Geologic Map of the Needles 7.5′ Quadrangle, California and Arizona

By Daniel V. Malmon, Keith A. Howard, and Susan S. Priest

Typical deposit of the Upper Pleistocene Chemehuevi Formation, containing the sand facies overlying the mud facies. Deposit occupies a paleovalley cut into Colorado River gravels of the Pliocene alluvium of Bullhead City, near the east edge of Needles 7.5' quadrangle. Photograph by Daniel Malmon.

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Introduction

The Needles 7.5’ quadrangle straddles the Colorado River in the southern part of the Mohave Valley (fig. 1), in Mohave County, Arizona, and San Bernardino County, California. The quadrangle contains part of the Havasu National Wildlife Refuge, sections of the Fort Mojave Indian Reservation, most of the city of Needles, and several major interstate highways and railroads. The quadrangle is underlain by structurally undeformed sediments of Pliocene and younger age that were deposited by the Colorado River, as well as alluvial fan deposits on the piedmonts below the Black Mountains (in Arizona) and the Sacramento Mountains (in California) (fig. 2). No exposures of rock units older than Pliocene have been found in the quadrangle.

The historically active valley floor of the Colorado River bisects the Needles quadrangle, creating three well-defined zones, each having a distinctive geomorphology and stratigraphy: (1) the lower half of an alluvial fan piedmont at the base of the Sacramento Mountains, on the California side of the valley; (2) the eroded toe of piedmont alluvial fans emanating from the Black Mountains, on the Arizona side of the valley; and (3) the Colorado River valley floor, consisting of segregated deposits of sand, silt, and clay deposited by the Colorado River in late prehistoric and historic time.

Multiple cycles of aggradation of the Colorado River, each followed by episodes of downcutting, are recorded by Pliocene through historic deposits on the piedmonts that border the floodplain. Regionally, the complex stratigraphy related to the Colorado River has been the subject of geologic interest for over 150 years (Ives, 1861; Lee, 1908; Longwell, 1936; Metzger and others, 1973; Lee and Bell, 1975; Blair, 1996; Spencer and Patchett, 1997; House and others, 2005b; Lundstrom and others, 2008). Although previous studies in the region have elucidated many aspects of this stratigraphy, the understanding of the record is incomplete and will require more research. The deposits in the Needles quadrangle contain Colorado River sediments and locally derived piedmont gravels that constitute a subset of this incompletely understood stratigraphic record. Thus, the stratigraphic sequence presented on this map (fig. 3) is considered preliminary and subject to revisions from mapping of other areas and from evolving interpretations of the history of the river.

Previous geologic mapping in the Needles quadrangle has been of a reconnaissance nature. Reconnaissance geologic mapping in the quadrangle was conducted as part of a series of investigations to examine mineral resources in land owned by Southern Pacific Railroad (Coonrad, 1960). This mapping distinguished some Colorado River–related sediments from alluvial fan gravels and identified no evidence of important mineral deposits in T. 8 N., R. 23 and 24 E. (which includes the California piedmont part of the quadrangle). The only potential economic deposits were patches of clay suitable for construction use, identified by Coonrad (1960) as “Chemehuevi Lake Bed clay” (the description of this clay, which is close to but not within the Needles quadrangle, suggests that it is associated not with the Chemehuevi Formation as mapped herein but, instead, with the Pliocene Bouse Formation, which is widely exposed south of the quadrangle). In 1960, a regional groundwater study was begun in an effort to determine the distribution and extent of aquifers in the Colorado River system. This investigation, which included pump tests, surficial investigations, and drilling of auger holes with a powered rig, produced a 1:125,000-scale map of Mohave and Chemehuevi Valleys that contained five map units (Metzger and Loeltz, 1973). Although the deposits in the Needles quadrangle were grouped as either “older alluviums” (including all ancestral Colorado River and piedmont deposits) or “younger alluvium” (including deposits on the historically active valley floor), many other observations and interpretations of Metzger and Loeltz (1973) are relevant to the current study.

Methods

Mapping of the piedmont parts of the Needles quadrangle was done primarily by field investigations of vertical exposures, sediments, soils, and geomorphic surfaces, supplemented by interpretation of remotely sensed data. Sediments derived from three primary sources — the Colorado River, the Black Mountains, and the Sacramento Mountains — can be easily differentiated in the field. Colorado River–derived gravels are well sorted and contain a high proportion of well-rounded and exotic clasts (particularly chert and quartzite cobbles and pebbles). Colorado River sands contain abundant rounded quartz grains, have a high degree of sorting, and show ripple- to dune-scale crossbedding. In contrast, sand and gravel of local origin is more poorly sorted and is dominated by angular to subrounded clasts derived from local bedrock sources. Gravel derived from the Black Mountains in piedmont fans on the east side of the quadrangle is dominated by clasts of Miocene vesicular basalt. Piedmont gravel from the Sacramento Mountains on the west side of the quadrangle includes a wider variety of clasts, including granite, gneiss, and silicic volcanic rocks.

Local ephemeral washes that are tributaries of the Colorado River are incised as many as tens of meters into surfaces underlain by Colorado River sediments and locally derived fan materials, providing extensive vertical exposures and

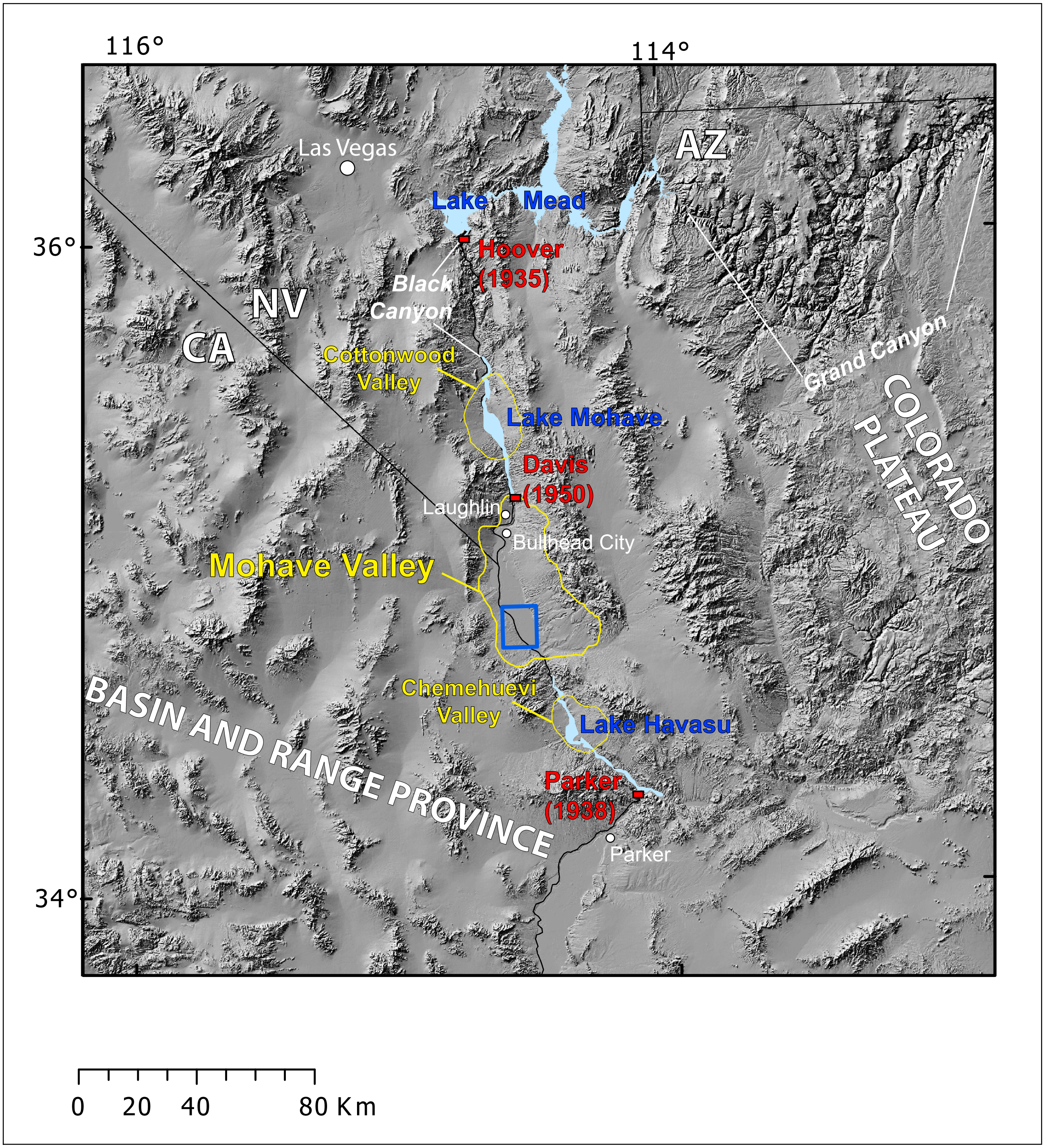

Figure 1. Shaded-relief map showing physiography of Needles 7.5' quadrangle (blue outline) in Basin and Range Province. Colorado River forms boundary between California and Arizona through middle of quadrangle. Red rectangles show locations of lower Colorado River dams; names and dam-closure dates (in parentheses) are labeled in red; corresponding reservoirs are labeled in blue. Needles quadrangle is near delta at upstream end of Lake Havasu.

showing observable contacts, buried soils, and other stratigraphic relations not visible in aerial photographs. Stratigraphic relations and sedimentary characteristics were investigated in these incised banks and in excavated faces along highways and railways. Characteristics such as deposit lithology, stratigraphic position relative to other units that include ancestral Colorado River deposits, and general physiography and surface characteristics were systematically described in detail for each of the piedmont-gravel map units in at least one location (and, in most cases, two or three locations). Where uneroded fan surfaces were preserved, geomorphic parameters indicative of age were described, including elevation, degree of pavement and varnish development, degree of dissection, surface drainage characteristics, weathering characteristics of surface clasts, and basic descriptions of soil development. These descriptions were used to correlate piedmont-gravel units across the quadrangle. Colorado River sediments were mapped on the basis of stratigraphic position, lithology, bedding characteristics, color, degree of cementation, and fluvial structures. Field observations of contacts, lithology, and geomorphology were supplemented by remotely sensed data. Contacts on the map were partly delineated and then digitized using 1-m resolution digital orthophotographs (DOQs) flown in 2004, viewed on a monitor at a scale of 1:4,000. Multiple sets of analog aerial photographs were consulted both in the field and in the office, but mapping of the piedmont parts of the quadrangle relied most heavily on a set of low-altitude, black and white stereo pairs of aerial photographs (scale 1:20,000) flown in 1969. In addition, images from an airborne thermal-infrared remote sensing unit (MASTER), processed by Simon Hook of NASA to emphasize silica content (Hook and others, 2005), were used to help determine locations of contacts between Colorado River sands rich in quartz and locally derived sediments having low quartz content. Assessment of flood hazards for mapped piedmont-gravel units was based on the presence or absence of geologic evidence for recent fluvial activity, including accumulations of flotsam, relict bar-and-swale topography, and lack of soil development.

The delineation of deposits in the valley-floor part of the quadrangle (fig. 2) was based on the hypothesis that deposits in the areas that formerly were channels of the Colorado River are characterized by coarser grained sediments compared with areas that formerly were floodplains. Areas appearing as channel and floodplain environments were identified in each data set. Eight discrete fluvial map units were identified on the basis of cross-cutting relations, as well as interpretation of sets of old maps, aerial photographs, and data from a chronology of dam and levee construction. The data sets include stereo-pair aerial-photograph coverage from 1938, 1947, 1969, and 1972; DOQs from 2004; and topographic maps from 1902 (U.S. Geological Survey, 1927), 1950 (U.S. Geological Survey, 1950), and 1975 (U.S. Geological Survey, 1975). Interpretations of parts of the valley-floor stratigraphy were based on depictions of the river in the exploration map made in 1857 by the Ives expedition (Ives, 1861) and in its associated journal descriptions. Comparison of the 1938 aerial photographs with younger and older maps allowed subdivision of deposits on the valley floor as either predating or postdating the 1935 closure of Hoover Dam, which eliminated most of the large floods that resulted in overbank sedimentation and channel shifting. Contacts between units on the valley floor were drawn where they could be identified in the modern DOQs and as patterns seen in the airborne thermal-infrared MASTER imagery, supported by interpretation of the older data sets. Relative ages of units were assigned using the principle of cross-cutting relations. Although all contacts on the map are approximately located, the contacts between units in the valley floor are considered less precise than those in the piedmont. Where possible, interpretations of the deposits underlying disturbed and tilled ground were based on observations in predisturbance aerial photographs and patterns observed in the 2004 DOQs. Data reported from five auger holes drilled across the floodplain by Metzger and Loeltz (1973) also helped to interpret the subsurface stratigraphy on the floodplain.

In addition to the mapping methods described above, we examined the chemistry of a tephra bed found in the northeast part of the quadrangle. Glass shards from a sample of the tephra were separated and then chemically analyzed using an electron microprobe at the U.S. Geological Survey Tephrochronology Laboratory in Menlo Park, Calif. The major-element chemistry of this glass was compared with a database of glass chemistry from over 6,000 tephra samples from the western United States.

Age Designations

In this map, the term "historic" describes deposits and features of the valley floor that postdate the first map of the Colorado River in the study area made by the Ives expedition in 1857 (Ives, 1861). "Prehistoric" sediments are deposits in the valley floor that are inferred to be older than the Ives (1861) map. "Present" refers to the time of study (2008). "Ancestral" Colorado River sediments are river deposits that were deposited during the Pleistocene and Pliocene epochs, which have been exposed in the piedmont areas of the quadrangle.

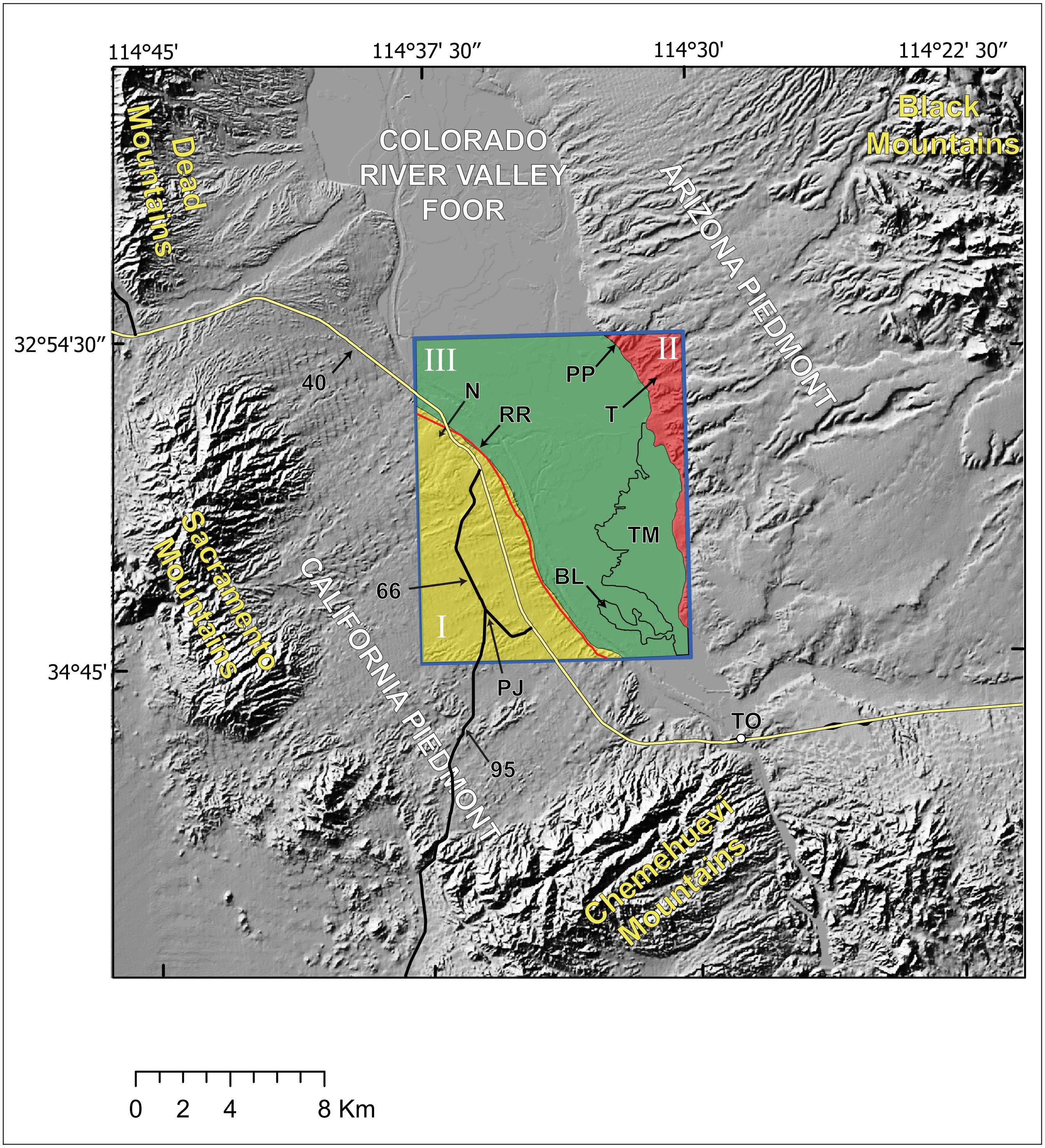

Figure 2. Shaded-relief map of southern Mohave Valley and Needles 7.5’ quadrangle (blue outline), showing physiography and locations mentioned in text. Quadrangle is divided into three physiographic regions: I, California piedmont (yellow shading); II, Arizona piedmont (red shading); and III, historically active Colorado River valley floor (green shading). Abbreviations: 40, U.S. Interstate Highway 40; 66, old Route 66; 95, California Highway 95; BL, Beal Lake; N, city of Needles, Calif.; PJ, Parker Junction; PP, Southpoint Power Plant; RR, Atchison Topeka and Santa Fe Railroad grade; T, tephra locality; TM, Topock Marsh; TO, Topock.

Stratigraphic Nomenclature and Mapping Conventions

This map, in part, follows the map-unit naming and symbol conventions used in recent mapping of the lower Colorado River region by the Arizona and Nevada state geological surveys (Faulds and others, 2004; House and others, 2004; Pearthree and House, 2004; House and others, 2005a). Piedmont gravels deposited on alluvial fans, which are denoted by the letter a, are subdivided into young (Qay, recently or historically active washes), youngest inactive (Qayi, latest Pleistocene through middle Holocene), intermediate-age (Qau, Pleistocene, and Qai and Qao, Middle? and Late Pleistocene), and old (QTab, QTar, and QTas, Early Pleistocene and (or) late Pliocene) piedmont gravels, as well as colluvium (Qac, prehistoric to present).

Sediments dominated by Colorado River–derived material are designated by the letter c. For example, Qch refers to the Upper Pleistocene Chemehuevi Formation of Longwell (1963), and Tcb refers to the Pliocene alluvium of Bullhead City of House and others (2005b); these units are subdivided locally into mappable sedimentary facies.

Valley-floor map units dominated by fluvially deposited sediment are labeled Qc#xx, where # is a number between 1 and 4 indicating relative age (1 is oldest), and xx denotes an alphabetic descriptor of the inferred fluvial environment (fp, floodplain; ch, channel; hc, high-flow channel). In general, higher numerical values refer to surfaces that have been more recently active, although some historic and late prehistoric deposits may, in part, be contemporaneous and, thus, span overlapping time intervals.

This map includes some alluvial units that are similar to those described by Bull (1975) and dated by Ku and others (1979) for the California piedmont part of the Colorado River valley near Parker, Ariz.; however, the mapping convention used herein differs from that of Bull (1975) in that the piedmont-gravel units in the Needles quadrangle have been differentiated primarily on their lithology and stratigraphic position relative to distinctive ancestral Colorado River aggradational packages and secondarily by geomorphic and soil criteria. The model developed by Bull (1975) identifies six time-stratigraphic alluvial units primarily on the basis of the degree of geomorphic and soil development. Although Bull's (1975) stratigraphic model originally was used to map alluvial fans graded to the lower Colorado River, it did not incorporate the major stratigraphic unconformities and intervening Colorado River deposits that are observed in the Needles quadrangle. Nonetheless, some units in the quadrangle may be correlated stratigraphically and chronologically with units in the widely used stratigraphy of Bull (1975). Possible correlations between the map units in this map and those of Bull (1975), and the corresponding isotopic ages of Ku and others (1979), are noted where appropriate in the Description of Map Units.

Geologic and Tectonic Setting

The Needles quadrangle occupies the south-central part of Mohave Valley, one of a series of low-elevation valleys along the course of the Colorado River in the Basin and Range Province (fig. 1). The Mohave Valley is one of several structural basins within the Colorado River extensional corridor, a 100-km-wide zone of Miocene crustal extension in the Mojave and Sonoran Deserts (Howard and John, 1987). The Colorado River was integrated through the Basin and Range Province after 6 Ma (Lucchitta, 1967; Faulds and others, 2001; Spencer and others, 2001). The oldest dated Colorado River gravel below the Grand Canyon is buried by a 4.4-Ma basalt flow at Sandy Point, near the east end of Lake Mead (Faulds and others, 2001). The first arrival of Colorado River water in the Mohave Valley and other structural basins along the Colorado River is closely associated with the deposition of the latest Miocene to early Pliocene Bouse Formation (not present in the map area): a thick estuarine or lacustrine sequence consisting of a basal limestone, interbedded mud deposits, and a discontinuous tufa deposit (Metzger, 1968; Metzger and Loeltz, 1973; Metzger and others, 1973; Spencer and Patchett, 1997; House and others, 2005b; House and others, 2008). The Bouse Formation was originally thought to be estuarine in origin and, thus, was thought to have been deposited near sea level and subsequently uplifted tectonically to its current elevation since the Pliocene (see, for example, Metzger, 1968; Metzger and others, 1973; Lucchitta, 1979; Buising, 1990). More recent research presented isotopic and stratigraphic evidence that the Bouse Formation was deposited in a chain of lakes formed in extensional basins, including Mohave Valley, as the Colorado River cascaded southward from the Colorado Plateau towards the Gulf of California during late Miocene to early Pliocene time (Spencer and Patchett, 1997; Poulson and John, 2003; House and others, 2008)

The Bouse Formation is not exposed in the Needles quadrangle; however, abundant thick exposures of the Bouse Formation are well exposed just outside the quadrangle near its south edge. In addition, the distinctive blue clays of the formation underlie the quadrangle at depth (fig. 3), as observed in well logs and cuttings. In one well at Parker Junction (fig. 2), Bouse Formation clays were reported below a depth of 65 m (9N/23-32K1; table 11, Metzger and Loeltz, 1973). All deposits exposed in the Needles quadrangle are younger than the Bouse Formation and, thus, postdate the arrival of the Colorado River in the Mohave Valley. The oldest deposit exposed in the quadrangle is the alluvium of Bullhead City

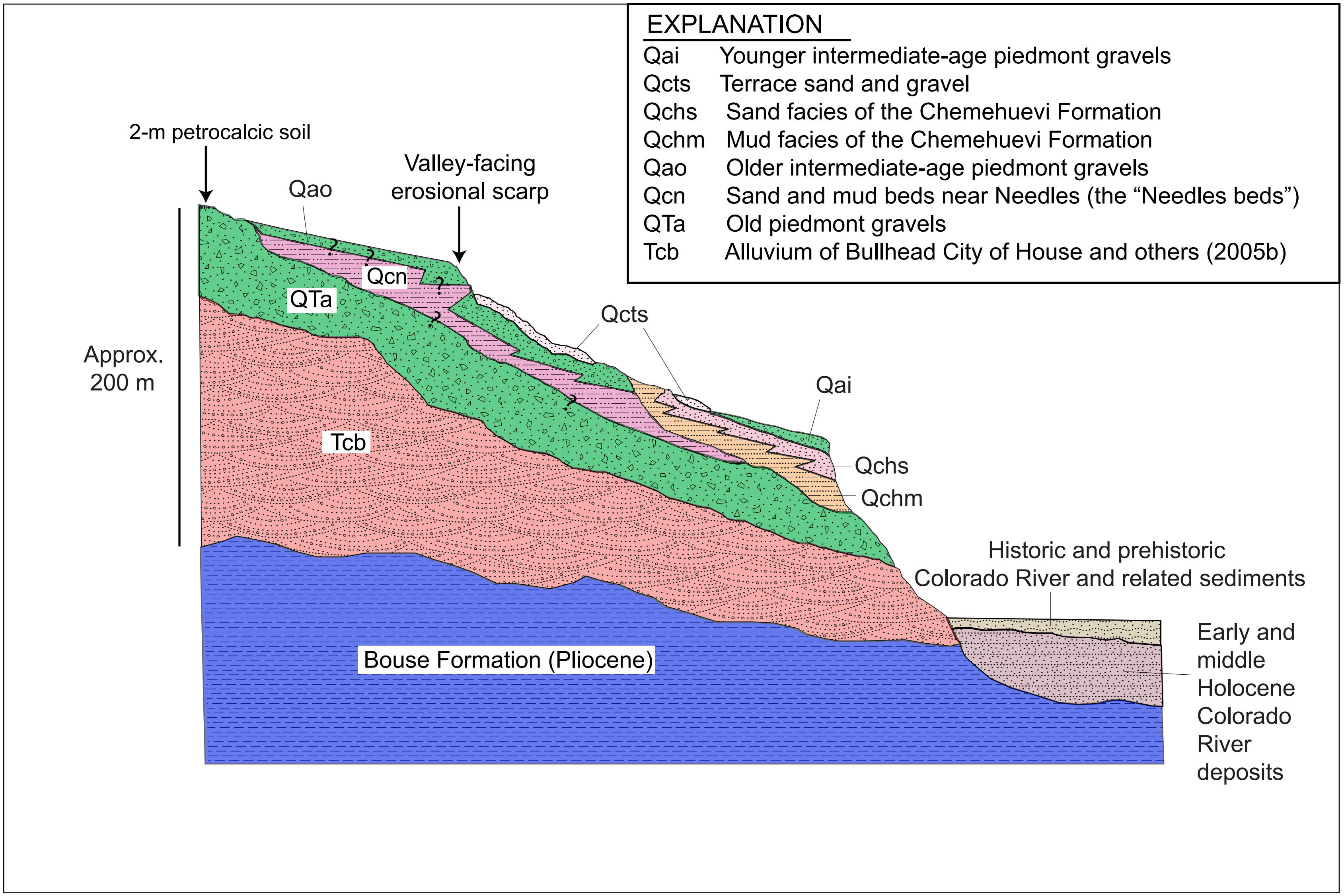

Figure 3. Conceptual diagram showing stratigraphic relations in California and Arizona piedmonts in Needles 7.5’ quadrangle and adjacent areas. Colorado River–dominated sediments are shown in shades of orange and pink; piedmont-gravel units, in green; pre–Colorado River sediments (Bouse Formation), in blue. Early and middle Holocene river deposits and the Pliocene Bouse Formation are not found at surface in quadrangle, but they have been identified in drill cores in quadrangle and also in cores and outcrops in adjacent quadrangles. Queries on upper and lower contacts of the “Needles beds” indicate that stratigraphic position and age of unit are uncertain.

of House and others (2005b) (Tcb; see also, fig. 3), which is estimated to be between about 4 and 3.3 Ma in the northern Mohave Valley and in Cottonwood Valley (House and others, 2008).

Geologic History and Interpretations

The deposits in the piedmont areas southwest and northeast of the historically active valley floor in the Needles quadrangle (areas I and II, respectively, fig. 2) record the interplay between the Colorado River and local alluvial fans since Pliocene time (fig. 3). These deposits represent multiple episodes of long-term aggradation of the valley with Colorado River–derived sediment, to thicknesses of as much as hundreds of meters. Downcutting of the river followed each of these aggradational periods, resulting in the excavation of much of the river-derived material and the formation of erosional topography, followed by deposition of piedmont gravel derived from the valley-bounding mountains. Piedmont-gravel deposition also occurred contemporaneously with river aggradation, as can be seen in many outcrops that show Colorado River sediments interfingering with locally derived alluvial fan gravel. Each subsequent backfilling episode of the Colorado River buried this erosional topography and associated soils, resulting in erosional contacts (some mantled by carbonate soils) that separate the various piedmont-gravel and river-derived deposits. Further cycles of erosion resulted in the partial removal of some of this record and the selective preservation of more resistant units. The following discussion presents a version of the Pliocene and Pleistocene history of river aggradation, degradation, and piedmont alluvial fan deposition, as interpreted from the stratigraphic sequence observed in the Needles quadrangle.

Pliocene and Early Pleistocene

The oldest and stratigraphically lowest unit in the Needles quadrangle, exposed in widespread areas on the northeast piedmont (fig. 2), is fluvial gravel and sand deposited by the ancestral Colorado River early in its history. This deposit consists of well-sorted sand and rounded exotic gravel derived from the Colorado Plateau and shows imbricated clasts, crossbeds as much as one meter high and several meters long, and zones of strong carbonate cementation. This sequence, which was referred to as unit B of the older alluviums by Metzger and others (1973), is mapped herein as the alluvium of Bullhead City of House and others (2005b) (Tcb).

The alluvium of Bullhead City (Tcb) underlies all alluvial fans and younger river sediments on the Arizona side of the Needles quadrangle (fig. 4). The coarse grain size and scale of crossbedding in the deposits suggest that most of these sediments were deposited as bed material in a braided river that had a large supply of coarse-grained detritus. At one locality on the east edge of the quadrangle (sec. 22, T. 17 N., R. 21 W.), a 6-m-thick interval of a finer grained mud facies (unit Tcbm) interfingers with the gravel facies; these sediments are interpreted as correlative with the coarser grained facies of unit Tcb, which were deposited in a floodplain setting.

In northern Mohave Valley and in Cottonwood Valley, the alluvium of Bullhead City interfingers with alluvial fan gravels that contain an ash bed identified as a 4.1±0.5 Ma lower Nomlaki tephra layer, which is in turn overlain by alluvial fan gravels containing tephra correlated with the 3.3-Ma Nomlaki Tuff (House and others, 2008), establishing its age as Pliocene. The alluvium of Bullhead City is similar lithologically to, and may correlate with, the oldest dated Colorado River sediment in the Basin and Range Province, which is interbedded with a 4.4-Ma basalt flow at Sandy Point, in eastern Lake Mead (Faulds and others, 2001). Pliocene-age fossilized logs are common in the alluvium of Bullhead City at the head of the river delta north of Yuma, Ariz. Correlative deposits have been documented over a 200-m range of elevation in northern Mohave and Cottonwood Valleys (House and others, 2008) and over an even greater range of elevation near the mouth of Grand Canyon (Howard and Bohannon, 2001).

The alluvium of Bullhead City records one or more major aggradational events of the Colorado River early in its history, and the alluvium probably relates to the integration of the river in the Basin and Range Province (House and others, 2008). The alluvium of Bullhead City is dominated by clasts derived from the Colorado Plateau, which suggests that it also may be, in part, related to upstream canyon incision on the Colorado Plateau following the lowering of regional base level that occurred when the river became integrated.

In many places on the Arizona piedmont in the Needles quadrangle (fig. 2), the alluvium of Bullhead City is overlain by poorly sorted, partially cemented boulder deposits derived from the Black Mountains, which are mapped as the basalt-boulder conglomerate unit (QTab; see also, fig. 4); however, boulder-rich piedmont gravels (units QTab, QTar, QTas) that postdate the alluvium of Bullhead City are present on both the Arizona and California piedmont areas (fig. 2). These old piedmont gravels, which vary in thickness, are characterized by a high proportion of angular to subrounded vesicular-basalt boulders, moderate cementation, and as much as 5 percent well-rounded chert and quartzite pebbles and cobbles, lithologies that are not found in the Black and Sacramento Mountains. The rounded exotic clasts are herein interpreted to indicate that the old piedmont-gravel deposits are, in part, composed of material reworked from the alluvium of Bullhead

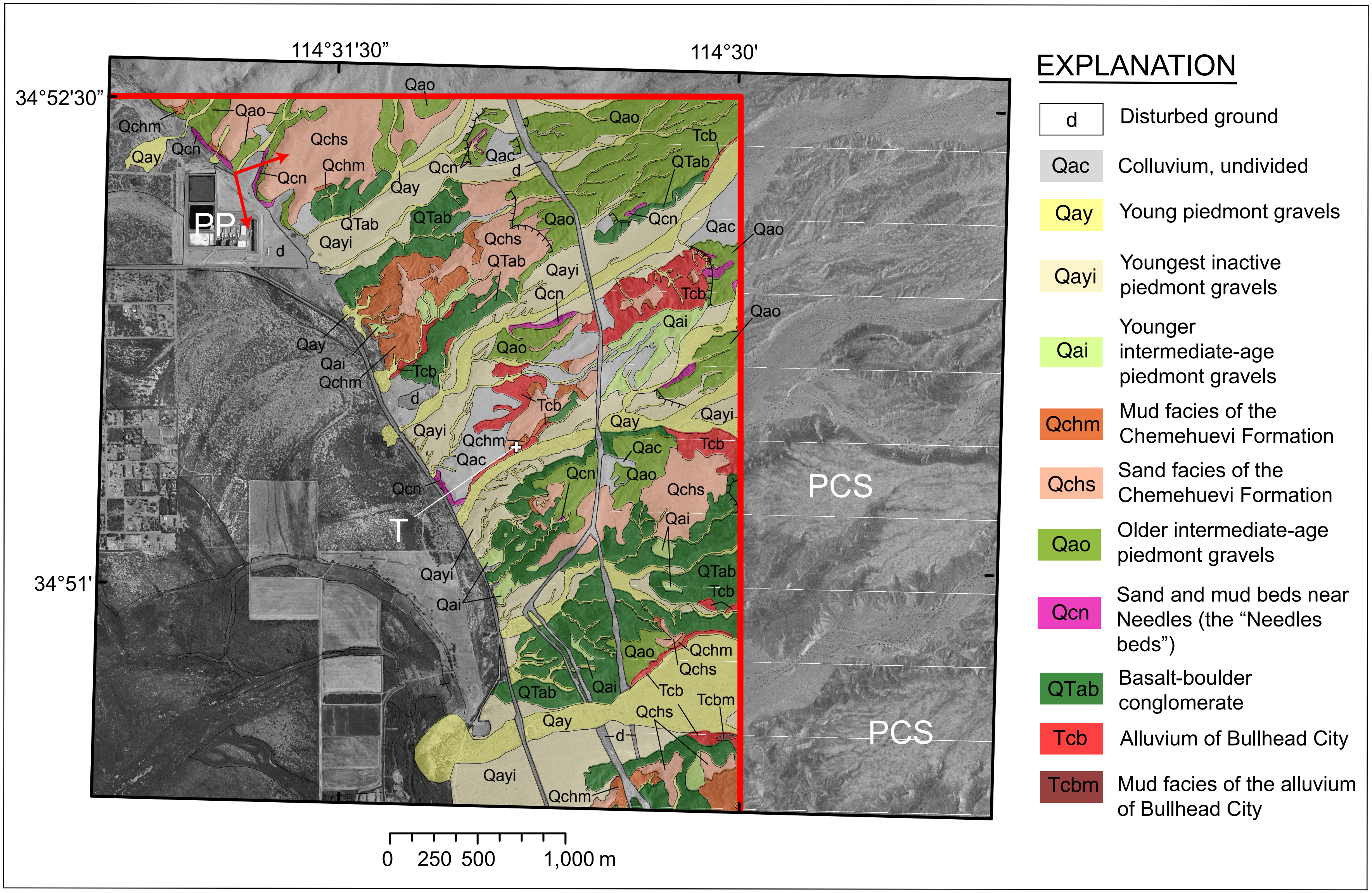

Figure 4. Geology in northeast corner of Needles 7.5' quadrangle (red outline) draped over digital orthophotograph. Valley-facing erosional scarps indicated by hachured lines (hachures point downscarp); red arrows near power plant indicate field of view shown in figure 7. Image shows that the basalt-boulder conglomerate (QTab) can be traced to beds underlying 2-m-thick petrocalcic soil east of quadrangle. Abbreviations: PCS, 2-m-thick petrocalcic soil; PP, Southpoint Power Plant; T, tephra locality 06-1222-2 (white "plus" sign).

City. The abundant boulders in the basalt-boulder conglomerate unit (QTab) make it more resistant than younger sediments, and as a result of differential erosion, the unit crops out over a large area on the Arizona piedmont (fig. 4). Uneroded surfaces of these old piedmont gravels are not preserved in the Needles quadrangle; however, the deposits can be traced to uneroded surfaces higher on the piedmont east of the quadrangle that contain strong stage V petrocalcic soils (PCS, fig. 4), suggesting that they may be as old as Pliocene. These deposits may correlate to unit C of Metzger and others (1973), to units Q1a and Q1b of Bull (1975), and to a thick old gravel unit mapped as Unit 1 (QTs1) by Howard and others (2000) and described by Wilshire and Reneau (1992). Likely correlative deposits exposed along Silver Creek, east of Bullhead City, contain the 3.3-Ma Nomlaki Tuff (House and others, 2008), and so the old piedmont gravels (units QTab, QTar, and QTas) are collectively assigned herein to the Early Pleistocene and (or) late Pliocene. However, these gravels may contain unconformities not identified here, and so they may span a longer time period.

The abundant boulders in the old piedmont gravels, along with their high content of rounded exotic clasts, suggest that they may have been deposited during and following a period of deep downcutting of the Colorado River that followed the deposition of the alluvium of Bullhead City (Tcb). At localities to the north in the Davis Dam and Topock 7.5' quadrangles (House and others, 2005b; Howard and Malmon, 2007), deposits interpreted as the basal part of the alluvium of Bullhead City overlie pre–Colorado River bedrock on erosional surfaces above the elevation of the current floodplain. In the subsurface, river gravel and sand is present to a depth of more than 50 m (Metzger and Loeltz, 1973). Thus, the local base level of the Colorado River was at least 50 m higher before deposition of the alluvium of Bullhead City than at some point afterwards. Part of this incision may have occurred prior to, or concurrent with, the deposition of the old piedmont gravels. Deep incision of the Colorado River could be expected to produce steep slopes between the mountains and the valley axis. This high relative relief may partly explain the coarse grain size of the deposits: the large component of boulder-sized clasts and the poor sorting and lack of bedding suggest that they may have been partly deposited by landslides or debris flows that reached the lower extent of the piedmonts. In contrast, boulders are absent and stratification is more prevalent in the younger piedmont-gravel deposits.

Middle and Late Pleistocene

The Chemehuevi Formation of Longwell (1963) and Overlying Terrace-Forming Sediments

The most conspicuous elements of the Pleistocene stratigraphy of the lower Colorado River valley are distinctive Colorado River–derived sand, silt, clay, and minor amounts of gravel, which disconformably overlie the alluvium of Bullhead City (Tcb) and the old piedmont gravels (units QTab, QTar, and QTas). These deposits, mapped herein as the Chemehuevi Formation of Longwell (1963), have been variously referred to as the "Chemehuevis gravel" (Lee, 1908); the "Chemehuevis formation" (Longwell, 1936); units D and E of the "older alluviums" (Metzger and Loeltz, 1973; Metzger and others, 1973); the intermediate-age fluvial deposits (their unit Qrd) (Lee and Bell, 1975); and the "Chemehuevi beds" (House and others, 2005b). These sediments were first described by J.S. Newberry (*in* Ives, 1861) and have been studied by many geologists since; however, a type section has not been designated and the stratigraphy of these beds has not yet been described systematically, leading to inconsistent usage of nomenclature and confusion about what lithologic units should be included in the formation. In the Needles quadrangle, the deposits consist of beds of dominantly river derived sand and mud that lacks major erosional breaks. Thus, as mapped in the Needles quadrangle, the formation is interpreted as consisting of the remnants of the most recent major aggradational episode of the Colorado River in the lower Mohave Valley.

In the Needles quadrangle, deposits of the Chemehuevi Formation are unconsolidated, well-sorted beds of sand, silt, and clay, as well as some scattered gravel and probably a basal gravel member. Throughout its range, the formation contains a variety of sedimentological and structural features characteristic of fluvial environments, including ripple and trough crossbedding, lenses of imbricated well-rounded gravel, and silt and clay beds that contain ostracode assemblages characteristic of off-channel settings (J. Bright, Northern Arizona University, written commun., 2008). Deposits sharing these lithologic characteristics that lie in a similar stratigraphic position are preserved and are conspicuous throughout the Colorado River valley downstream from the Grand Canyon (Lee, 1908). The maximum height of the formation above the modern valley floor decreases downstream from nearly 140 m near the mouth of Grand Canyon to less than 30 m at the head of the delta near Yuma (D. Malmon, unpub. data, 2007). On the basis of the regional distribution of the formation, the maximum elevation of the deposits is projected to be approximately 90 m above the floodplain in the vicinity of the Needles quadrangle (Malmon and Howard, 2007). The maximum elevation of the unit in the Needles quadrangle is near the 760-ft (232-m) contour, approximately 85 m above the modern floodplain. Thus, the maximum elevation of sediment mapped as the Chemehuevi Formation in the Needles quadrangle is close to the peak of the Chemehuevi Formation aggradational episode in the lower Mohave Valley.

In many places outside the Needles quadrangle, the Chemehuevi Formation is overlain disconformably by fluvial sediment underlying large, relatively flat terraces. These sediments, which have been referred to as the “terrace gravels” by Longwell (1936, 1963), are referred to herein as the terrace sand and gravel unit (Qcts). The terrace sand and gravel unit apparently was deposited during temporary pauses in the overall downcutting phase that followed the Chemehuevi Formation aggradational episode. In the Needles quadrangle, the unit in this stratigraphic position is dominated by quartz-rich rounded sand and scattered gravel. Outside the Needles quadrangle, including in the Topock 7.5’ quadrangle to the south, correlative sand and gravel beds include at least one boulder-rich bed (Howard and Malmon, 2008).

Where the Chemehuevi Formation and the terrace sand and gravel unit are found together along the Colorado River valley, they can sometimes be distinguished by stratigraphic context (see, for example, Longwell, 1936, 1963; Lundstrom and others, 2008); however, in the Needles quadrangle, the two units have not been found together. Sediment deposited during the aggradational and degradational phases of the most recent aggradation/degradation cycle during Late Pleistocene time are indistinguishable on the basis of lithology alone, and in some places may grade into one another. For example, sediments deposited against and over erosional scarps on the California side of the quadrangle (fig. 5) are mapped as the terrace sand and gravel unit (Qcts) on the basis of their relation to the scarps, and they are inferred to have been deposited close to and (or) following the peak of aggradation. Criteria for separating the terrace sand and gravel unit (Qcts) from the sand facies (Qchs) of the Chemehuevi Formation are specified in the Description of Map Units; however, it is acknowledged that in some places this separation is speculative.

The age of the Chemehuevi Formation aggradational episode and subsequent downcutting remains poorly constrained. No ages have been obtained from the formation in the Needles quadrangle, although correlative sediments have been dated elsewhere as Late Pleistocene. Early uranium-series analyses (Bell and others, 1978) estimated the age of the formation to be between 200 and 100 ka; however, more recent numerical age estimations, which were based on infrared and optically stimulated luminescence (Malmon and others, 2007; Lundstrom and others, 2008), suggested that the sediments may have been deposited between 70 and 40 ka. Thus, on the basis of multiple dating methods (uranium-series, magnetostratigraphy, and luminescence dating), as well as fossil evidence, the deposits are estimated to have been deposited between 100 and 40 ka (Lee and Bell, 1975; Bell and others, 1978; Malmon and others, 2007; Lundstrom and others, 2008), placing them within the most recent (Wisconsin-age) glacial period and likely within marine oxygen-isotope stages 3 and (or) 4. It is not known whether the range of ages represents uncertainty in dating methods or whether the ages of the dated sediments actually span this range.

In the northeast corner of the Needles quadrangle (loc. 06-1222-2, fig. 4), a layer of volcanic tephra locally forms the basal part of the Chemehuevi Formation where it rests unconformably on the alluvium of Bullhead City (fig. 6). A sample of glass shards from that site, analyzed by the U.S. Geological Survey Tephrochronology Laboratory, consists of two chemically distinct populations, the minor mode of which appears to include reworked Miocene or Pliocene tephra incorporated in the sample; the major population mode is a probable match with a tephra layer found at three other sites elsewhere in the Chemehuevi Formation (House and others, 2005b; Lundstrom and others, 2008; D. Malmon, unpub. data, 2008). The major population of glass in the sample chemically resembles glass from ash beds found in cores from Walker and Owens Lakes, in western Nevada and eastern California, respectively, whose suggested source area is Mammoth Mountain (E. Wan, USGS, written commun., 2007), in eastern California. Mammoth Mountain was active between about 110 and 57 ka (W. Hildreth, USGS, oral commun., 2007), a time period that mostly coincides with the dates obtained from isotopic methods. At this time, the tephra has not been tied to any particular eruption that is more precisely dated.

One interpretation of the Chemehuevi Formation is that it records the most recent major climate-driven aggradational episode of the Colorado River, which occurred sometime during the last glacial period (between about 110 and 10 ka). Changes in temperature, precipitation, and vegetative cover in the Rocky Mountains and the Colorado Plateau may have led to a rapid change in the timing and in the amount of sediment and water delivery from the watershed (Malmon and others, 2007). An increase in the ratio of bed-material sediment to water would cause the river to aggrade its bed and overtop its banks more frequently, leading to gradual deposition of both floodplain and channel sediments. The steeper gradient of deposits related to this event compared with the modern valley gradient also suggests that upstream changes are responsible for the deposition of the Chemehuevi Formation, rather than downstream changes. The steeper gradient further demonstrates that the unit was not deposited in a large Pleistocene lake caused by damming of the river by lava, landslides, or regional uplift (see, for example, Longwell, 1936, 1963). Aggradational steepening of the valley gradient likely increased the ability of the river to transport the increased load, and, following cessation of the sediment pulse, the river cut downward through this fill, depositing the terrace sand and gravel unit (Qcts) during temporary periods of base-level stability.

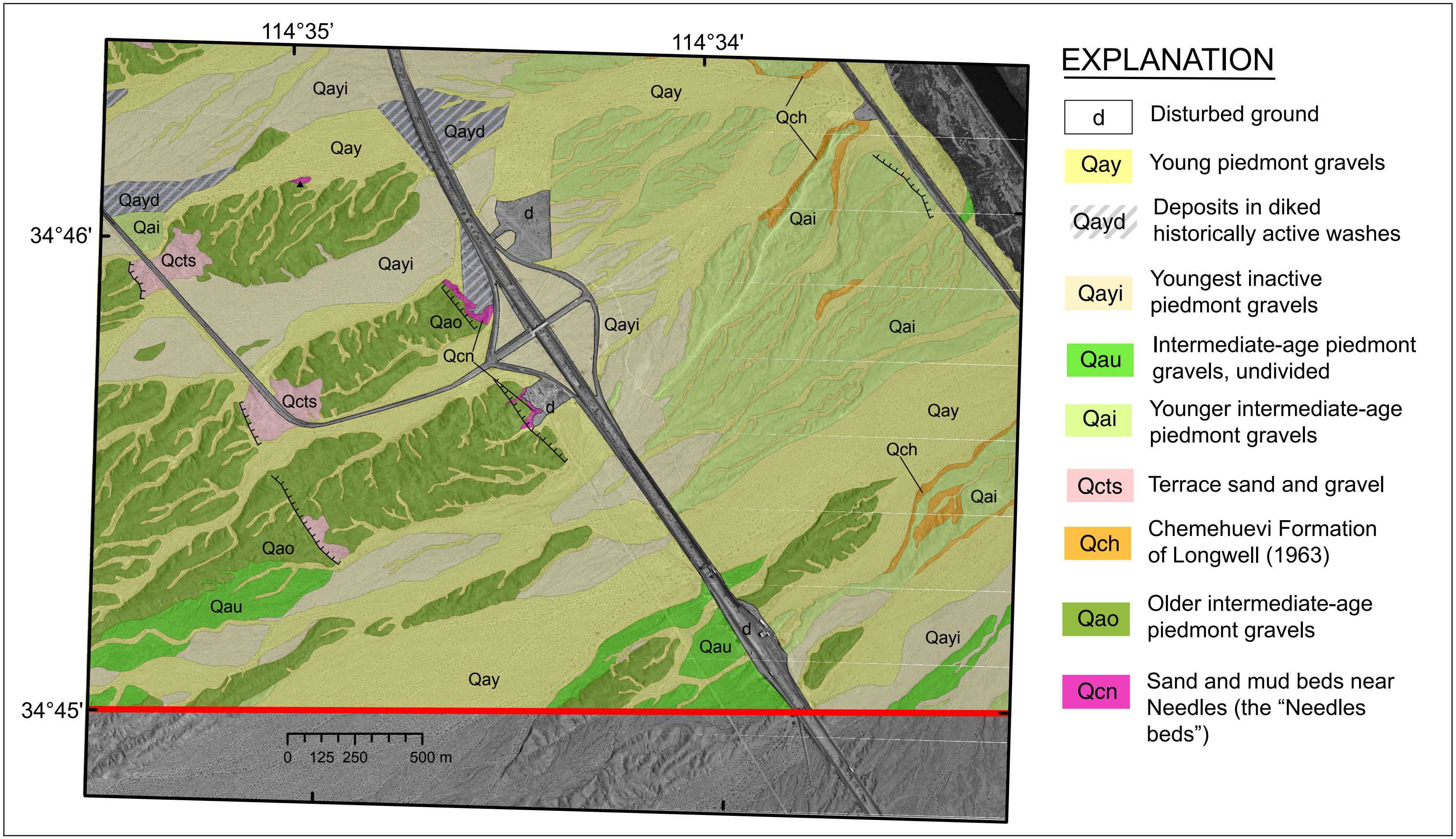

Figure 5. Geology of part of California piedmont in southern part of Needles 7.5' quadrangle draped over digital orthophotograph (red line, south edge of quadrangle). Image shows spatial relations and differing degrees of dissection of various Quaternary piedmont-gravel units (Qao, Qai, Qayi, Qayd, Qay), as well as geomorphic relations between piedmont-gravel units, valley-facing erosional scarps (hachured lines; hachures point downscarp), and several Colorado River–derived sediments (Qcn, Qch, Qcts). Black triangle indicates location of buried calcic soil. The older intermediate-age piedmont gravels (unit Qao) overlie the "Needles beds," are cut by valley-facing scarps, and are more dissected than the younger intermediate-age piedmont gravels (unit Qai).

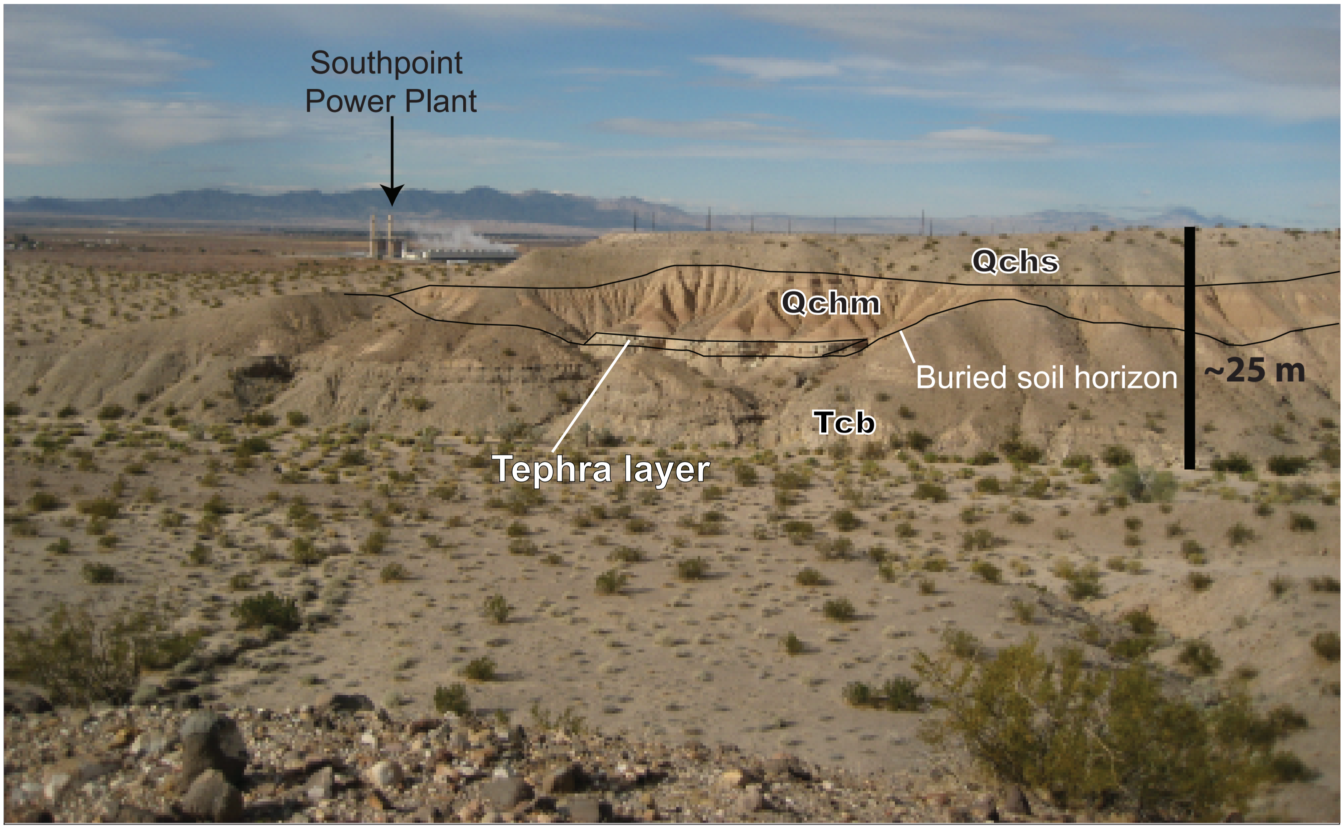

Figure 6. Photograph to north showing stratigraphic context of tephra layer (site 06-1222-2) at local base of the Chemehuevi Formation (see figs. 2 and 4 for location). Age of tephra is unknown, but ash contains glass whose chemistry is similar to glass in ash found elsewhere within the Chemehuevi Formation. Map symbols: Qchs, the sand facies of the Chemehuevi Formation; Qchm, the mud facies of the Chemehuevi Formation; Tcb, the alluvium of Bullhead City.

The “Needles Beds”

If the most recent major aggradational episode was instigated by climatic change in the Colorado River watershed, it is logical to speculate that earlier climatic changes also resulted in the deposition of similar aggradational deposits along the lower Colorado River. Small exposures of partially cemented Colorado River sediment that underlie the older intermediate-age piedmont gravels (unit Qao) may contain remnants of such deposits. These deposits are mapped herein as the sand and mud beds near Needles (unit Qcn) — hereafter referred to informally as the “Needles beds” — after the best example of these deposits in the Needles quadrangle, an outcrop around the 800-ft (240-m) contour near the west edge of the quadrangle (sec. 7, T. 8. N., R. 22 W.), 2.5 km south of Needles. At that locality, a streambank exposes a sequence 4 to 5 m thick of quartz-rich, crossbedded sand and subordinate beds of silt and clay. The crossbeds have amplitudes greater than 1 m and lengths of several meters and contain minor erosional surfaces and inset channel forms. The “Needles beds” are found on both the California and Arizona piedmonts in the quadrangle (figs. 4, 5), always under alluvial fan deposits mapped as the older intermediate-age piedmont gravels (unit Qao). The southernmost locality of the “Needles beds” on the California side of the quadrangle contains a meter-thick clay bed, suggestive of deposition in a floodplain setting. Both examples are present near and (or) above the 800-ft (244-m) contour, higher than any exposures of the Chemeheuvi Formation (Qch) or other younger Colorado River–derived units in the quadrangle.

On the basis of their stratigraphic and topographic context and on their slight cementation, at least some of the river sediments mapped herein as the “Needles beds” are interpreted to be older than the Chemehuevi Formation and younger than the alluvium of Bullhead City (Tcb). Some of the “Needles beds” are higher in elevation (near the 800-ft contour) than the highest deposits of the Chemehuevi Formation (near the 740-ft contour) in lower Mohave Valley; in addition, they underlie the older intermediate-age piedmont gravels (unit Qao), which overlie the Chemehuevi Formation. The “Needles beds” are tentatively distinguished from the alluvium of Bullhead City (Tcb) because that unit (Tcb) commonly is overlain by older boulder conglomerates (units QTab, QTar, QTas), whereas the “Needles beds” are overlain by the older intermediate-age piedmont gravels (unit Qao), which lack boulders. Such stratigraphic and topographic relations indicate that at least some of the “Needles beds” may be the scattered remnants of one or more Colorado River aggradational deposit(s) that are intermediate in age between the Pliocene alluvium of Bullhead City and the Pleistocene Chemehuevi Formation. Other stratigraphically similar Colorado River deposits that are intermediate in age between the Chemehuevi and the Bullhead City units have been proposed at least at one other site (House and others, 2005b).

Latest Pleistocene through Holocene

Following the deposition of the Chemehuevi Formation, the Colorado River incised to a level substantially lower than the modern valley floor, as indicated by wood fragments having early Holocene radiocarbon ages that were found in cores more than 30 m below the modern floodplain, both downstream of Parker Dam (Metzger and others, 1973) and in the lower Mohave Valley (D. Malmon and K. Howard, unpub. data, 2008). The Colorado River has aggraded since the early Holocene and possibly earlier, resulting in the deposition of early to middle Holocene sediments below the level of the modern floodplain (fig. 3), which Metzger and others (1973) referred to as the “younger alluvium.” The cause of this aggradational episode is not known but is likely related to Holocene sea level rise (Metzger and others, 1973) and (or) watershed climatic changes.

The latest Pleistocene and (or) early to middle Holocene deposits on the California and Arizona piedmonts are the youngest inactive piedmont gravels (unit Qayi), which underlie the youngest alluvial fan surfaces that are no longer active. Uneroded depositional surfaces of unit Qayi, which are 1 to 4 m above the adjacent active washes, may contain subdued bar-and-swale topography, but in most places they lack evidence of recent fluvial activity other than local surface wash and minor rilling. In places, the height of the uneroded surfaces of unit Qayi relative to the active channel decreases with distance from the Colorado River, suggesting that these deposits possibly are being buried by Holocene sedimentation in active washes. Long-term sedimentation in active washes may have been caused partly by the Holocene aggradation of the Colorado River; however, early and middle Holocene surfaces are also present elsewhere in the region, including places not graded to the Colorado River.

Exposure at the Southpoint Power Plant

A well-exposed outcrop near the northeast corner of the Needles quadrangle, directly east of the Southpoint Power Plant, exposes at least two erosional-unconformity surfaces in Colorado River sediment, each of which has as much as several meters of relief (fig. 7). These unconformities juxtapose layered sand, silt, and clay typical of Colorado River sediments, as well as locally derived angular alluvial fan gravel. A partially cemented calcic soil that formed on one of

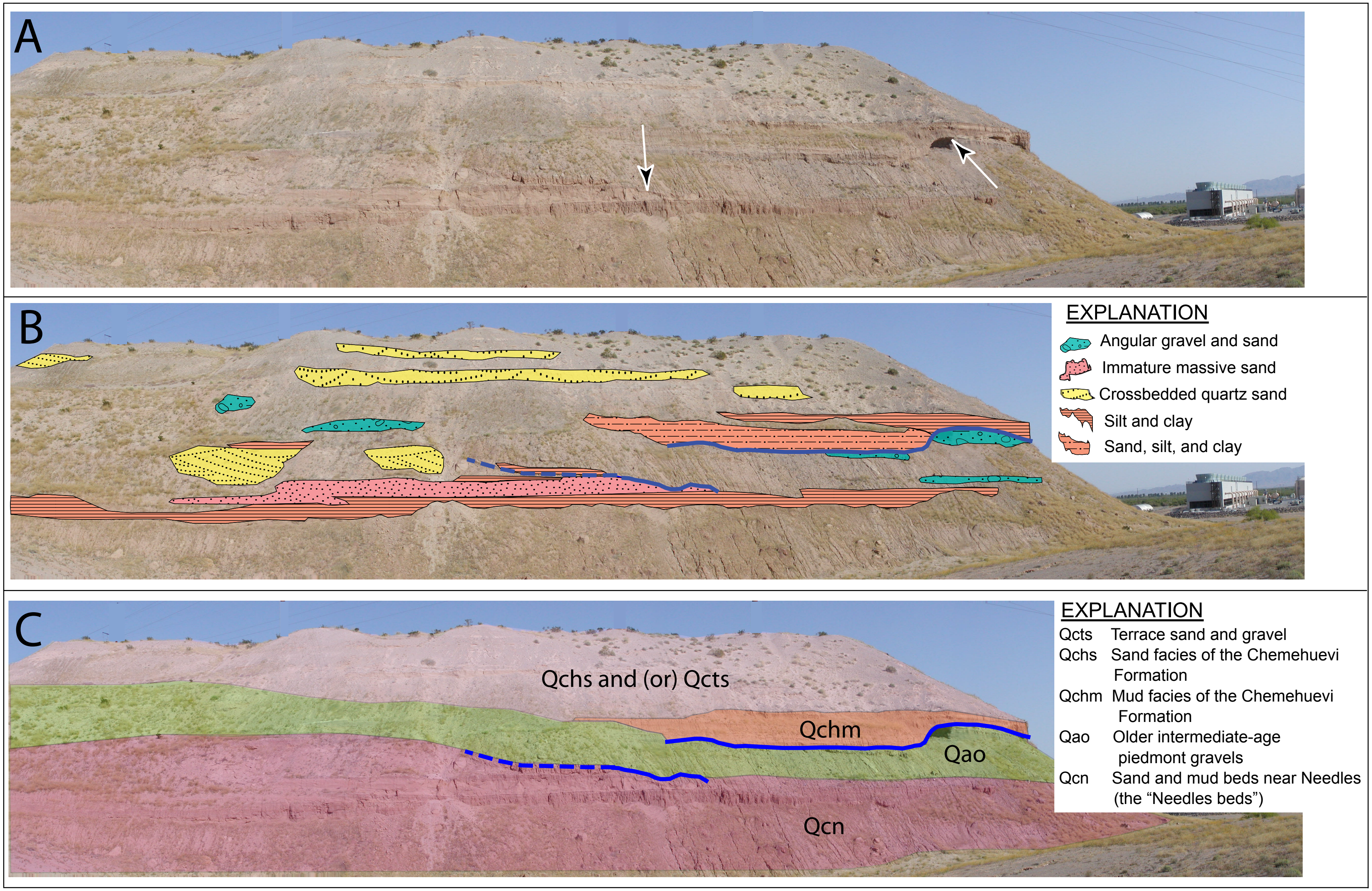

Figure 7. Panoramic photograph to south of north-facing outcrop east of Southpoint Power Plant (visible in lower right of photograph; see fig. 2 for location). A, Arrows point to unconformable surfaces; right arrow also points to buried calcic soil (stage II) on unconformity. B, Lithologic observations visible in outcrop. Unconformable surfaces, blue lines; dashed where probably continued. C, Geologic interpretation of outcrop.

these surfaces (fig. 7A, right arrow) suggests a prolonged period of exposure at the ground surface. The other unconformity (fig. 7A, left arrow) truncates bedded Colorado River sand, silt, and clay, but the soil is weakly developed; thus, it could be a minor erosional unconformity produced as a result of channel shifting that juxtaposed layers that are closely related in time.

Colorado River–derived sediment and locally derived gravel are interlayered at the Southpoint Power Plant outcrop (fig. 7B). The upper one-third of the outcrop, above the upper unconformity, consists of as much as 10 m of well-sorted, crossbedded sand, which forms steep slopes typical of the sand facies (unit Qchs) of the Chemehuevi Formation and (or) the terrace sand and gravel unit (Qcts). The lowest one-third of the outcrop, below the lower unconformity, contains predominantly massive sand, silt, and clay, partially cemented with carbonate. Locally derived angular gravel predominates between the two unconformities, although Colorado River–derived sand, silt, and mud also is present (fig. 7B).

A possible interpretation of this outcrop, which is consistent with the stratigraphic model presented above, is that the deposits above and below the unconformities are the Chemehuevi Formation (Qch) and the "Needles beds" (unit Qcn), respectively (fig. 7C). The angular gravel between the two unconformities is interpreted to be the older intermediate-age piedmont gravel unit (Qao). The interpretation that the Colorado River–derived sediment at the base of the outcrop is substantially older than the material at the top of the outcrop is further supported by another outcrop to the north of the one at the Southpoint Power Plant (fig. 7), at a similar elevation and close to the location from which the photograph shown in figure 7 was taken (see fig. 4). In the northern outcrop, two fine-grained, Colorado River–derived sediment deposits are separated by a carbonate-rich paleosol horizon on an erosional unconformity. The sediment overlying the paleosol is typical of the Chemehuevi Formation, and the underlying sediment is slightly cemented Colorado River sand and mud that is lithologically similar to the "Needles beds" on the California side of the quadrangle.

Another interpretation of the local stratigraphy portrayed in figure 7C is that both unconformities are relatively minor erosional surfaces created by short-term channel shifting and bank erosion and that all the Colorado River sediment exposed in the outcrop belongs to the same aggradational sequence and, thus, has a nearly uniform age. Alternatively, the Colorado River sediment beneath the lower unconformity may belong to the Pliocene alluvium of Bullhead City (Tcb), which more clearly underlies the Chemehuevi Formation (Qch) several kilometers southeast of the power plant. However, we favor the interpretation portrayed in figure 7C because it is consistent with the lithologic and stratigraphic relations seen elsewhere in the quadrangle.

Distribution of Sediment on the Valley Floor

The distribution of geologic materials on the valley floor reflect both the natural condition of the lower Mohave Valley and the response to major river engineering during the 20th century. Like all large rivers, the Colorado River sorts its load by grain size, and these different grain-size fractions are deposited in different environments on the valley floor. In general, the sediment is sorted into the following two grain-size classes: wash load, which consists of fine-grained particles suspended by turbulence in typical flows, and bed-material load, which consists of coarser grain sizes commonly found in the bed of the river. Prior to human intervention, wash load sediment (fine sand, silt, and clay) could only be deposited in overbank (floodplain) areas, and deposition of bed-material sediment (fine to coarse sand and gravel) would be confined to formerly active channels. Therefore, it is expected that areas of the modern valley floor that were formerly floodplain environments would contain grain sizes typical of wash load facies, and areas underlain by former channel deposits would be dominated by bed-material load facies.

Eight fluvial units on the Colorado River floodplain were identified using both old and modern maps and aerial photographs, in addition to cross-cutting map relations, to delineate historic channel deposits (fig. 8). The sedimentary characteristics of the valley-floor units are based on inferences drawn from depositional environments observed in both old and modern maps and aerial photographs. Only brief, qualitative field checking of lithologic characteristics was performed in this study; therefore, use of this map for resource-management purposes within the historically active valley floor will require additional field checking and laboratory analyses of particle size. However, this map could serve as a framework for designing an efficient program of sampling the floodplain for particle size.

A line of five auger holes drilled in the floodplain near the north edge of the Needles quadrangle (fig. 9) provided additional information about the deposits underlying the valley floor (Metzger and Loeltz, 1973). Sand and silt overlying a gravel (pebble and cobble) layer occupies the uppermost 40 to 90 ft (12-27 m) of all five holes (fig. 9). The depth to the top of the gravel layer varies across the floodplain from 40 to 50 ft (12-15 m) at the margins of the valley to 70 to 90 ft (21-27 m) in the center of the floodplain. The upper sand and silt layers could, in part, be historic floodplain deposits overlying channel sands and gravels. On the basis of the similarity of these sections to more abundant subsurface data collected near Parker, Ariz., Metzger and Loeltz (1973) interpreted the subsurface gravel to represent a basal gravel of their "younger alluvium" unit, which has accumulated during aggradation of the Colorado River since the early Holocene.

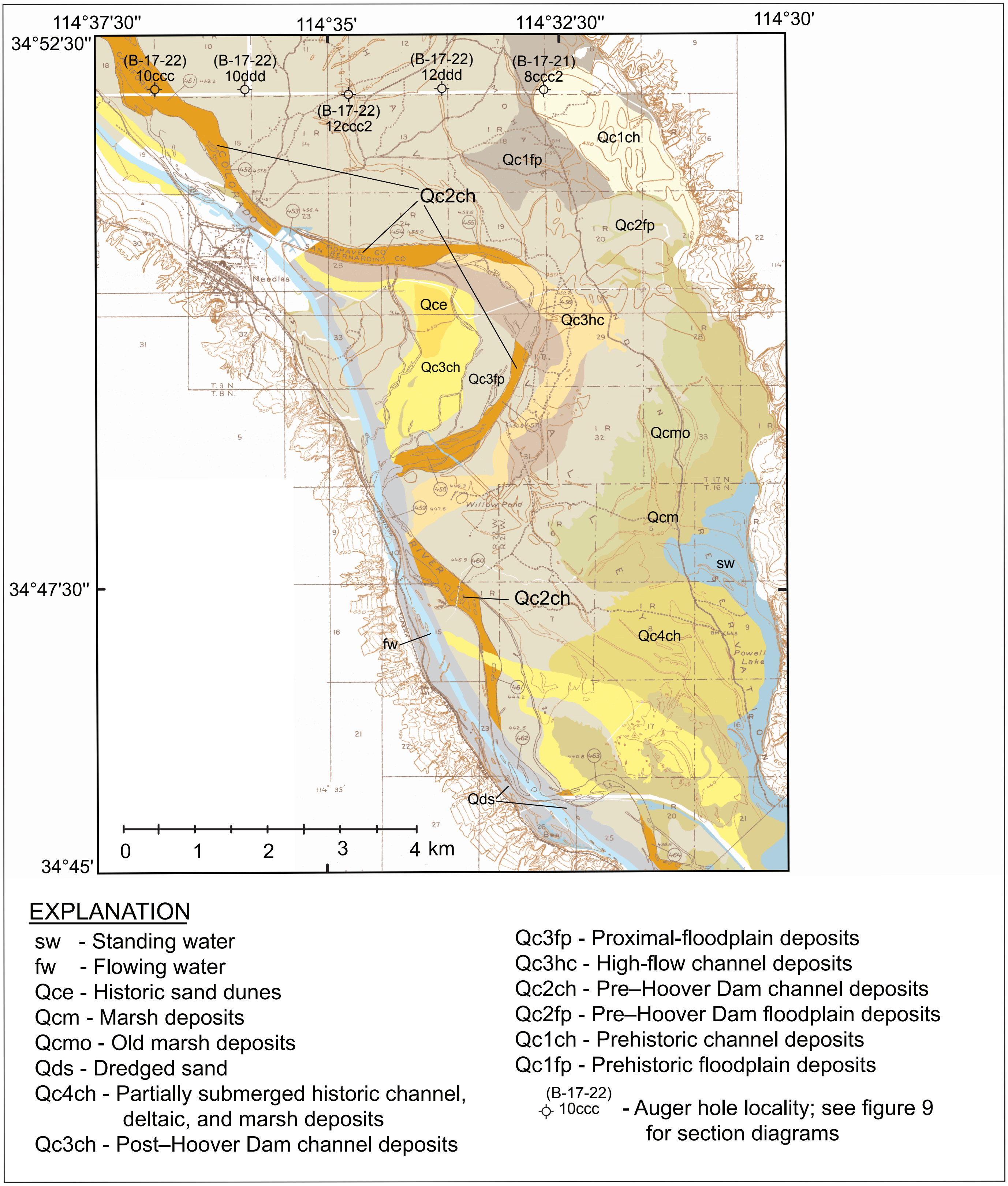

Figure 8. Map showing geology of historically active valley floor in Needles 7.5' quadrangle. Geology is draped over plane-table survey map of lower Colorado River (U.S. Geological Survey, 1927); modern highways and airport also are shown for orientation. Figure shows how historic data are used to delineate valley-floor deposits. Areas shown as active channel in the 1902 survey map are mapped as the pre–Hoover Dam channel deposits (unit Qc2ch), except where cut by later Colorado River units. Also shown are locations of auger holes drilled across floodplain near north edge of quadrangle.

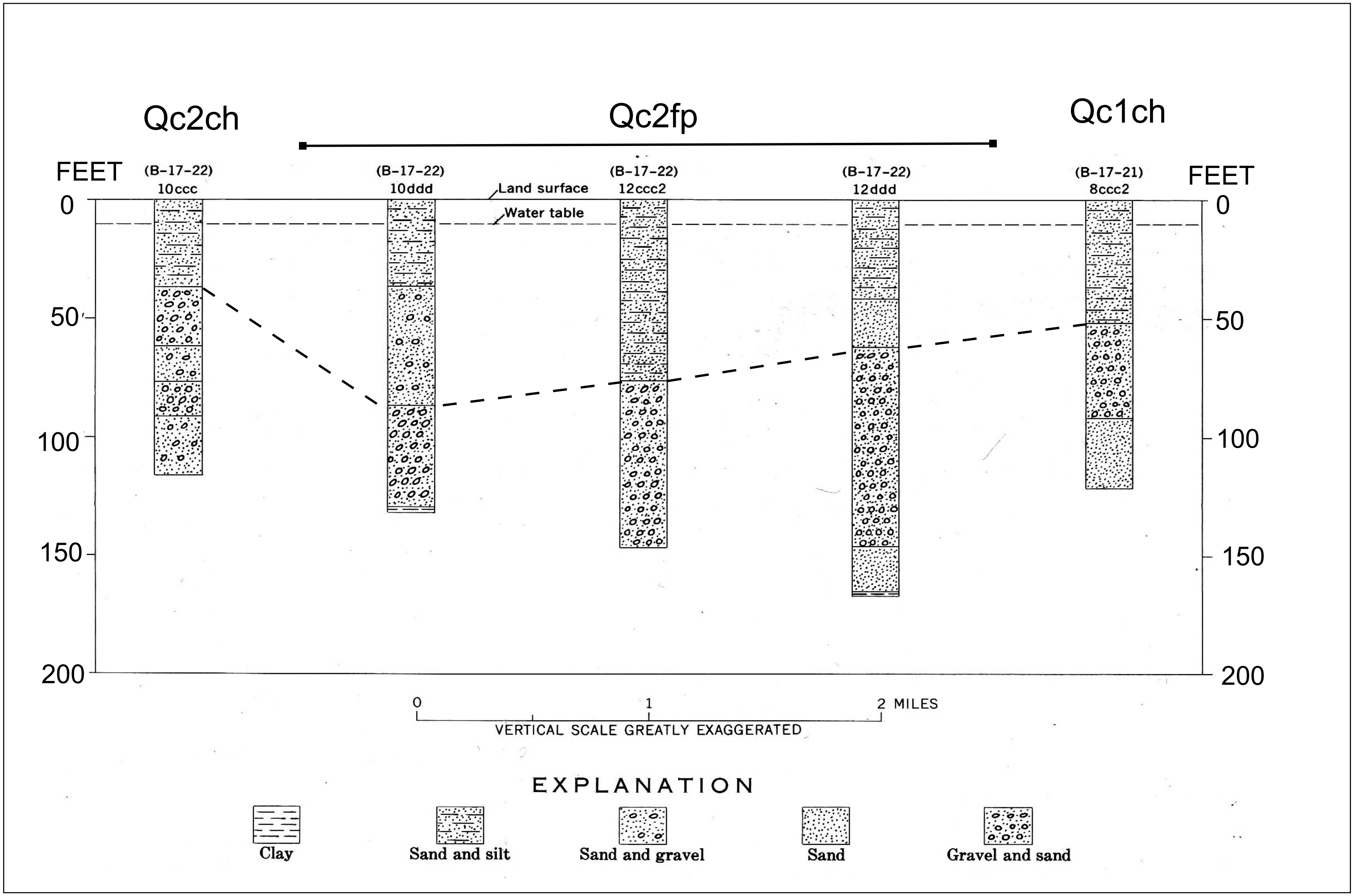

Figure 9. Lithologic sections from auger holes drilled across historically active floodplain near north edge of Needles 7.5' quadrangle (modified from Metzger and Loeltz, 1973) (see fig. 8 for locations). Unit symbols shown above sections indicate map unit overlying each well: Qc2ch, pre–Hoover Dam channel deposits; Qc2fp, pre–Hoover Dam floodplain deposits; Qc1ch, prehistoric channel deposits. Heavy dashed line indicates possible correlation between neighboring sections at top of gravel and sand layer.

The depositional processes and environments of the Colorado River in the lower Mohave Valley were dramatically altered in the 20th century by the construction of large dams upstream (Hoover Dam, 1935, and Davis Dam, 1951) and downstream (Parker Dam, 1938), followed by dredging and channelization of the Colorado River within the study area. The Needles quadrangle includes a stretch of the river at or just above the delta into Lake Havasu, impounded behind Parker Dam (fig. 1). The filling of Lake Havasu reduced the gradient of the river upstream, causing sedimentation in sand bars and deltaic deposits in the quadrangle and persistent wetted conditions across much of lower Mohave Valley. Topock Marsh formed as a result of this aggradation, and the marsh areas (mapped herein as units sw, Qcm, Qcmo, and Qc4ch) quickly became valuable riparian habitat for fish and birds, which led to the establishment of Havasu National Wildlife Refuge in 1941. The aggrading channel bed approached the height of the banks, burying the active channel and causing flooding problems as far north as the town of Needles (Metzger and Loeltz, 1973). By 1944, the water-surface elevation (presumably at low flow) had increased by 1.5 m in Needles, causing the abandonment of nearly 100 dwellings and threatening the main line of the Atchison, Topeka, and Santa Fe Railway (Johns, 1976). To alleviate this problem, the U.S. Bureau of Reclamation conducted a dredging operation between 1949 and 1953 to confine the Colorado River to a single, relatively straight channel along the west side of the valley between Needles and Topock. This resulted in the deposition of dredged sand (mapped herein as unit Qds) along the margins of the straightened channel and the abandonment of previously active fluvial surfaces. Eolian activity over one of the historically active channel surfaces has reworked sand-sized Colorado River channel deposits into dunes as high as 6 m (mapped herein as the historic sand dunes, unit Qce).

Flood Hazards in the Needles Quadrangle

Piedmont Flooding

Two distinct types of flood hazards exist or have existed in the Needles quadrangle, flooding of the Colorado River valley and flooding in local tributary streams on the California and Arizona piedmonts. The primary flood hazard on the lower piedmonts in the quadrangle is the potential for flash flooding during and following local thunderstorms and, occasionally, long-duration winter rainfall. The lack of evidence of debris-flow activity, which would include boulders (such as those found in the old piedmont gravels, units QTab, QTar, and QTas), coarse-grained lobate deposits, and debris-flow levees, in active washes and in young piedmont deposits suggests that the potential debris-flow hazard in the quadrangle related to large, boulder-producing mass failures in the Sacramento or Black Mountains may be small, at least on the lowermost parts of the piedmonts within the Needles quadrangle.

On the piedmonts, flooding is confined to active (in areas of unit Qay) and potentially active (in areas of units Qayd and Qayi) washes and alluvial fan surfaces. Alluvium mapped as unit Qay is identified by having evidence for recent flooding on its surfaces, such as sparse vegetation, recently formed bar-and-swale topography, lack of soil development, and accumulations of flotsam. Such evidence for flooding in the recent past also is a good indicator of the potential for future flooding on alluvial fan surfaces. Thus, geologic mapping can be used to delineate flood-hazard risks on active alluvial fans, as was demonstrated in Laughlin, Nev., 30 km north of the Needles quadrangle, where flood-hazard maps produced from geologic maps predicted appreciably different hazard zones than the standard Flood Insurance Rate Maps produced by the Federal Emergency Management Agency (FEMA) (House, 2005). In addition to detailed topographic information, the FEMA maps are based on models of hydrologic and hydraulic processes that incorporate substantial uncertainty. Thus, geologic mapping of deposits can be used to supplement the FEMA maps in areas containing active alluvial fans, such as in the Needles area.

A preliminary map of flood-hazard zones in the Needles quadrangle (fig. 10), which is based on geologic mapping, delineates the distribution of flood-prone areas (yellow), potential flood-prone areas (beige), and not flood-prone areas (gray and black) (note that disturbed drainage patterns in the city of Needles were not possible to map using aerial photographs, and so the flood hazard could not be assessed). In general, areas underlain by the young piedmont gravels (unit Qay) are considered to be at risk of flooding from events having recurrence intervals of between 1 and 10 years or longer. In addition, areas underlain by deposits in diked active channels (unit Qayd) that are downstream of berms or dikes meant to divert floodwater also may be prone to flooding during large, local runoff events that overtop or damage diversion structures.

Flood hazards in areas mapped as the youngest inactive piedmont gravels (unit Qayi) vary across the quadrangle. This unit is generally considered to be inactive and not flood prone during normal runoff events; however, the surfaces underlain by this unit range in height from less than 1 m to over 4 m above active channels. Thus, some of the surfaces may be locally flood prone during extreme runoff events, including floods that have recurrence intervals of between 10 and 1,000 years. Further assessment of the flood hazard of areas underlain by units Qayd and Qayi should be determined locally by observing the heights of surfaces relative to active channels, as well as indicators of recent flooding activity.

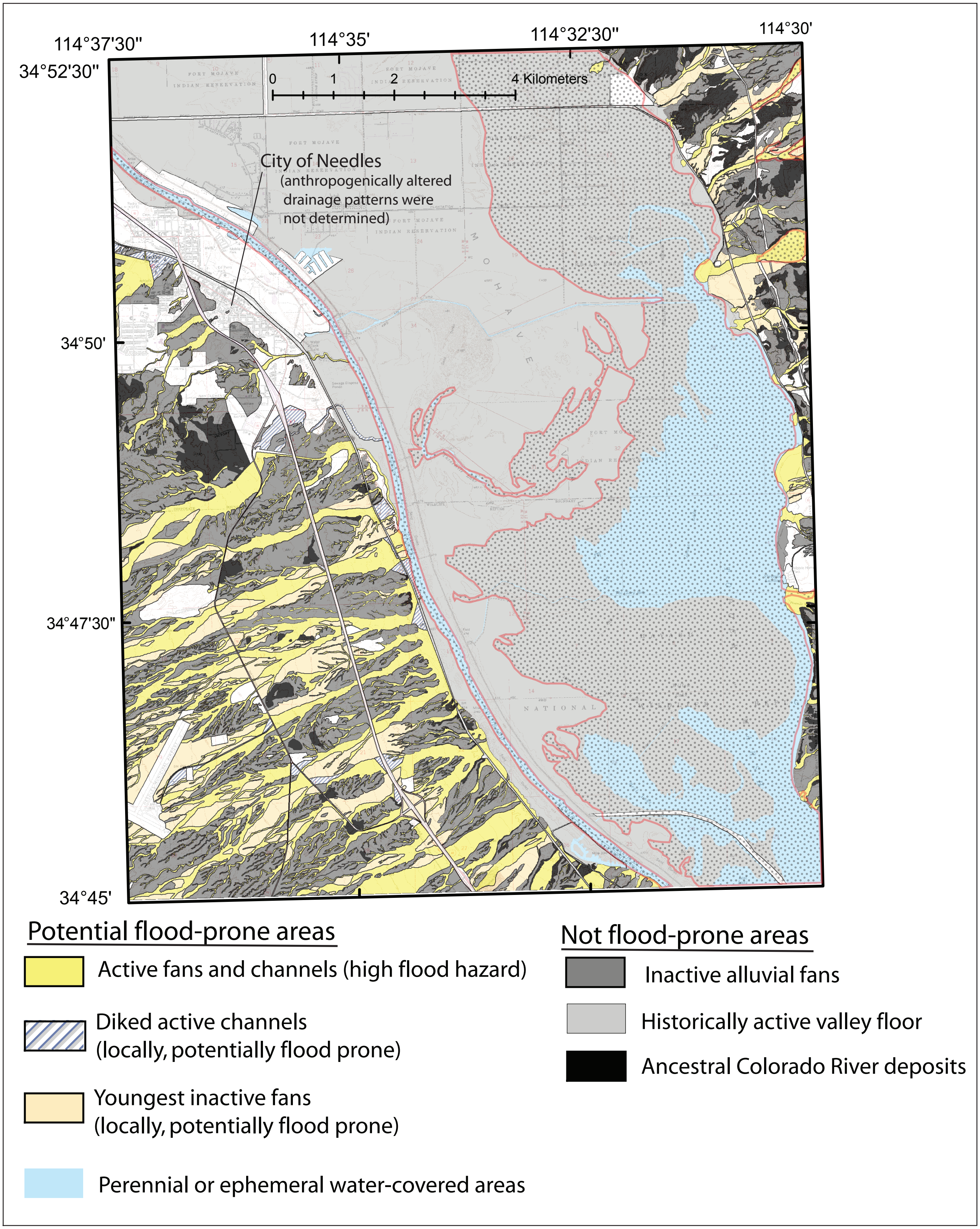

Figure 10. Map of Needles 7.5' quadrangle, showing distribution of flood-prone, potentially flood-prone, and not flood-prone areas mapped on basis of geologic mapping. Stippled areas outlined in red approximately delineate special flood-hazard areas in Mohave County, Ariz., which are mapped by Federal Emergency Management Agency (FEMA, 2008) as "subject to inundation by the 1% annual chance flood" (FEMA flood zones in California not shown).

For comparison, figure 10 shows the approximate extent of flood hazards as depicted in the Digital Flood Insurance Rate Map for Mohave County, Ariz. (Federal Emergency Management Agency, 2008). The FEMA map shows three potential flood zones in washes on the Arizona part of the quadrangle; however, it “does not necessarily identify all areas subject to flooding, particularly from local drainage areas of small size” (FEMA, 2008). Thus, the flood-hazard zones on the piedmonts mapped herein (fig. 10) are more detailed and, in addition, are likely more reliable than those shown on the FEMA map.

Valley-Floor Flooding

Prior to human intervention, much of the Colorado River valley floor was flooded seasonally during and following periods of snowmelt in the Rocky Mountains, at which time the Colorado River reached its annual maximum discharge. The closure of Hoover Dam in 1935 partially eliminated the hazard of seasonal floods of the Colorado River on the valley floor in the Needles quadrangle. However, in 1983, major flooding occurred along the lower Colorado following an unusually wet winter when upstream reservoirs were full. Despite this, expected long-term trends of reduced average annual precipitation and snowfall in the Colorado River basin (see, for example, McCabe and Wolock, 2007) make it unlikely that such a situation will occur again in the foreseeable future. Thus, the potential for valley-floor flooding in the Needles quadrangle caused by major flooding of the Colorado River is low.

Downstream dam construction also influences flooding in the Needles quadrangle. Following construction of Parker Dam (fig. 1) in 1938, sedimentation in the lower Mohave Valley led to rapid channel shifting and increased the chances of flooding as far north as Needles. This situation was remedied by a major U.S. Bureau of Reclamation dredging program undertaken between 1949 and 1953, which confined the Colorado River to a narrow channel on the west side of the valley. Confinement of the channel led to gradual and continuing degradation of the channel bed in the reach through the Needles quadrangle, necessitating the installation of pumps near Needles to supply water via canals to Topock Marsh (J. Earle, Havasu National Wildlife Refuge, oral commun., 2008).

The FEMA map (FEMA, 2008) estimates of flooding on the valley floor are based on estimates of the 1-percent and 0.2-percent chance (100-year and 500-year, respectively) floods in the Colorado River, as well as measured topographic cross sections and also hydraulic models (FEMA, 2008); however, because gradual lowering of the bed is occurring in places, and because upstream floods along the Colorado River are less likely to occur in the future, the FEMA map may possibly overestimate the likely extent of future flooding in the valley floor caused by floods from upstream. The extent of inundation in the valley floor in the quadrangle is controlled by several other factors, including the rate of water released from Davis Dam (upstream), the level of Lake Havasu behind Parker Dam (downstream) (fig. 1), and the configuration of the channel. In the Topock Marsh area (fig. 2), the apparent area of wetted marsh land decreased significantly between 1975, when the topographic base map (U.S. Geological Survey, 1975) was last revised, and 2004, when the DOQs that were used to map marsh deposits (modern and old) were flown. The reduction in inundated area is shown herein by the areas mapped as the old marsh deposits (unit Qcmo). One possible reason for the apparent reduction in inundated area is that gradual degradation of the channel of the Colorado River has lowered the water table on the floodplain.

Acknowledgments

The geologic interpretations presented here grew out of discussions with many people, including Zach Anderson, Sue Beard, Luke Blair, Tracey Felger, Scott Lundstrom, Donald Metzger, Dave Miller, Chuck Powell, and Paul Stone (USGS); John Bell, Kyle House, and Jim Faulds (Nevada Bureau of Mines and Geology); Phil Pearthree (Arizona Geologic Survey); Bob Reynolds (LSA Associates); and others. Tracey Felger provided digital map data, GIS support, and useful advice throughout this project. The USGS Tephrochronology Project (Andrei Sarna-Wojcicki, Dave Wahl, and Elmira Wan) chemically analyzed a sample of volcanic ash from the quadrangle and helped correlate it with others in the lower Colorado River area. The map and manuscript were improved by thorough and helpful reviews by John Bell (Nevada Bureau of Mines and Geology) and by Tracey Felger, Richard Hereford, Dave Miller, and Chuck Powell (all USGS). Taryn Lindquist provided detailed edits of the map and manuscript, and Taryn Lindquist and Mike Diggles (Menlo Park Publishing Service Center, USGS) helped with layout and the publication process. Funding for this work was provided by the National Cooperative Geologic Mapping Program of the U.S. Geological Survey, the Western Region Science on the DOI Landscape Program (Colorado River task), and the Mendenhall Postdoctoral Fellowship Program.

DESCRIPTION OF MAP UNITS

[For this map, "historic" refers to time period after 1857, date of earliest available map of Colorado River in study area (Ives, 1861); "prehistoric" refers to late Holocene time, exclusive of "historic" period; "present" refers to time of study (2008). Dates of data used to compile map units: 1857, map of Colorado River (Ives, 1861); 1902, pre-dam plane-table survey maps (U.S. Geological Survey, 1927); 1938, aerial photographs; 1947, aerial photographs; 1950, Needles 15' quadrangle topographic map (U.S. Geological Survey, 1950); 1975, Needles 7.5' quadrangle 1970 topographic map, photorevised 1975 (U.S. Geological Survey, 1975); 2004, digital orthophotographs. Other significant dates: 1935, closure of Hoover Dam; 1938, closure of Parker Dam; 1951, closure of Davis Dam; 1949-1953, channelization of Colorado River in lower Mohave Valley. Absolute dates of units in historically active valley floor are approximate and may overlap more than stated here]

HYDROLOGIC FEATURES

c **Canals (historic)**—Canals used to convey water across floodplain

sw **Standing water (historic)**—Areas appearing as standing water or as isolated bodies of water in 2004 digital orthophotographs (DOQs)

fw **Flowing water (1953 to present)**—Actively flowing trace of Colorado River, as seen in 2004 DOQs

ANTHROPOGENIC DEPOSITS

d **Disturbed ground (historic)**—Surfaces profoundly altered by urban development or by road, railway, or pipeline construction and excavation. Mapped where underlying geologic units cannot be ascertained from available information

Qds **Dredged sand (1949-1953)**—Sand excavated during U.S. Bureau of Reclamation channelization project from 1949 to 1953 and dumped along banks of engineered channel. Thickness as much as several meters

COLORADO RIVER AND RELATED SEDIMENTS

HISTORIC AND PREHISTORIC COLORADO RIVER AND RELATED SEDIMENTS

Eolian and Marsh Deposits

Qce **Historic sand dunes (1953 to present)**—Active eolian dunes composed of medium sand that contains high proportion of rounded quartz grains. Located near center of quadrangle (sec. 34, T. 9 N., R. 22 W.). Dunes are developed in area formerly occupied by main channel of Colorado River, and they overlie, and appear to be derived from, post–Hoover Dam channel deposits (unit Qc3ch). Age is therefore younger than abandonment of channel following dredging and channelization by U.S. Bureau of Reclamation from 1949 to 1953. Thickness as much as 6 m

Qcm **Marsh deposits (1938 to present)**—Marshy areas seen in 2004 DOQs. Water table is near or at surface. Area includes Goose Lake and Beal Lake, identified on 1975 photorevision of quadrangle base map (U.S. Geological Survey, 1975). Thickness uncertain but assumed to be mostly less than several meters

Qcmo **Old marsh deposits (1938-1990s)** —Areas that are shown as marsh on quadrangle base map (photorevised 1975) (U.S. Geological Survey, 1975) but that do not appear to be watered in 2004 DOQs. Thickness uncertain but assumed to be less than several meters

Channel Deposits

Qc4ch **Partially submerged historic channel, deltaic, and marsh deposits (historic)**—Sand, mud, and gravel deposited by Colorado River and partially submerged by Topock Marsh. Located in southeastern part of quadrangle in historically active valley floor, within Havasu National Wildlife Refuge (secs. 7-9 and 16-17, T. 16 S., R. 21 W.). Includes "Willow Lake" on quadrangle base map (photorevised 1975) (U.S. Geological Survey, 1975). In 1938 aerial photographs, area has crescent-shaped eastern margin, high-albedo meander scrolls, and evidence of recent channel migration by point-bar growth. On basis of past depositional environments, unit is inferred to consist of relatively thin veneer of finer grained deltaic and marsh sediments and underlying thicker, coarser sand body. Uppermost deltaic and marsh layer is inferred to be younger than closure of Parker Dam in 1938 and subsequent flooding by Lake Havasu; underlying inferred channel deposit would mostly predate 1938 aerial photographs. Thickness uncertain but interpreted to be as much as 5 to 10 m, on basis of estimated range of likely maximum scour depths

Qc3ch **Post–Hoover Dam channel deposits (1935-1953)**—Sand, mud, and gravel deposited by Colorado River. Located in area formerly occupied by main channel of Colorado River, as seen in 1938 and 1947 aerial photographs. Locally, surfaces contain some relict bar-and-swale topography. Map pattern of unit delineates shape of meandering channel through central part of quadrangle. Cuts across older pre–Hoover Dam channel and floodplain deposits (units Qc2ch and Qc2fp). On basis of past depositional environments and reconnaissance field and aerial-photographic evidence, unit is inferred to contain mostly medium- and coarse-grained, quartz-rich sand, typical of channel environments. Channel deposits postdate 1902 plane-table maps (U.S. Geological Survey, 1927) but predate channelization from 1949 to 1953. Thickness uncertain but interpreted to be as much as 5 to 10 m, on basis of estimated range of likely maximum scour depths

Qc3hc **High-flow channel deposits (prehistoric through 1953)**—Sand, mud, and gravel deposited by Colorado River. Forms crescent-shaped band as wide as 400 m and several kilometers long in center of historically active valley floor. Partly coincides with main portion of active channel as mapped in 1902 (U.S. Geological Survey, 1927) and also in 1857 (Ives, 1861). Ives (1861), during exploration of Colorado River to investigate its navigability, reported “slight rapid” in area underlain by unit. In 1938 aerial photographs, area is channel-shaped feature parallel to, and outside (east) of, large bend of main channel, which apparently was only occupied during higher flow stages. As mapped, unit includes irregularly shaped crevasse-splay deposit along apex of bend. Area was partly occupied by “Threemile Lake,” apparent oxbow lake on 1950 Needles 15’ quadrangle map (U.S. Geological Survey, 1950). On basis of past depositional environments, unit is inferred to contain relatively thin mantle of fine-grained overbank and lacustrine mud over thicker sand facies that possibly contains some gravel where Ives (1861) encountered rapid. Deposits span historic period: channel sand deposits are older than 1857, and overlying mud deposits date from between 1938 and 1953. Thickness uncertain but interpreted to be as much as 5 to 10 m, on basis of estimated range of likely maximum scour depths

Qc2ch **Pre–Hoover Dam channel deposits (prehistoric through 1935)**—Sand, mud, and gravel deposited by Colorado River. Mapped as band of deposits along trace of channel on 1902 maps (U.S. Geological Survey, 1927), in west half of historically active valley floor (fig. 8), except where truncated by post–Hoover Dam channel deposits (unit Qc3ch) and post–Hoover Dam high-flow channel deposits (unit Qc3hc). Upper 11 m in auger hole (loc. ‘(B-17-22)10ccc’, on map sheet) that penetrates unit consists of sand to silty sand and scattered gravel overlying at least several meters of pebble to cobble gravel (Metzger and Loeltz, 1973, p. J16; see also, fig. 9). On basis of depositional environments seen in sequence of aerial photographs, unit is inferred to contain lenses of overbank fine sand and mud over relatively thick deposit of channel sediment (medium- through coarse-grained sand). Bulk of deposit is interpreted to predate 1938 aerial photographs but, in places, may be as old as or predate 1857 map (Ives, 1861). Thickness uncertain but interpreted to be as much as 5 to 10 m, on basis of estimated range of likely maximum scour depths

Qc1ch **Prehistoric channel deposits (prehistoric)**—Sand, mud, and gravel deposited by Colorado River. Located in northeast quadrant of historically valley floor. On 1902 map (U.S. Geological Survey, 1902) and in all later maps and aerial photographs, unit has distinct crescent-shaped northwest boundary, suggestive of northward-migrating channel bend. Unit truncates prehistoric floodplain deposits (unit Qc1fp). Upper 20 m of auger hole (loc. ‘(B-17-21)8ccc2’, on map sheet) drilled near west edge of unit contains sand to silty sand and scattered gravel overlying pebble to cobble gravel (Metzger and Loeltz, 1973, p. J16; see also, fig. 9). On basis of past depositional environments, unit is inferred to contain high proportion of quartz-rich, medium sand and coarser grained sediment, possibly overlain by younger overbank fine sand and mud. Because shape of channel is discernable on 1902 maps and in 2004 DOQs, much of sediment making up this deposit likely was deposited during 19th century or earlier. Thickness uncertain but interpreted to be as much as 5 to 10 m, on basis of estimated range of likely maximum scour depths

Floodplain Deposits

Qc3fp **Proximal-floodplain deposits (historic through 1935)**—Mud and sand deposited by Colorado River. Mapped as crescent-shaped band approximately 500 m wide and several kilometers long in center of historically active valley floor, between and around post–Hoover Dam channel deposits (unit Qc3ch) and post–Hoover Dam high-flow channel deposits (unit Qc3hc). Area appeared as island between two distributary channels in locally anastomosing section of Colorado River, as mapped in 1857 (Ives, 1861) and as seen in 1938 aerial photographs. On basis of past depositional environments, unit is inferred to consist of relatively coarse facies of proximal-overbank sediment (layers of sand, silt, and clay) and (or) crevasse splays (meter-scale, upward-fining lenses characterized by high sand fraction). Age is approximately coeval with post–Hoover Dam channel deposits (unit Qc3ch) and post–Hoover Dam high-flow channel deposits (unit Qc3hc). Deposits mostly are younger than those mapped as pre–Hoover Dam channel deposits (unit Qc2ch) and pre–Hoover Dam floodplain deposits (unit Qc2fp), and they are estimated to span late prehistoric and historic time until channelization in 1953. Thickness uncertain but estimated to be less than 5 m, on basis of typical thicknesses of fine-grained floodplain deposits observed in bank exposures outside quadrangle

Qc2fp **Pre–Hoover Dam floodplain deposits (prehistoric through 1935)**—Mud and sand deposited by Colorado River in areas interpreted as seasonally inundated floodplain prior to closure of Hoover Dam in 1935. Covers much of historically active valley floor. Truncated by post–Hoover Dam channel deposits (unit Qc3ch) and post–Hoover Dam high-flow channel deposits (unit Qc3hc). In aerial photographs, areas underlain by unit contained variety of floodplain environments, including natural levees, crevasse splays, and distal floodplain settings. On basis of past depositional environments, these deposits are inferred to contain mostly overbank fine sand and mud, and some coarser grained lenses related to crevasse splays. Deposits span late prehistoric and early historic periods, through channelization in 1953. Metzger and Loeltz (1973) reported that, in three auger holes drilled into unit, upper 10 to 25 m consisted of sand to silty sand and scattered gravel overlying pebble to cobble gravel (Metzger and Loeltz, 1973, p. J16; see also, fig. 9). Thickness uncertain but is estimated to be less than 5 m, on basis of typical thicknesses of fine-grained floodplain deposits observed in bank exposures outside quadrangle

Qc1fp **Prehistoric floodplain deposits (prehistoric)**—Mud and sand deposited by Colorado River. Located in northeast part of historically active valley floor. Area underlain by unit appears to have been distal floodplain prior to 1902, having been less often inundated during historic time than the younger floodplain deposits (units Qc2fp and Qc3fp). On basis of past depositional environments, unit is inferred to be relatively fine grained, having a high proportion of wash load–sized sediment (fine sand, silt, and clay). Deposit is inferred to contain oldest Colorado River sediment preserved on surface of valley floor in quadrangle because it is cut by next oldest unit, the prehistoric channel deposits (unit Qc1ch). Thickness uncertain but is estimated to be less than 5 m, on basis of typical thicknesses of fine-grained floodplain deposits observed in bank exposures outside quadrangle

ANCESTRAL COLORADO RIVER SEDIMENTS

Qcts **Terrace sand and gravel (Upper Pleistocene)**—Well-sorted sand and gravel containing high proportion of rounded quartz-sand grains. Dominated by medium and coarse sand, but 2- to 3-m-thick, imbricated rounded-gravel facies is exposed at south edge of city of Needles (W 1/2 sec. 5, T. 8 N., R. 22 W.), at intersection of Spikes Road and Schultz Road. Outside quadrangle, likely correlative deposits are gravel rich (Longwell, 1963; Howard and Malmon, 2007; Lundstrom and others, 2008) and include at least one boulder bed (Howard and Malmon, 2008). Lithologically resembles sand facies of Chemehuevi Formation (unit Qchs) but is generally thinner and does not form steep, loose sand slopes at angle of repose. Surface expression typically is hummocky topography covered with loose quartz sand and scattered rounded pebbles. Overlies, or is inset into, valley-facing, 5- to 10-m high erosional scarps cut into the older intermediate-age piedmont gravels (unit Qao) along old Route 66 in California. Also found as thin veneer on much older deposits, such as those along toe of Arizona piedmont in southeast corner of quadrangle. Lundstrom and others (2008) reported Th/U ages that range from about 60 ka to 32 ka obtained on pedogenic carbonate coatings on possibly correlative terrace gravels on Arizona side of Colorado River 75 km north of quadrangle. On basis of its grain size distribution, elevation range, numerical age dates, and relation to other units and scarps, unit is interpreted to have been deposited over irregular topography by Colorado River at end of most recent major aggradation episode and (or) during subsequent period of overall downcutting. Thus, unit is inferred to be youngest ancestral Colorado River–derived sediment in quadrangle. Thickness varies from thin veneer to several meters

Qch **Chemehuevi Formation of Longwell (1963), undivided (Upper Pleistocene)**—Beds of sand, mud, and subordinate amounts of rounded gravel; well sorted, containing high proportion of rounded quartz-sand grains; also contains at least one layer of reworked volcanic tephra. Found on both Arizona and California piedmonts below 760-ft (232-m) contour. Disconformably overlies the alluvium of Bullhead City (unit Tcb), the old piedmont gravels (units QTab, QTar, and QTas), and the older intermediate-age piedmont gravels (unit Qao); underlies the younger intermediate-age piedmont gravels (unit Qai). In some places, unit overlies erosional surfaces that show evidence of soil formation. Outside quadrangle, deposits of formation are overlain by sediments correlative to the terrace sand and gravel (unit Qcts) (Longwell, 1936). Evidence from fossils (Ives, 1861; Metzger and Loeltz, 1973; Agenbroad and others, 1992), from paleomagnetic analyses and from amino-acid racemization and uranium-series dating of vertebrate fossils (Lee and Bell, 1975), from single radiocarbon date (Blair, 1996), from uranium-series dates on carbonate coatings on clasts (Lundstrom and others, 2008), and from luminescence ages (Malmon and others, 2007; Lundstrom and others, 2008) collectively suggests that the Chemehuevi Formation throughout Colorado River valley is Late Pleistocene, likely between 100 and 40 ka. Widespread exposures of the Chemehuevi Formation at toe of Arizona piedmont, in northeastern part of quadrangle, are as thick as 20 m. Deposits of the Chemehuevi Formation in quadrangle cover entire range of elevation from floodplain surface near 460-ft (140-m) contour to above 760-ft (232-m) contour. Locally, subdivided into following facies:

Qchs **Sand facies**—Well-sorted medium sand, scattered gravel, and discontinuous minor mud beds, having high proportion of rounded quartz-sand grains. Typically poorly exposed. However, some exposures show meter-scale tabular crossbedding; discontinuous beds of imbricated, rounded pebble and cobble gravel; interbedded lenses of locally derived, angular gravel; reddish, pebbly carbonate-rich layers; and discontinuous layers of horizontally bedded and laminated silt and clay less than 0.5 m thick. Found in steep, loose slopes lying close to angle of repose of well-sorted, dry sand (about 32º) on Arizona piedmont. Interpreted to have been deposited mostly within active channel of Colorado River during period of long-term valley aggradation. Lithology of unit closely resembles that of the terrace sand and gravel unit (Qcts), but unit can be distinguished from unit Qcts because it typically is thicker, it commonly overlies mud facies (Qchm) of the Chemehuevi Formation on abrupt unconformity, and it is not necessarily associated with valley-facing erosional scarps. Distinction between this unit and the terrace sand and gravel unit (Qcts) commonly is difficult because two units are similar lithologically and may be partly correlative with one another. Thickness of individual exposures as much as 12 m

Qchm **Mud facies**—Well-bedded sand, silt, and clay deposited by Colorado River. Commonly consists of discrete beds 5 to 50 cm thick made up of layers of mud alternating with layers of fine and very fine sand. Some beds show ripple cross bedding in fine sand layers. Large exposures characteristically form pinkish badlands (typical outcrops are very pale orange gray, 10 YR8/2). Geomorphic expression as badlands and vertical bluffs contrasts strongly with angle-of-repose slopes formed by the sand facies (unit Qchs).

Found in large areas in northeast corner of quadrangle. Exposed in cliffs underlying younger intermediate-age piedmont gravels (unit Qai) along east edge of California piedmont. Overlies the alluvium of Bullhead City (unit Tcb), the old piedmont gravels (units QTab, QTar, and QTas), the sand and mud beds near Needles (unit Qcn), and the older intermediate-age piedmont gravels (unit Qao), in many places on sharp, soil-mantled erosional surfaces. Age is inferred to be Late Pleistocene, likely between 70 and 40 ka, on basis of ages of similar deposits in other parts of Colorado River valley using multiple dating techniques (Lee and Bell, 1975; Blair, 1996; Malmon and others, 2007; Lundstrom and others, 2008). High proportion of mud to sand in unit, as well as its rhythmically bedded nature, suggests that sediments were deposited in floodplain environments during overbank flooding. Locally, thickness as much as 35 m; collectively, thickness as much as 90 m, which suggests they record long-term period of valley filling. At one location (loc. 06-1222-2, in SE 1/4 sec. 16, T. 17 N., R. 21 W.; fig. 4), basal bed of unit is 0.2- to 0.5-m thick, fine-grained, light-gray, sandy, reworked volcanic ash bed containing abundant pumiceous-glass shards, which was deposited on soil-mantled unconformity on the alluvium of Bullhead City (unit Tcb) (fig. 6). Glass shards in basal bed are either subrounded, very finely ribbed, or of webby or frothy texture and consist of two populations of chemically distinct volcanic glass (E. Wan, USGS, written commun., 2007). More abundant population consists of glass that is chemically similar to glass in primary ashes found entirely within the Chemehuevi Formation near Monkey Rock in Black Canyon (Lundstrom and others, 2008) and elsewhere in Colorado River corridor (House and others, 2005b; D. Malmon, unpub. data, 2008). Age of eruption that produced ash is not known but is inferred to be Late Pleistocene

Qchg **Gravel facies**—Rounded, imbricated, clast-supported, well-sorted gravel containing abundant far-traveled clasts of exotic origin. Mapped in low-elevation exposures at base of California piedmont 2 km south of Needles and at base of Arizona piedmont north of Fivemile Landing. Gravel bed projects toward position directly under lowest outcrops of the mud facies (unit Qchm). May correlate with gravel described as lying at base of the mud facies by Longwell (1963) and Metzger and others (1973). Alternatively, gravel may belong to higher stratigraphic level within the Chemehuevi Formation. Thickness as much as 5 m

Qcn **Sand and mud beds near Needles (Middle? Pleistocene)**—Unconsolidated, interbedded sand and mud deposited by Colorado River. Thicknesses of individual beds range from several decimeters to several meters. Sand beds are moderately well sorted and have high proportion of rounded quartz sand grains. Contains zones of moderate cementation in sandy beds. Cliff exposure near west edge of quadrangle, about 2 km south of city of Needles (NW 1/4 sec. 7, T. 8 N., R. 23 E.), contains interval of crossbedded sand more than 4 m thick that includes small-scale erosional surfaces. Unit is found in small exposures on California and Arizona piedmonts, in some places above 800-ft (244-m) contour. Underlies, and may interfinger with, deposits mapped as the older intermediate-age piedmont gravels (unit Qao), which underlie the Chemehuevi Formation (fig. 3). Absolute age is uncertain, but deposits are estimated to be Early to Middle Pleistocene, on basis of degree of cementation and interpreted age of overlying piedmont gravel deposits. Sediments were deposited by ancestral Colorado River in channel and floodplain environments. Interpreted to be rare, preserved remnants of one or more mostly eroded Colorado River valley-fill sequences that are intermediate in age between the late Pliocene alluvium of Bullhead City (unit Tcb) and the Upper Pleistocene Chemehuevi Formation. Base of unit is not exposed and so total thickness is unknown

Tcb **Alluvium of Bullhead City of House and others (2005b) (Pliocene)**—Well-sorted sand and gravel that mainly consists of intervals of crossbedded, quartz-rich sand and intervals of imbricated pebble and cobble gravel containing abundant rounded quartzite and chert clasts derived from Colorado Plateau. Includes strongly cemented conglomerate and sandstone containing iron-oxide zones. To southeast in Topock 7.5’ quadrangle, lower part of unit contains boulder-gravel bed (Metzger and Loeltz, 1973; Howard and Malmon, 2008), which has not been observed in Needles quadrangle. Unconformably overlies the Bouse Formation in subsurface within quadrangle, as well as in many outcrops outside quadrangle (Metzger and Loeltz, 1973). Unit, which is oldest major fluvial aggradational sequence of Colorado River, is oldest deposit exposed in quadrangle, and it is only exposed on Arizona piedmont. Unconformably overlain by boulder-conglomerate subunits (units QTab, QTar, QTas) of the old piedmont gravel unit. Correlated with unit B of the "older alluviums" of Metzger and Loeltz (1973), which interfingers with and underlies coarse-grained fanglomerate containing the 4.1±0.5 Ma (lower) Nomlaki Tuff (House and others, 2008). Exposed thickness as much as 20 m but base not clearly exposed. Locally subdivided into following facies:

Tcbm **Mud facies**—Poorly consolidated, rhythmically bedded silt, sand, and clay, in discrete 5- to 50-cm-thick beds. Mapped in one exposure on Arizona piedmont, on south side of wide wash at east edge of quadrangle (sec. 22, T. 17 N., R. 21 W.), where it is interbedded with gravel-dominated facies of the alluvium of Bullhead City. In this exposure, the alluvium of Bullhead City is disconformably overlain by deposit of the basalt-boulder conglomerate (unit QTab) that underlies 1- to 2-m-thick, stage V petrocalcic soil east of quadrangle. Interpreted as floodplain facies. Thickness approximately 6 m

PIEDMONT GRAVELS

Qac **Colluvium, undivided (prehistoric to present)**—Undivided gravel and sand transported and deposited by hillslope and eolian processes

Qay **Young piedmont gravels (prehistoric to present)**—Deposits in active washes on California and Arizona piedmonts. Poorly sorted, poorly bedded, subangular to subrounded sand, gravel, and silt of local origin, having small to negligible component of boulders. Rounded quartzite and chert pebbles are present but rare. Surfaces are sparsely vegetated, lack soil development, and show braided and anastamosing channel patterns. Bar-and-swale topography characterized by less than 1 m relief. Surfaces show widespread evidence of recent fluvial activity. Generally correlative to unit Q4 of Bull (1975). Areas underlying unit are zones of high flood hazard during and following frequent local rainfall events that have recurrence intervals from 1 to 100 years (fig. 10). Thickness estimated to be 1 to 2 m

Qayd **Deposits in diked, historically active washes (prehistoric to historic)**—Deposits in historically active washes that are no longer active owing to anthropogenic drainage diversions upstream, such as dikes and engineered levees. Poorly sorted, poorly bedded sand, gravel, and silt of local origin. Gravel clasts are subangular to subrounded and have small to negligible component of boulders. Rounded quartzite and chert pebbles are present but rare. Surfaces are sparsely vegetated, lack soil development, and show braided and anastamosing channel patterns of remnant bar-and-swale topography that has less than 1 m relief. Unit includes local veneers of wind-reworked sand deposited around vegetation, as well as patches of winnowed gravel. Mapped in and around city of Needles and along main north-south-trending highways and railways on California piedmont. Areas underlying unit may be prone to flooding during large local flood events that overtop or breach diversion structures. Thickness estimated to be 1 to 2 m

Qayi **Youngest inactive piedmont gravels (lower to middle Holocene and (or) Upper Pleistocene)**—Poorly sorted, poorly bedded, subangular to subrounded sand, gravel, and silt of local origin and small to negligible component of boulders. Rounded quartzite and chert pebbles are present but rare. Surfaces show little or no evidence of recent fluvial activity but, in places, contain relict depositional bar-and-swale topography that has less than 0.5 m relief. Surface clasts may be weakly varnished. Surfaces have minimal soil development that, in places, includes incipient vesicular Av horizon 1 to 2 cm thick. Located adjacent to active washes throughout piedmonts of Black and Sacramento Mountains. Age is uncertain but, on basis of degree of varnish and soil development, is estimated to span latest Pleistocene through middle Holocene. May be correlative to unit Q3 of Bull (1975), whose age is estimated to be between 11 and 2 ka, primarily on basis of soil-profile development. In some places, height above subjacent active washes (mapped as the young piedmont gravels, unit Qay) decreases with distance from Colorado River, where unit is interpreted as being buried by Holocene sedimentation in active washes. In these settings, unit is less than 2 m above active washes, and so these surfaces may be overtopped by large, infrequent floods (fig. 10). Typically, 1 to 4 m thick above active washes; greater thicknesses may be concealed

Qau **Intermediate-age piedmont gravels, undivided (Pleistocene)**—Poorly sorted, poorly bedded, subangular to subrounded sand, gravel, and silt of local origin and small to negligible component of boulders. Rounded quartzite and chert pebbles are present but rare. Deposits are highly dissected, and uneroded surfaces contain stage II and III calcic soils. Deposits overlie Colorado River sediments of varying ages. Mapped in locations where it was difficult or impractical to separate the younger intermediate-age piedmont gravels (unit Qai) from the older intermediate-age piedmont gravels (unit Qao). Thickness as much as 15 m

Qai **Younger intermediate-age piedmont gravels (Upper Pleistocene)**—Poorly sorted, poorly bedded, subangular to subrounded sand, gravel, and silt of local origin and small to negligible component of boulders. Rounded quartzite and chert pebbles are present but rare. Uneroded alluvial surfaces are covered with well-developed, varnished pavements lacking original depositional bar-and-swale topography. Deposits are less dissected than the older intermediate-age piedmont gravels (unit Qao); however, they are dissected by gullies as deep as 10 m near margin of Colorado River floodplain. Widespread on lower part of piedmont on California side of quadrangle. Deposits overlie the Chemehuevi Formation (unit Qch) on erosional unconformities and are inset into the older intermediate-age piedmont gravels (unit Qao). On California side of quadrangle, fan surfaces underlain by unit are graded to river elevation close to modern valley floor. Unit may be partly correlative to unit Q2b of Bull (1975) near Parker, Ariz., which originally was estimated to be between 50 and 11 ka, primarily on basis of soil-profile development; age of unit Q2b later was estimated to be 83±10 ka, on basis of 14 Th^{230}-U^{234} dates obtained from carbonate coatings on gravel clasts from unit (Ku and others, 1979). Near floodplain on California side of quadrangle, uneroded surfaces are as much as 10 m above floodplain and adjacent active washes. Flood hazard on surfaces underlain by unit is assumed to be negligible; however, in area between Interstate 40 and old Route 66, these surfaces merge with deposits mapped as the youngest inactive piedmont gravels (unit Qayi), where they may be subject to rare occasional flooding during large runoff events. Unit is interpreted to have formed when Colorado River was within 10 to 20 m of its modern elevation, following partial erosion of the Chemehuevi Formation (Qch). Thickness as much as 10 m

Qao **Older intermediate-age piedmont gravels (Upper and (or) Middle? Pleistocene)**— Poorly sorted, poorly bedded, subangular to subrounded sand, gravel, and silt of local origin and small to negligible component of boulders. Rounded quartzite and chert pebbles are present but rare. Rhyolite clasts show some desert-varnish development and 1- to 3-mm-deep etching, and granitic clasts are partly weathering by disaggradation. Stable surfaces have weak to strong pavement development and stage II-III(?) calcic soils having 1 to 2 mm coatings on tops and bottoms of cobbles. Deposits are dissected by gullies as much as 15 m deep and spaced 10 to 30 m apart; uneroded surfaces having intact soils are rare. Unit forms widespread fans in lower Mohave Valley, covering much of southwestern part of quadrangle. Valley-facing erosional scarps 5 to 10 m high cut unit between 650 and 750 ft (200 and 230 m) elevation on both sides of valley; thin deposits of Colorado River–derived sand and scattered rounded pebbles, mapped as the terrace sand and gravel (unit Qcts), are deposited against these scarps. Deposits underlie the Late Pleistocene terrace sand and gravel (unit Qcts) in southwestern part of city of Needles and along railroad grade on west edge of Colorado River floodplain. Deposits overlie Colorado River–derived sediment mapped as the sand and mud beds near Needles (unit Qcn). Along railroad grade about 3 km east of Parker Junction (N 1/2 sec. 22, T. 8 N., R. 22 W.), unit underlies Chemehuevi Formation (Qch). In northeast corner of quadrangle, unit overlies buried stage III calcic soil horizons about 5 m below fan surfaces. May be partly correlative to Q2a of Bull (1975) near Parker, Ariz., originally estimated to be between 200 and 50 ka, primarily on basis of soil-profile development; Ku and others (1979) later obtained ages ranging from 172±25 to 66±3 ka obtained from carbonate coatings on four clasts from unit Q2a. Age of unit estimated to be Middle or Late Pleistocene, on basis of its stratigraphic position below the Chemehuevi Formation and observation that uneroded surfaces of correlative deposits outside quadrangle have not developed strongly indurated petrocalcic soils. Flood hazard on surfaces underlain by unit is low to nonexistent. Thickness as much as 15 m

Old piedmont gravels (Lower Pleistocene and (or) upper Pliocene)—Conglomerates of local origin, containing perceptible calcium-carbonate cement. Deposits may correlate to unit C of Metzger and others (1973), to units Q1a and Q1b of Bull (1975), and to thick old gravel unit mapped as QTs1 by Howard and others (2000) and described by Wilshire and Reneau (1992). Age unknown but may correlate with deposits north of quadrangle that contain 3.29±0.05 Ma Nomlaki Tuff (House and others, 2008). Thickness as much as 20 m. Subdivided into following:

QTab **Basalt-boulder conglomerate**—Poorly sorted, poorly bedded sand, gravel, and silt of local origin, angular to rounded. Moderately cemented, poorly sorted conglomerate characterized by angular to subrounded vesicular basalt boulders derived from Black Mountains. Gravel fraction includes as much as 10 percent rounded exotic clasts, including pebbles and cobbles of quartzite and chert. Deposits are widespread on Arizona piedmont in quadrangle. Overlies the alluvium of Bullhead City (unit Tcb) and underlies the Chemehuevi Formation (unit Qch), as seen in multiple exposures at foot of Arizona piedmont. Can be traced east of quadrangle to gravels underlying fans containing well-developed, indurated petrocalcic soils. Inferred to be late Pliocene or Early Pleistocene in age, on basis of ages of bounding units and degree of calcic soil development on uneroded surfaces east of quadrangle. Maximum local thickness as much as 15 m; maximum total thickness unknown

QTar **Rhyolite-boulder conglomerate**—Boulder-rich conglomerate covered with scattered, darkly varnished rhyolite cobbles and boulders, likely derived from the rhyolite of Eagle Peak of Simpson and others (1991) in Sacramento Mountains. Gravel fraction includes as much as 10 percent rounded exotic clasts, including pebbles and cobbles of quartzite and chert. Unit includes wider variety of clast types than the basalt-boulder conglomerate (unit QTab), including granite, gneiss, and silicic volcanic rocks. Varnished subrounded rhyolite cobbles and boulders give surface dark appearance on aerial photographs. Forms prominent, discrete ridge on California piedmont that is as much as 15 m higher than adjacent active washes. Surface is relatively undissected, likely owing to high resistance to erosion of boulder-rich deposit; surface shows valley-parallel lineations that are visible in aerial photographs, and it is overlain by thin remnants of the terrace sand and gravel (unit Qcts). Surface has stage III carbonate soil and 2-m-deep zone of 10-cm-diameter carbonate nodules under 30-cm-thick silty vesicular horizon; however, because it is overlain by the terrace sand and gravel (unit Qcts), it is likely that surface is exhumed fan surface stripped by Colorado River, and so stage III calcic soil does not reflect soil formation over entire time since deposition of bulk of deposit. Underlying units not exposed. On basis of its degree of cementation and presence of overlying veneer of the terrace sand and gravel (unit Qcts), unit is thought to underlie the older intermediate-age piedmont gravels (unit Qao) higher on California piedmont to west. Thus, unit probably is much older than the Chemehuevi Formation (Qch), and possibly is time-correlative to both the (adjacent) boulder conglomerate from Sacramento Mountains (unit QTas) and the basalt-boulder conglomerate (unit QTab) on Arizona side of quadrangle. Thickness as much as 20 m

QTas **Boulder conglomerate from Sacramento Mountains**—Poorly sorted, poorly bedded, angular to rounded sand, gravel, and silt of local origin. Gravel fraction consists of darkly varnished crystalline rocks, which include boulders derived from Sacramento Mountains and abundant rounded exotic pebbles and cobbles of quartzite and chert. Deposit is highly dissected and lacks uneroded surfaces; however, chips of pedogenic calcrete and massive calcite accumulations more than 1 cm thick on clasts scattered on regolith are remnants of stage IV to stage V petrocalcic soil. Underlies two discrete fan segments southwest of city of Needles on California piedmont. Underlying units not exposed. Unit may be correlative to the rhyolite-boulder conglomerate (unit QTar), but surface of unit is more dissected. Thickness as much as 20 m

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