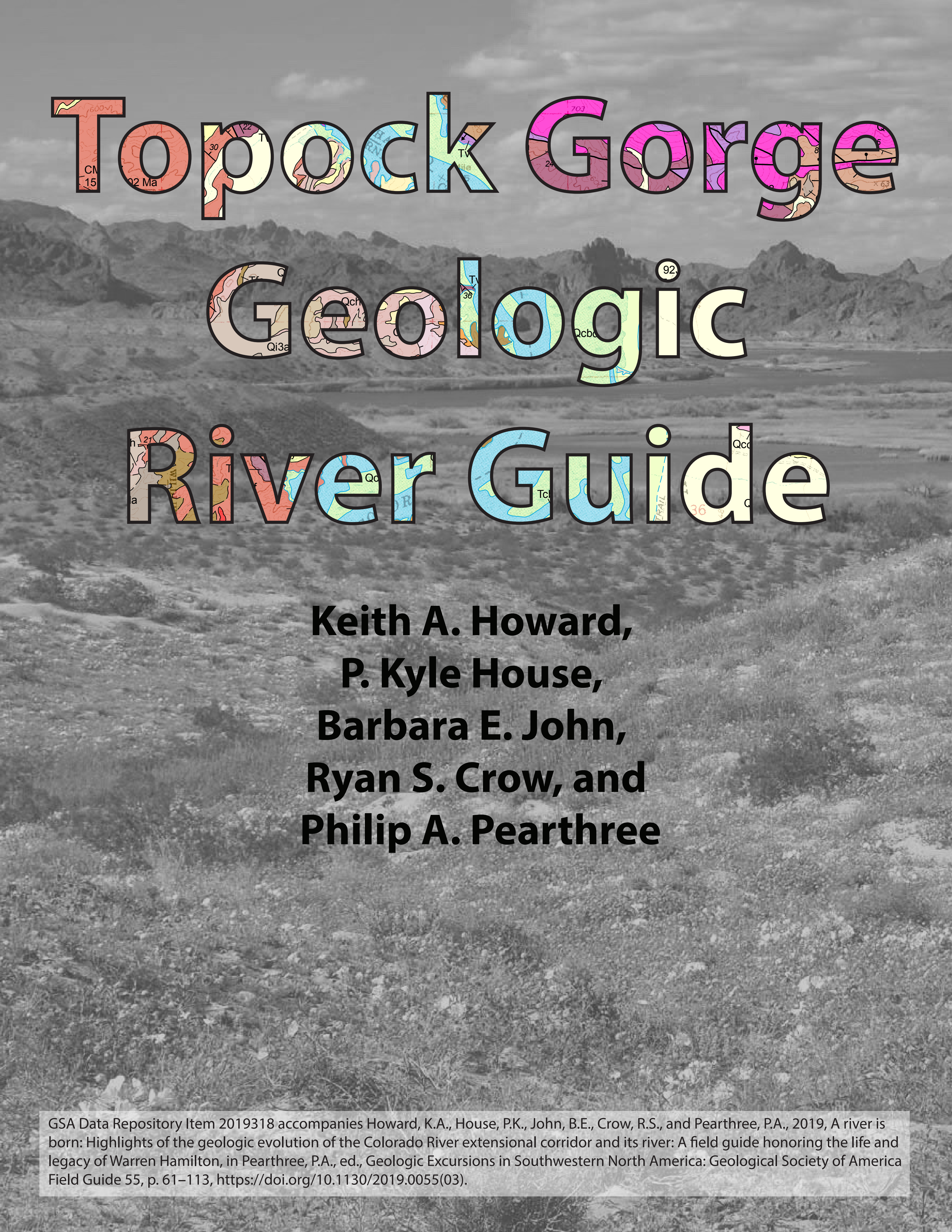

Topock Gorge Geologic River Guide

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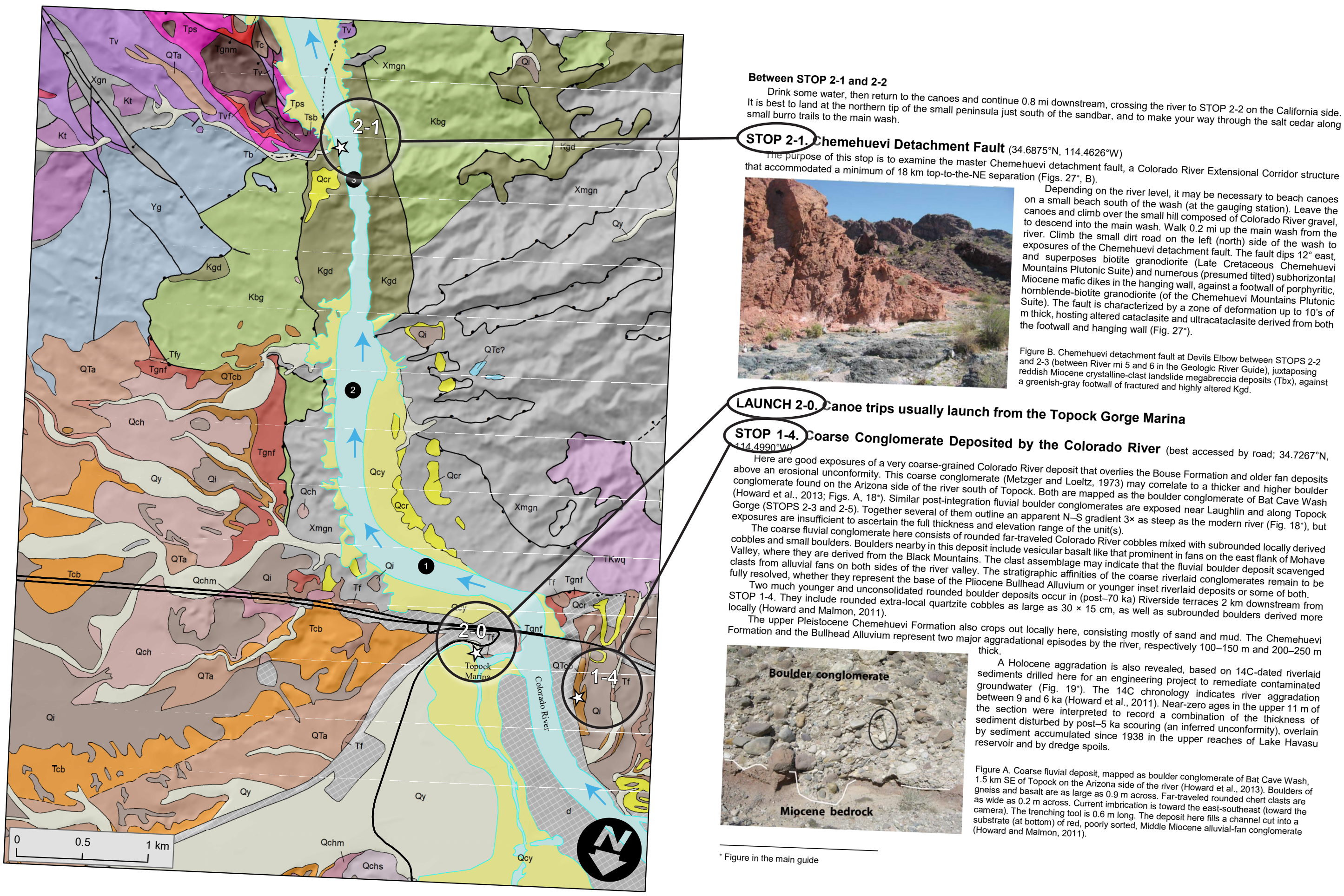
GSA Data Repository Item 2019318 accompanies Howard, K.A., House, P.K., John, B.E., Crow, R.S., and Pearthree, P.A., 2019, A river is born: Highlights of the geologic evolution of the Colorado River extensional corridor and its river: A field guide honoring the life and legacy of Warren Hamilton, in Pearthree, P.A., ed., Geologic Excursions in Southwestern North America: Geological Society of America Field Guide 55, p. 61–113, https://doi.org/10.1130/2019.0055(03).

How to use this geologic river guide



This geologic river guide is designed in the "read-as-you-run" format. Every page is oriented with downstream at the top such that the maps are always roughly orientated while you are traveling downstream (with the current) and holding the guide as you would a book. As a result of this and the changing course of the river, north is oriented differently on most pages.

If you are traveling downstream, you will pass features on the bottom of the page before those at the top. The facing-page descriptions of sites of interest are ordered in the same way, so you should start reading from the bottom. This format preserves the relative order of features on the map and their descriptions on the facing page. Generally, points on the map and their description on the facing page will be across from each other.

The descriptions of features are taken directly from the main text of the associated GSA Field Guide (Howard et al., 2019), but in many cases they had to be abbreviated to fit the space. This is particularly true for figures, some of which could not be shown in the space allotted. Figures reproduced in the river guide have been lettered and those that could not be shown for space reasons are referenced using the original figure numbers from the main text of the larger Field Guide (see the footnotes on subsequent pages). See the main text of the associated GSA Field Guide for much more information about the geology of the area: Howard, K.A., House, P.K., John, B.E., Crow, R.S., and Pearthree, P.A., 2019, A river is born: Highlights of the geologic evolution of the Colorado River extensional corridor and its river: A field guide honoring the life and legacy of Warren Hamilton, in Pearthree, P.A., ed., Geologic Excursions in Southwestern North America: Geological Society of America Field Guide 55, p. 61–113, https://doi.org/10.1130/2019.0055(03).

The geologic maps shown are based on those by Howard et al. (2013) and House et al. (2018); however, they have be modified for this purpose. Namely, they have been simplified and made seamless by correlating map units and line types across map boundaries.

Geologic Map Explanation

River Miles (downstream from Topock)

Field Trip Stops

Contacts And Faults

Contact—Identity and existence certain, location accurate
Contact—Identity and existence certain, location approximate
Contact—Identity and existence certain, location inferred
Contact—Identity or existence questionable, location accurate
Contact—Identity or existence questionable, location approximate
Contact—Identity or existence questionable, location inferred
Fault (generic)—Identity and existence certain, location accurate
Fault (generic)—Identity and existence certain, location concealed
Fault (generic)—Identity and existence certain, location inferred
Fluvial terrace scarp—Identity and existence certain, location accurate
Fluvial terrace scarp—Identity and existence certain, location approximate
Fluvial terrace scarp—Identity or existence questionable, location accurate
Gradational contact—Identity and existence certain, location accurate
Low-angle normal fault—Identity and existence certain, location accurate
Low-angle normal fault—Identity and existence certain, location concealed
Map neatline
Normal fault—Identity and existence certain, location accurate
Normal fault—Identity and existence certain, location concealed
Normal fault—Identity and existence certain, location inferred
Shoreline—Identity and existence certain, location accurate
Shoreline—Identity and existence certain, location approximate

Map Units

MISCELLANEOUS

w - Water
d - Disturbed land

DEPOSITS OF THE MODERN REGULATED COLORADO RIVER

Qcy - Deposits of the modern regulated Colorado River

RIVERSIDE TERRACES

Qcr - Riverside terrace sediments (Post-Chemeheuvi), undivided
Qcr5 - Riverside terrace sediments (Post-Chemeheuvi), terrace 5
Qcr4 - Riverside terrace sediments (Post-Chemeheuvi), terrace 4
Qcr3 - Riverside terrace sediments (Post-Chemeheuvi), terrace 3

CHEMEHUEVI FORMATION

Qch - Chemehuevi Formation, undivided
Qch? - Chemehuevi Formation, undivided?
Qchs - Chemehuevi Formation, sand facies
Qchm - Chemehuevi Formation, mud facies
Qchg - Chemehuevi Formation, gravel facies

OLDER COLORADO RIVER DEPOSITS

Qco - Older Colorado River deposits (Pre-Chemehuevi)
QTc - Colorado River sediments, undivided
QTc? - Colorado River sediments, undivided (Bullhead thru Chemhuevi age deposits)?

BULLHEAD ALLUVIUM

QTcb - Bullhead Alluvium(?) Boulder Conglomerate
Tcb - Bullhead Alluvium
Tcb? - Bullhead Alluvium?

BOUSE FORMATION CARBONATE FACIES

Tbocm - Bouse Formation, marl facies

BOUSE FORMATION NEARSHORE FACIES

Tbogg - Bouse Formation, golden gravel facies (underlies carbonate sequence)
Tbogs - Bouse Formation, golden sand facies (underlies carbonate sequence)

YOUNG ALLUVIUM

Qy - Young piedmont alluvium, undivided
Qy2 - Young piedmont alluvium, unit 2 (youngest: active)
Qy1 - Young piedmont alluvium, unit 1 (oldest; inactive)
Qe - Eolian sand

INTERMEDIATE AGE ALLUVIUM

Qi - Intermediate age piedmont alluvium, undivided
Qi4 - Intermediate age piedmont alluvium, unit 4 (youngest)
Qi4a - Intermediate age piedmont alluvium, unit 4a
Qi4b - Intermediate age piedmont alluvium, unit 4b
Qi3 - Intermediate age piedmont alluvium, unit 3
Qi3? - Intermediate age piedmont alluvium, unit 3?
Qi3b - Intermediate age piedmont alluvium, unit 3b
Qi3a - Intermediate age piedmont alluvium, unit 3a
Qi2 - Intermediate age piedmont alluvium, unit 2
Qi2? - Intermediate age piedmont alluvium, unit 2?

OLD ALLUVIUM

QTa - Oldest piedmont alluvium
QTa? - Oldest piedmont alluvium?

FANGLOMERATE AND SEDIMENTARY ROCKS

Tf - Fanglomerate, undivided
Tfy - Younger fanglomerate (post river integration; coeval with Bullhead Alluvium)
Tfo - Older fanglomerate (pre river integration; pre to barely coeval with Bouse)
Tfo? - Older fanglomerate (pre river integration; pre to barely coeval with Bouse)
Tfc - Paleochannel-fill conglomerate
Tac - Fanglomerate of Castle Rock (pre-river integration)

ROCKS DEPOSITED DURING EXTENSIONAL DEFORMATION

Tss - Sandstone and siltstone (post-Tps)
Tgf - Granite-clast fanglomerate
Tsb - Sedimentary Breccia
Tvpm - Peach Spring Tuff megabreccia
Tc - Conglomerate and sandstone (post-Tps?)
Ts - Sedimentary rocks, undivided (pre-Tps)
Tgnf - Gneiss-clast fanglomerate
Tgnm - Gneiss-clast megabreccia
Tvm - Volcanic-clast megabreccia
Tgm - Granite megabreccia
Tbx - Megabreccia, undifferentiated
Tvf - Volcanic-clast fanglomerate

VOLCANIC ROCKS

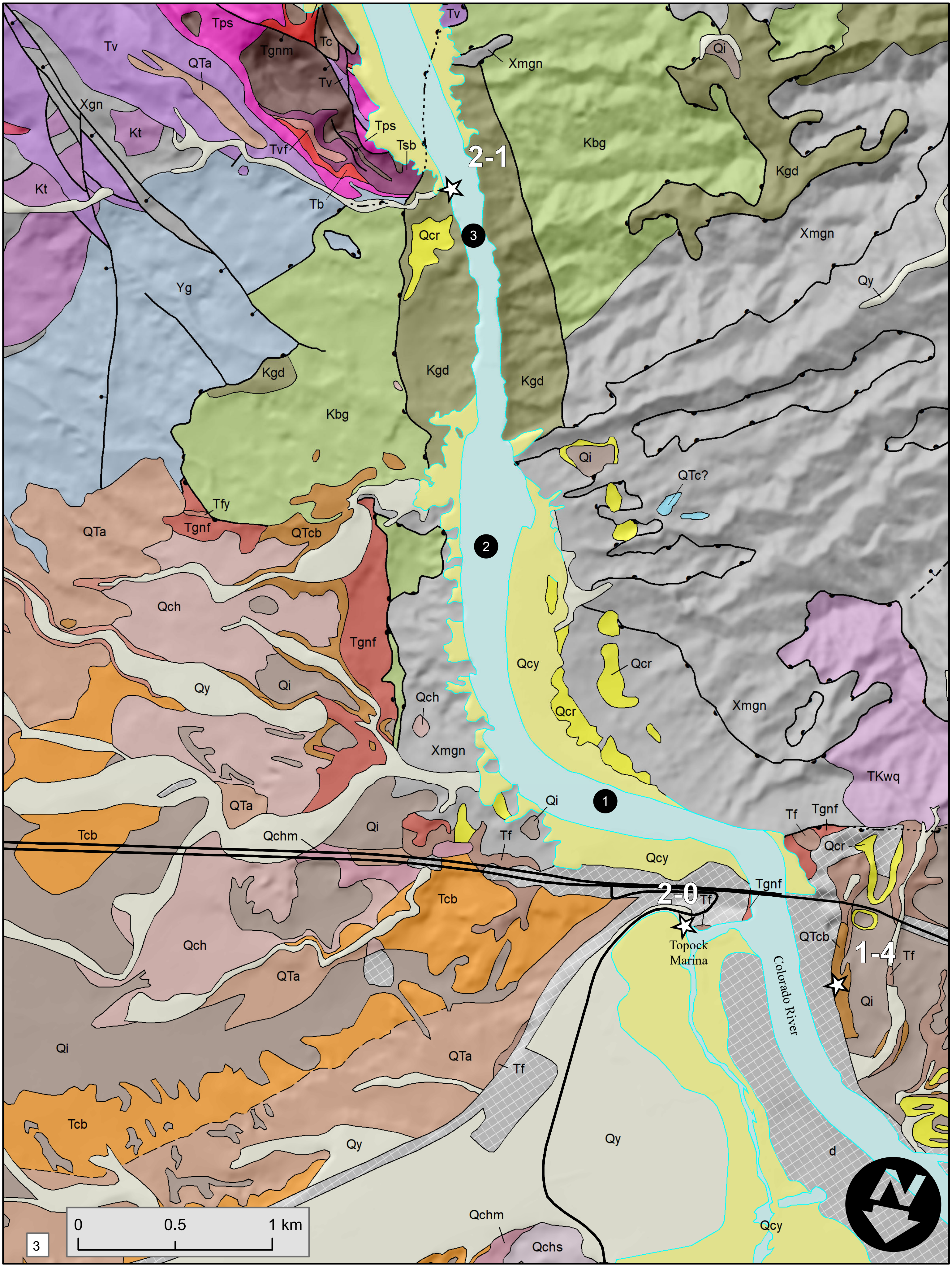
Tb - Basalt, undivided
Tps - Peach Spring Tuff
Tv - Volcanic flows and intrusions, undivided

PLUTONIC ROCKS AND INTRUSIONS

Ti - Hypabyssal intrusions
Tdl - Light-colored dikes
TKq - Quartz porphyry
TKwq - Quartz monzonite
Kt - Diorite of Topock
Kbg - Biotite granodiorite
Kgd - Porphyritic hornblende-biotite granodiorite

PROTEROZOIC CRYSTALLINE ROCKS

Yg - Porphyritic monzogranite
Xag - Augen gneiss
Xga - Amphibolite
Xgl - Leucocratic gneiss
Xgp - Pegmatite and granite gneiss
Xgs - Mixed granite gneiss and metasedimentary rocks
Xgn - Gneiss and migmatite
Xmgn - Mylonitized gneiss and migmatite



Tps
Tv
Tgnm
Tc
QTa
Xgn
Kt
Tvf
Tps
Tsb
2-1
Xmgn
Kbg
Kgd
Qi
Tb
Kt
Qcr
3
Xmgn
Yg
Qy
Kgd
Kgd
Kgd
Kbg
Qi
QTc?
Tfy
QTa
Tgnf
QTcb
2
Qch
Tgnf
Qcy
Qcr
Qy
Qi
Qch
Qcr
Xmgn
Xmgn
TKwq
QTa
Qi
1
Tcb
Qchm
Qi
Tf
Tf
Tgnf
Qcr
Qcy
Tcb
2-0
Tf
Tgnf
Topock
Marina
QTcb
Qch
1-4
Tf
QTa
Colorado River
Qi
Qi
QTa
Tf
Tcb
Qy
Qy
d
0
0.5
1 km
Qchm
Qchs
Qcy
3

Between STOP 2-1 and 2-2

Drink some water, then return to the canoes and continue 0.8 mi downstream, crossing the river to STOP 2-2 on the California side. It is best to land at the northern tip of the small peninsula just south of the sandbar, and to make your way through the salt cedar along small burro trails to the main wash.

STOP 2-1. Chemehuevi Detachment Fault (34.6875°N, 114.4626°W)

The purpose of this stop is to examine the master Chemehuevi detachment fault, a Colorado River Extensional Corridor structure that accommodated a minimum of 18 km top-to-the-NE separation (Figs. 27*, B).

Depending on the river level, it may be necessary to beach canoes on a small beach south of the wash (at the gauging station). Leave the canoes and climb over the small hill composed of Colorado River gravel, to descend into the main wash. Walk 0.2 mi up the main wash from the river. Climb the small dirt road on the left (north) side of the wash to exposures of the Chemehuevi detachment fault. The fault dips 12° east, and superposes biotite granodiorite (Late Cretaceous Chemehuevi Mountains Plutonic Suite) and numerous (presumed tilted) subhorizontal Miocene mafic dikes in the hanging wall, against a footwall of porphyritic, hornblende-biotite granodiorite (of the Chemehuevi Mountains Plutonic Suite). The fault is characterized by a zone of deformation up to 10's of m thick, hosting altered cataclasite and ultracataclasite derived from both the footwall and hanging wall (Fig. 27*).

Figure B. Chemehuevi detachment fault at Devils Elbow between STOPS 2-2 and 2-3 (between River mi 5 and 6 in the Geologic River Guide), juxtaposing reddish Miocene crystalline-clast landslide megabreccia deposits (Tbx), against a greenish-gray footwall of fractured and highly altered Kgd.

LAUNCH 2-0. Canoe trips usually launch from the Topock Marina.

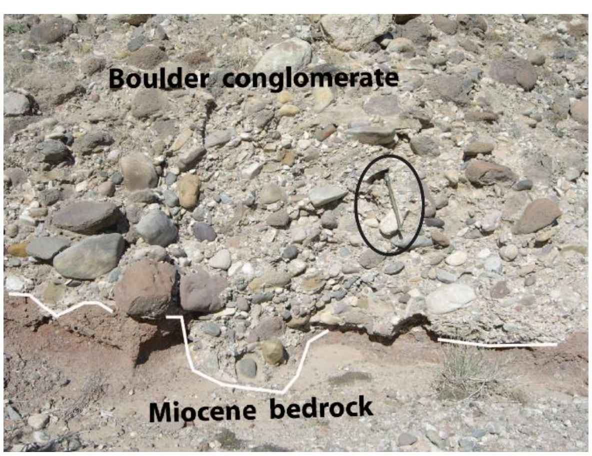
STOP 1-4. Coarse Conglomerate Deposited by the Colorado River (best accessed by road; 34.7267°N, 114.4990°W)

Here are good exposures of a very coarse-grained Colorado River deposit that overlies the Bouse Formation and older fan deposits above an erosional unconformity. This coarse conglomerate (Metzger and Loeltz, 1973) may correlate to a thicker and higher boulder conglomerate found on the Arizona side of the river south of Topock. Both are mapped as the boulder conglomerate of Bat Cave Wash (Howard et al., 2013; Figs. A, 18*). Similar post-integration fluvial boulder conglomerates are exposed near Laughlin and along Topock Gorge (STOPS 2-3 and 2-5). Together several of them outline an apparent N–S gradient 3× as steep as the modern river (Fig. 18*), but exposures are insufficient to ascertain the full thickness and elevation range of the unit(s).

The coarse fluvial conglomerate here consists of rounded far-traveled Colorado River cobbles mixed with subrounded locally derived cobbles and small boulders. Boulders nearby in this deposit include vesicular basalt like that prominent in fans on the east flank of Mohave Valley, where they are derived from the Black Mountains. The clast assemblage may indicate that the fluvial boulder deposit scavenged clasts from alluvial fans on both sides of the river valley. The stratigraphic affinities of the coarse riverlaid conglomerates remain to be fully resolved, whether they represent the base of the Pliocene Bullhead Alluvium or younger inset riverlaid deposits or some of both.

Two much younger and unconsolidated rounded boulder deposits occur in (post–70 ka) Riverside terraces 2 km downstream from STOP 1-4. They include rounded extra-local quartzite cobbles as large as 30 × 15 cm, as well as subrounded boulders derived more locally (Howard and Malmon, 2011).

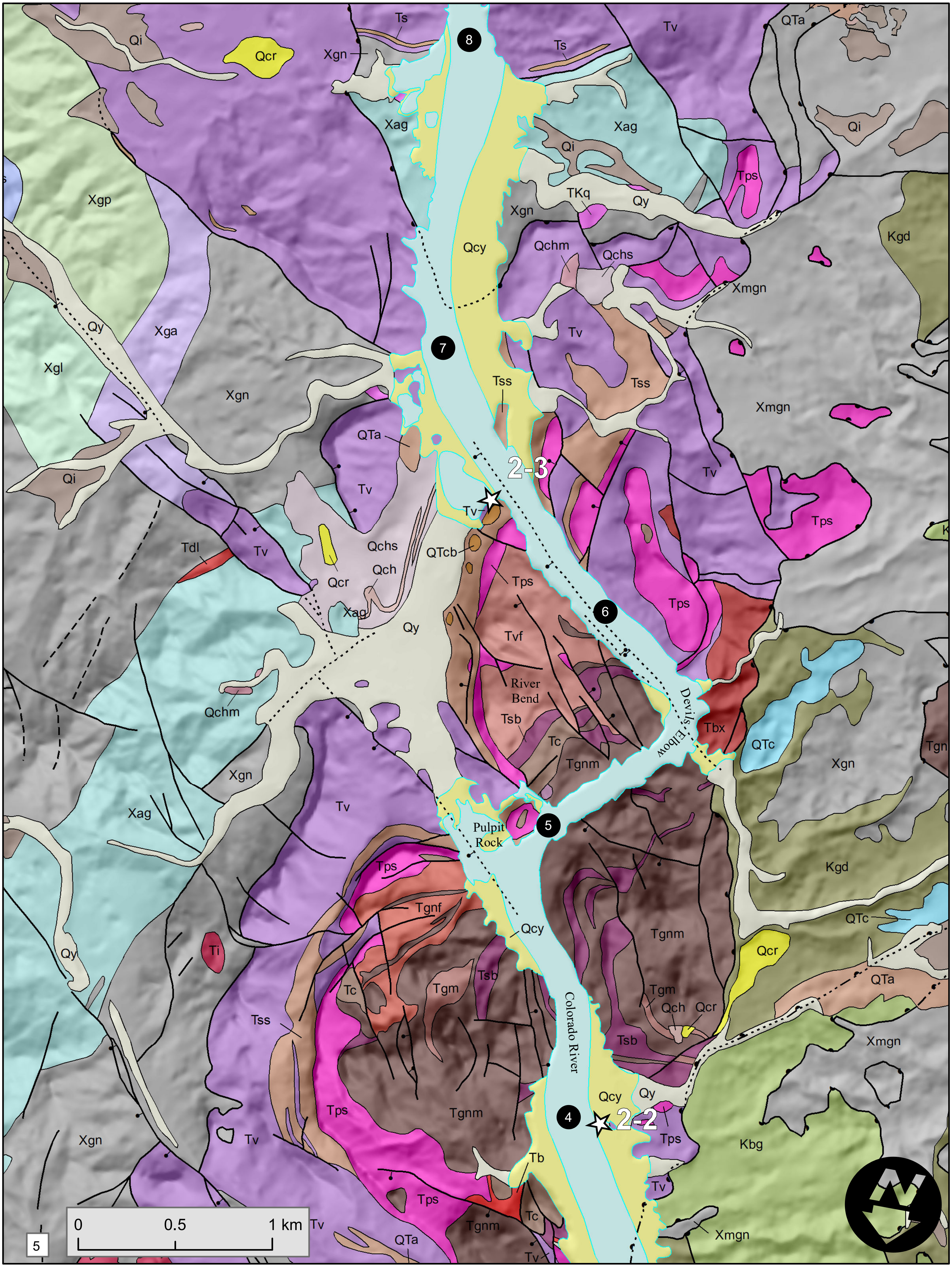
The upper Pleistocene Chemehuevi Formation also crops out locally here, consisting mostly of sand and mud. The Chemehuevi Formation and the Bullhead Alluvium represent two major aggradational episodes by the river, respectively 100–150 m and 200–250 m thick.



A Holocene aggradation is also revealed, based on 14C-dated riverlaid sediments drilled here for an engineering project to remediate contaminated groundwater (Fig. 19*). The 14C chronology indicates river aggradation between 9 and 6 ka (Howard et al., 2011). Near-zero ages in the upper 11 m of the section were interpreted to record a combination of the thickness of sediment disturbed by post–5 ka scouring (an inferred unconformity), overlain by sediment accumulated since 1938 in the upper reaches of Lake Havasu reservoir and by dredge spoils.

Figure A. Coarse fluvial deposit, mapped as boulder conglomerate of Bat Cave Wash, 1.5 km SE of Topock on the Arizona side of the river (Howard et al., 2013). Boulders of gneiss and basalt are as large as 0.9 m across. Far-traveled rounded chert clasts are as wide as 0.2 m across. Current imbrication is toward the east-southeast (toward the camera). The trenching tool is 0.6 m long. The deposit here fills a channel cut into a substrate (at bottom) of red, poorly sorted, middle Miocene alluvial-fan conglomerate (Howard and Malmon, 2011).

* Figure in the main guide



Ts
QTa
Tv
Qi
Qcr
Xgn
Ts
8
Xag
Xag
Qi
Tps
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Qy
Xgn
Qcy
Kgd
Qchm
Qchs
Xmgn
Qy
Xga
Tv
Xgl
7
Tss
Tss
Xgn
Xmgn
QTa
2-3
Tv
Tv
Qi
Tv
Tps
Tdl
Tv
Qchs
QTcb
Qcr
Qch
Tps
Tps
Xag
6
Qy
Tvf
River
Bend
Devils
Elbow
Qchm
Tsb
Tbx
Tc
QTc
Xgn
Tgn
Xgn
Tgnm
Xag
Tv
Pulpit
Rock
5
Kgd
Tps
Tgnf
Qcy
QTc
Qy
Tgnm
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Qcr
Tsb
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Tc
Tgm
Tgm
Qch
Qcr
Tss
Colorado River
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Xmgn
Qcy
Qy
4
2-2
Tps
Xgn
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Kbg
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Tv
Tps
0
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1 km
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Tc
Tgnm
Xmgn
5
QTa
Tv

STOP 2-3. River Island and Abandoned River Valley (34.6491°N, 114.4462°W)

The purposes of this stop are to examine the Peach Spring Tuff and to view the abandoned river valley, which contains both the Chemehuevi Formation and older fluvial boulder conglomerate.

At the southern end of River Island and east of a hogback of Peach Spring Tuff, boulder-rich fluvial conglomerate is inset into the deformed Miocene rocks as exposed in the abandoned river valley. The thalweg of the boulder-filled paleochannel is 10 m above the level of Lake Havasu. Subrounded boulders (as large as 1 m across) are estimated to be 70% gneiss, 20% volcanic rocks, and 10% Proterozoic and Mesozoic granite, rock types that are local. Extralocal quartzite, chert, and limestone clasts are abundant among the pebble and cobble fraction of the deposit.

The upper Pleistocene Chemehuevi Formation viewed up the paleovalley is also inset into the Miocene lower volcanic sequence, and is partly wind reworked (Fig. D). Most of the full thickness of the Chemehuevi Formation here consists of sands. This supports a model that channel sands formed the bulk of the formation; peripheral overbank mudstones are preserved only along valley margins (Malmon et al., 2011). What caused the massive aggradation in the late Pleistocene? It remains perplexing.

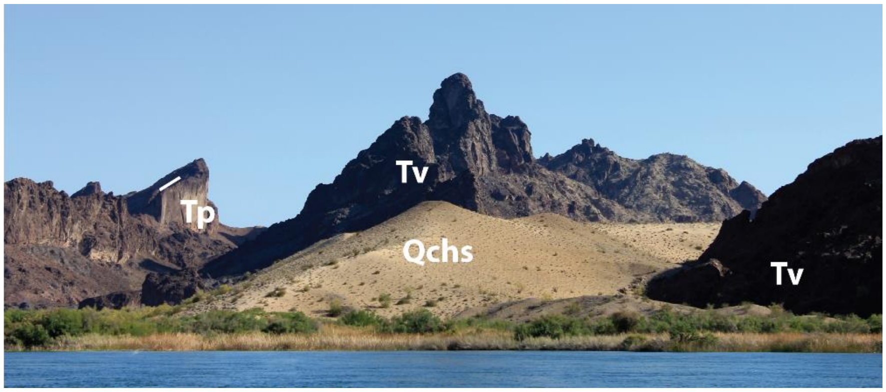


Figure D. View upstream near STOP 2-3. Sand facies of the Chemehuevi Formation (Qchs), partly reworked by the wind, occupies paleovalley east of River Island.

Between STOP 2-2 and 2-3

Continue downriver in the gorge as it cuts through moderately to steeply southwest-dipping volcanic and sedimentary rocks, cut by numerous high-angle and low-angle faults. The Miocene section lies nonconformably above light-colored Proterozoic gneisses and granites, all in the hanging walls of the Chemehuevi and Devils Elbow faults just seen. Rocks on the west shore (right) include a thick sequence of rock avalanche and crystalline megabreccia deposits >1 km long and a few 10's of m thick, wholly of cracked Proterozoic crystalline rocks interstratified in sedimentary breccia (Miller and John, 1999). At 1.2 mi past STOP 2-2, a small bay east of Pulpit Rock on the Arizona side at the river bend marks the bed of an old abandoned valley of the Colorado River that veers southeast into Arizona and bounds the east side of River Island (Lee, 1908; Howard et al., 2008). STOP 2-3 is at the south end of this abandoned valley.

Beyond a big bend in the river back to the left (Devils Elbow), rocks on the right (west) are dominantly the Peach Spring Tuff and the lower volcanic sequence, cut by numerous down-to-the-east normal faults. Rocks in the vertical walls along the east bank (left) include post–Peach Spring Tuff sedimentary breccia and megabreccia deposits.

STOP 2-2. Devils Elbow Fault (34.6770°N, 114.4572°W)

The purpose of this stop is to examine the Devils Elbow fault, an extensional fault that is structurally higher than the Chemehuevi detachment fault and the deeper Mohave Wash fault, and to discuss stratigraphic and structural features in its hanging wall. From the west river bank, walk southwest 0.5 mi (0.8 km). Exposures on the right (north) include the Peach Spring Tuff above older mafic volcanic rocks. At the fork in the wash, keep left and follow the burro trail 0.3 mi (0.5 km) over the low saddle through Colorado River gravels that unconformably overlie altered and fractured granitic rocks in the hanging wall of the Chemehuevi detachment fault. Red rocks to the east include altered Miocene volcanic deposits, with interstratified sedimentary breccia and megabreccia deposits in the hanging wall (upper plate) of the Devils Elbow fault. The fault at this exposure dips 35° east with well-preserved slickenside striae plunging 33° downdip (Fig. C). Although poorly constrained, top-to-the-east-northeast slip on the Devils Elbow fault is several km (John, 1987a). Rocks in the footwall of this fault form the hanging wall to the Chemehuevi detachment fault, and are part of the Chemehuevi Mountains Plutonic Suite, with associated mafic and felsic dikes (now subhorizontal) derived from a footwall location ~18 km to the west-southwest.

Drink some water and return to the canoes. Before leaving the beach, look east across the river to the high peaks on the Arizona skyline. A tan-colored tuff dip-slope there is the 18.8 Ma Peach Spring Tuff, which served as the substrate to the syntectonic sedimentary succession. The tuff occupied a paleovalley here and thins northward to near zero thickness near STOP 2-1. Viewed from here, tan exposures of the tuff form a spectacular, well-defined syncline, plunging moderately toward the southwest (Figs. 5*, 26A*). The syncline is interpreted as a fault-related fold that formed during extension, where a steep, now-transverse fault, which bounds two steeply tilted blocks of basement rocks, propagated upward into the layered Miocene section (Figs. 29*, 30*; John and Howard, 1994; Howard and John, 1997). Deformation of the folded rocks is complex and includes bedding-plane faults and at least one small reverse fault (Howard et al., 2013). The core of the syncline is filled with coarse sedimentary breccia and thick, irregular megabreccia deposits, made up of clasts of crystalline rocks (Miller and John, 1999).

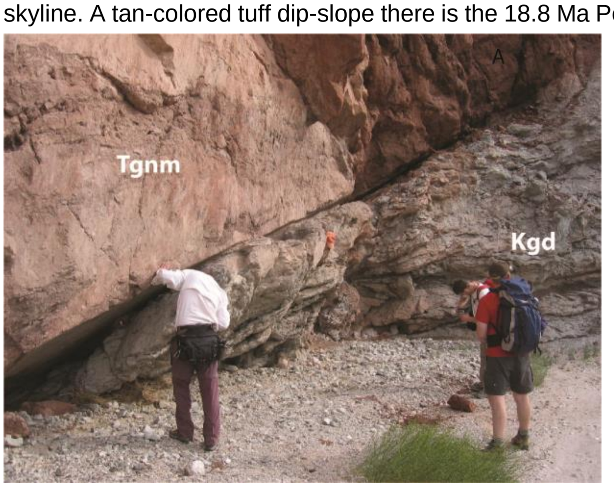
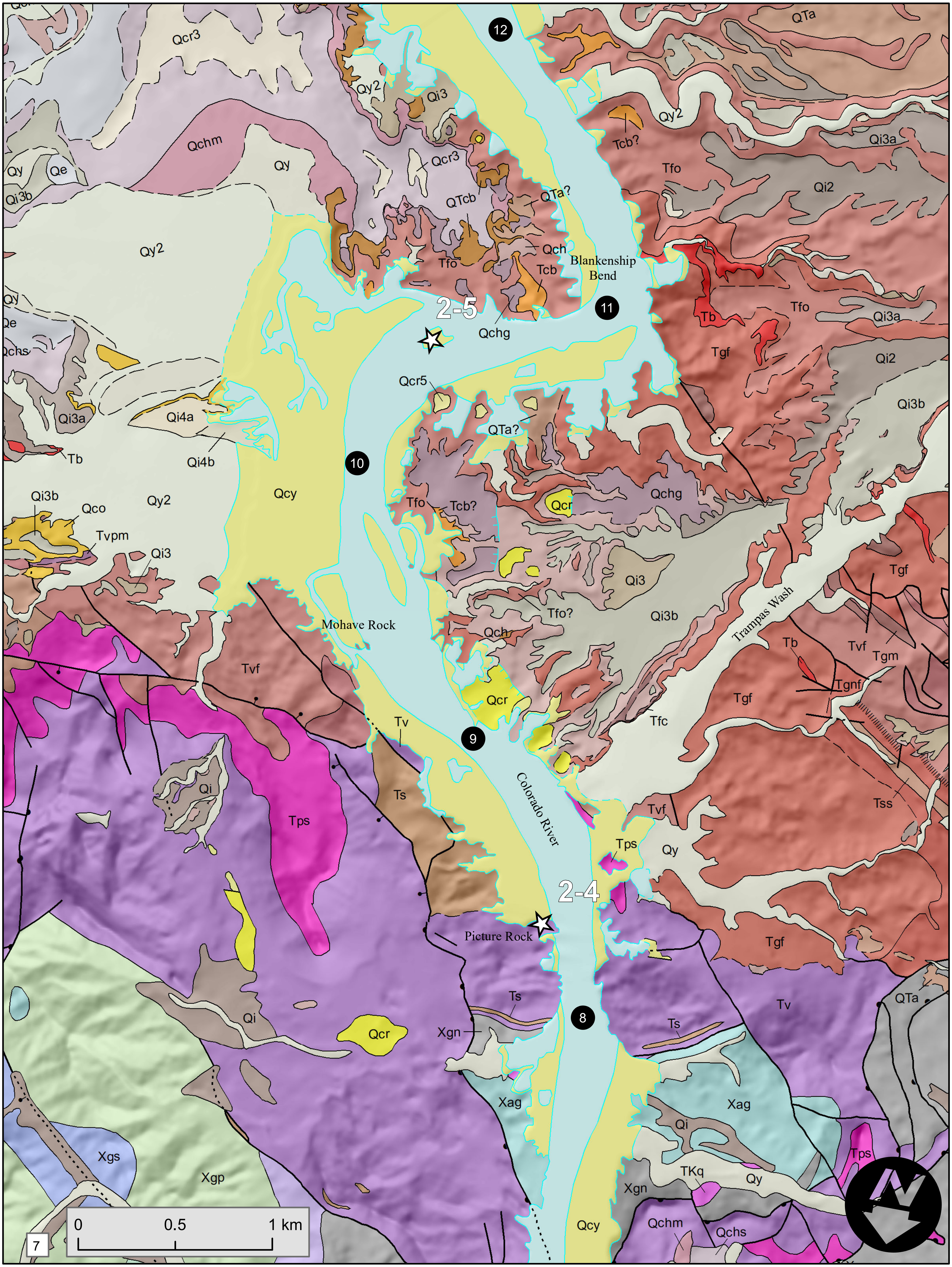


Figure C. Devils Elbow fault at STOP 2-2 juxtaposing reddish Miocene gneissic-clast landslide megabreccia deposits (Tgnm), against a footwall of fractured and altered porphritic hornblende-biotite granodiorite (Kgd).

* Figure in the main guide


Blankenship Bend
Mohave Rock
Picture Rock
Colorado River
Trampas Wash
2-5
2-4
12
11
10
9
8
Qcr3
Qchm
Qy
Qe
Qi3b
Qy2
Qi3
QTcb
QTa?
Qch
Tfo
Tcb
Qchg
Tcb?
QTa
Qi3a
Qi2
Tb
Tgf
Qcr5
Qi4a
Qi4b
Qcy
Qco
Tvpm
Qcr
Tfo?
Tvf
Tgm
Tgnf
Tfc
Tv
Ts
Tps
Qi
Tss
Xgn
Xag
Xgs
Xgp
TKq
Qchs
0
0.5
1 km

STOP 2-5. Blankenship Bend: Chemehuevi Formation and Older Sediments (34.5977°N, 114.4295°W)

The purposes of this stop are to view the Chemehuevi Formation and older fluvial boulder conglomerate. The white cliff exposures along the east shore of the Colorado River at Blankenship Bend are part of an island-like peninsula underlain by gently dipping post-extension upper Miocene conglomerate derived from felsic members of the Chemehuevi Mountains Plutonic Suite to the west. The peninsula is bounded on the west by the modern Colorado River channel and on the east by a paleochannel filled with mud and sand of the upper Pleistocene Chemehuevi Formation. Fluvial boulder conglomerate unconformably overlies the upper Miocene conglomerate, and in turn is overlain by pinkish sands and muds of the upper Pleistocene Chemehuevi Formation. The boulders in the fluvial conglomerate are clearly winnowed from the underlying coarse alluvial-fan deposit by the ancient Colorado River (Fig. F). Where exposed, the boulders are moderately to deeply weathered. Good exposures of the fluvial conglomerate reveal that it is a mix of coarse, far-traveled cobble gravel and locally derived river-sculpted boulders. This facies association of far-traveled cobbles and locally derived boulders is typical of ancient Colorado River flood deposits, and is particularly pronounced near the bases and margins of paleochannels cut into old alluvial fan deposits. The stratigraphic position of the boulder deposit is unresolved, whether part of the Bullhead Alluvium or younger, which clouds the significance of the flood it records. Is the boulder conglomerate the same one seen at River Island (STOP 2-3) and yesterday's STOP 1-4? And/or the conglomerate of Laughlin seen while traveling between STOPS 1-6 and 1-7?

The younger Chemehuevi Formation fills paleotopography including a Colorado River paleovalley cut through the boulder deposit and into underlying fanglomerate. The aggradation of the Chemehuevi Formation ca. 70 ka is second only to the Bullhead Alluvium in its volume and thickness (Malmon et al., 2011), making it an enigmatic singular event of the Quaternary, a period of time in which the Colorado River was apparently dominated by net incision into the thick fill packages of the Bouse Formation and Bullhead Alluvium. Did other Pleistocene aggradation events come and go as the river worked through its thick ancestral fill? Or does the Chemehuevi Formation record a particularly rare series of events in the river's Quaternary history?

Figure F. River-sculpted and imbricated boulders, up to 1 m across, of Chemehuevi Peak Granodiorite (under field book) and other rocks in boulder conglomerate near the crest of Blankenship Bend peninsula.

Between STOP 2-4 and 2-5

Continue downstream past the mouth of Trampas Wash on river right at the site of an obvious outcrop of a tephra bed in Miocene rocks near the river. Near the mouth of the wash (not stopping there on this trip) is an exposure of a series of small paleochannels that cut transversely in a downstream direction across older dipping fanglomerates. These features are strongly reminiscent of the Newberry channels discussed at STOP 1-6. About 1.2 mi up Trampas Wash at a local tributary, there is an intriguing exposure of a paleochannel filled with a granodiorite boulder–rich conglomerate (Fig. E). The paleochannel cuts across the depositional and structural grain of older strata, is reminiscent of the spillover-linked channels of the Pyramid gravel visited at STOP 1-6, and possibly could be linked to the early Pliocene spillover integration of Mohave-Cottonwood Valleys with Chemehuevi Valley. In other words, the boulder deposit may have resulted from flood breaching of the Topock divide by overflow from the Mohave paleolake as the incipient Colorado River began to find its path toward the sea.

At 1.3 mi downstream from Picture Rock, a small island of megabreccia near the east shore of the river, is Mohave Rock. It reputedly was used by steamship captains to winch their boats up the rapids described by Ives, before flooding in Lake Havasu when Parker Dam was built in the 1930s. Rowboats were sent upriver carrying the ship's anchor, which was attached to Mohave Rock and hauled in, moving the ship slowly up the rapids toward smoother water. Continue downriver to the upstream curve of Blankenship Bend on the Arizona side of the Colorado River.

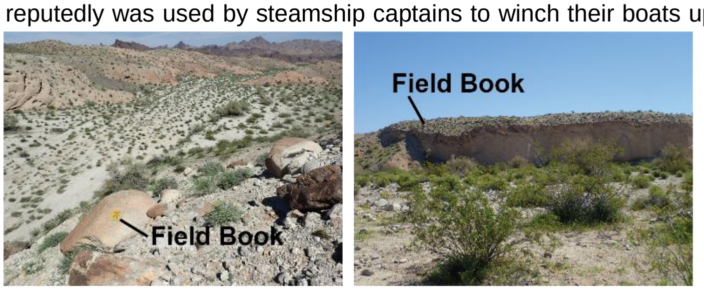


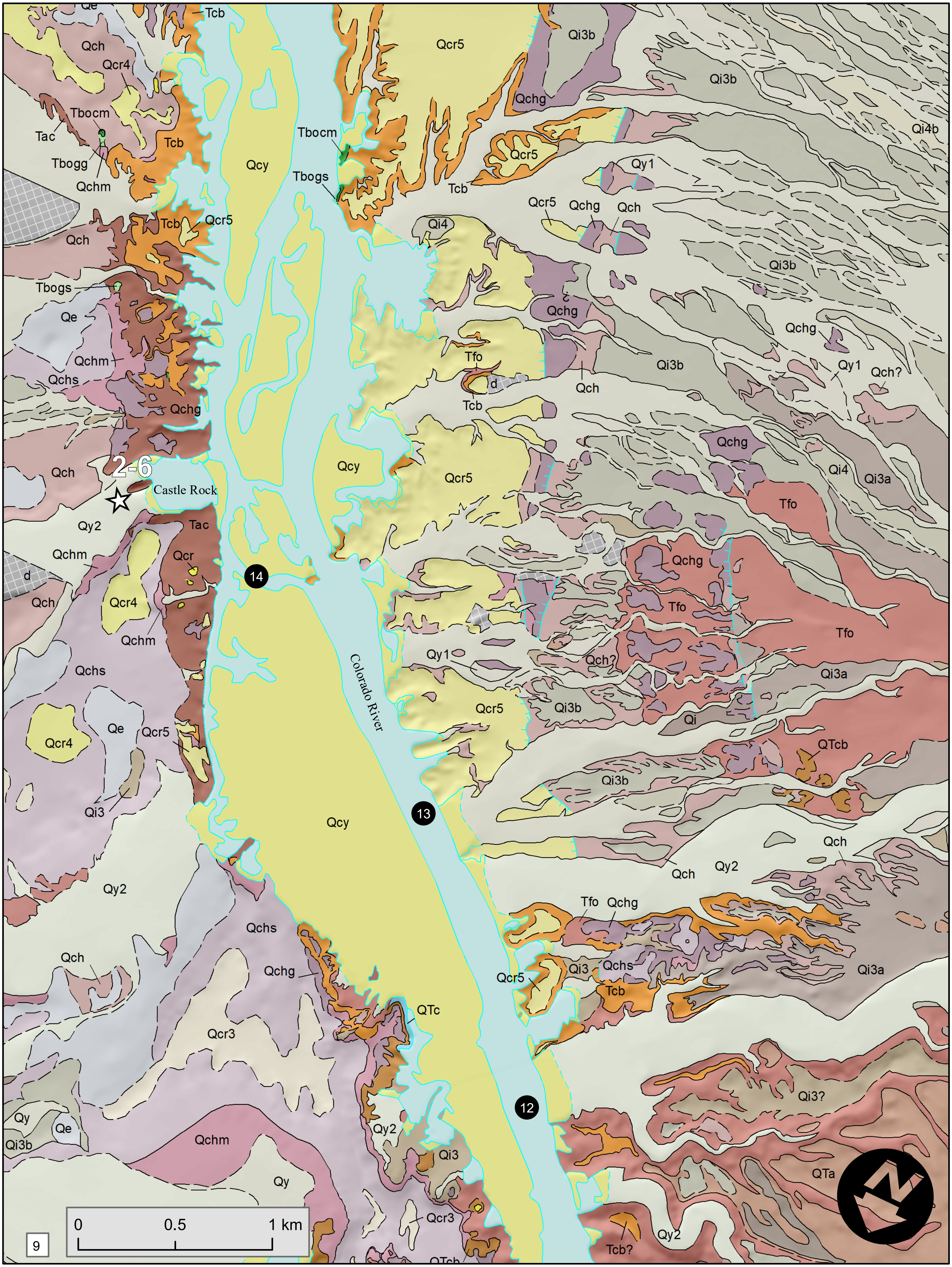
Figure E. Two views of a boulder-filled paleochannel in Trampas Wash, 1.5 mi (2.4 km) upstream (southwest) of the Colorado River. This feature filled with locally derived and subrounded large boulders is reminiscent of the Pyramid gravel at STOP 1-6.

STOP 2-4. Volcanic Rocks at Picture Rock (34.6242°N, 114.4382°W)

The purpose of this stop is to examine the older Miocene volcanics and related features. STOP 2-4 is on the east side of the Colorado River near the lower end of Topock Gorge. A plaque placed here by the Mohave (Aha-Makaav) and Chemehuevi (Nüw) Tribes refers to this area of petroglyphs as Hum-Me-Chomp: "the [place] where the river once churned to make this place inaccessible to the living." This area is said to have once included a trading site between the nomadic Chemehuevi Indians who roamed the area west of the Colorado River, and the Mohave Indians who lived in the river valleys and along the east side of the river. The rocks are part of a south-dipping sequence of mafic and intermediate volcanic flows of the lower volcanic sequence, which locally overlies a very thin basal arkose resting directly on the Paleoproterozoic gneiss. The lavas are unconformably overlain locally by the Peach Spring Tuff, and younger syntectonic sedimentary rocks exposed in Trampas Wash directly to the west, and in Blankenship Wash to the south and east.

Between STOP 2-3 and 2-4

Leaving STOP 2-3 will offer a view from the river of the Chemehuevi Formation in the paleovalley (Fig. D). As we boat downriver 4 mi to STOP 2-4, we pass through a series of folds associated with the large, upended tilted blocks of crystalline rock, above the Chemehuevi fault system (similar to that viewed from a distance at STOP 2-2). The stratified rocks drape around the corners of adjoining basement blocks, forming the moderately to steeply plunging folds, interpreted as forced drape folds, with amplitudes as great as 2 km (John and Howard, 1994). The folds in the stratified rocks contrast with the simply tilted, monoclinal blocks of crystalline basement around which the strata drape. The drape folds here and elsewhere in the southern Basin and Range province demonstrate that major plunging folds can form during extensional tectonism (Howard and John, 1997), and not only during regional shortening deformation.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STOP 2-6. Castle Rock and Canoe Takeout (34.5641°N, 114.3938°W)

Castle Rock exposes cliffs of the pre–Bouse alluvium of Castle Rock. Pinkish fine sands of the Chemehuevi Formation overlie it and Chemehuevi Formation mud fills erosional niches in it. At the takeout, note how the contact between the Chemehuevi Formation sand facies and underlying mud facies coincides with a beveled surface on the alluvium of Castle Rock. What does this tell us about the age difference between the mud and sand facies here? Optically stimulated luminescence analyses from recently collected samples in this sequence are in progress.

Nearby exposures of the Bullhead Alluvium atop the bluffs of Castle Rock alluvium contain rip-up blocks of Bouse Formation marl, and in situ outcrops of the marl are found in close association with them (House et al., 2018). On the west side of the lake, flat to gently dipping outcrops of Bouse Formation limestone line the shoreline and extend into the lake. We will travel by car to lodging in Lake Havasu City.

Between STOP 2-5 and 2-6

Along the west side of the Colorado River at Blankenship Bend, a gently dipping vesicular basalt flow records one of the last gasps of volcanism associated with extension in the area. It is interstratified within the upper part of the post–Peach Spring Tuff sedimentary section that makes up the Trampas Wash (California) and Blankenship (Arizona) basins. The basalt has been correlated on both sides of the river based on rare earth element chemistry, tying the two basins together at a late stage in their depositional history.

Downstream from Blankenship Bend, Chemehuevi Valley (Chemehuevi basin) opens up, and synextensional units are hidden below bluff exposures of upper Miocene fanglomerate (alluvium of Castle Rock), inset younger boulder conglomerate that may be lower Bullhead Alluvium, and pinkish mud and fine sands of the Chemehuevi Formation. Here, also, the river's delta at the head of the Lake Havasu reservoir becomes strongly apparent and the current of the river begins to wane. The primary channel is lined with vegetated marshes that form placid backwaters and intricate discontinuous channels. The delta has been accumulating here since the completion of Parker Dam in 1938. Owing to the sediment-trapping efficiency of Hoover Dam (completed in 1936) and Davis Dam (completed in 1950), the bulk of this delta is likely dominated by sediment recycled from the floodplains of Cottonwood and Mohave Valleys.

On our way to the takeout at Castle Rock, we pass extensive exposures of the Chemehuevi Formation on river left. The Chemehuevi deposits fill a paleochannel cut into the granite-rich fanglomerate and overlying Colorado River boulder conglomerate. The Chemehuevi Formation has a characteristic stratigraphy of a light-brown, slope-forming, sand-dominated facies atop a bluff and badland forming reddish-brown mud-dominated facies (Malmon et al., 2011). The outcrops in the Blankenship Bend area sit at the northern end of a string of remnants that track a paleochannel position east of the present channel location. Well logs from a neighborhood built atop the Chemehuevi Formation indicate a channel depth of 15 m below the pre-reservoir river elevation (~20 m below the average lake elevation in this area) (House et al., 2018). Evidence from the Blankenship Bend area, and from sites upstream in Mohave and Cottonwood Valleys, indicates that the Chemehuevi Formation buries an eroded landscape having well-developed calcic soils on the slopes of erosional landforms.

Continue in the main Colorado River channel 3 mi beyond Blankenship Bend past heavily vegetated young delta bars and banks to the northern (upstream) end of The Island, toward the left. Paddle left (east) into the smaller channel (34.5655° N, 114.4044° W) and continue south to Castle Rock Bay, a large embayment in the cliffs to the east. The entrance to Castle Rock Bay is through a small channel at the very south (34.5621° N, 114.3962° W), just barely downstream from Castle Rock. The canoe takeout requires boating between patches of dense vegetation (and very shallow water) to Castle Rock on the left (east). Once we land, be sure to haul all equipment (paddles, canoes, personal flotation devices, shoes, water bottles, cameras, and any trash) to the parking lot roughly 250 m east past Castle Rock itself.

References mentioned in the text are cited in the main GSA field guide: Howard, K.A., House, P.K., John, B.E., Crow, R.S., and Pearthree, P.A., 2019, A river is born: Highlights of the geologic evolution of the Colorado River extensional corridor and its river: A field guide honoring the life and legacy of Warren Hamilton, in Pearthree, P.A., ed., Geologic Excursions in Southwestern North America: Geological Society of America Field Guide 55, p. 61–113, https://doi.org/10.1130/2019.0055(03).