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Map Showing Quaternary Geology and Geomorphology of the Granite Park Area, Grand Canyon, Arizona

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View to west-northwest showing map area and setting of Granite Park; Grand Canyon, Arizona. The Colorado River flows from right to left. Granite Park Wash is the light-colored area in foreground of photograph. The debris fan of 209 Mile Canyon is at left center. Pleistocene gravel is exposed in the steep, light-colored bank above 209 Mile Rapids at left edge of photograph. The black-colored ledge that forms the dark cliff at upper right of photograph is the basalt flow of Hamblin (1994). Sand dunes, debris fans, and terraces of the Colorado River cover the lower half of this area shown in this photograph.

DESCRIPTION OF MAP UNITS

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

ALLUVIUM

Alluvial deposits of the Colorado River

Post-dam channel-side bar deposits

mf **Moderated-flow sand (1991–1995)**—Very fine grained, light-gray (N7) to very light gray (N8) sand; exposed thickness about 1 m. Maximum elevation of deposit near Granite Park Canyon is 443 m. Deposited by flows up to 570 m^3/s (20,000 ft^3/s)

ff **Fluctuating-flow sand (1986–1991)**—Very fine grained, light-gray (N7) to very light gray (N8) sand; exposed thickness about 1 m. Maximum elevation of deposit near Granite Park Canyon is 445 m. Deposited by flows as large as 910 m^3/s (32,000 ft^3/s)

hf **High-flow sand[1] (1984–1986)**—Very fine grained, light-gray (N7) to very light gray (N8) sand; exposed thickness about 1 m. On east side of river upstream from Granite Park Canyon, small mesquite trees were planted during phase I of Glen Canyon Environmental Studies (Anderson and Ruffner, 1987) at discharge level of 1,100 m^3/s (40,000 ft^3/s). Near Granite Park Canyon, elevation of deposit ranges from 445–446 m; deposited by flows between about 910 to 1,400 m^3/s (32,000 to 50,000 ft^3/s)

fs **Flood sand of summer 1983 (June–August 1983)**—Very fine grained, distinctive light-gray (N8), well-sorted sand; silt and clay content less than 5 percent. Well exposed upriver from the mouth of Granite Park Canyon where thickness is about 3 m. Elevation of deposit near Granite Park Canyon ranges from 446–447 m; deposited by flows ranging from 1,400 to 2,700 m^3/s (50,000 to 96,000 ft^3/s)

Pre-dam terrace and terrace-like features and deposits

pda **Pre-dam alluvium (early 1920s to 1957–1958)**—Very fine grained to fine-grained, light-gray (N7) silty sand; exposed thickness 1–2 m. Large, mature saltcedar trees are partly buried in deposit; mesquite rare to absent. At Palisades Creek in eastern Grand Canyon (Hereford, 1996), a tree-ring date from a saltcedar partly buried in this deposit indicates germination in 1935. On large island south of mapped area, flood debris in sand of unit pda contains abundant cut wood and cans and bottles dating from early to mid 1950s. Elevation of deposit near Granite Park Canyon ranges from 448–449 m. Topographic position of unit pda above flood sand of June 1983 (fs) suggests deposition by flows larger than about 2,700 m^3/s (96,000 ft^3/s)

lmt **Lower mesquite terrace (1884 to early 1920s)**—Very fine grained to fine-grained, light-gray (N7) silty sand; exposed thickness about 3 m. Typically has relatively small mesquite trees rooted on or beneath surface; saltcedar not present on terrace. Flood debris contains cut wood. Maximum elevation near Granite Park Canyon is 451 m. At Palisades Creek in eastern Grand Canyon, this terrace is present in a photograph taken in 1890 (Hereford, 1996), which suggests the alluvium was initially deposited in July 1884 by the largest flood of the historic record with estimated discharge of 8,500 ft^3/s

(300,000 ft^3/s). Terrace overtopped in 1921 by a flood of 6,200 m^3/s (220,000 ft^3/s; Hereford, 1996), the largest flood of the gaged record

umt **Upper mesquite terrace (around 1400 to 1882–1883)**—Very fine grained to fine-grained, light-gray (N7) silty sand; exposed thickness about 4 m. Well exposed in south cutbank of Granite Park Canyon where it consists of at least nine Colorado River flood sands interbedded with slightly indurated, clayey sand and pebble to cobble-size gravel of debris-flow origin from Granite Park wash. Section contains continuous diffuse charcoal horizons of possible cultural origin and several thin beds of finely laminated clay which are probably quiet water flood deposits of Colorado River. Unit has marker bed in Two Hundred and Nine Mile Canyon and Granite Park Canyon with five parallel strata of fine-grained, cross-laminated silty sand that are probably Colorado River flood deposits. Charcoal from base of marker bed dates from 1470–1880 (no. 3, table 1), and charcoal 60 cm below marker bed dates from 1000 to 1380 (no. 2, table 1). Charcoal from small roaster on unit umt surface on north side of Two Hundred and Ninemile Canyon dates from 1520–1870 (no. 4, table 1). Deposit generally has inset stratigraphic relation with unit alluvium of Pueblo-II age and striped(?) (unit sp), although on south side of Two Hundred and Nine Mile Canyon unit umt overlies unit sp. Elevation of top of deposit near Granite Park Canyon is 452–456 m. Unit umt typically has large, mature mesquite trees and shrubs rooted on or beneath surface and senescent or dead mesquite trees present locally. Flood debris not abundant. Deposit correlates by age and position in terrace sequence with upper mesquite terrace of eastern Grand Canyon (Hereford, 1996; Hereford and others, 1996a, b). Terrace probably overtopped by floods larger than 6,200 to 8,500 m^3/s (220,000 to 300,000 ft^3/s) including estimated flood of 14,000 m^3/s (500,000 ft^3/s) in the early 1860s (U.S. Bureau of Reclamation,1990)

Terrace-forming deposits of prehistoric age

sp **Alluvium of Pueblo-II age and striped(?) alluvium, undivided (before 1300 B.C. to 1200)**—Very fine grained to fine-grained silty sand with minor interbedded sand and gravel; exposed thickness about 7 m. Unit well exposed in deep arroyo 1.5 km upstream of map area on west bank of river. At this locality charcoal is abundant through most of stratigraphic section. Seven calibrated radiocarbon ages from unit sp (nos. 11–17, table 1) range from 1260 B.C. at base to 330 near top of section (Helen Fairley, written commun.,1993; Fairley and others, 1994). Pueblo-II archeologic remains near surface of unit provide a younger age of around 1200 (Helen C. Fairley, personal commun., 1992; Fairley and others, 1994). One sample in mapped area yielded a calibrated age of 690–970 (no. 10, table 1). Unit broadly correlates with alluvium of Pueblo-II age and striped alluvium in eastern Grand Canyon (Hereford and others, 1996a, b) on basis of archeologic remains and similar position in terrace sequence. However, in Granite Park area, the two alluviums do not form separate, mappable terraces and were mapped together. "Archeologic unit" of Lucchitta and others (1995) is equivalent to unit sp

Gravel deposits

gv **Gravel deposits, undivided (prehistoric? to post-dam age)**—Unconsolidated, cobble- to medium-boulder-size gravel with coarse-sand matrix. Deposits consist of subrounded to rounded boulders of local Proterozoic and Paleozoic formations, Tertiary basalt, and Quaternary agglomerate; exposed thickness up to 6 m. Well developed on large island downstream of Granite Park Canyon. Mostly tributary debris flow and streamflow deposits reworked by Colorado River

gvy **Younger gravel deposits (late Pleistocene)**—Weakly consolidated, cobble- to small-boulder-size gravel with coarse-sand matrix on west side of river; very large basalt boulders present locally. Deposits consist of subrounded to rounded clasts of local Proterozoic and Paleozoic formations, widely scattered pebbles and small cobbles of quartzite and porphyritic rocks of Colorado River origin, and rounded pebbles and cobbles of basalt from Toroweap area. Lucchitta and others (1995) report Stage-II carbonate development on the upper surface, indicating exposure age of 20–30 ka. Unit cross-cuts marker bed in older gravel deposits (unit gvo) and contact with older gravel dips steeply toward river, indicating deposition in a channel incised into older gravel deposits. Base of deposit extends below water at 209 Mile Rapids. On east side of Granite Park unit gvy forms high terrace sloping gently toward river and deposit consists of grus-like accumulation from granular disintegration of schist and granite (unit Xbr)

gvo **Older gravel deposits (late Pleistocene)**—Weakly to moderately consolidated, cobble- to medium-boulder-size gravel with coarse-sand matrix. Deposits consist mainly of subrounded to rounded clasts derived from local Paleozoic formations, Quaternary basalt, and widely scattered very well rounded pebbles of far-traveled quartzite and porphyritic rocks of Colorado River origin; includes locally abundant small to medium boulder-size, angular to sub-angular Paleozoic and Tertiary basalt clasts from headwaters of Two Hundred and Ninemile Canyon (Tertiary basalt flows in Two Hundred and Ninemile Canyon drainage basin dated 6–8 Ma; Wenrich and others, 1995.). Unit contains marker bed of basaltic sand and gravel at elevation of 456–459 m. Forms west bank of river downstream from Two Hundred and Ninemile Canyon. Lucchitta and others (1995) reported Stage-III carbonate development on upper surface, indicating exposure age of 85–120 ka (Caffee and others, 1994). Thickness greater than 30 m. Contact with underlying bedrock dips steeply toward river. Base of deposit not exposed. Older gravel deposits are covered by and mapped with older talus (to) above 465–470 m

gvb **Basal gravel deposits (late Pleistocene)**—Moderately consolidated, cobble-to small-boulder-size gravel consisting of locally derived Paleozoic and Proterozoic formations and Quaternary basalt, and rare pebbles and small cobbles of very well rounded, far-traveled quartzite and porphyritic rocks of Colorado River origin. Gravel present only on west side of river where it underlies basaltic lava flow (unit blb). Base of gravel not exposed

Tributary stream deposits

Alluvial fans

afa **Active alluvial-fan deposits (about 1950s to 1995)**—Pebble to cobble gravel grading downslope to poorly sorted, fine- to medium-grained sand; clasts subangular to rounded; derived from reworking of younger gravel deposits (unit gvy) and older gravel deposits (unit gvo). Forms gently sloping surface north of ridge of units gvo and gvy south of mouth of Two Hundred and Ninemile Canyon; feeds arroyo containing active arroyo deposits (unit ad)

Arroyo deposits

ad **Active arroyo deposits (about 1950s to 1995)**—Pebble gravel to poorly sorted, fine- to medium-grained sand. Deposited in floor of arroyo draining active alluvial-fan deposits (unit afa) at mouth of Two Hundred and Ninemile Canyon. Arroyo grades to Colorado River and actively erodes the pre- and post-dam deposits

Streamflow gravels

sfg **Streamflow gravel (early? Holocene to before 1600 B.C.)**—Weakly consolidated, cobble- to boulder-size gravel with coarse-sand matrix. Deposit consists of subrounded to rounded clasts derived from local Proterozoic and Paleozoic formations in Granite Park drainage basin. Sandy matrix and clast-supported fabric suggest deposition by streamflow from Granite Park Canyon. Tapeats Sandstone (Cambrian) clasts on surface are darkly varnished. Underlies unit a of the older debrisflow deposit (unit dfoa) on north side of Granite Park Canyon

COLLUVIUM

Debris-flow deposits

Fan forming debris-flow deposits of Granite Park Canyon, Two Hundred and Nine-mile Canyon, and unnamed wash in Granite Park

dfyc **Unit c of younger debris-flow deposits (after 1884 and before late 1920s)**—Cobble to boulder-size gravel consisting mainly of angular to subangular clasts of Paleozoic carbonate and sandstone and Proterozoic granite and schist; some scattered boulders are larger than 1–2 m in diameter. Clast-supported texture with matrix of coarse silt to very fine sand; includes interbedded streamflow gravel. Surface boulders have negligible rock varnish and carbonate boulders are smooth without surface pitting. Mean varnish darkness (Bull, 1991, p. 63–64; value + chroma / 2) of sandstone boulders is 5. Debris flow was deposited on lower mesquite terrace (unit lmt) and toe of debris flow is truncated at level of pre-dam alluvium (unit pda); unit dfyc equivalent to lower mesquite terrace (unit lmt). Present only near mouth of unnamed wash in Granite Park; thickness about 1–2 m

dfyb **Unit b of younger debris-flow deposits (around 1490)**—Cobble to boulder-size gravel consisting mainly of angular to subangular clasts of Paleozoic carbonate and sandstone and Tertiary basalt; some scattered boulders are larger than 1–2 m in diameter. Clast-supported fabric with matrix of coarse silt to very fine sand; includes interbedded streamflow gravel. Unit dfyb present only near mouth of Two Hundred and Ninemile Canyon where exposed thickness is about 2 m. Deposits of unit dfyb interbedded with upper part of upper mesquite terrace (unit umt). Radiocarbon date of plant material from debris-flow matrix gives calibrated age of 1460–1800 (no. 1, table 1). Surface clasts lightly varnished with mean varnish darkness of 4.7 for sandstone and 3 for basalt. Solution pits on weathered upper surfaces of carbonate boulders poorly developed; average pit depth 1.2 mm. Depth of solution pits on carbonate boulders on debris fans elsewhere in Grand Canyon is directly related to exposure time of debris-fan surface, and varnish darkness on sandstone boulders increases with average depth of solution pits. These relations and weathering stages of fan surfaces are described in Hereford and others (1996a, figs. 3 and 5; 1996b, figs. 3–5). Rate of solution-pit deepening is estimated to be 2.4±0.2mm/ka (fig. 1; Hereford and others, 1997; 1998). Using this deepening rate, age of unit dfyb is 500 years, or around 1490, in general agreement with radiocarbon date no. 1 in table 1

dfya **Unit a of younger debris-flow deposits (around 1320)**—Cobble to boulder-size gravel consisting mainly of angular clasts of Paleozoic carbonate and sandstone and Proterozoic granite and schist; some scattered boulders are larger than 1–2 m in diameter. Clast-supported texture with matrix of coarse silt to very fine sand. Present in mouth of Granite Park Canyon and mouth of unnamed wash in Granite Park; thickness about 1 m. Unit dfya is truncated by upper mesquite terrace (unit umt) and deposited on alluvium of Pueblo-II age and striped(?) alluvium (unit sp). Beneath the surface, underside of carbonate boulders have thin, barely visible, very light gray (N8) to white (N9) coatings of calcium carbonate (Stage-I carbonate morphology; Birkeland and others, 1991). Solution pits on surface of carbonate boulders average 1.6 mm deep and mean varnish darkness is about 4

dfib **Unit b of intermediate debris-flow deposits (around 620)**—Cobble to boulder-size gravel consisting mainly of angular to subangular clasts of Paleozoic carbonate and sandstone and Tertiary basalt; some scattered boulders are larger than 1–2 m in diameter. Clast-supported fabric with matrix of coarse silt to very fine sand. Thickness about 1–2 m near mouth of Two Hundred and Ninemile Canyon. Beneath the surface, underside of all carbonate and some basalt and sandstone clasts have thin, discontinuous, very light gray (N8) to white (N9) coatings of calcium carbonate (Stage-I morphology). Mean varnish darkness of surface boulders is 4.4 and solution pits on carbonate boulders average 3.3 mm deep

dfia **Unit a of intermediate debris-flow deposits (around 410)**—Cobble to boulder-size gravel consisting mainly of angular to subangular clasts of Paleozoic carbonate and sandstone and Proterozoic granite and schist; some scattered boulders are larger than 1–2 m in diameter. Clast-supported fabric with matrix of coarse silt to very fine sand. Unit dfia exposed only in unnamed wash in Granite Park where thickness is about 2 m. Beneath the surface, underside of most clasts typically have thin, discontinuous, very light gray (N8) to white (N9) coatings of calcium carbonate (Stage-I morphology). Mean varnish darkness of surface boulders is 2.9 and solution pits on carbonate boulders average 3.8 mm deep

dfob **Unit b of older debris-flow deposits (around 600 B.C.)**—Cobble to boulder-size gravel consisting mainly of angular to subangular clasts of Paleozoic carbonate and sandstone and Proterozoic granite and schist in unnamed wash in Granite Park and Granite Park Canyon; deposit contains Tertiary basalt clasts in Two Hundred and Ninemile Canyon; some scattered boulders are larger than 1–2 m in diameter; thickness 2–3 m. Clast-supported texture with matrix of coarse silt to very fine sand. Part of alluvium of Pueblo-II age and striped(?) alluvium (unit sp) is deposited against and around unit dfob suggesting partial equivalence. Beneath the surface, clasts typically have obvious, continuous, very light gray (N8) to white (N9) coatings of calcium carbonate and weak Stage-II carbonate morphology (Birkeland and others, 1991). Boulders on surface of unit are spalled and disintegrated; rock varnish well-developed with mean darkness 2.7. Carbonate boulders have solution pits averaging 6.2 mm deep

dfoa **Unit a of older debris-flow deposits (around 1600 B.C.)**—Cobble to boulder-size gravel consisting mainly of angular to subangular clasts of Paleozoic carbonate and sandstone and Proterozoic granite and schist; some scattered boulders are larger than 1–2 m in diameter. Clast-supported fabric with matrix of coarse silt to very fine sand. Exposed thickness about 3 m in Granite Park Canyon and large unnamed wash in Granite Park. Alluvium of Pueblo-II age and striped(?) alluvium (unit sp) inset against southern margin of unit dfoa in Granite Park Canyon indicating debris flow pre-dates deposition of unit sp. Beneath the surface, clasts typically have obvious, continuous, very light gray (N8) to white (N9) coatings of calcium carbonate (Stage-II morphology). Sandstone boulders on surface of unit dfoa are spalled and disintegrated with well-developed rock varnish; mean varnish darkness 2.2. Carbonate boulders have solution pits averaging 8.6 mm deep

Channelized debris-flow deposits of Granite Park Canyon, Two Hundred and Ninemile Canyon, and unnamed wash in Granite Park

dcy **Younger channelized debris-flow deposits (1994)**—Pebble to mediumboulder-size gravel with scattered boulders up to 1 m in diameter that are unweathered and fresh appearing. Mainly debris-flow and local streamflow deposits composed of Paleozoic carbonate and sandstone and Proterozoic granite and schist. Tertiary basalt clasts present in Two Hundred and Ninemile Canyon. Deposits in Granite Park Canyon and Two Hundred and Ninemile Canyon date to floods of March 6, 1994. Five days of inclement weather culminated in heavy rain during early morning of March 6; resulting floods mobilized sediment in channels causing erosion of channel margin and older channelized debris-flow deposits unit dco). Deposition at mouth of Granite Park Canyon temporarily closed east channel of Colorado River (channel reopened by flood releases of March 22 to April 8, 1996)

dco **Older channelized debris-flow deposits (early to late 1900s)**—Pebble to medium-boulder-size gravel with scattered boulders up to 1 m in diameter. Mainly debris-flow and local streamflow deposits composed of Paleozoic carbonate and sandstone and Proterozoic granite and schist. Tertiary basalt clasts present in Two Hundred and Ninemile Canyon

Debris-flow deposits of small tributary streams

da **Active small tributary debris-flow (modern)**—Pebble to small-boulder size, angular to subangular gravel derived from reworking of nearby talus- and gravel-covered slopes and Proterozoic bedrock. Surface of deposit is fresh and unweathered. Probably interbedded locally with streamflow deposits

dy **Younger small tributary debris-flow and channel-fill deposits (500 to 700)**—Pebble to small-boulder size, angular to subangular gravel derived from reworking of nearby talus- and gravel-covered slopes and Proterozoic bedrock. Mean varnish darkness of Tapeats Sandstone clasts is 3.6, suggesting surface weathering and exposure time of deposit is comparable with intermediate debris-flow deposits (units dfia and dfib)

do **Older small tributary debris-flow and channel-fill deposits (around 1600 B.C.)**—Pebble to small-boulder size, angular to subangular gravel derived from reworking of nearby talus- and gravel-covered slopes and Proterozoic bedrock. Overlies unit a of older debris-flow deposits (unit dfoa). Mean varnish darkness of Tapeats Sandstone clasts is 2.3, which is similar to clasts in unit dfoa

Talus

ty **Talus deposits (modern)**—Pebble to very large boulder-size gravel consisting of angular, blocky clasts of Cambrian bedrock. Clasts are fresh and unweathered; forms recently active slope

to **Older talus deposits (late Pleistocene? to Holocene)**—Pebble to very large boulder-size gravel consisting of angular blocks of Black Ledge basalt (blb), Bright Angel Shale (_ba), and Proterozoic schist and granite (Xbr). Moderately consolidated to locally well consolidated; forms inactive talus slope

EOLIAN

Sand dunes

Coppice sand dune deposits

ea **Coppice sand dunes (1920s to 1995)**—Very fine grained, moderately well sorted sand; silt and clay content less than 6 percent. Forms lightly vegetated, active dune fields and isolated mounds with 1–2 m of relief; typically associated with mesquite shrubs. Derived from reworking of younger pre-dam deposits (units lmt and pda) and postdam deposits (units fs, hf, ff, and mf)

ey **Younger coppice sand dunes (after 1400 to early 1920s)**—Very fine grained, moderately well sorted sand; silt and clay content less than 6 percent. Forms lightly to moderately vegetated, locally inactive coppice dune fields with 1–4 m relief; typically associated with mesquite shrubs and small trees. Derived mainly from reworking of alluvium of the upper and lower mesquite terraces (units umt and lmt)

eo **Older sand dunes (after 300 to around 1200)**—Very fine grained, moderately well sorted sand; silt and clay content less than 6 percent. Forms lightly to moderately vegetated, mostly inactive dune fields and sand sheets with up to 6 m of relief, typically associated with mesquite trees. Derived mainly from reworking alluvium of Pueblo-II age and striped(?) alluvium unit sp)

VOLCANIC ROCKS

Basalt flows

blb **Black ledge basalt flow (late Pleistocene) of Hamblin (1994)**—Darkblack, columnar-jointed, intracanyon basalt flow exposed as remnants from river miles 179 to 263 (miles downstream of Lees Ferry, Arizona). Unit is aphyric and contains minor scattered olivine phenocrysts, abundant olivine glomerocrysts, minor gneissic inclusions, and minor pyroxene phenocrysts. Distinctive thin basal colonnade, thick entablature, and clinkery upper zone (Hamblin, 1994). K/Ar date by Damon (personal commun. to Hamblin, 1990) of 550 ± 30 ka. Lucchitta and others (1995) obtained seven ^{39}Ar/^{40}Ar dates from unit that average 600 ka. Wenrich and others (1995) reported a K/Ar date of 174 ± 90 ka from the same flow at river mile 206.

BEDROCK

Sedimentary rocks

Ɛbr **Bright Angel Shale (Cambrian)**—Greenish shale interbedded with gray platy siltstone, dark-magenta to pale-greenish-buff very fine grained sandstone, and rusty-brown sandy dolomite; distinctive red-brown sandstone near base (Middleton and Elliot, 1990). Formation is downthrown 230 m on west side of Granite Park fault zone (Huntoon and others, 1981)

Schist and granite

Xbr **Schist and granite (Early Proterozoic)**—Rocks of a layered mafic, intrusive complex metamorphosed to moderately foliated hornblende/tremolite- and plagioclase-assemblage schist. Includes layers and zones of metagabbroic pegmatite (Babcock, 1990)

Contact—Dashed where approximately located or inferred

Fault—Dashed where approximately located, dotted where concealed; bar and ball on downthrown side

Small tributary stream channel—Arrow indicates channel that does not extend to Colorado River

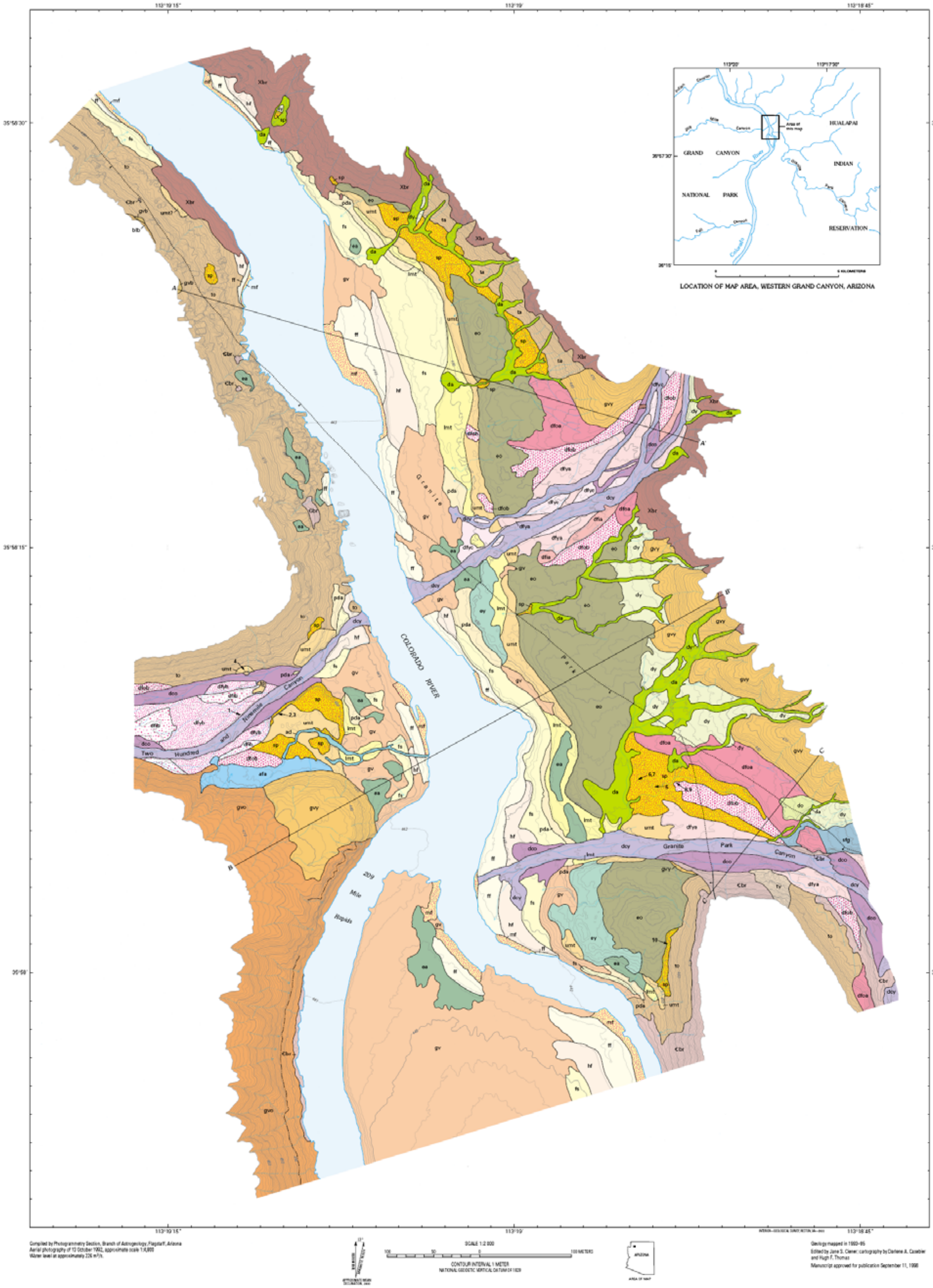
Mesquite line—West side of river downstream of 209 Mile Rapids

Black volcanic sand and gravel marker bed—In unit gvo on west side of river at 209 Mile Rapids

1 → **Radiocarbon (14C) sample locality at point of arrow**—Number refers to table 1

[1] Between March 22 and April 8, 1996, flow rates were increased to 1,270 m^3/s (45,000 ft^3/s) in an experimental, controlled-flood release designed to reposition sand submerged in the channel onto subaerial river banks. The flood stage of the experimental flood should have been near the upper limit of the high-flow sand (hf). Although we have not visited the map area since the flood release, we anticipate that sand from the experimental flood was deposited at the level of the moderated flow, fluctuating flow, and high-flow sands (mf, ff, hf).

MAP SHOWING QUATERNARY GEOLOGY AND GEOMORPHOLOGY OF THE GRANITE PARK AREA, GRAND CANYON, ARIZONA



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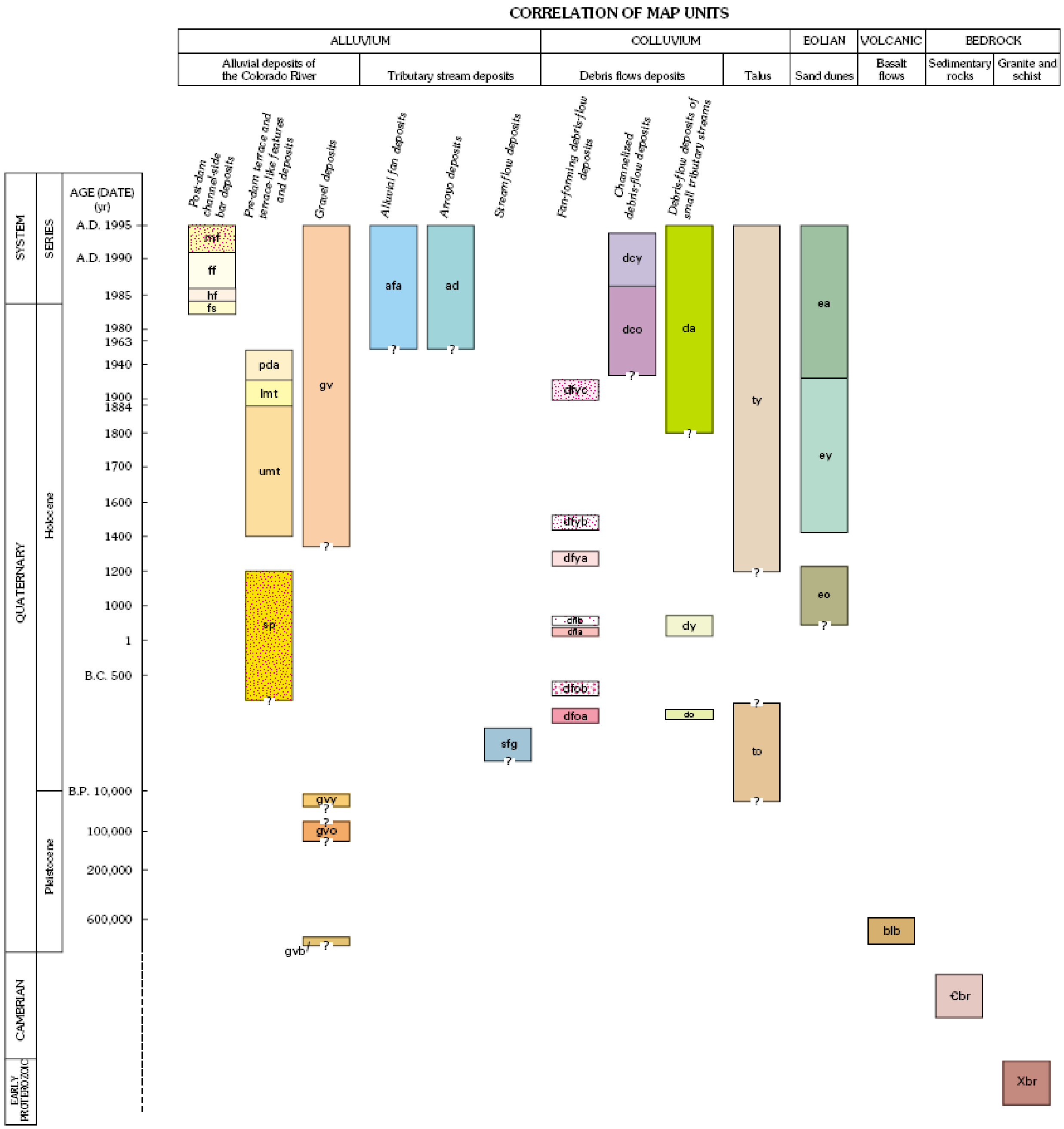

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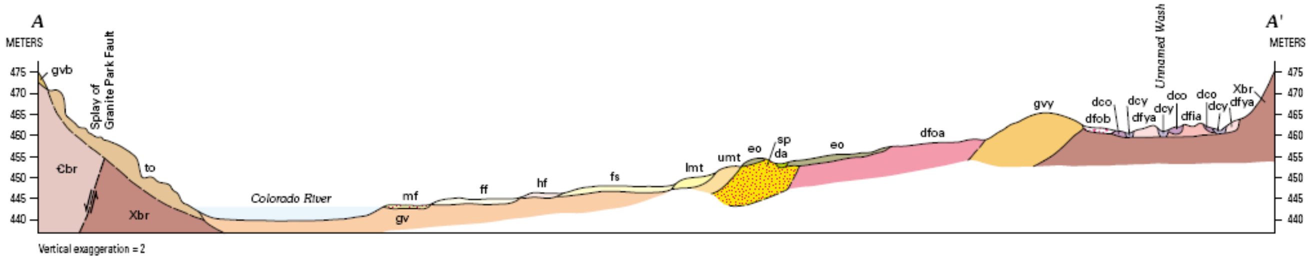
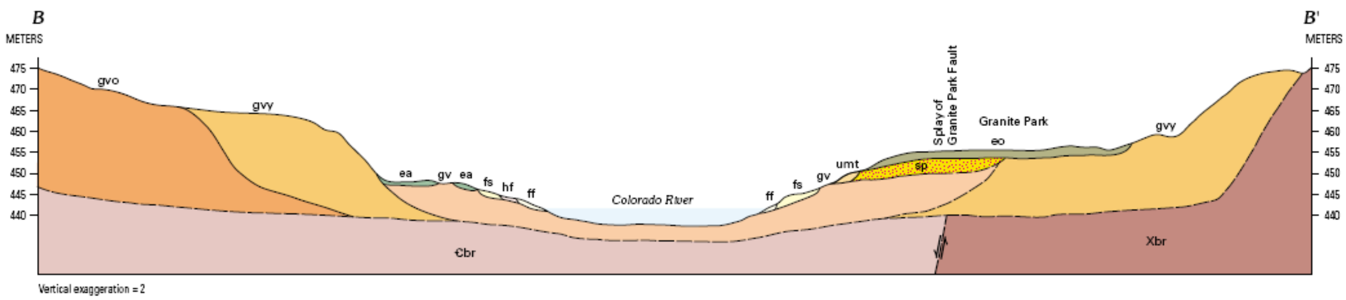
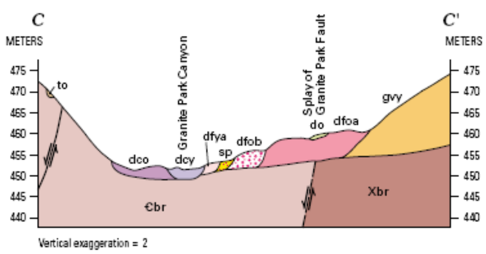






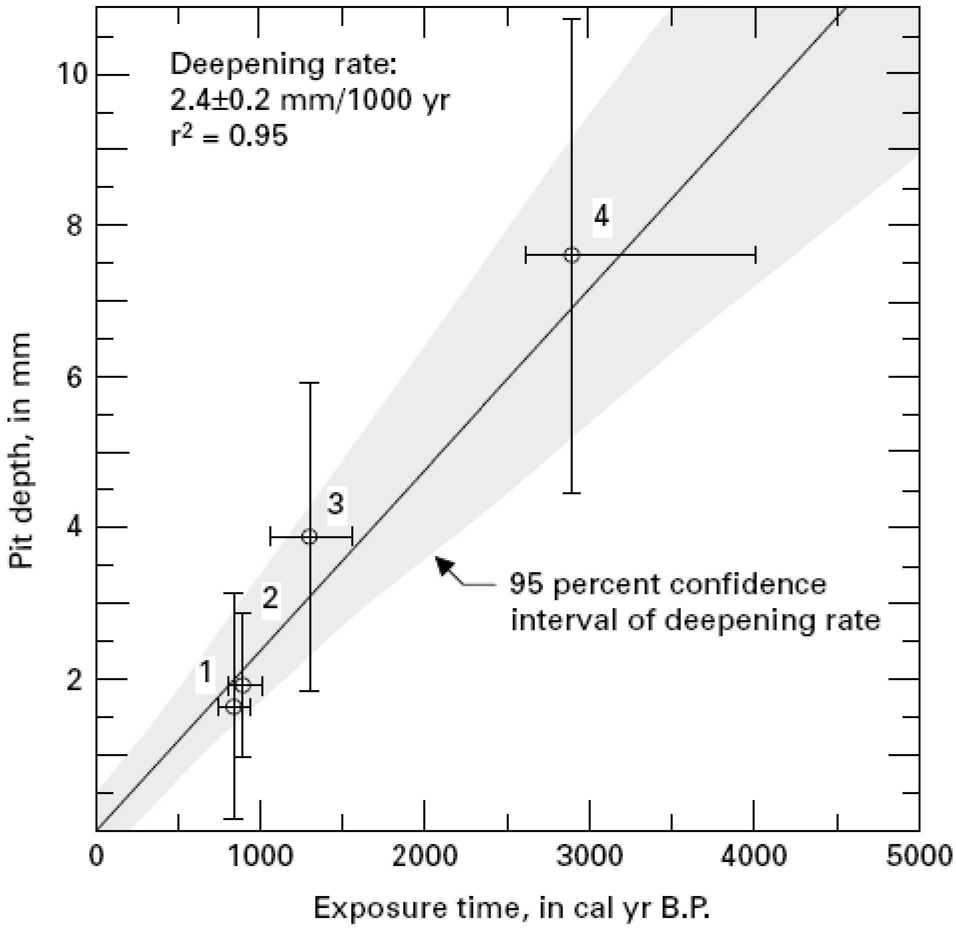
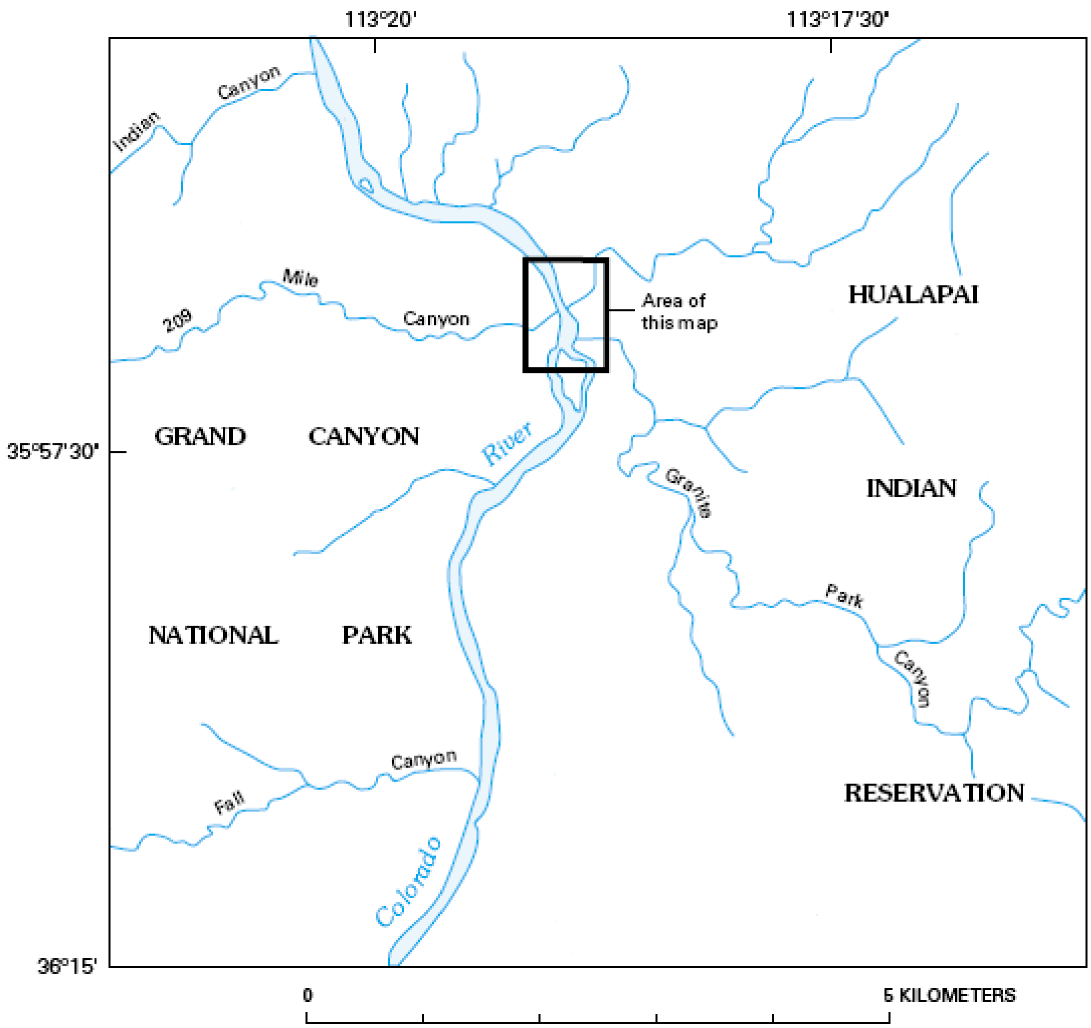


Figure 1. Average depth of solution pits on carbonate boulders as a function of time along Colorado River in Grand Canyon, Arizona (Hereford and others, 1997). Estimated rate of pit deepening is the slope of the solid diagonal line, which is 2.4±0.2 mm/ka. This deepening rate was used to estimate age of debris-fan surfaces in Granite Park area. Depth measurements shown in figure 1 are from three dated debris-fan surfaces (points 1, 3, and 4) and boulders in a closely dated archeologic feature (point 2). Depth measured with a depth micrometer with resolution of 2.5μ. Vertical bars of points 1 to 4 are the (2 standard deviation range of depth measurements. Horizontal bars of points 1, 3, and 4 are the range of calibrated ^{14}C ages. Point 2 horizontal bar is age range of an archeologic feature. Data points one and three are radiocarbon-dated debris-flow deposits. The location and stratigraphic context of these dated deposits and surfaces are described in Hereford (1996, table 1, localities 2, 3 and 4; Hereford and others, 1996a, fig. 10, table 3). Data point two is from an archeologic feature near the head of Nankoweap Canyon (Hereford and others, 1996a, b). This archeologic structure is a small check-dam built of Redwall Limestone (Mississippian) boulders by the Kayenta Anasazi. Potsherds indicate clearly that the structure was built in Pueblo-II time between 800–950 B.P. (the error bar in fig. 1); median construction date is 875 B.P. Data point four is a cosmogenic ^{3}He surface exposure age from basalt boulders (Cerling and others, 1995; Thure E. Cerling, written commun., 1996) on the topographically highest and oldest surface on the Prospect Canyon debris fan (Webb and other, 1996) in western Grand Canyon near river mile 179, which is 48 km upstream of Granite Park.



LOCATION OF MAP AREA, WESTERN GRAND CANYON, ARIZONA

Table 1. *Radiocarbon dates of alluvium, debris-flow related deposits, and archeologic features,Granite Park area, Grand Canyon, Arizona*

	Sample number		Location(3)					
No	Field(1) Number	Lab. number(2)	Latitude DMS	Longitude DMS	Material	Date, in years B.P.	Calibrated age(4)	Description
1	RHWRC 1	GX-18035	35 58 09	113 19 12	Wood	280±60	A.D. 1460–1680 A.D. 1740–1800	Matrix of dfyb
2	TONRC 1	W-6441	35 58 09	113 19 05	Charcoal	830±100	A.D. 1000–1300 A.D. 1360–1380	60 cm below base of umt marker bed (of fine-grained Colorado River flood deposits)
3	TONRC 2	W-6442	35 58 09	113 19 05	Charcoal	250±70	A.D. 1470–1700 A.D. 1720–1820 A.D. 1830–1880	Base of marker bed in umt
4	TONRC 4	USGS 3561	35 58 11	113 19 14	Charcoal	215±35	A.D. 1520–1570 A.D. 1630–1690 A.D. 1730–1820 A.D. 1850–1870	Small roaster
5	G:3:26-2	β-59769	35 58 07	113 18 54	Charcoal	190±50	A.D. 1640–1890	Discard pile (feature)
6	G:3:26-3A	β-59770	35 58 07	113 1855	Charcoal	270±50	A.D. 1480–1680 A.D. 1740–1800	Large roaster, collected 15–40 cm below surface
7	G:3:26-3B	β-59771	35 58 07	113 18 55	Charcoal	380±50	A.D. 1440–1540 A.D. 1540–1640	Large roaster, collected 15–40 cm below surface
8	G:3:26-8A	β-59772	35 58 07	113 18 53	Charcoal	360±50	A.D. 1450–1640	Large roaster, collected 30 cm below surface
9	G:3:26-8B	β-59773	35 58 07	113 18 53	Charcoal	520±50	A.D. 1300–1360 A.D. 1380–1450	Large roaster, collected 30 cm below surface
10	GPWRC 1	β-66254	35 58 01	113 18 53	Charcoal	1180±60	A.D. 690–750 A.D. 760–970	From sp alluvium overlain by eo. Date is Pueblo I–II age
11	RC7	β-66257	35 59 00	113 20 15	Charcoal	2870±60	1260–1240 B.C. 1220–910 B.C.	From sp in large arroyo 1.5 km north of map
12	RC1	β-59774	35 59 00	113 20 15	Charcoal	2670±140	1210–1190 B.C. 1160–410 B.C.	ditto
13	RC8	β-66260	35 59 00	113 20 15	Charcoal	2180+60	390–110 B.C.	ditto
14	RC4	β-66255	35 59 00	113 20 15	Charcoal	2170+80	390–50 B.C.	ditto
15	RC2	β-59775	35 59 00	113 20 15	Charcoal	2100±60	360–290 B.C. 260 B.C.–A.D.10	ditto
16	RC6	β-66259	35 59 00	113 20 15	Charcoal	2050±60	340–320 B.C. 200 B.C.–A.D.70	ditto
17	RC5	β-66258	35 59 00	113 20 15	Charcoal	1880±70	40 B.C.–A.D.260 A.D. 290–330	ditto
18	RC3	β-59776	35 59 00	113 20 15	Charcoal	170±50	A.D. 1650–1890	ditto

(1) RHW=Robert H. Webb date; TON=Two Hundred and Ninemile Canyon; GPW=Granite Park Canyon (wash)

(2) GX=Kreuger Enterprises, Inc., Geochron Laboratories Division, Cambridge, Massachusetts; W=U.S. Geological Survey Radiocarbon Laboratory, Reston, Virginia; USGS=Geological Survey Radiocarbon Laboratory, Menlo Park, California; Beta Analytic Inc., Miami, Florida

(3) DMS=Degrees, minutes, seconds

(4) 95 percent confidence interval in calendar years of the radiocarbon date, which was calibrated to calendar years using relations developed through measurement of ^{14}C activity of dendrochronologically dated wood (Klein and others, 1982). Multiple dates are possible because of atmospheric ^{14}C fluctuations. Gronigen Radiocarbon Calibration Program was used to calibrate radiocarbon dates

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