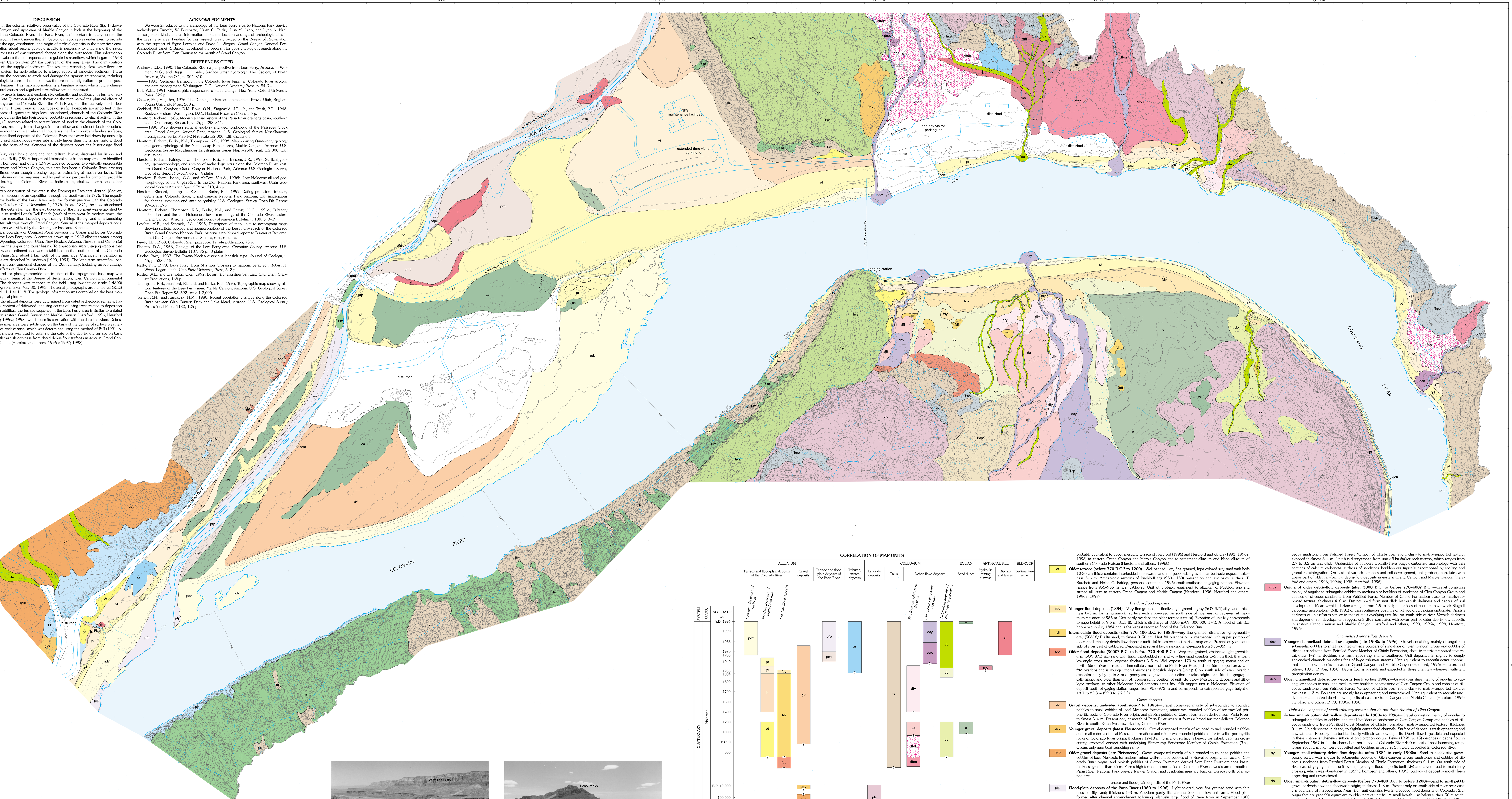
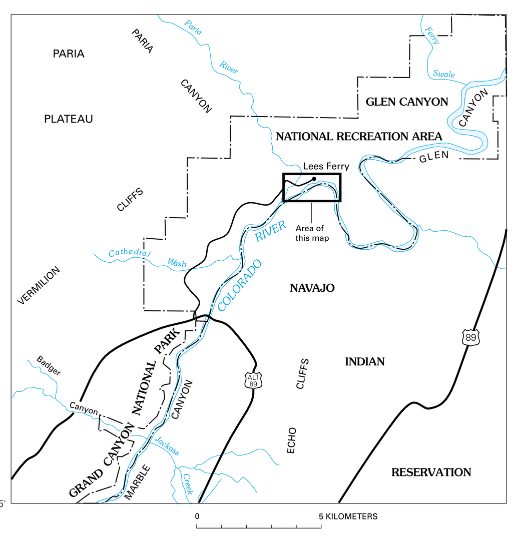
DISCUSSION

ACKNOWLEDGMENTS

REFERENCES CITED



Present (1996) and Past (1921) Views of the Lees Ferry Area



LOCATION OF MAP AREA, WESTERN GRAND CANYON, ARIZONA

Figure 1. (A) Colorado River and Lees Ferry area from Spencer Trail; view to the southwest; photograph taken May 8, 1996 by Richard Hereford. (B) Approximately same scene as 1A, photograph taken 1921. Several of the mapped units are shown with labels; line across river is cableway. From Emery Kolb Collection (accession no. 568-4600), Special Collections Library, Northern Arizona University, Flagstaff.

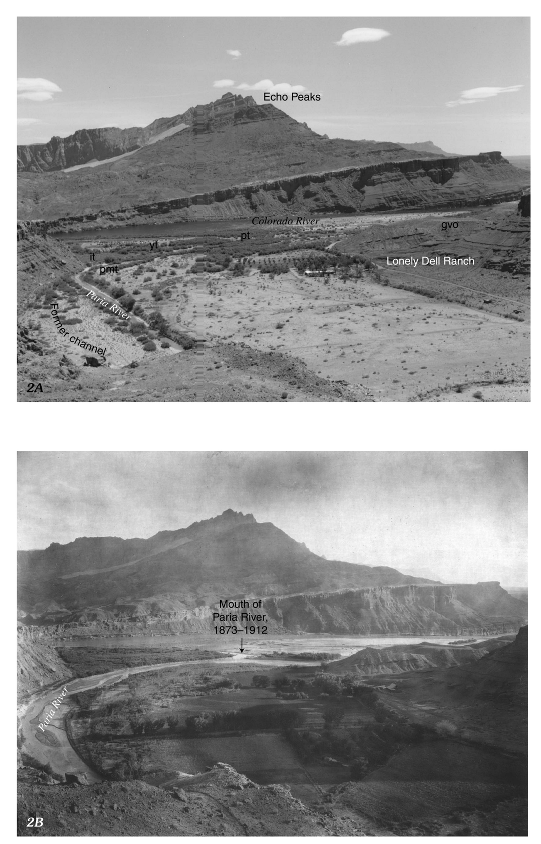


Figure 2. (A) Lonely Dell Ranch and Lees Ferry area; view to southeast; photograph taken May 7, 1996 by Richard Hereford. (B) Approximately same scene as 2A, photograph taken 1921. Several of the mapped units are shown where they occur at the north boundary of map area. From Emery Kolb Collection (accession no. 568-1363), Special Collections Library, Northern Arizona University, Flagstaff.

CORRELATION OF MAP UNITS

DESCRIPTION OF MAP UNITS

[All ages are anno Domini (A.D.) unless otherwise indicated. Color codes from Goddard and others, 1948]

ALLUVIUM

Terrace and flood-plain deposits of the Colorado River

Post-dam deposits and surfaces

pdz **Post-dam zone (1963–1996)**—Very fine grained, light-colored sand and gravel; deposits poorly preserved; thickness 0–2 m. Elevation ranges from 949–952 m near cableway. Mostly an erosional zone along margin of Colorado River. Sand spottily distributed on gravel; bounded by steep, erosional cutbanks adjoining older terraces. Dense groves of small, relatively mature saltcedar trees present locally; tree-ring counts indicate germination in 1963. Equivalent to units ff, hf, and fs of Hereford (1996), Hereford and others (1993; 1996a; 1998), and Leschin and Schmidt (1995)

Pre-dam terraces and related deposits

pt **Pre-dam terrace (early 1920s to 1957–1958)**—Well-bedded, very fine grained, light-colored silty sand with beds 10–20 cm thick; exposed thickness 1–3 m. Interbedded with lower part of alluvium of modern terrace of Paria River (unit pmt) at mouth of Paria Canyon. Elevation ranges from 951–953 m near cableway. Mature saltcedar trees in dense groves partly buried in alluvium are typical; part of unit post-dates 1935 on basis of ring counts from tree rooted beneath terrace on south side of river upstream of gaging station. Driftwood on terrace contains abundant cut-and-milled wood and cans and bottles dating from mid-1950s. Unit equivalent to pre-dam alluvium of Hereford and others (1993; 1996a; 1998) and Hereford (1996) in Marble Canyon and eastern Grand Canyon on basis of similarities in vegetation, position in channel relative to post-dam zone (unit pdz), and flood debris

yt **Younger terrace (1884 to early 1920s)**—Well-bedded, very fine grained, light-colored silty sand with beds 10–20 cm thick; contains interbedded tributary sheetwash sand and pebble-size gravel near tributaries; exposed thickness 3–4 m. Interbedded with unmapped alluvium of Paria River at mouth of Paria Canyon. Elevation ranges from 953–955 m on north side of river downstream of cableway. Saltcedar locally abundant on terrace; trees are rooted on surface and post-date deposition; ring counts indicate germination in early to mid-1960s. Stumps of willow present locally. Unit yt probably correlates with lower mesquite terrace of Hereford and others (1993; 1996a; 1998) and Hereford (1996) in Marble Canyon and eastern Grand Canyon

it **Intermediate terrace (1400? to 1883)**—Well-bedded, very fine grained, light-colored silty sand with beds 10–20 cm thick; contains interbedded sheetwash sand and pebble gravel near tributaries; thickness 4–5 m. Unit interbedded with unmapped alluvium of Paria River at mouth of Paria Canyon. Elevation ranges from 953–956 m on north side of river downstream of cableway. Saltcedar and willow not present on terrace. A photograph of north bank of Colorado River taken in 1873 shows intermediate terrace (unit it) between present parking area and boat-launch ramp (Turner and Karpiscak, 1980, plates. 32A, 33A); at that time terrace was densely covered with rabbitbrush and fresh-appearing driftwood. Intermediate terrace is probably equivalent to upper mesquite terrace of Hereford (1996) and Hereford and others (1993; 1996a; 1998) in eastern Grand Canyon and Marble Canyon and to settlement alluvium and Naha alluvium of southern Colorado Plateau (Hereford and others, 1996b)

ot **Older terrace (before 770 B.C.? to 1200)**—Well-bedded, very fine grained, light-colored silty sand with beds 10-30 cm thick; contains interbedded sheetwash sand and pebble-size gravel near bedrock; exposed thickness 5–6 m. Archeologic remains of Pueblo-II age (950–1150) present on and just below surface (T. Burchett and Helen C. Fairley, personal commun., 1996) south-southeast of gaging station. Elevation ranges from 955–956 m near cableway. Unit ot probably equivalent to alluvium of Pueblo-II age and striped alluvium in eastern Grand Canyon and Marble Canyon (Hereford, 1996; Hereford and others, 1996a; 1998)

Pre-dam flood deposits

fdy **Younger flood deposits (1884)**—Very fine grained, distinctive light-greenish-gray (5GY 8/1) silty sand; thickness 0–3 m; forms hummocky surface with arrowweed on south side of river east of cableway at maximum elevation of 956 m. Unit partly overlaps the older terrace (unit ot). Elevation of unit fdy corresponds to gage height of 9.6 m (31.5 ft), which is discharge of 8,500 m^3/s (300,000 ft^3/s). A flood of this size happened in July 1884 and is the largest recorded flood of the Colorado River

fdi **Intermediate flood deposits (after 770–400 B.C. to 1883)**—Very fine grained, distinctive light-greenish-gray (5GY 8/1) silty sand; thickness 0–50 cm. Unit fdi overlaps or is interbedded with upper portion of older small tributary debris-flow deposits (unit do) in easternmost part of map area. Present only on south side of river east of cableway. Deposited at several levels ranging in elevation from 956–959 m

fdo **Older flood deposits (3000? B.C. to before 770–400 B.C.)**—Very fine grained, distinctive light-greenish-gray (5GY 8/1) silty sand with finely interbedded silt and very fine sand couplets 1–5 mm thick that form low-angle cross strata; exposed thickness 3–5 m. Well exposed 170 m south of gaging station and on north side of river in road cut immediately north of the Paria River Road just outside mapped area. Unit fdo overlaps and is younger than Pleistocene landslide deposits (unit pls) on south side of river; overlain disconformably by up to 3 m of poorly sorted gravel of solifluction or talus origin. Unit fdo is topographically higher and older than unit ot. Topographic position of unit fdo below Pleistocene deposits and lithologic similarity to other Holocene flood deposits (units fdy, fdi) suggest unit is Holocene. Elevation of deposit south of gaging station ranges from 958–973 m and corresponds to extrapolated gage height of 18.7 to 23.3 m (59.9 to 76.3 ft)

Gravel deposits

gv **Gravel deposits, undivided (prehistoric? to 1983)**—Gravel composed mainly of sub-rounded to rounded pebbles to small cobbles of local Mesozoic formations, minor well-rounded cobbles of far-travelled porphyritic rocks of Colorado River origin, and pinkish pebbles of Claron Formation derived from Paria River; thickness 3–4 m. Present only at mouth of Paria River where it forms a broad fan that deflects Colorado River to south. Extensively reworked by Colorado River

gvy **Younger gravel deposits (latest Pleistocene)**—Gravel composed mainly of rounded to well-rounded pebbles and small cobbles of local Mesozoic formations and minor well-rounded pebbles of far-travelled porphyritic rocks of Colorado River origin; thickness 12–13 m. Gravel on surface is heavily varnished. Unit has cross-cutting erosional contact with underlying Shinarump Sandstone Member of Chinle Formation (Ꞧcs). Occurs only near boat launching ramp

gvo **Older gravel deposits (late Pleistocene)**—Gravel composed mainly of sub-rounded to rounded pebbles and cobbles of local Mesozoic formations, minor well-rounded pebbles of far-travelled porphyritic rocks of Colorado River origin, and pinkish pebbles of Claron Formation derived from Paria River drainage basin; thickness greater than 25 m. Forms high terrace on north side of Colorado River downstream of mouth of Paria River. National Park Service Ranger Station and residential area are built on terrace north of mapped area

Terrace and flood-plain deposits of the Paria River

pfp **Flood-plain deposits of the Paria River (1980 to 1996)**—Light-colored, very fine grained sand with thin beds of silty sand; thickness 1–3 m. Alluvium partly fills channel 2–3 m below unit pmt. Flood plain formed after channel entrenchment following relatively large flood of Paria River in September 1980 (Hereford, 1986)

pmt **Modern terrace of the Paria River (early 1940s to 1980)**—Light-colored, very fine grained sand with thin, lenticular beds of gravel and continuous beds of silty sand; thickness 2–3 m. Unit is well exposed near Paria River gaging station 0.6 km northwest of mapped area where deposits were dated and described by Hereford (1986). In map area, unit has three distinct levels that are probably related to diversion of the Paria River channel by construction of levees (unit rl). Unit pmt correlates with the modern alluvium of the Virgin River and other southern Colorado Plateau streams (Hereford and others, 1996b)

Tributary stream deposits

af **Alluvial-fan deposits (after 1884 to 1996)**—Sand to small-cobble gravel having a roughly fan-shaped surface beneath steep slopes of gravel and bedrock; thickness 0–1 m. Unit overlaps hydraulic mining outwash (unit mo) in northern part of mapped area and overlies the younger terrace (unit yt) in western part of mapped area

COLLUVIUM

Landslide deposits

pls **Pleistocene landslide deposits (middle? to late Pleistocene)**—Poorly sorted blocks of brown and red sandstone and large, steeply dipping, rotated segments of Glen Canyon Group (Mesozoic) sandstone, which are Toreva blocks as defined by Reiche (1937). Deposits present in eastern part of mapped area at outcrops of the Petrified Forest Member of Chinle Formation; bentonitic clays of Petrified Forest Member combined with moisture resulted in slope failure and landslides

Talus

ts **Talus, undivided (Holocene)**—Occurs in five styles or modes: (1) Cobble to large boulder-size, angular blocks of Glen Canyon Group sandstones; (2) talus cones and sheets beneath walls of Glen Canyon; (3) cobble gravel reworked from older gravel deposits (unit gvo); (4) sheets of small to medium boulder-size blocks of Shinarump Sandstone Member of Chinle Formation beneath outcrops of Shinarump Sandstone; and (5) sheets of small boulder-size talus derived from reworking of Pleistocene landslide deposits (unit pls). Thickness of unit varies widely from less than 1 m to greater than 10 m. Older talus deposits are typically dissected and expose underlying bedrock. Sandstone blocks are distinctly and darkly varnished; younger talus deposits overlying unit fdo have mean varnish darkness of 2.8 (Bull, 1991, p. 63–64; value + chroma/2; small numbers indicate dark varnish and relatively large numbers indicate light varnish)

Debris-flow deposits

Fan-forming debris-flow deposits of large tributaries draining rim of Glen Canyon

dfy **Younger fan-forming debris-flow deposits (after 1400? to early 1900s)**—Gravel consisting mainly of angular to sublangular cobbles to small boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; clast- to matrix-supported texture; thickness 1–2 m. Boulders are fresh appearing with none to slight rock varnish. Overlies unit fdy on south side of river 300 m east-southeast of gaging station. Equivalent to younger fan-forming debris-flow deposits of eastern Grand Canyon and Marble Canyon (Hereford, 1996; Hereford and others, 1993; 1996a; 1998) on basis of lack of varnish and soil development

dfi **Intermediate debris-flow deposits (660? to 1200)**—Gravel consisting mainly of angular to subangular cobbles to medium-size boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; clast- to matrix-supported texture; thickness 1–3 m. On south side of river 120 m south-southeast of gaging station, unit dfi is interbedded with flood deposits of Colorado River (unit fdi) at 957 m elevation. Boulders are distinctly varnished; varnish darkness ranges from 3.2 to 3.5. Beneath surface, undersides of boulders have incipient Stage-I carbonate morphology (Bull, 1991) of thin discontinuous white coatings of calcium carbonate. Unit correlates with intermediate-age, fan-forming debris-flow deposits of eastern Grand Canyon and Marble Canyon (Hereford and others, 1993; 1996a; 1998; Hereford, 1996) on basis of varnish darkness and incipient soil development

dfob **Unit b of older debris-flow deposits (before 770–400? B.C. to 660)**—Gravel consisting mainly of angular to subangular cobbles to medium-size boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; clast- to matrix-supported texture; exposed thickness 3–4 m. Unit b is distinguished from unit dfi by darker rock varnish, which ranges from 2.7 to 3.2 on unit dfob. Undersides of boulders typically have Stage-I carbonate morphology with thin coatings of calcium carbonate; surfaces of sandstone boulders are typically decomposed by spalling and granular disintegration. On basis of varnish darkness and soil development, unit probably correlates with upper part of older fan-forming debris-flow deposits in eastern Grand Canyon and Marble Canyon (Hereford and others, 1993; 1996a; 1998; Hereford, 1996)

dfoa **Unit a of older debris-flow deposits (after 3000 B.C. to before 770–400? B.C.)**—Gravel consisting mainly of angular to subangular cobbles to medium-size boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; clast- to matrix-supported texture; thickness 4–6 m. Distinguished from unit dfob by varnish darkness and degree of soil development. Mean varnish darkness ranges from 1.9 to 2.4; undersides of boulders have weak Stage-II carbonate morphology (Bull, 1991) of thin continuous coatings of light-colored calcium carbonate. Varnish darkness of unit dfoa is similar to that of talus overlying unit fdo on south side of river. Varnish darkness and degree of soil development suggest unit dfoa correlates with lower part of older debris-flow deposits in eastern Grand Canyon and Marble Canyon (Hereford and others, 1993; 1996a; 1998; Hereford, 1996)

Channelized debris-flow deposits

dcy **Younger channelized debris-flow deposits (late 1900s to 1996)**—Gravel consisting mainly of angular to subangular cobbles to small and medium-size boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; clast- to matrix-supported texture; thickness 1–2 m. Boulders are fresh appearing and unweathered. Unit deposited in slightly to deeply entrenched channels on debris fans of large tributary streams. Unit equivalent to recently active channelized debris-flow deposits of eastern Grand Canyon and Marble Canyon (Hereford, 1996; Hereford and others, 1993; 1996a; 1998). Debris flow is possible and expected in these channels whenever sufficient precipitation occurs.

dco **Older channelized debris-flow deposits (early to late 1900s)**—Gravel consisting mainly of angular to subangular cobbles to small and medium-size boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; clast- to matrix-supported texture; thickness 1–2 m. Boulders are mostly fresh appearing and unweathered. Unit equivalent to recently inactive older channelized debris-flow deposits of eastern Grand Canyon and Marble Canyon (Hereford, 1996; Hereford and others, 1993; 1996a; 1998)

Debris-flow deposits of small tributary streams that do not drain the rim of Glen Canyon

da **Active small-tributary debris-flow deposits (early 1900s to 1996)**—Gravel consisting mainly of angular to subangular pebbles to cobbles and small boulders of sandstone of Glen Canyon Group and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; matrix-supported texture; thickness 0–1 m. Unit deposited in deeply to slightly entrenched channels. Surface of deposit is fresh appearing and unweathered. Probably interbedded locally with streamflow deposits. Debris flow is possible and expected in these channels whenever sufficient precipitation occurs. Péwé (1968, p. 15) describes a debris flow in September 1967 in the da channel on north side of Colorado River 400 m east of boat launching ramp; levees about 1 m high were deposited and boulders as large as 5 m were deposited in Colorado River

dy **Younger small-tributary debris-flow deposits (after 1884 to early 1900s)**—Sand to cobble-size gravel, poorly sorted with angular to subangular pebbles of Glen Canyon Group sandstones and cobbles of siliceous sandstone from Petrified Forest Member of Chinle Formation; thickness 0–1 m. On south side of river east of gaging station, unit overlaps younger flood deposits (unit fdy) and covers road to main ferry crossing, which was abandoned in 1929 (Thompson and others, 1995). Surface of deposit is mostly fresh appearing and unweathered

do **Older small-tributary debris-flow deposits (before 770–400 B.C. to before 1200)**—Sand to small pebble gravel of debris-flow and sheetwash origin; thickness 1–3 m. Present only on south side of river near eastern boundary of mapped area. Near river, unit contains two interbedded flood deposits of Colorado River origin that are probably equivalent to older part of unit fdi. A small hearth 1 m below surface 50 m southwest of river contains charcoal that dates to 2,430 ± 55 years, which calibrates to 770–400 B.C.; 100 m south of river, Pueblo-II archeologic remains are present on surface of unit and suggest surface of unit could be as young as 1200 (Lisa Leap and Lynn A. Neal, written commun., 1992)

EOLIAN

ea **Active sand dunes (1996)**—Very fine grained to fine-grained, well-sorted sand forming lightly vegetated active dune fields; thickness 1–3 m

e **Sand dunes (after 700? to 1200)**—Very fine grained to fine-grained, well-sorted sand forming lightly vegetated mostly inactive dune field on south side of river; thickness 1–4 m. Pueblo-II archeologic remains are present on surface of unit (T. Burchett, oral commun., 1995) and suggest surface could be as young as 1200. Derived mainly from reworking of older alluvial deposits

ARTIFICIAL FILL

mo **Hydraulic mining outwash (around 1910)**—Pale-greenish clay overlain by granule to pebble-size gravel; total thickness about 50 cm. Clay resembles Petrified Forest Member of Chinle Formation and gravel is similar to talus on nearby hillslopes. Unit forms low-relief fan downstream of area mined hydraulically around 1910 (Thompson and others, 1995) near northern edge of mapped area

rl **Riprap and levees (1963 to 1996)**—Angular blocks of Kaibab Formation up to 1 m used to construct bridge and road abutments, and local surface material piled into levees and other structures used to divert surface water

BEDROCK

Chinle Formation (Upper Triassic)

Ꞧcp **Petrified Forest Member**—Bentonitic mudstone and claystone with distinctive shades of green, blue, and red; top of unit not present in mapped area; thickness 190 m (Phoenix, 1963); typically forms talus-covered slopes

Ꞧcps **Sandstone unit**—Light-colored, medium- to coarse-grained, moderately well sorted siliceous sandstone; cross-stratified in beds 20–50 cm thick; forms ledge about 90 m above base of Petrified Forest Member; thickness about 3–5 m

Ꞧcs **Shinarump Sandstone Member**—Conglomeratic sandstone cross-stratified in lenticular beds 50–150 cm thick; sharp erosional contact with underlying Moenkopi Formation; forms distinctive light-brown cliff; thickness 0–50 m (Phoenix, 1963)

Ꞧm **Moenkopi Formation (Middle? and Lower Triassic)**—Gypsiferous, pale-red to dark-brown, slope-forming mudstone, siltstone, and silty limestone; thickness 100–140 m (Phoenix, 1963)

Pk **Kaibab Formation (Lower Permian)**—Cherty, yellowish-gray to light-gray silty dolomite, dolomitic sandstone, and minor sandstone; thickness 70–100 m (Phoenix, 1963); base of unit not present in mapped area. Forms cliffs along Colorado River and along Paria River in western part of mapped area

Contact

Strike and dip of bedrock

Driftwood

disturbed **Disturbed area of mostly covered, unmappable surficial geologic materials**—Disturbance caused by construction and presence of roads, bridges, vehicle parking lots, boat launching ramps, gravel pits, and National Park Service maintenance facilities

Roads, parking lots and other automobile facilities

Buildings and other structures

Foot trail

MAP SHOWING QUATERNARY GEOLOGY AND GEOMORPHOLOGY OF THE LEES FERRY AREA, ARIZONA

By

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2000

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—2000

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