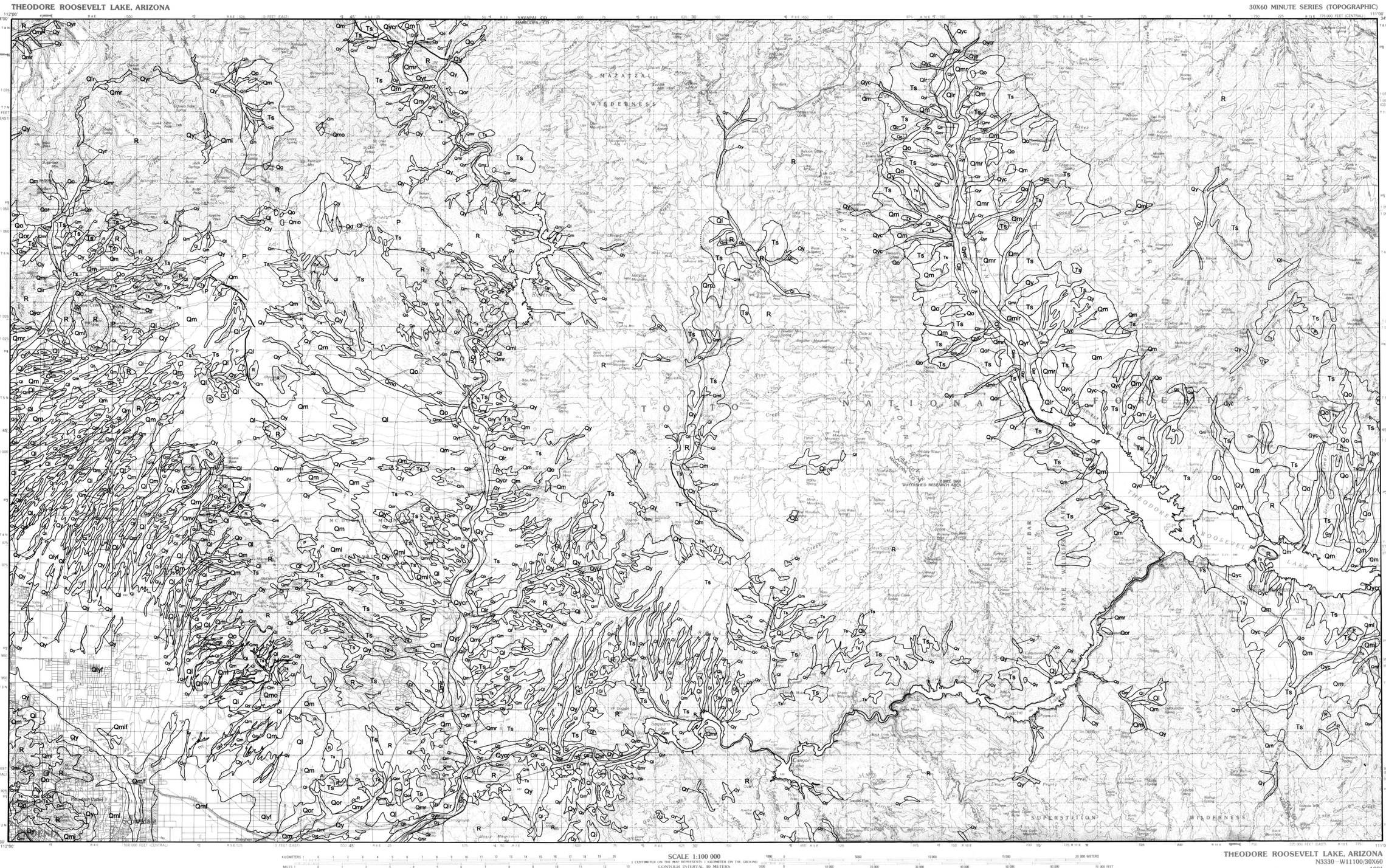

THEODORE ROOSEVELT LAKE, ARIZONA
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1981

Surficial Geologic Map of the Theodore Roosevelt Lake 30' x 60' Quadrangle, Arizona

by

Philip A. Pearthree, Steven J. Skotnicki, and Karen A. Demsey

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Introduction

This map summarizes the surficial geology of the Theodore Roosevelt Lake 30' x 60' Quadrangle in central Arizona. A substantial part of this quadrangle, including the rapidly growing northeastern Phoenix metropolitan area, is covered with Quaternary and Tertiary surficial deposits. On this map, we differentiate surficial deposits based; and their position in the regional landscape (stream deposits within mountains and on the broad piedmonts that slope gently down from mountain ranges, fine-grained deposits on basin floors, and river deposits) and their ages. The distribution and physical characteristics of different surficial geologic units have environmental and engineering implications. For example, areas covered by young deposits of the major rivers generally are flood prone and have the greatest potential for ground-water recharge. Old river and piedmont deposits typically have strongly developed, clay- and calcium carbonate-rich soils, whereas young deposits typically have sandy soils with minimal clay or calcium carbonate accumulation. The distribution of deposits of different ages on piedmonts provides information about areas that might be flood prone (areas covered with young deposits) and areas where excavation might be difficult (areas covered with old deposits). In addition, the distribution and character of surficial deposits of different ages provides information regarding the recent geologic history of the Theodore Roosevelt Lake Quadrangle (TRLQ).

The surficial geology and geomorphology of the TRLQ are fascinating because of their diversity. The TRLQ straddles the boundary between the Basin and Range physiographic province of southern and western Arizona and the Transition Zone of central Arizona. Thus, the northern, central, and eastern parts of the TRLQ have the rugged topography and deep dissection typical of the Transition Zone, whereas the southwestern part of the quadrangle has broad, minimally dissected valleys and low mountain ranges typical of the Arizona Basin and Range. The transition between these desparate landscapes exists in a broad band stretching from the Cave Creek-Carefree area southeastward along the lower Verde Valley. The Salt and Verde rivers and several of their large tributary streams also traverse the TRLQ. The deposits left by these streams and rivers add to the diversity of the surficial geology and provide hints about the nature of regional landscape evolution.

Methods

This map was developed through compilation of large-scale surficial geologic maps and original reconnaissance mapping of areas that have not been previously mapped. Most areas with extensive surficial deposits in the TRLQ are covered by published large-scale (1:24,000 or 1:48,000) surficial geologic maps completed in the past decade or so (figure 1). Preliminary 1:24,000-scale surficial geologic maps were prepared for several quadrangles in the Paradise Valley-Scottsdale area where no recent surficial geologic mapping had been done. Detailed surficial geologic mapping was generalized and modified in order to represent it at a smaller scale. The remainder of the TRLQ was mapped on a reconnaissance basis. Reconnaissance mapping involved review and compilation of alluvial deposits shown on existing geologic maps, interpretation of surficial geologic units utilizing aerial photographs, and limited field-checking of surficial geologic relationships. Most of the surficial geology of the southwesternmost corner of the TRLQ has been obscured by urban development or agricultural activity. In this area, published detailed soil surveys provide information about the distribution of soils of different types. Using soils information, we inferred the distribution of alluvial deposits of different ages on a reconnaissance basis.

Map Units

The surficial geologic units of this map are defined by their age and their location in the landscape. Surficial deposits of different ages in the TRLQ are recognized based on topographic position in the landscape, soil development, and surface characteristics. Age estimates of surficial deposits are based on correlation with other dated soil/deposit chronosequences in the southwestern United States. Age categories used in this map are as follows: Qy, Holocene (<10 ka; ka stands for thousands of years before the present); Ql, late Pleistocene (10 to 250 ka); Qm, middle Pleistocene (250 to 750 ka); Qo, early Pleistocene to late Pliocene (750 ka to ~2 Ma; Ma stands for millions of years before the present); and Tertiary (> 1.6 Ma). The three landscape categories used here are (1) intramontane and piedmont stream deposits (no letter added; e.g., Q); (2) fine-grained basin-floor deposits (letter f added; e.g., Qlyf); and (3) deposits of major rivers (letter r added; e.g., Qmr). Areas of exposed bedrock are subdivided into bedrock mountains and hills (R) and low-relief, fairly planar bedrock erosion surfaces or pediments (p).

Piedmont and Intramontane Deposits

Surficial deposits that mantle the piedmonts of this region and the limited deposits in the mountains are described in this section. Intramontane surficial deposits consist primarily of narrow stream channels and stream terraces and high, deeply dissected remnants of Tertiary basin-fill deposits. Piedmonts, the broad plains that slope gently down from mountain ranges toward basin floors or axial drainages, are predominantly covered by thin Quaternary surficial deposits. These deposits typically are poorly sorted, containing particles ranging in size from silt or clay to cobbles or boulders. Subangular gravel-sized clasts are generally an important component of these deposits, and the deposits are finer-grained away from mountain source areas. Piedmont channels, alluvial fans, and terraces range in age from modern to early Pleistocene. Erosional dissection and topographic relief on piedmonts varies dramatically across the quadrangle. In the southwestern part of the quadrangle, extensive bedrock pediments exist on the eastern and northern fringe of the Phoenix basin. There typically is less than a few meters of relief between piedmont alluvial deposits ranging in age from Holocene to middle Pleistocene. Piedmont deposits grade or interfinger downslope into finer-grained basin-floor deposits. Farther east or north, there typically is 10 m or more of topographic relief between Holocene and middle or early Pleistocene alluvial fans and terraces. In these areas, piedmont deposits typically grade downslope to terraces of the Salt and Verde rivers and their larger tributaries. Dissected early Pleistocene relict alluvial fans and Tertiary basin-fill deposits are fairly common in the northern, central, and eastern parts of the TRLQ.

Qyr (< 0.5 ka)

Very young deposits in the channels of larger ephemeral streams draining piedmonts and mountain areas are labeled Qyc. Qyc deposits are composed of unweathered sand, silt, pebbles, cobbles, and boulders. Qyc deposits are typically coarse and very poorly sorted within mountain areas and on upper piedmonts, with particles ranging from silt to cobbles or boulders. In areas subject to overbank flooding, however, Qyc deposits are primarily sand and silt. Drainage patterns of Qyc channels are generally dendritic in the mountains and on upper piedmonts. Within the larger Qyc channels and on the lower piedmonts distributary and anastomosing channel patterns are common. Many Qyc channels on lower piedmonts have discontinuous entrenched and unentrenched reaches.

Qyc alluvium is generally well-stratified and lacks any appreciable soil formation. Qyc soils are classified as Torrifluvents or Torriorthents. Most of the channel surfaces are modern in age, but vegetated bars may be several hundred years old.

Relatively large and dense vegetation tends to be associated with Qyc deposits because of the greater supply of moisture along modern drainages. Some of the larger drainages that originate in the mountains support streamflow in the mountains and upper piedmont areas during the winter and spring. These drainages may sustain large and lush riparian vegetation, such as cottonwood, sycamore, desert willow and tamarisk. Most Qyc channels only flow during or immediately after rainfall events, however. These channels typically are lined with palo verde, mesquite, or ironwood. Qyc surfaces are prone to flooding unless structures have been constructed to divert water from them. Due to relatively frequent wetting and high permeability, areas mapped as Qyc have high potential for ground-water recharge.

Qy (<10 ka)

Holocene alluvial deposits are mapped as Qy. Unit Qy consists primarily of small active channels and low terraces along them in the montane and upper piedmont areas and broad alluvial fans on middle and lower piedmonts. Many small active channels are also included in unit Qy on piedmonts or in the mountains where they could not be differentiated from slightly older deposits at the map scale. Qy deposits typically are associated with narrow stream channels and low terraces on upper piedmonts and within the mountains. In contrast, Qy alluvial fans cover much of the middle and lower piedmonts some portions of the TRLQ. Drainage networks on Qy alluvial-fan surfaces on middle and lower piedmonts typically are distributary or anastomosing, with discontinuous entrenched and unentrenched reaches. In upper piedmont and intramontane areas, Qy deposits are associated with dendritic drainage networks. Qy terraces and alluvial fan surfaces are 0 to 2 m above active channels. In the mountains and on upper piedmonts particle sizes range from fine sand to boulders; on lower piedmonts, sand, silt, and pebbles predominate.

Qy soils are weakly developed and primary fluvial bedforms (gravel bars and finer-grained swales) are commonly preserved. Surface colors typically are light brown to yellowish brown (color hues of 10 YR to 7.5 YR); slight reddening deeper in the soil profile is common. Surfaces have minimal or no rock varnish or desert pavement development. Pedogenesis is generally limited to surface enrichment of silt from eolian sources, slight reddening due to oxidation, and weak calcium carbonate accumulation, but Qy soils formed in higher altitude locations or areas with enhanced dust influx within the TRLQ show more evidence of clay translocation and accumulation (Huckleberry, 1997). Generally, late Holocene soils are minimally developed, whereas middle and early Holocene soils typically contain cambic horizons, weak calcic horizons (Stage I or less; morphologic stages of calcium carbonate accumulation are after Gile and others, 1981, and Machette, 1985), and are noticeably reddened. Qy soils classify as Torrifluvents, Torriorthents, Camborthids, and Calciorthids.

Based soil development and a few radiometric dates (Huckleberry, 1997), we estimate Qy surfaces range in age from modern to 10 ka. We correlate Qy deposits with the Q4, Q3c, and Q3b surfaces (< 8 ka) in the lower Colorado River valley (LCR) (Bull, 1991); and with the Fillmore alluvium (< 7 ka) in southern New Mexico near Las Cruces (SNM) (Gile and others, 1981).

Qy includes many small active channels, relatively low stream terraces, and active alluvial fans. All areas mapped as Qy may be subject to inundation during large floods and should be considered as potentially flood prone unless geomorphologic or hydrologic/hydraulic analyses indicate they are not. Due to relatively high permeability and the variable potential for inundation, areas mapped as Qy have moderate to high potential for ground-water recharge.

Ql (10 to 250 ka)

Late Pleistocene alluvial fan surfaces and terraces with moderate soil development are mapped as unit Ql. These deposits are common along mountain streams and on piedmonts. Ql units are typically alluvial fans on middle and lower piedmonts and terraces on upper piedmonts and in mountain areas. Alluvial sediment sizes range from sand to cobbles and boulders, coarser in upper piedmont and mountain areas. Drainage patterns on Ql surfaces are dendritic, with surface dissection varying from about 1 to 4 m. Desert pavement and rock varnish development is quite variable, ranging from nonexistent to moderate. Subdued depositional bar-and-swale surface topography is common.

Ql soils are more strongly developed than Qy soils, but their characteristics vary substantially. Ql surface colors typically are similar to or slightly redder than Qy surfaces (light brown to reddish yellow). Ql soils commonly contain argillic horizons (zones of clay accumulation) that are weakly to moderately strongly developed. These upper horizons of Ql soils are slightly (7.5 YR) to obviously (5 YR to 2.5 YR) reddened relative to their parent material. Calcic horizon morphologies are also quite variable, ranging from minimal carbonate accumulation in higher altitude locations to Stage III development in the western part of the quadrangle. Ql soils classify as Haplargids, Camborthids, and Calciorthids.

Unit Ql includes deposits of several different ages, probably ranging from slightly greater than 10 ka to as much as 100 to 200 ka. We correlate Ql deposits with the Q2c (12-70 ka) and possibly Q2b (70-200 ka) surfaces of the LCR (Bull, 1991), and the Isaac's Ranch (8-15 ka) and Jornada II (25-125 ka) surfaces of the SNM (Gile and others, 1981). The substantial time span covered by unit Ql and the altitudinal variations across the TRLQ probably are responsible for the considerable morphological variability displayed by Ql soils. All Ql soils have developed at least in part during times when the regional climate was wetter and cooler than the Holocene, but the oldest soils may be an order of magnitude older than the youngest soils. Although well developed, none of these soils have not yet reached the stage of pedogenic development when subsequent soil formation is impeded by plugged and indurated horizons. These late Pleistocene soils thus display greater morphological variability compared to older soils that have strong argillic horizons or petrocalcic horizons.

Ql units generally are not flood prone, except immediately adjacent to active washes. In lower piedmont areas where topographic relief is minimal, some areas mapped as Ql may be subject to inundation during extreme floods or may become subject to inundation as a result of relatively minor changes in the stream systems. Areas mapped as Ql generally have low recharge potential; their soils have moderate permeability but they are isolated from major washes.

Qm (250 to 750 ka)

Dissected middle Pleistocene alluvial-fan and terrace deposits with moderate to strong soil development are mapped as Qm. Both alluvial fans on middle and lower piedmonts and upper piedmonts throughout the TRLQ. Small Qm fans and terraces are also fairly common along streams and in small basins in mountain areas. Sediment grain sizes range from sand to boulders, fining downstream. Qm alluvial-fan surfaces typically have dendritic drainage and are heavily dissected by streams that head on them. Qm surfaces typically are 2 to 10 m above modern channels, with dissection increasing downslope as Qm surfaces converge with younger surfaces. Desert pavement and rock varnish development are moderate to strong on stable Qm surfaces, but may be variable or weak on surfaces that have experienced significant erosion.

Qm soils typically exhibit strong soil development. Surface color range from strong brown to reddish brown. Qm soils typically contain reddened argillic horizons (typically 5 YR to 2.5 YR) that are moderately to strongly enriched in pedogenic clay. Clasts within argillic horizons may be highly weathered. Calcic horizon development typically is fairly strong (Stage II-IV), but Qm units generally do not have cemented petrocalcic horizons (caliche). These soils classify as Calciorthids and Haplargids.

We estimate the age of Qm deposits to be 250 to 750 ka. Soils associated with the Qm unit typically are much more strongly developed than those associated with Ql, implying that Qm is substantially older than Ql. We correlate the Qm unit with Q2a surfaces (400-700 ka) of the LCR (Bull, 1991) the Jornada I (250-400 ka) and possibly Doña Ana (> 400 ka) surfaces of SNM (Gile and others, 1981).

Areas mapped as Qm are generally not flood prone except in and adjacent to washes. Because of their relatively impermeable argillic and petrocalcic horizons, Qm surfaces are not areas of significant ground-water recharge.

Qml (10 to 750 ka)

Qml is a composite map unit that contains both middle Pleistocene (Qm) and late Pleistocene (Ql) terrace and alluvial-fan deposits. Qml is used in in piedmont areas where Qm and Ql surfaces interfinger in a complex fashion and in mountain areas that were mapped on a reconnaissance basis. In piedmont areas, this unit includes middle and late Pleistocene deposits that have been distinguished on larger scale maps but cannot be represented separately at this scale. In the areas of reconnaissance mapping, it typically is difficult to confidently distinguish between middle and late Pleistocene deposits without extensive field investigations and soil descriptions, so an undifferentiated unit is employed. Areas mapped as Qml are not prone to flooding except in and immediately adjacent to washes, and they are not areas of significant recharge.

Qmo (500 ka to 1 Ma)

Dissected middle to early Pleistocene alluvial-fan deposits with to strong soil development are mapped as Qmo. Deposits typically are quite coarse and very poorly sorted, ranging from sand to boulders. Qmo alluvial-fan surfaces typically have dendritic drainage and are extensively dissected by streams that head on them. Qmo surfaces typically are 2 to 10 m above modern channels, with dissection decreasing downslope as Qmo surfaces converge with younger surfaces. Desert pavement and rock varnish development are typically strong on stable Qmo surfaces, but may be variable or weak on surfaces that have experienced significant erosion.

Qmo soils typically exhibit strong soil development. Surface colors are reddish brown, and soils contain reddened argillic horizons (typically 5 YR to 2.5 YR) that have clay texture. Clasts within argillic horizons commonly are highly weathered. Calcic horizon development typically is strong (Stage III-IV); Qmo units generally have weakly cemented petrocalcic horizons. These soils classify as Haplargids.

We estimate the age of Qmo deposits to be 500 ka to 1 Ma. Soils associated with the Qmo unit typically are more strongly developed than those associated with Qm, and dissection is deeper, implying that Qmo is older than Qm. We correlate the Qm unit with Q2a surfaces (400-700 ka) of the LCR (Bull, 1991) and the Doña Ana (> 400 ka) surfaces of SNM (Gile and others, 1981).

Areas mapped as Qmo are not flood prone except at their downslope termini, where topographic relief with younger surfaces diminishes. Because of their relatively impermeable argillic and petrocalcic horizons, Qmo surfaces are not areas of significant ground-water recharge.

Qo (750 ka to 2 Ma)

Deeply dissected remnants of very old Quaternary to late Pliocene alluvial fans with strong soil development are mapped as Qo. These relict alluvial fans exist in some upper piedmont areas throughout the TRLQ, and are quite extensive in the dissected basins of the TRLQ. Qo surfaces range from 5 to about 100 m above modern channels. The highest levels of Qo mark the highest stand of basin deposits along the upper piedmont in some places. Older deposits underlying and downslope from preserved Qo surfaces are mapped as Tertiary basin-fill deposits (Ts). In several areas in the central and northern TRLQ (the Tonto and Carefree basins, for example), however, basin-fill deposits exist at levels substantially higher than Qo surfaces. Qo deposits typically are cobbly to bouldery and are very poorly sorted, with grain sizes ranging from sand to boulders. Desert pavement on Qo surfaces varies from none to moderate; rock varnish varies from none to strong. Qo surfaces exist in areas where the clasts are composed of relatively resistant lithologies, such as fine-grained felsic volcanic rocks, gneissic, or metasedimentary rocks.

Qo soils range are characterized by strong carbonate and silica cementation and variable clay accumulation, depending on their preservation. In areas where fairly extensive planar Qo surfaces are preserved, Qo soils typically include reddish brown to red (5 YR to 2.5 YR), clay-rich argillic horizons and cemented duric (silica cemented) or petrocalcic horizons with laminar caps (caliche; Stage V). In areas where Qo remnants are of limited extent, or on slopes below planar fan surfaces, argillic horizons may have been removed by erosion leaving a duric or petrocalcic horizon as the uppermost soil horizon at the surface. Qo soils classify as Paleargids, Durargids, and Durorthids. The common presence of cemented fragments on Qo surfaces indicates erosion or bioturbation of the original surface.

We estimate the age of Qo alluvium to be 1 to 2 Ma. Unit Qo correlates with the Q1 surface in the LCR (Bull, 1991) and possibly the Doña Ana surface of the middle Rio Grande Valley (Gile and others, 1981). Both of these surfaces have open-ended age estimates (> 1.2 Ma for Q1 and > 400 ka for Doña Ana). Qo also correlates with the Martinez surface and equivalent surfaces (Menges and McFadden, 1981; Morrison, 1985), that are common to the basins of southeastern Arizona. Menges and McFadden (1981) estimate the age of the Martinez surface as 1-3 Ma based on very strong soil formation and magnetostratigraphy of underlying sediments.

Areas mapped as Qo are not flood prone. Impermeable argillic and petrocalcic horizons, high topographic positions, and relatively steep slopes associated with unit Qo severely limit the amount of groundwater recharge in these areas.

Ts (2 to 38 Ma)

Unit Ts consists primarily of late Tertiary alluvial sediment that was deposited in basins formed during extensional tectonism. Dissection of these deposits is variable, but they typically are deeply eroded into ridges and intervening valleys with as much as 100 m of local relief between modern stream channels and the highest levels of unit Ts. In some portions of the TRLQ, Ts sediment is capped by fan gravels of unit Qo. Generally, however, no original depositional surfaces are preserved at the highest levels of this unit. Ts deposits are poorly to extremely poorly sorted, subangular to subrounded pebbles, cobbles and boulders, with a sand, silt and clay matrix. Bedding ranges from crude to well-defined, and consolidation varies from weak to moderate. Unit Ts consists primarily of untilted Pliocene to middle Miocene deposits (unit Tly of Skotnicki, 1995), but locally includes tilted middle Miocene to Oligocene deposits (Skotnicki, 1992).

Basin-Floor Deposits

The fine-grained surficial deposits that mantle the undissected basin floors and lowermost piedmonts of the TRLQ are described in this section. The area covered by basin-floor deposits is the central portion of Paradise Valley, in the southwesternmost corner of the TRLQ. These deposits range in age from modern to middle Pleistocene, and their soil characteristics vary with age. Fine-grained basin-floor deposits interfinger with distal piedmont deposits in lower piedmont areas. Mapping basin-floor deposits is exceedingly difficult due to the lack of topographic relief, similarity of surface characteristics between deposits of different ages, and especially the extensive agricultural tillage of these areas. We relied heavily on published soil surveys to assess soil development in order to interpret the extent of basin-floor deposits of different ages. In addition, we employ fewer map units and more areas are mapped as composite units.

Qlyf (< 100 ka)

Unit Qlyf comprises the relatively young, fine-grained deposits with minimal to moderate soil development that mantle much of the lowermost piedmonts in Paradise Valley. Extensive Qlyf deposits typically surround young channel deposits (Qy), and they tend to increase in width downslope, indicating that they fine-grained alluvial-fan/sheet-flood deposits associated with ephemeral drainages. Unit Qlyf includes many small channels as well, and these commonly exhibit alternating entrenched and unentrenched reaches. Qlyf deposits typically are composed of sand, silt and clay, with some fine gravel. Original depositional bedding may be preserved, but more typically bioturbation has obscured sedimentary structures.

Soil development associated with Qlyf deposits is weak to moderate, consisting mainly of minor silt, clay and carbonate accumulation (stage I). Soils are primarily Torrifluvents, except where Qlyf deposits are thin (< 50 cm) over older soils. The minimal soil development associated with most deposits mapped as Qlyf implies that they are of Holocene age (< 10 ka), but some late Pleistocene fine-grained deposits are included in this unit.

Qlyf is composed of sheet-flood and overbank deposits. All of these areas should be considered as potentially flood prone unless they have been protected by flood-control structures or geomorphologic/hydrologic/hydraulic analyses indicate they are not. Due to moderate permeability and the potential for widespread inundation during large floods, areas mapped as Qlyf have moderate potential for ground-water recharge.

Qmlf (10 to 500 ka)

Unit Qmlf comprises fine-grained basin-floor deposits characterized by moderate to strong soil development indicative of some antiquity. Virtually all of these areas have been disturbed by urban development, so the original surface morphology and drainage patterns have been obscured. Qmlf deposits are composed of sand, clay and silt, with some fine gravel. Areas mapped as Qmlf have minimal local topographic relief, generally less than 1 m. These areas are not topographically distinct from areas covered by younger deposits (Qlyf and Qmlf), and commonly grade into areas of younger deposits.

Soil clay and calcium carbonate accumulation associated with unit Qmlf is moderate to strong. Qmlf soils are classified as Haplargids (older elements) and Camborthids (younger elements). Haplargids typically have moderately thick argillic horizons with clay loam textures and moderate calcic horizon development (stage II to III). Surface colors typically are brown (7.5 YR), but argillic horizons are reddish brown (5 YR). Camborthids typically have much less clay, but similar calcic horizon development. Moderate calcic horizon development and the presence some well-developed argillic horizons implies that older Qmlf deposits are of middle to late Pleistocene age.

Qmf (250 to 750 ka)

Unit Qmlf comprises fine-grained basin-floor deposits characterized by strong soil development indicative of some antiquity. Virtually all of these areas have been disturbed by agricultural activity or urban development, so the original surface morphology and drainage patterns have been obscured. Qmf deposits are composed of sand, clay and silt, with some fine gravel. Areas mapped as Qmf have minimal local topographic relief, generally less than 1 m. These areas are not topographically distinct from areas covered by younger deposits (Qlyf and Qmlf), and commonly grade into areas of younger deposits.

Soils associated with unit Qmf are strongly developed. Qmf soils are classified as Haplargids, with thick argillic horizons with clay or clay loam textures and moderate to strong calcic horizon development (stage III to IV). Surface colors typically are brown (7.5 YR), but argillic horizons are reddish brown (5 YR). The presence strongly developed argillic horizons implies that older Qmf deposits are of middle to late Pleistocene age. The existence of these old deposits at the surface implies that some basin-floor areas have received minimal sediment aggradation since the middle Pleistocene, even though there is little topographic relief in these areas.

Major-River Deposits

Deposits of the major rivers that traverse the TRLQ are described in this section. The Salt and Verde rivers drain nearly all of central Arizona. Deposits of each of these rivers and their major tributaries consist of active channels and one or more terraces that represent former, higher positions of the stream channels. These river terraces, which range from Holocene to early Pleistocene or Pliocene in age, record the recent geologic evolution of the major rivers. The heights of river terraces above modern stream channels increase relative to modern channels from west to east and south to north across the TRLQ. This phenomenon has been interpreted by several authors as evidence for regional uplift of the Transition Zone of central Arizona relative to the Basin and Range province of south-central Arizona (Péwé, 1978; Menges and Pearthree, 1989; Huckleberry, 1993a).

Major river deposits are distinguished from piedmont and basin-floor deposits by their diverse lithologic composition, their clast rounding, and their landform morphology. These rivers drain large, geologically-complex areas, so their sediment is composed of many different lithologies. River sediment typically has been transported a long distance prior to its deposition in this area, so clasts generally are much more rounded than those of piedmont gravels. River terraces typically are elongate landforms that mimic the general trend of the modern rivers. Terraces are bounded on at least one side by a scarp (or riser) that either drops down to the next younger terrace or rises up to the next older terrace. Modern river channels and terraces of different ages are similar sedimentologically, and are distinctly different from piedmont gravels (Kokalis, 1971).

Qycr (< 0.1 ka)

Modern channels of the Salt and Verde rivers and their larger tributaries are mapped as unit Qycr. The channels of these major streams have been shaped primarily by large floods, with some modification by human activity. The form and extent of modern channels have varied substantially during the historical period (for example, Pearthree, 1996). The locations of channels shown on this map are as they existed when original, large-scale geologic mapping was completed (see earlier section for data sources). Channel banks are commonly well-defined, ranging from 1 to 3 m in height. Along some stream reaches, however, channel depth decreases and the channel diverges into several smaller, anastomosing channels. Channel deposits consist primarily of sand, cobbles, and boulders, with local accumulations of silt. The Salt River channel especially has distinctly coarse sediment, dominated by rounded cobbles and small boulders. Deposits within Qycr channels are modern to historical in age.

Areas mapped as Qycr have been flooded one or more times during the historical period and should be considered flood prone. Even though upstream dams on the Salt and Verde rivers provide some mitigation of flooding, channel areas suffer serious inundation during large flow events. Due to the permeability of the sediment and the frequency of flow, major river channels are the areas with the greatest potential for ground-water recharge in the TRLQ.

Qyr (< 10 ka)

Low terrace deposits with weak soil development are mapped as unit Qyr. Several different levels of terraces are included in this map unit. The lowest and youngest of these terraces are discontinuous and contain both channel (crudely bedded coarse sands, gravels, and cobbles) and overbank (finely laminated clays, silts, and fine sands) sediments. Soil development is limited to slight organic accumulation at the surface and some bioturbation; soils classify as Torrifluvents.

Somewhat older Holocene terraces comprise the majority of unit Qyr. Included in this subdivision are the Lehi terrace of the Salt and Verde rivers (Péwé, 1978) and the Hidden View terrace of Cave Creek (Gorey, 1990). These terraces range from 1 to 5 m above active channels. They are fairly continuous and broad; they contain both channel and overbank deposits, with the latter dominating the upper part of the terrace. Alluvial bedforms near the surface are absent or weakly expressed due to bioturbation. There is organic accumulation in uppermost soil horizons, and slightly oxidized horizons exist at deeper levels. In places, fine nodules of calcium carbonate have begun to accumulate. Soils on the Qyr terraces are Torrifluvents and Camborthids.

Many areas mapped as Qyr may be subject to flood hazards. Portions of Qyr terraces have been inundated in large historical floods (Péwé, 1978), even after dams were constructed upstream. Lateral bank erosion during floods is also a major hazard, because major changes in channel form and position have occurred in large floods (Pearthree, 1996) and the weakly consolidated deposits of Qyr terraces typically are susceptible to erosion. Qyr terraces may be areas of significant ground-water recharge if they are inundated during large floods.

Qlr (10 to 250 ka)

Late Pleistocene river terraces with moderate soil development are mapped as unit Qlr. Terraces of this age include the Blue Point Terrace of the Salt River (Péwé, 1978) and the Cahava Ranch terrace of Cave Creek (Gorey, 1990). Qlr terraces are limited in extent in the TRLQ, and Qlr terrace deposits typically are thin. Qlr terrace surfaces range from about 2 to 15 m above modern channels. In mountain areas along the Salt River, Qlr terraces are relatively narrow straths eroded into bedrock, with thin (< 3 m) caps of alluvial deposits. Qlr terrace surfaces have undergone some dissection by small streams that flow across them.

Based primarily on soil development, we believe that Qlr terraces are moderately old, but substantially younger than the next older river terraces described below. Soil development on Qlr terraces is moderate, with 5 to 7.5 YR reddening, moderate clay accumulation, and stage II calcium carbonate accumulation (Anderson and others, 1986).

Qlr terraces are not prone to flooding from the major rivers, although minor flooding might occur along small drainages on the terraces. Lateral bank erosion could be a hazard where Qlr terraces abut the active river channels (unit Qycr). Qlr deposits are fairly permeable, but inundation is limited, so Qlr terraces are not areas of significant recharge.

Qmr (250-400 ka)

Unit Qmr includes intermediate terraces with moderately strong soil development along the Verde River. Terraces grouped in this map unit are equivalent to the McDowell terrace (Pope, 1974; Péwé, 1978). Qmr terraces are about 30 m above the modern channel. Soil development includes relatively thick argillic horizons with clay textures and abundant carbonate, but no cemented petrocalcic horizons.

Qmr (400 to 750 ka)

Unit Qmr includes prominent high terraces with strong soil development. Terraces grouped in this map unit include the Mesa terrace along the Salt and Verde rivers (Péwé, 1978) and the Mesquite Tank terrace along Cave Creek (Gorey, 1990). Qmr terraces range in height above the modern channel from 5 to 10 m in the south and west to as much as 30 to 70 m in the east. Qmr alluvium is composed of sand, gravel, and cobble channel deposits with interfingered silty and clayey overbank sediments. Desert pavement and rock varnish development is weak to moderate. Some Qmr terraces have broad, well-preserved alluvial surfaces. In many areas, however, Qm surfaces do not have a planar morphology because they have been eroded by streams that head on them or that flow across them. Eroded Qmr landforms consist of series of low, rounded ridges and moderately incised stream channels.

Soils associated with Qmr terraces are strongly developed where they have not been seriously eroded. Clay accumulation in Qmr soils is variable; well-preserved soils have fairly strong, red argillic horizons with loam to clay loam textures (Anderson and others, 1987). Qmr soils typically have strongly developed calcic or petrocalcic horizons (Stage III-V) (Péwé, 1978; Anderson and others, 1986) and classify as Calciorthids, Paleorthids and Paleargids. Strongly developed surface soils and the extent of surface dissection suggest that Qmr terraces are at least several hundred thousand years, and possibly as much as 1 million years old (see Péwé, 1978). Using total soil development in a Mesa terrace soil, Anderson and others (1986) estimated an age range of 350 to 775 ka for the terrace.

Qor (1 to 2 Ma)

Very old, very high, degraded river terrace remnants are mapped as Qor. Unit Qor includes the Sawik terrace along the Salt and Verde rivers (Péwé, 1978) and the Little Elephant terrace along Cave Creek (Gorey, 1990). Along the Salt River and in the lower Verde River valley, Qor terraces exist as isolated remnants standing high above the Mesa (Qmr) terrace. They are found up to 180 m above modern stream channels in Tonto basin above Theodore Roosevelt Dam (Anderson and others, 1987). Because Qor terrace deposits have been exposed to erosion for most of the Quaternary, they seldom retain their original terrace form and instead form a series of isolated ridges and hills. Qor deposits are coarse, with clasts ranging in size from pebbles to boulders. Coarse-grained rocks at the surface are highly pitted, and fine-grained rocks are commonly fractured. There is no desert pavement development in areas that have undergone significant erosion, but in a few places where depositional surfaces are preserved desert pavement and rock varnish are moderately to strongly developed.

Qor soils are dominated by thick petrocalcic horizons with Stage IV-V morphology. Secondary silica incorporated within the petrocalcic horizons appears as light brown, thin laminae. Based on the extremely strong soil development and the height of Qor terraces above modern stream channels, their age is likely to be at least 1 million years old, and they may be as old as late Pliocene (Péwé, 1978; Anderson and others, 1986).

Bedrock Areas

Pediments (p)

Extensive bedrock pediments exist around the northeastern margin of the Phoenix metropolitan area and locally within some of the bedrock areas in the central part of the TRLQ. The very broad Pinnacle Peak pediment surrounds the northern McDowell Mountains. Bedrock pediments are low-relief erosion surfaces with minimal alluvial cover that have developed by erosional backwearing of mountain masses. On this map, we show pediments only where exposed bedrock predominates, and alluvial cover is scarce or nonexistent. Pediments mantled by thin alluvial cover undoubtedly are much more extensive than exposed pediments. Pediments probably form by a combination of deep chemical weathering of bedrock and lateral erosion by streams that flow across the pediment (see Huckleberry, 1993b, for more detailed review of processes of pediment formation). Pediments thus are commonly developed on lithologies that are susceptible to chemical weathering in the subsurface. In the TRLQ, pediments are developed primarily on granitic rocks.

Bedrock (R)

Bedrock lithologies are not differentiated on this map.

Quaternary faults

Faults that have documented middle or late Quaternary activity are shown on this map. Each of these faults has probably generated one or more large (magnitude 6.5 or greater) earthquakes during the past few hundred thousand years. Recurrence intervals between large earthquakes on these faults are on the order of 100,000 years. See Piety and Anderson, 1990, Pearthree and others, 1995, and Skotnicki and others, 1997, for more detailed discussion of these faults.

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References

Adams, E.D., 1974, Soil survey of eastern Maricopa and northern Pinal counties area, Arizona: U.S. Dept. of Agriculture, Soil Conservation Service, 62 p., map scale 1:20,000.

Anderson, L.W., Piety, L.A., and Hansen, R.A., 1986, Seismotectonic investigation, Stewart Mountain Dam, Salt River Project, Arizona: U.S. Bureau of Reclamation, Denver, Seismotectonic Report 86-2, 41 p., 3 plates, scales 1:24,000 and 1:12,000.

Anderson, L.W., Piety, L.A., and LaForge, R.C., 1987, Seismotectonic investigation, Theodore Roosevelt Dam, Salt River Project, Arizona: U.S. Bureau of Reclamation, Denver, Seismotectonic Report 87-5, 46 p., scale 1:48,000.

Bull, W.B., 1991, Geomorphic responses to climatic change: New York, Oxford University Press, 326 p.

Camp, P.D., 1986, Soil survey of Aguila-Carefree area, parts of Maricopa and Pinal counties, Arizona: U.S. Dept. of Agriculture, Soil Conservation Service, 306 p., map scale 1:24,000.

Christenson, G.E., Welsch, D.G., and Péwé, T.L., 1978, Environmental geology of the McDowell Mountains area, Maricopa County, Arizona: Arizona Geological Survey Geologic Investigations Folio GI-1, 10 sheets, scale 1:24,000.

Gilbert, W.G., and Ferguson, C.A., 1997, Geology of the Horse Mesa Dam quadrangle, Maricopa and Gila counties, Arizona: AZGS OFR 97-15, 14 p. scale 1:24,000.

Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology in the basin and range area of southern New Mexico — guidebook ot the Desert Project: New Mexico Bureau of Mines and Mineral Resources Memoir 39, 222 p.

Gorey, T.L., 1990, Stream terraces of middle Cave Creek, Maricopa County, Arizona: Tempe, Arizona State University, unpublished M.S. thesis, 96 p., 2 plates, map scale 1:24,000.

Huckleberry, Gary, 1993a, Surficial geology of the Middle Gila River area, north-central Pinal County, Arizona: AZGS OFR 93-3, 52 p., 5 maps, scale 1:24,000.

Huckleberry, Gary, 1993b, Surficial geology of the Superstition Mountain piedmont area, northern Pinal and eastern Maricopa counties, Arizona: AZGS OFR 93-15, 33 p., 6 maps, scale 1:24,000.

Huckleberry, Gary, 1997, Rates of Holocene formation in south-central Arizona: AZGS OFR 97-7, 27 p.

Kokalis, P.G., 1971, Terraces of the lower Salt River Valley, Arizona: Tempe, Arizona State University, unpublished M.S. thesis, 103 p., 2 plates, map scale 1:24,000.

Leighty, R.S., Skotnicki, S.J., and Pearthree, P.A., 1997