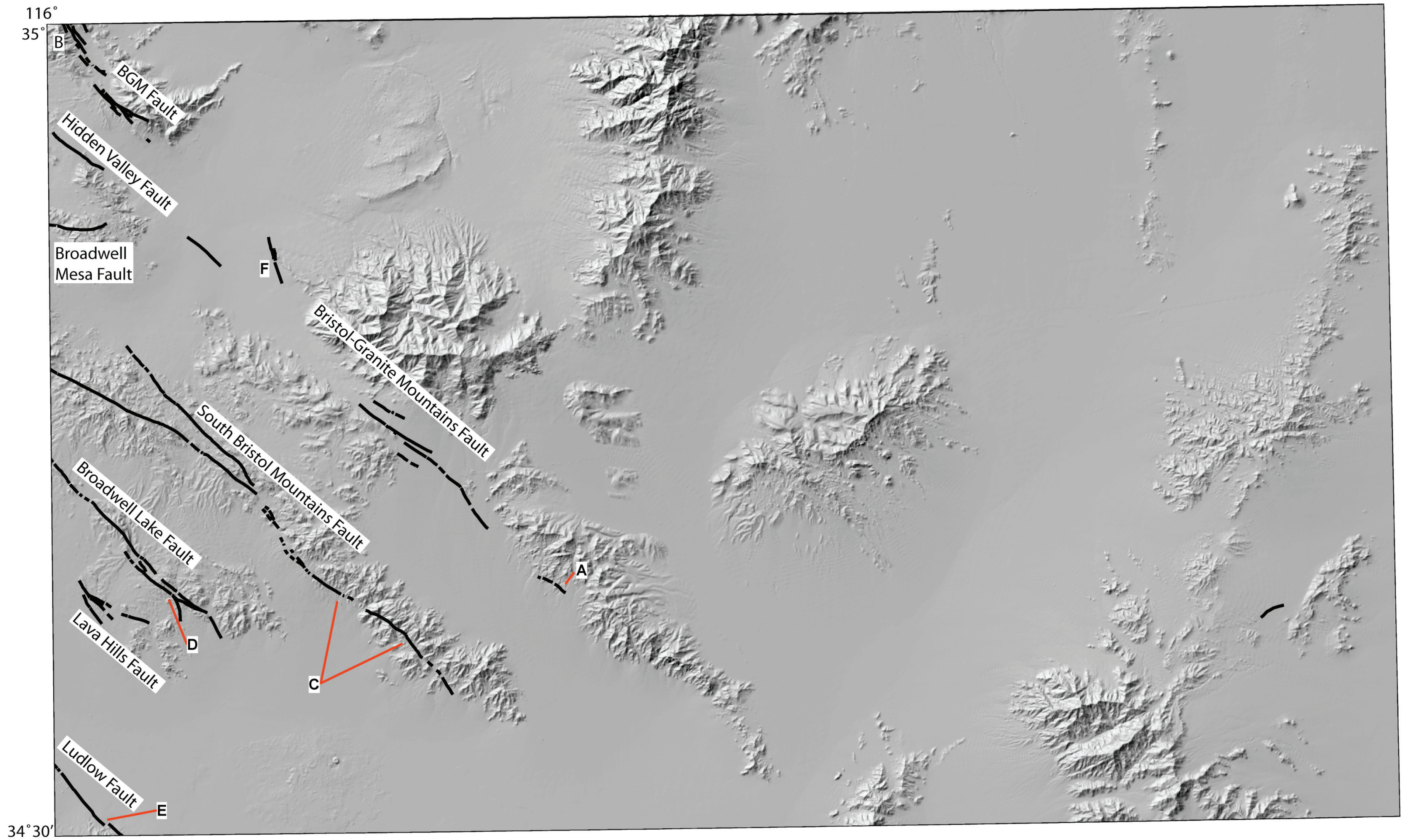

Figure 3. Shaded-relief image showing Quaternary faults in the Amboy 30′ x 60′ quadrangle: (A) Location of the Bristol-Granite Mountains (BGM) Fault cutting middle to early Pleistocene deposits; (B) Location of the Bristol-Granite Mountains Fault cutting late Pleistocene deposits; (C) South Bristol Mountains Fault cutting Pleistocene deposits; (D) The Broadwell Lake Fault cutting mid- Pleistocene deposits; (E) Ludlow Fault cutting older Pleistocene deposits; (F) Unnamed fault in the northern Granite Mountains showing evidence of late Pleistocene rupture. Hidden Valley Fault, Broadwell Mesa Fault, and Lava Hills Fault are newly named faults.

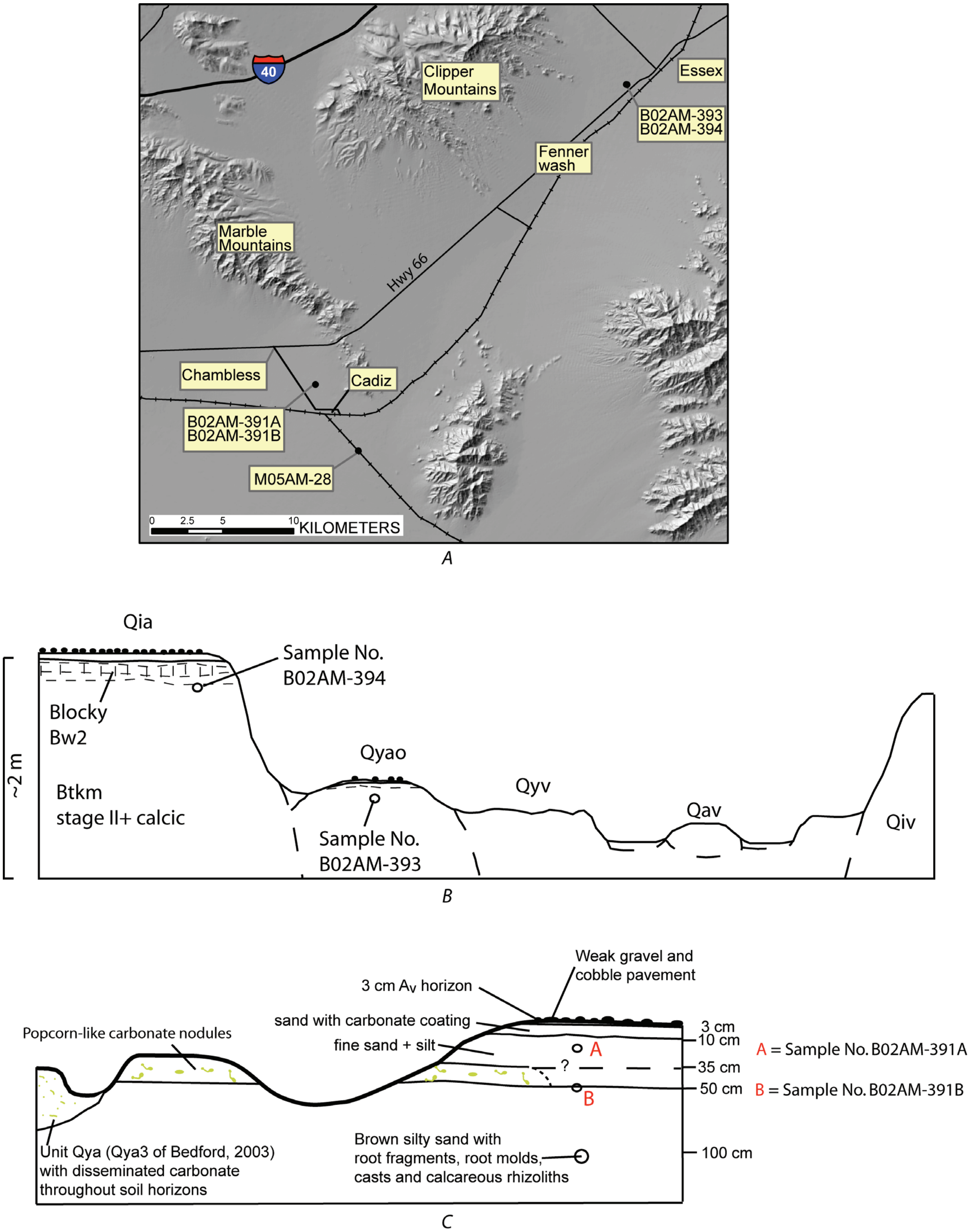

Figure 4. Shaded-relief image showing locations and relations of chronologic information. *A*. Map of sample locations, *B*. stratigraphic relations of alluvial deposits and luminescence sample in Fenner wash, *C*. stratigraphic relations of groundwater discharge deposits and luminescence samples near the town of Chambless.

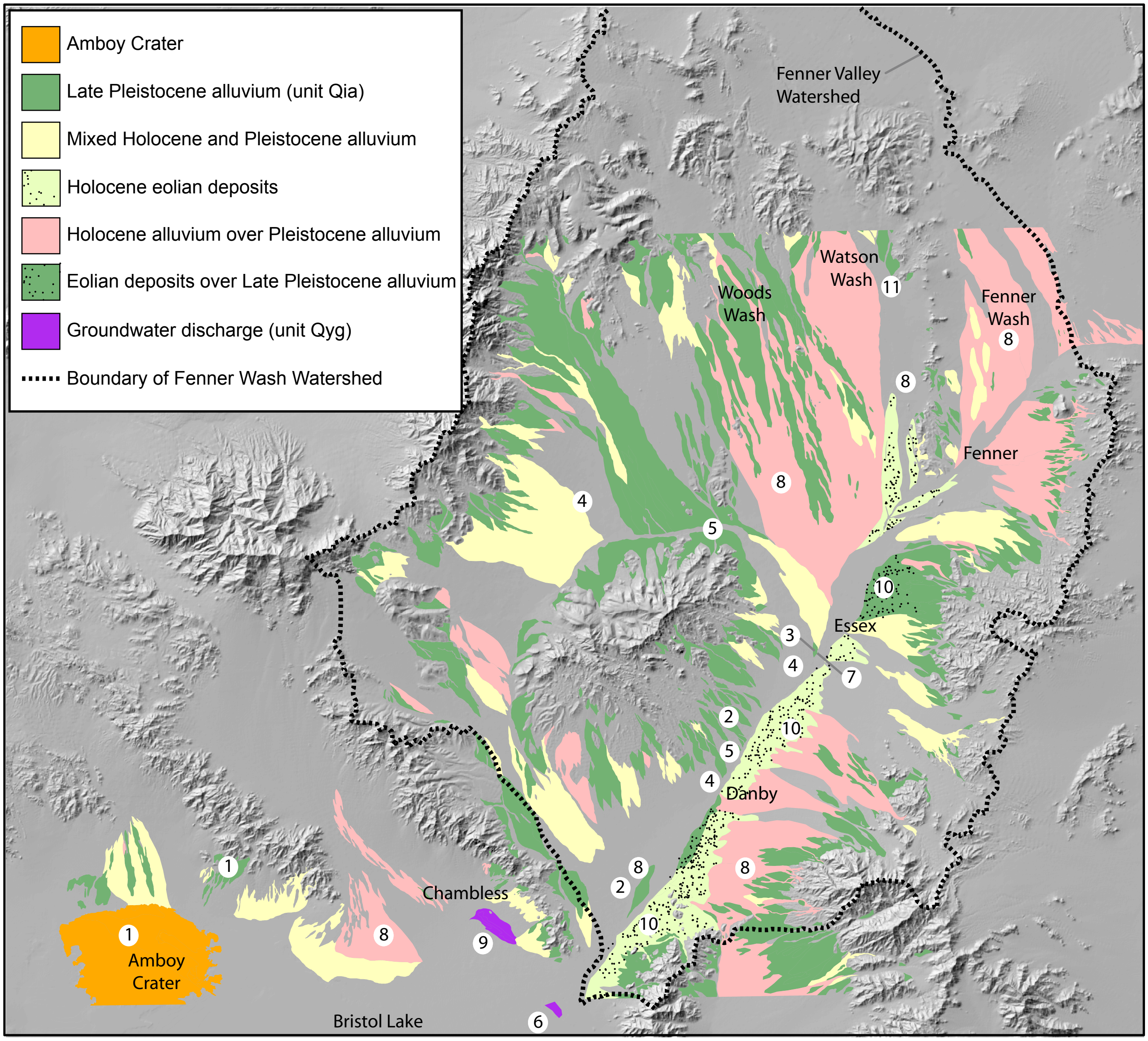

Figure 5. Shaded-relief image showing surficial deposits used to determine the evolution of Fenner Valley and Bristol Basin. Numbers refer to assigned chronology discussed in the Evolution of Fenner wash and Adjacent Piedmonts.

1. A large lake has not occupied Bristol Lake Basin in the late Pleistocene as shown by the lack of lake features cutting Amboy Crater, dated at ~79 ka by Phillips (2003), and by the absence of shoreline features on piedmonts flanking the basin. The youngest known lake deposit contains the 4.83 Ma Lawlor Tuff (A.M. Sarna-Wojcicki, written commun., 2003).
2. Mid-Pleistocene to late Pleistocene deposits along Fenner Valley grade down to the valley center, suggesting that base level along the valley has not varied greatly in the late Pleistocene.
3. The youngest of these deposits, unit Qia, that is correlated to deposits dated at 27–29 ka by McDonald and others (2003) is present in the valley bottom near the town of Essex.
4. A period of stability and deposition of unit Qia, an eolian system developed in the valley, is seen in soil development with increased fine sand fraction in unit Qia near Essex and Danby. The eolian deposition may correlate to sand-ramp activity 14 to 15 ka at Iron Mountain (Lancaster and Tchakerian, 2003).
5. A basin-wide incision of ~2 m occurred in the late Pleistocene is shown by entrenchment of Fenner, Woods, and Black Canyon Washes. Causes for this may be decreased groundwater discharge activity in Bristol Lake Basin or a combination of increased precipitation with low sediment availability following Qia deposition.

6. Groundwater discharge resumes in Bristol Basin between 14 and 9.5 ka. Ages of these deposits are based on luminescence dates of similar deposits in the Kelso Valley (Shannon Mahan, written commun., 2003). Our luminescence dates on these surfaces are ~9.5–11 ka.
7. Contemporaneous (?) to groundwater-discharge activity in Bristol Lake Basin, deposition of unit Qyao occurred in the incised channel of Fenner Valley and in other places in the basin. These deposits are correlated to the 12.4–10.4 ka unit Qf5 of McDonald (1994) and are the same unit that lies on top of 13 ka deposits in Kelso Valley. Deposition of unit Qyao may be a result of backfilling of Fenner Valley due to raised base levels or blockage of channels by groundwater discharge deposits.
8. Fan aggradation and penecontemporaneous eolian activity began in all parts of the basin at some point in the mid-Holocene. Alluvial fan activity typically resulted in burial of older Qia surfaces, particularly along Fenner wash northeast of the town of Fenner. Sediments continued to be deposited in the incised Fenner wash channels. Sources of eolian sand and silt are dominantly from Fenner wash, because of the lack of eolian sediments on the leeward side of Fenner wash.
9. Groundwater-discharge activity resumed following mid-Holocene fan building near Chambless and is expressed as a wide platform of massive and disseminated calcium carbonate accumulations deposited in mid-Holocene fan sediments.
10. Eolian activity in the mid-Holocene to late Holocene is time transgressive from north to south in Fenner Valley. Soils in areas near Fenner are enriched in eolian-sized sediments and lack any active eolian activity at the surface. Eolian sediments on the east (windward) side of Fenner Valley become less soil-stabilized and more active to the south.
11. Minor (~0.2–.03 m) incision along most of Fenner Valley channels predates deposition of ~20th century terrace sediments. Headwaters of Watson Wash have been incised as much as 2 to 3 m (Richard Hereford, written commun., 2001).