GEOLOGY OF CENTRAL AND NORTHERN ARIZONA
GEOLOGICAL SOCIETY OF AMERICA
ROCKY MOUNTAIN SECTION GUIDEBOOK
J.D. NATNONS, C.M. CONWAY, and G.A. SWANN, EDITORS
FLAGSTAFF, ARIZONA, 1986

STRUCTURE AND GEOMORPHIC CHARACTER OF WESTERN COLORADO PLATEAU IN THE GRAND CANYON-LAKE MEAD REGION

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Route

The fieldtrip starts in Flagstaff and follows Interstate 40 west to Seligman, where it continues on Arizona Highway 66, formerly US 66. This road is followed west to Antares (20 miles or 32 km west of Peach Springs), where we turn onto a graded dirt road along the east side of Hualapai valley to Meadview and Lake Mead, some 60 miles (100 km) to the north. The rest of day 1 will be spent in the Lake Mead area. On day 2 we will go to Kingman on a graded dirt road along the west side of Hualapai Valley. In Kingman we will rejoin Interstate 40, which will be followed back to Flagstaff. Time permitting; we will make a brief sidetrip into the Cottonwood Cliffs at the edge of the Colorado Plateau.

The formal field trip starts at Seligman. Nevertheless, the Guide provides a few introductory statements and a generalized log for the stretch from Flagstaff to Seligman for the convenience of the participants.

Fieldtrip guide

The fieldtrip leaves from Flagstaff, a small city on the Colorado Plateau located at an altitude of 7,000 feet (2130 m), in the middle of a large forest of Ponderosa pine, and graced to the north by the San Francisco Peaks. These volcanic peaks, remnants of a composite volcano, reach an altitude of 12,600 feet (3840 m) and are the most imposing feature of the San Francisco volcanic field.

Flagstaff owes its altitude to the Coconino uplift, a broad and subdued domal upwarp that trends a few degrees west of north and is continuous with the higher and more sharply defined Kaibab Plateau north of the Grand Canyon. In places, the altitude of the Coconino uplift is increased by volcanic rocks of the San Francisco volcanic field. This late Cenozoic field is one of several occurring conspicuously along the southern edge of the Colorado Plateau. The oldest volcanic rocks of the field consist of widespread basalt flows that are 6 to 4 Ma old. Younger volcanic features are of two kinds: the most numerous are basaltic cinder cones and associated lava flows. The cones number more than 300 and are progressively younger to the northeast. The youngest is Sunset Crater, which erupted in 1066-1067 A.D. Less numerous but more conspicuous are intermediate to silicic stratovolcanoes and domes that trend roughly northeast and reach their culmination in Mt. Humphrey's, one of the San Francisco Peaks. Going northeast, these volcanoes are: Bill Williams Mountain (9,255 feet, 2821 m), Sitgreaves Mountain (9,380 feet, 2859 m), Kendrick Peak (10,418 feet, 3175 m), San Francisco Peaks (12, 611 feet, 3844 m), and O'Leary Peak (8, 925 feet, 2720 m). The ages range from 4.2 Ma (Bill Williams) to about 0.2 Ma (O'Leary). These data suggest a northeastward migration of activity for the intermediate-silicic volcanism as well.

The San Francisco volcanic field ends a few miles west of Williams, where the highway drops off the west edge of the Coconino upwarp onto a platform at an average altitude of 5,000 feet (1500 m). The platform is underlain by Paleozoic rocks with local veneers of upper Cenozoic sedimentary and volcanic rocks.

SET ODOMETER TO ZERO.
ODOMETER 0.0
Little America parking lot: start of field trip.

3.0
I-17 Intersection.

12.5 MP 186
Navajo Army Depot on left. San Francisco Peaks at 3:30, Kendrick Mountain at 2:00, Sitgreaves Mountain at 12:30.

15.6 MP182

Rest area with bathrooms on right side.

19.7 MP178
Bill Williams Mountain (straight ahead).

21.3
Garland Prairie on left; Sitgreaves Mountain on right.

31.7
Offramp to Arizona Highway 64 to Grand Canyon.

33.2 MP165
View of the town of Williams and of Bill Williams Mountain to left. Williams is a lumbering, ranching and tourist town that came into being because of the Santa Fe railroad.

38.3 MP160
Distant views westward of Picacho Butte and the Mount Floyd volcanic field (north of Picacho), and of the Granite Mountains near Prescott to the south. Picacho Butte has been dated at 9.8 Ma from hornblende rhyodacite at crest (Goff and others, 1983). Mount Floyd is a complex of basaltic and silicic flows and intrusive masses, dated variously at 7.4 and 14.0 Ma (McKee and McKee, 1972) and 5.1 and 2.4 Ma (Nealey, 1980). The Granite Mountains are composed of coarsely porphyritic Proterozoic granite.

42.8 Near MP155
Beginning of long descent from Coconino uplift and lava plateau. Another good view of Picacho Butte at 11:30, Mount Floyd field at 1:00. These features rise from terrain typically about 5000 feet (1500 M) in altitude and are underlain by Paleozoic rocks. These rocks are visible south of Picacho Butte, where their gentle dip to the northeast is visible. This dip is typical of the southwest margin of the Colorado Plateau and reflects a Laramide (pre-Tertiary rifting) uplift southwest of the Plateau margin (Mogollon Highlands). Road cuts show basalt flows overlying well-bedded tan-colored ash.

43.9 MP154
Roadcut in cream-colored Kaibab Limestone.

51.0
Exit to Ashfork. Like many other towns along the railroad, Ashfork got its start as a place where steam engines tanked up on water. Now it is a center for quarrying and working stone. The stone quarried locally is the flaggy Coconino Sandstone of Permian age, in which reptilian tracks are common.

55.1
Worked-stone abutments of old Santa Fe railroad line on the right (north).

55.8 MP142
The topographic depression visible in the distance to the south is Chino Valley, one of the northwest-trending structural basins that are characteristic of the Transition Zone (between the Colorado Plateau and Basin and Range provinces) in Arizona. The fault bounding Chino Valley on the northeast displaces Quaternary fans. The town of Chino Valley is near the epicenter of a 5.2 M_1 earthquake that occurred 10 years ago along the southwest prolongation of the northeast-trending Mesa Butte fault zone, which can be traced to near the Grand Canyon.

57.6 MP140
Exit 139 (Crookton Road). A few miles north of this exit are spectacular collapse features formed by solution of Paleozoic rocks and collapse of Paleozoic and Tertiary volcanic rocks into the resulting cavities.

66.5 MP131
Mount Floyd at 2:30. The high lumpy ground is composed principally of silicic extrusives.

69.7 MP128
Tertiary basalt flow in road cut. View of town of Seligman at 12:30, with Aubrey Cliffs beyond, which are underlain by the Permian Supai, Coconino, and Kaibab Formations. Skyline at 10:00 is in Mississippian and Devonian rocks.

75.4 MP122

Town of Seligman at 3:00. Seligman is a small ranching center that got its start as a railroad town when the Santa Fe railroad was built in the 1870's. The town lies near the head of the Chino Valley structural depression. The valley probably also was an ancient drainage system that predated structural differentiation between the Colorado Plateau and the Transition Zone, and carried the so-called rim gravels northward onto what is now the Plateau. Rim gravels of southerly provenance are common all along the southern margin of the Colorado Plateau. Drilling logs indicate 145 feet (44 m) to 234 feet (71 m) of lava and cinders in the valley floor. The top of the Redwall Limestone (or limestones near the base of the Supai Group) are at a depth of 832 feet (254 m).

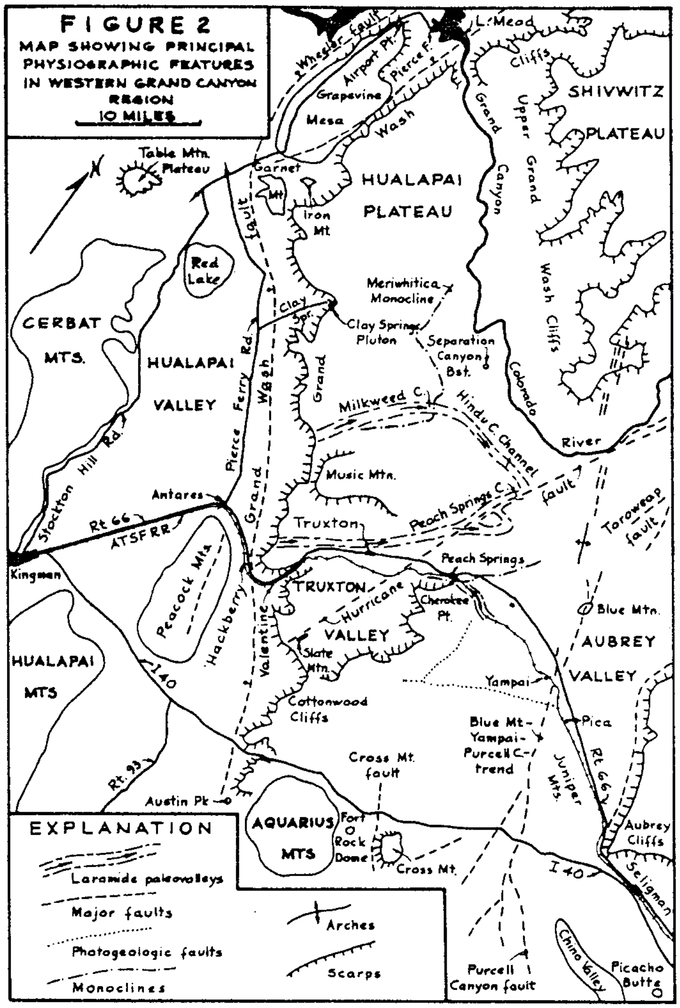

Figure 1. *Map showing principal physiographic features in western Grand Canyon.*

76.0 MP121

Take exit 121 to State Highway 66. Turn westward on Arizona 66, toward Peach Springs and Kingman.

This portion of the trip along Highway 66 on day 1 (and the return on day 2 via Interstate 40) crosses terrain characterized by a pronounced northwest-trending structural fabric that has not been mapped in detail on a regional basis. The trend parallels Chino Valley south of Seligman and continues along the southern Aubrey Cliffs north of Highway 66. The western edge of the Colorado Plateau has the same structural trend from near Red Lake (Hualapai Valley) to the Mohon Mountains. The trend (approximately N25°W to N45°W) comprises features such as regional orientations of the retreating Kaibab scarp, Laramide monoclines, folds and faults, and mid-Tertiary or younger normal faults. All of these features may reflect an early Tertiary (or older) structural grain that was reactivated during various episodes of Tertiary deformation. The more obvious trends are clearly visible on Skylab 5-inch color photographs, and closely parallel prominent structures and lineaments mapped in the adjacent Shivwits Plateau, Coconino Plateau, and Verde Valley region by Lucchitta, Elston, Shoemaker, Abrams, and Squires in Goetz and others (1975). For the purpose of this log this northwest trend will be referred to either as the Chino-Aubrey Valley trend or the Hualapai-Big Sandy trend. South of the western Grand Canyon, this northwest trend contrasts with the N25°E Hurricane-Toroweap fault trend. Extensional faulting with the NNE trend appears to be superimposed on the older NW trend throughout the southwest plateau and the transition zone, although a few youthful-looking Quaternary scarps occur with either trend. The strike of probable Laramide-age folds and faults appears to change gradually from a NW direction to a NNE direction as one goes from the Hurricane fault zone to the Lake Mead region. Individual Laramide monoclines on the Hualapai Plateau follow both trends.

The present physiography and geomorphology of the region are dominated even today by the NW and NNE structural trends. The most conspicuous such feature, an unmapped "structure" apparent on Skylab photographs, is herein designated the "Blue Mt.-Yampai-Purcell Canyon trend". This feature, 40 miles (65 km) long, begins in the Blue Mt. arch, runs south through the Juniper Mts., then coincides with the Purcell Canyon fault of Goff and others (I 983). Further south, the alignment coincides with the extreme western margin of Chino Valley. North of the Colorado River, on the southern Shivwits Plateau, the structure is colinear with faults of moderate to low displacement and also with the alignment of volcanic centers. Between Aubrey Valley and Interstate 40 (including Highway 66) the feature consists of a zone of closely-spaced parallel to en-echelon faults, flexures, graben, and elongate tilted fault blocks with conspicuous topographic alignment.

The Chino Valley, which is east of and parallel to the trend, probably was one of the main Laramide valleys carrying "rim gravels" northwestward from central Arizona into the Aubrey Valley region. Some of the drainage continued northwest across the Colorado River region; a prominent tributary followed Yampai Canyon to join the Hurricane-Peach Springs paleovalley at Peach Springs. Other northwest-trending drainages may have converged on the Hurricane fault-Peach Springs paleovalley, but mid-Tertiary faulting and volcanism have obliterated most details of any Laramide drainage connections between the Seligman and Peach Springs areas.

81.0 MP136
Chino Point (south end of Aubrey Cliffs). Brick-red outcrop on right (north) is Pennsylvanian and Permian Supai Group capped by lighter colored Permian Coconino, Toroweap, and Kaibab Formations. The Hermit Shale is not present here as it pinches out about 20 to 25 miles (32 to 40 km) to the northwest, near Blue Mountain. Three miles north of the highway, at the base of the Aubrey Cliffs, Toroweap limestones in the downdropped (western) block are in fault contact with Supai beds, giving as estimated displacement of 500 to 600 feet (150 to 180 m) (Blissenbach, 1952).

83.5 Near MP134
Basal Supai limestones (possibly some Redwall) on west side of highway.

91.3 Near MP125
Outcrop of basal Supai (Blissenbach, 1952) south of highway at 9:00 along ATSFRR, bounded by fault that is down to the east.

93.7 Near MP123
On right, intersection with Pica Camp Road, which follows Aubrey Valley toward the north. Aubrey Valley is bounded on east and west sides by complex, intersecting faults. Mapping by Blissenbach (1952) appears to be somewhat oversimplified judging by obvious lineaments visible on Skylab and aerial photographs.

94.3 Near MP122
On left, turnoff to the old Pica Station on the AT&SFRR. Deep well near station (large tanks 1 mile or 1.6 km south of highway) encountered Supai/Redwall contact at 144-foot depth (elev. 5100 feet t). Small Tertiary volcanic center at 10:00 along Supai ledge is one of the volcanic centers aligned with early Tertiary structural trends.

96.85 MP120
Roadcut in Tertiary arkosic Blue Mountain Gravels of Koons, 1948 (early to middle Tertiary rim-gravel gravel equivalents) derived from southeast along ancestral Chino Valley. AT&SFRR turns south away from highway and crosses bedrock ridge (basal Supai) in fault block of Blue Mountain-Yampai-Purcell Canyon trend.

98.8 MP118
Highway continues parallel to structural block of Blue Mountain-Yampai-Purcell Canyon trend. Rocks are basal Supai according to Blissenbach (1952).

99.8 MP117
Hyde Park (abandoned) on right. Highway descends into small graben.

101.4 Near MP115
Entrance to Grand Canyon Caverns.

104.3 Near MP113
Cut in gravels of Willow Springs (Late Miocene to Pliocene). These are postvolcanic basin-fill gravels that generally preceded Grand Canyon erosion cycle.

104.4
Fence at Hualapai Indian Reservation Boundary.

104.8 MP112
Gravels of Neogene Willow Springs Formation of Young (1979) in road cut. Ranch road intersection on right, Nelson Dome at 9:00, 0.5 to 1 mile (0.8 to 1.6 km) away. Erosion has exposed Cambrian Muav limestone and Devonian limestone around the dome (about 1 mile or 1.6 km in diameter). West boundary of structure is a fault; a small basaltic intrusive lies a short distance to the south.

106.1
Frazier Wells-Supai Road on right.

108.3 MP108
Gravels along road are Willow Springs and recent alluvium.

109.6 MP107

Begin series of cuts through axis of east-facing Peach Springs monocline. Road curves southwest nearly parallel to axis of monocline for about 1.5 miles (2.5 km). Several faults and local departures from regional northeast dip of strata are apparent in cuts through Redwall limestone and Devonian limestone as mapped by Twenter (1962). North of highway, monocline trends north northeast for about 4 miles (6 km), but has little preserved topographic expression. Twenter (1962) measured 300 to 400 feet (90 to 120 m) of throw near the highway.

110.6 MP106

Monocline curves to a southerly trend away from highway and across low ridge into adjacent Yampai Canyon (AT&SFRR route).

111.1 Near MP105

At 3:00: Scarp along Hurricane fault in middle distance. Horizon is Shivwits Plateau edge, forming the north rim of the Grand Canyon. These are the upper Grand Wash Cliffs formed by retreating Kaibab/Toroweap limestones over Hermit/Supai clastic rocks. Closest large canyon is the Peach Springs, along Hurricane fault. Prominent horizontal surface of Hualapai Plateau is beyond. West-facing, slightly upturned edge of Hualapai Plateau visible in places near 2:00. Town of Peach Springs at 10:00 in middle distance, Music Mountain on skyline. In the distance, beyond and west of Music Mountain, the Hualapai Mountains in the Basin and Range Province reach an altitude of 8266 feet (2579 m), about.3000 feet (900 m) above the plateau level in the foreground. Dip of strata in Music Mountain (Muav cliffs) is slightly steeper than regional dip. On the Shivwits Plateau, uppermost Miocene basalts dated at 7.5 and 6.0 Ma (Lucchitta and McKee, 1975) overlie a nearly flat surface cut into upper Paleozoic rocks. Yet, the Shivwits Plateau is a narrow south-trending finger surrounded on three sides by the deeply dissected Grand Canyon, with 5000 feet (1500 m) of relief. The flat surface over which the basalts flowed is not compatible with deep Grand Canyon dissection in the immediate vicinity. The inference is that the Grand Canyon is younger than the Shivwits lava, i.e. it is post-latest Miocene.

When looking toward edge of Shivwits Plateau, note small isolated butte on Hualapai Plateau (near Colorado River and Separation Canyon). Butte is basalt-capped, Miocene gravel remnant marking general level of fluvial-aggradation surface before Grand Canyon erosion cycle. Middle Miocene basalts flowed toward present site of Grand Canyon and Shivwits Plateau before erosion of surrounding deep tributaries (not visible from this perspective). Upper Grand Wash Cliffs forming edge of Shivwits Plateau had already retreated to position of butte by Eocene time because Eocene Milkweed Canyon-Hindu Canyon paleochannel had formed immediately to west (left) of butte and flowed toward viewers at base of retreating scarp. Scarp had retreated from west edge of plateau to approximate position of butte in Laramide time (Late Cretaceous to early Eocene), but has only retreated from near butte to present position since the Eocene. The latter interval includes the Grand Canyon erosion cycle. Retreat of scarp in Laramide time was a minimum of 24 miles (38 km), whereas subsequent retreat accompanying drainage incision has been only 5 miles (8 km).

Gravels beneath lava butte are younger than rim gravels and are derived from the Shivwits Plateau and also from the backslope of Grand Wash Cliffs (upturned edge of plateau) to the west. Some Precambrian clasts are included from reworked rim gravels or from limited Precambrian exposures along channels incised into plateau edge.

112.6 MP104

Limestones in cut were mapped as Devonian by Twenter (1964), but actually are Cambrian Muav Limestone (G. Billingsley, pers. comm.).

113.0 Near MP104

Peach Springs monocline swings back into parallelism with railroad and highway as shown by five deep drill holes at Peach Springs (Hualapai Tribal Headquarters). Tertiary lacustrine limestones 300 to 400 feet (90 to 120 m) thick are present on the east (downthrown) side of the monocline in Yampai Canyon, the narrow valley leading into Peach Springs along the railroad right-of-way. This is the canyon that carried rim gravels westward from the Seligman-Chino Valley region into the Peach Springs paleovalley. View of canyon mouth looking back (east) from Peach Springs along railroad. No comparable limestone or lacustrine facies are present in the two deepest wells in the Peach Springs paleovalley near Truxton, 9 miles (15 km) west on Route 66, even though Truxton lies near the axis of the paleovalley along the Hurricane fault trend. Thus, deformation on the monocline at Peach Springs dammed drainage coming from the east through ancestral Yampai Canyon, but not that coming from the southwest along the main valley at Truxton, which flowed northeast into lower Peach Springs Canyon (Young, 1979).

113.6 MP103

Basalt flows near Peach Springs are interbedded with the 17 to 18 Ma Peach Springs Tuff (Young and Brennan, 1974) on north side of hill to right of highway. Post-volcanic gravels that crop out along highway for next several miles are the Willow Springs Formation, which fills the Truxton Valley (ahead). These locally derived gravels and associated finer grained sediments are as much as 375 feet (115 m) thick, and were emplaced after substantial volcanic filling of the valley. The width of the present Truxton Valley is about 15 miles (24 km); Peach Springs Tuff outcrops can be traced discontinuously for at least 10 miles (16 km) across the valley. The tuff is mostly buried by gravels of the Willow Springs Formation and associated volcanic rocks.

114.5 MP102
Gravels of the Willow Springs Formation, derived from local scarps south (left) of highway (for several miles).

115.9
On right, intersection with Buck and Doe road, which provides access to Hualapai Plateau and Tertiary paleovalley system in Milkweed and Hindu Canyons. Straight ahead is Music Mountain, characterized by prominent cliffs of Cambrian Muav Limestone. Bench below is on Cambrian Tapeats Sandstone visible on left shoulder of mountain.

116.8 Near MP100
Cherokee Point at 9:00 is original "Music Mountain" on the 1858 Ives Survey maps. At some sun angles the upper slopes of the mountain are characterized by prominent limestone ledges that resemble the lines on a musical staff. Cliffs are part of fault-line scarp initiated by early Tertiary movements along the Hurricane fault trend. Erosion has caused the scarp to retreat about 9 miles (15 km) eastward from the fault line in the Truxton Valley.

117.4 MP99
View of Truxton and Truxton Valley. Exposures of Peach Springs Tuff straight ahead. At 11:00, Peacock and Hualapai Mountains beyond edge of Colorado Plateau. Slate Mountain at 10:00 is in belt of deformed Precambrian rocks along southwestern-most extension of Hurricane fault zone.

The trace of the Hurricane fault crosses the highway at approximately Mile 115.2. The fault trace is not visible on the ground, but a faint lineament can be traced on aerial photographs across the Truxton Valley and into Peach Springs Canyon. The lineament is most visible where it crosses volcanic outcrops partially buried by gravels of the Willow Springs Formation. To the south, the fault is clearly traceable from near the edge of the Colorado Plateau to the AT&SFRR, about 2 miles (3 km) south of Highway 66. North of the highway, the Peach Springs Tuff is offset 200 feet (60 m) along a branch of the fault. Visible displacement on one segment of the fault near the center of Truxton Valley is at least 100 feet (30 m).

120.1
Pump installation for Peach Springs water system on south (left) side of highway. Well penetrated 615 feet (190 m) of rim gravels, with an interbed of Miocene volcanic rocks at the 355- to 415-foot level. The volcanic rocks consist of 50 feet (15 m) of Peach Springs Tuff above 10 feet (3 m) of basalt and volcanic sediments. Coarsely crystalline granite was cored at bottom of hole from 615 to 623 feet. A deeper well 2 miles (3 km) to the southwest near Truxton went through a similar Tertiary section and encountered basement at a depth of 1610 feet (490m).

121.4 MP95
Truxton

122.4 MP96
Old terrace surface cut on Neogene Willow Springs Formation and Pleistocene alluvial fill at 9:00, 1 mile (1.6 km) southeast of highway. Modern drainage has cut nearly 100 feet (30 m) into fill that contains Pleistocene fossils.

122.7
Deep well (1610 feet) mentioned above, drilled by Bendix Corporation at 3:00 about 1000 feet (300 m) from highway. The well is on assumed axis of main Tertiary channel leading northeastward from edge of plateau near Hackberry into Peach Springs Canyon (Young, 1979, 1982).

Truxton Valley is early Tertiary erosional reentrant formed by northeast-flowing drainage along Hurricane structural trend. The drainage probably is contemporaneous with drainages flowing northwest through the Chino-Aubrey Valley system. All Tertiary sections in the Peach Springs, Hualapai Plateau, and Coconino Plateau areas contain similar rim gravel equivalents overlain by lacustrine limestones that are Middle Eocene or older on the Coconino Plateau (Young and Hartman, 1984; Young, 1985). A possible interpretation is that the stream that deposited the gravels originated in uplifts of Laramide age beyond the present margin of the Colorado Plateau, and flowed north and northeast towards the Paleocene and Eocene lakes in southern and central Utah, stripping the Plateau in the process.

The deep well at Truxton bottoms in Precambrian metamorphic basement. The lower 750 feet (230 m) of section is composed of rim gravel with a conspicuously weathered zone in the upper 100 feet (30 m). Above are 540 feet (165 m) of more locally derived, less weathered gravels that include volcanic clasts, 30 feet (9 m) of Peach Springs Tuff, then 240 feet

(71.5 m) of gravels of the Willow Springs Formation. The entire Tertiary section contains practically no fine-grained sediments or limestone that would be equivalent to the several hundred feet of lacustrine limestones at Peach Springs.

125 to 125.1
Gravels of the Willow Springs Formation and Peach Springs Tuff in road cuts. Outcrops of Precambrian granite overlain by Peach Springs Tuff and basalt about 1 mile (1.6 km) south of highway beyond AT&SFRR tracks. The low, eroded scarp of the Hurricane fault is visible to the east-southeast toward the center of Truxton Valley with exposures of basalts and Peach Springs Tuff in the upthrown block 350 feet (105 m) above equivalent outcrops along highway.

126.3 MP90
Road descends through basalts somewhat older than Peach Springs Tuff, which cap mesas on both sides of the highway. Several small faults are visible in the mesa-capping rocks for the next several miles.

127.3 MP89
Turn off to Walnut Spring Canyon (and ranch) on the right (west). Several tuff-capped mesas in the canyon are approximately over axis of Tertiary paleovalley penetrated by deep well at Truxton. East and south of the highway the tuff and basalts rest on a surface of considerable relief with channel gravels conspicuous in some places below the volcanic rocks.

127.8
Start Proterozoic exposures.

128.3 MP88
AT&SFRR rejoins highway on left, emerging from Truxton Wash Canyon. Beginning of Precambrian exposures that continue for several miles. Mesa on east (left) side of road exposes tuff interbedded with basalts and resting on Precambrian granite and Tertiary gravels. View back (north) along highway shows conspicuous but minor fault in tuff section east of highway.

130.8
Valentine

131.5
Ranch at 9:00 with poplars and orchards across from AT&SFRR was used for early scenes of 1960's film "Easy Rider". The canyon followed by the highway was also followed by Cortez, and the early Ives Expedition in 1859 as well. A Spanish gold dagger was found in one of the drainages on the Hualapai Plateau to the north by a Kingman prospector, and reputedly resides in the Kingman museum. The Ives Expedition, approaching from the west, found their first water in four days in this canyon and they were able to convince two "Hualpais" to guide them down the as yet unexplored Peach Springs Canyon. That expedition was reportedly the Hualapai Indians' first contact with whites (36th Congress, 1st Session, 1859, House Executive Document #90). Later in the 1800's the cliffs above the highway were the site of skirmishes between the Cavalry and Indians.

132.8
Gas stations and store.

133.2 MP83
Peacock Range straight ahead

133.7
On left (south), junction with road that follows Big Sandy Wash (Hackberry cutoff). On right just before turnoff is fault contact of Precambrian rocks with Tertiary gravels, possibly the main break of the southern "Grand Wash fault". South of highway in middle distance are several tilted fault blocks of Peach Springs Tuff and basalts in the valley east of the Peacock Range. These blocks document a 1000 foot (300 meter) post-middle Miocene offset on the plateau-margin faults.

134.9
Outcrop of Peach Springs Tuff along railroad cut south of highway. Tuff can be inspected here. Alternatively, take Hackberry Cutoff Road south for about 1/3 mile (0.5 km) across first wash and turn west to follow dirt road parallel to AT&SFRR; continue 1 mile (1.6 km) along railroad to excellent exposures of Peach Springs Tuff in railroad cut.

135.6
Hackberry turnoff. Volcanic plug at 10:00. It is reputed to cause extreme interference with short-wave C.B. radios.

136.6 MP80
Proterozoic basement rocks on right.

137.1 MP79
Locally derived basin fill composed of angular Proterozoic clasts. Beginning of long alluvial-fan stretch. View at 3:00 of channel filled with west-derived volcanic rocks on top of Grand Wash Cliffs. Thickest early Tertiary channel fill is along cliffs halfway between highway and this prominent volcanic cap.

137.8
Power line crossing. Excellent view of northern Grand Wash Cliffs, a fault-line scarp forming the east rim of Hualapai Valley. Grand Wash Cliffs are predominantly cut in Precambrian rocks capped by veneer of Paleozoic's (Tapeats to Muav).

140.1 MP76
Range on west side of Hualapai Valley is the Cerbat Mountains (saw tooth parts are in Peach Springs Tuff). Small outcrops in middle distance at 1:00 are Precambrian rocks.

141.3 Near MP75
Turn northward to Pierce Ferry at Antares. Two miles (3 km) northeast of intersection a 910 foot (280 m) well encountered Peach Springs Tuff at depth of 650 to 710 feet (200 to 215 m) or an elevation of 2680 feet for the base of the tuff. This is 2000 feet (600 m) below same tuff on Grand Wash Cliffs near Hackberry.

142.0
Knobs of Proterozoic rocks in valley indicate that Grand Wash fault splays out into segments, each with relatively small displacement. On skyline of Grand Wash Cliffs light-colored outcrops are composed of Cambrian Muav limestone.

147.0
View of another pre-Basin and Range channel along Grand Wash Cliffs near 3:00. At 1:00 exposure of cliff-forming members of Muav Limestone with Tapeats Sandstone bench below to west.

148.8
Crossing Truxton Wash which flows into Red Lake. Miocene lava cap on Grand Wash Cliffs at 3:00 above Precambrian spur marks north side of Laramide channel cut through cliffs at head of Milkweed Canyon (Hualapai Plateau). Lowest point of channel is below the right (south) edge of lava cap where Peach Springs Tuff crops out on small buttes. Tuff flowed 6 to 10 miles (10 to 16 km) down former Milkweed-Hindu channel system toward Shivwits Plateau. Tongue of tuff in Truxton Valley and Peach Springs Canyon extends at least 20 miles (32 km) onto Plateau. The tuff extends a similar distance onto the Plateau along the 1-40 alignment. First drainage to right of volcanic cap on Grand Wash Cliffs contains a "rim gravel" section almost down as far as head of modern alluvial fan. The channel containing the gravel is cut well into the Precambrian. East end of the same channel near Milkweed-Hindu Canyon junction on Hualapai Plateau is cut into Muav Limestone, approximately 1500 to 2000 feet (450 to 600 m) stratigraphically higher but 100 to 200 feet (30 to 60 m) lower in topographic elevation than the part of the channel visible from here. Limestone capping most of the cliff edge from Music Mountain to major change in cliff trend 20 miles (32 km) northwest is Muav Limestone (Upper Cambrian).

153.0
"Two Tooth" at 2:00 on cliff edge. This landmark composed of Muav Limestone pillars and visible from afar to the west was formerly used by Indians to estimate distances and travel times. Valley heading in cliffs immediately north of landmark follows small fault that cuts cliffs obliquely.

158.0
Junction with poor Clay Springs road to top of Cliffs. Kerr-McGee, El Paso, and Leonard Neal deep wells at 9:00, 3 to 5 miles (5 to 8 km) into Hualapai Valley south of Red Lake. Wells indicate 1800 feet (550 m) of basin fill, then thin clay-gypsum(?) cap over halite/sylvite section down to depth of 5994 feet (1827 m). Surface elevation of wells is near 2800 feet. Water table is at a depth of 450 feet (137 m) and slopes north toward Colorado River. Seismic section 6 miles (10 km) northwest indicates bedrock near 4400-foot (1340 m) depth where valley narrows near Pierce Ferry Road.

159
View of Red Lake playa at 11:00. Dark hills on west side of Hualapai Valley beyond the playa are composed of basalt also found on top(?) of Grand Wash Cliffs. As shown in Fig. 4, section c, basalt elevations and tilts and inferred position of Grand Wash fault line (supported by reconnaissance gravity survey) give a likely minimum of 18,000 feet (5500 m) of inferred displacement (throw) on the fault (Lucchitta, 1966). View toward cliffs up Clay Springs Canyon shows 65 Ma Laramide pluton (on right side of canyon) that intrudes Precambrian and Cambrian rocks and is unconformably overlain locally by Miocene basalts containing Peach Springs Tuff. No Peach Springs Tuff has been found north of these exposures.

163.2

Conspicuous westerly turn in road toward north end of Red Lake Playa, and road junction. Right fork leads to springs in Grand Wash Cliffs and jeep trail onto Hualapai Reservation. View back (east) is Clay Springs Canyon reentrant along Grand Wash Cliffs. This canyon is controlled by a northeast-trending fault with down-to-the-west displacement exceeding 250 ft (76 m).

167
Garnet Mountain at about 2:00, composed of Lower Proterozoic rocks, mainly granodiorite, quartz monzonite and migmatitic gneiss (Blacet, 1975).

173.0
Junction with Dolan Springs-Meadview-Pierce Ferry road. Turn right. After turn, Garnet Mountain at 2:00. Smooth slope climbed by road is fault-line scarp developed along northwest-trending fault with an en-echelon relation to the Grand Wash fault. The fault probably is southern continuation of Wheeler fault (see below).

Rounded hills forming skyline are composed of westerly-derived Proterozoic-clast fanglomerate that has been isolated from its source area by down-to-the-west movement on normal faults west of the Grand Wash fault. The source area, now probably buried by the alluvium and Tertiary basin fill of Hualapai Valley, is a matter of much economic interest because the fanglomerate is auriferous and has supported a profitable placer-mining district.

176.7
On left, westerly-derived fanglomerate. About 1mile (1.6 km) to west and at an altitude of about 3700 feet (1130 m), the fanglomerate rests in gently sloping depositional contact on Proterozoic metamorphic rocks. On right, Grand Wash Cliffs are composed of Precambrian rocks capped locally by Tertiary basalt and Cambrian Tapeats Sandstone at an altitude of about 5700 feet (1740 m). Assuming no rotation of the downthrown block, this gives a maximum throw on the fault of about 2000 feet (610 m) (Fig. 4, section b). Assuming 450 rotation of the downthrown block toward the fault, the corresponding figure for maximum throw is 10,000 feet (3050 m) (Lucchitta, 1966).

179.7
View of lower Grand Wash Cliffs to east and Grapevine Mesa to north. Prominent flat-topped mountain to east is Iron Mountain, with a 17.4 Ma basalt cap (J. Haman, personal communication). This basalt is equivalent in age to basalt found in many places on top of the Grand Wash Cliffs between here and Highway 66, and to the Peach Springs Tuff. Iron Mountain is 6437 feet (1962 m) high, so the basalts are sufficiently high to have flowed onto the Hualapai Plateau. From here north the Grand Wash Cliffs are composed chiefly of Paleozoic sedimentary rocks. Owing to the divergence between the trend of the cliffs and the attitude of the beds (Fig. 2), these rocks become progressively lower on the cliff face as one goes north.

The surface of Grapevine Mesa is close to the original top of the (Muddy Creek) basin fill. The south end of the mesa is its highest point and owes its altitude to the merging of east- and west- derived fans. These relations make it unlikely that an ancestral Colorado River would have flowed southward through this area, as has been proposed (Lovejoy, 1980) and as will be discussed later.

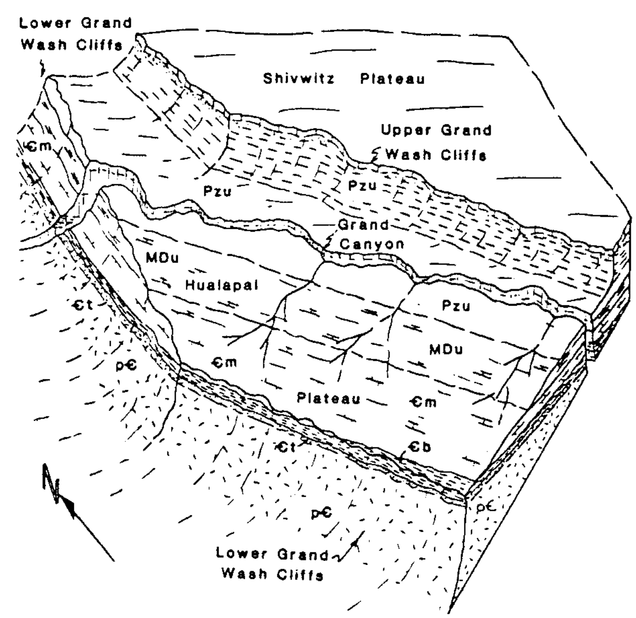

Figure 2. *Block diagram showing present erosion surface on northwestern part of Hualapai Plateau and the relation between dip of strata and trend of the Grand Wash Cliffs. Width of view is approximately 35 miles (56 km). PZU: Permian Kaibab Limestone, Toroweap Formation, and Coconino Sandstone, and Permian and Pennsylvanian Supai Group; MDU: Mississippian Redwall Limestone and Devonian Temple Butte Limestone; Em, Muav Limestone, Eb, Bright Angel Shale, and Et, Tapeats Sandstone, all of Cambrian age. pE: Precambrian igneous and metamorphic rocks.*

186.9
Boundary of Lake Mead National Recreation Area. Cuts are in the crystalline-clast facies of the Miocene Muddy Creek Formation, a widespread interior-basin deposit that filled the structural basin formed by the Grand Wash fault, and several other basins to the west in the Lake Mead area as well. The large, rounded granitic clasts in the cuts and littering the surface are composed of the distinctive Gold Butte Granite, a porphyritic rapakivi granite derived from Gold Butte in the south Virgin Mountains at 11:00.

189.2

Meadview junction (right). Gas, groceries, supplies, restaurant, bar.

189.8

Viewpoint to west. Virgin Canyon and Greggs Basin sections of Lake Mead visible below. South Virgin Mountains north and west of the lake, culminating in (clockwise) Bonelli Peak (5334 feet, 1626 m), Jumbo Peak (5763 feet, 1757 m) and Mica Peak (5758 feet, 1755 m). The latter two are in the general source area for the Gold Butte Granite. The viewpoint is on crystalline-clast facies of the Muddy Creek Formation, which rests unconformably on steeply tilted lower Paleozoic rocks of Wheeler Ridge. The southward pinchout of the Paleozoic rocks can be seen in this area.

194.0

Turnoff (right) to viewpoint at Airport Point.

AIRPORT POINT

196.8

This viewpoint is an excellent stop for examining the regional aspects of three geologic subjects of considerable interest, namely: (a) the Colorado Plateau: Basin and Range structural transition; (b) the stratigraphy of a classic interior-basin deposit; and (c) the history of the Colorado River. Most of the information presented here is from Lucchitta 1966, 1967, and 1975, and from Lucchitta in McKee and others, 1967.

Setting and morphology

The viewpoint is at the north end of Grapevine Mesa, near a WWII emergency landing strip. To the north is the Grand Wash trough, about 45 miles (70 km) long, and rimmed to the east by the Grand Wash Cliffs, which are the western edge of the Colorado Plateau; to the west by the south Virgin Mountains (Fig. 6). The trough is closed to the north by the Virgin Mountains (8064 feet, 2460 m max.), and interrupted in the near and middle distance by Wheeler Ridge, which trends north-northeast.

Upper Lake Mead is conspicuous north of the viewpoint. Pierce Ferry, a popular put-in spot for fishermen and take-out point for river runners, is visible 2.5 mi (4 km) from and 1700 feet (525 m) below the viewpoint. At its eastern end, Lake Mead enters the mouth of the Grand Canyon, which, however, is poorly visible from this angle.

South of the Grand Canyon, the Grand Wash Cliffs consist of a single step 2300 to 4000 feet (700 to 1200 m) high, cut chiefly in Cambrian, Devonian, and Mississippian rocks that dip northeast two to four degrees. The caprock is the Mississippian Redwall Limestone, but most of the cliffs are in the Cambrian Muav Limestone. Progressively higher stratigraphic units are exposed along the cliffs toward the north. Owing to the divergence between the trend of the cliffs and the dip of the beds, the Hualapai Plateau, which is between the Grand Wash Cliffs and the Grand Canyon, is similarly underlain by progressively younger rocks toward the northeast. This is because an erosional surface that slopes northeast bevels the more steeply dipping Paleozoic rocks.

North of the Grand Canyon, the Grand Wash Cliffs consist of two steps--the lower and upper Grand Wash Cliffs, respectively. The upper Grand Wash Cliffs are an erosional scarp formed by the hard-over-soft upper Paleozoic couplet (Kaibab and Toroweap over Hermit and Supai). The most prominent part of the upper Grand Wash Cliffs trends northwest, parallel to the Grand Canyon, and was formed by scarp retreat northeastward down the structural slope (Fig. 2). The part best visible from the viewpoint instead trends north-northeast, nearly parallel to the lower Grand Wash Cliffs and the Grand Wash fault that formed them. In this segment, the upper and lower cliffs are not parallel, but diverge southward, probably as a result of increasing displacement along the fault in that direction and consequent greater erosional retreat of the upper cliffs.

A structurally rotated block, once continuous with the upper Grand Wash Cliffs and the Hualapai Plateau, can be seen along Wheeler Ridge, which is composed of east-tilted Paleozoic rocks (Fig. 3). The reddish section and overlying gray section visible on Wheeler Ridge north of Lake Mead consist of the same upper Paleozoic rocks that form the upper cliffs (Supai and Hermit overlain by Toroweap and Kaibab). These rocks terminate abruptly just south of the lake, marking the location of the ancient scarp. Southward, Paleozoic rocks that are progressively lower stratigraphically are exposed along Wheeler Ridge almost to Meadview, where the featheredge of Paleozoic rocks in the Cambrian Bright Angel Shale and Tapeats Sandstone occurs.

The northeast dip of strata and the beveled surface on the Plateau, the upper Grand Wash Cliffs retreating northeastward, and the featheredging of Paleozoic strata toward the south all reflect a belt of uplift of Laramide age (Mogollon Highlands) that existed southwest of the present Plateau margin before the onset of basin-range extension in Miocene time.

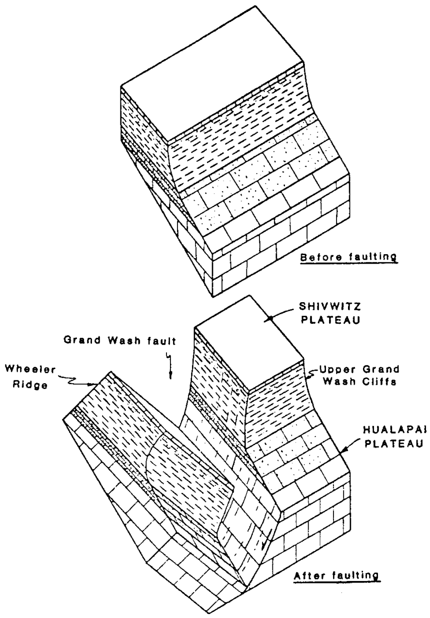

Figure 7. *Block diagram showing how outcrop pattern on the rotated block of Wheeler Ridge may correspond to erosion surface and erosional scarp in the western Grand Canyon.*

Structure

The Colorado Plateau block east of the Grand Wash Cliffs is structurally simple. Nearly horizontal Paleozoic strata are cut by normal faults that have displacements measuring tens to several hundreds of feet and form horsts and grabens. Some of the faults are late Miocene because they cut 7.5-6.0 Ma basalts (Lucchitta & McKee, 1975), others can only be dated as post-Paleozoic. Going west towards the Grand Wash Cliffs, many of the faults are systematically up to the west, a sense of movement contrary to that of the Grand Wash fault (Lucchitta, in Goetz and others, 1975). An excellent example of such fault movement occurs in the westernmost Plateau block, which forms a conspicuous butte about one kilometer north of the mouth of the Canyon. The persistent structural upwarping of the western edge of the Plateau may reflect a pre-faulting up-to-the-west monoclinal upwarp similar to that still visible in the Virgin Mountains, where movement along the Grand Wash fault is small and the pre-faulting features are well preserved.

The Grand Wash fault, the master structural feature of the area, consists of a system of en-echelon high-angle down-to-the-west normal faults that trend approximately north and extend from southern Utah into west-central Arizona. In the Lake Mead area, the Grand Wash fault is blanketed by late Miocene basin-fill deposits (Muddy Creek Formation), but to the north it cuts basalt flows no older than Miocene. Displacements vary along strike. At the Utah border, throw is several hundred feet at most. As shown in Fig. 4, throw at the mouth of the Grand Canyon is estimated at about 16,000 feet (5000 m) by projecting the dip of rotated strata on the downthrown block (Wheeler Ridge). Throw decreases to a maximum of about 10,000 feet (3050 m) at the south end of Grapevine Mesa, then increases in the Red Lake area to 18,000 to 20,000 feet (5500 to 6000 m).

In the Lake Mead area, the most recent displacement has occurred along Wheeler fault, on the west side of Wheeler Ridge (Fig. 6). Wheeler fault displaces the Hualapai Limestone, highest unit of the Miocene basin fill, about 1000 feet (305 m). Wheeler fault joins the main strand of the Grand Wash fault 20 miles (32 km) north of Lake Mead. It is north of this junction that the Grand Wash fault has had its most recent movement. To the south, Wheeler fault again merges with the Grand Wash fault near the south end of Grapevine Mesa.

Iceberg fault crops out about 1.9 miles (3 km) west of Wheeler fault, and follows Iceberg Canyon. Where now exposed, Iceberg fault dips 45° west; along most of its length, it is submerged by Lake Mead. However, according to Longwell, who mapped the area before filling of Lake Mead (1936), the fault is concave upward and flattens out markedly to the west. The geometry is that of a listric fault along which the rocks of the Iceberg and south Virgin Mountain blocks have rotated to face steeply eastward. Similar relations are present on the block between Iceberg and Wheeler faults (which presumably has rotated along Wheeler fault), and on Wheeler Ridge (which is the exposed part of the block that has rotated along Grand Wash fault). The overall arrangement of rotated blocks strongly resembles the structure in Anderson's (1971) thin-skin tectonics, which in turn resembles the structure typical of the upper plates of core-complexes. If these interpretations are correct, terrane of core-complex type would be present within a few km of relatively undisturbed Colorado Plateau, an observation of much importance in attempting to understand the relation between the extended and the stable terranes. Another consequence of the interpretation is that the south Virgin Mountain block may have rotated together with the Paleozoic strata along Iceberg Canyon. If this is the case, the western end of the block would expose rocks originally 9 to 11 miles (14 to 17 km) deep in the crust.

The Muddy Creek Formation

The Muddy Creek Formation is a classic interior-basin deposit that is well exposed in three dimensions in the Pierce Ferry area because the Colorado River has cut to a depth of about 2000 feet (600 m) beneath the original basin-fill surface. This dissection has revealed relations between facies in the vertical plane without obscuring them in the horizontal one (Fig. 8).

The Muddy Creek was deposited in a basin formed by movement of the Grand Wash fault, which occurred after deposition of the 17-18 Ma Peach Springs Tuff and basalts on the Grand Wash Cliffs, and also of the 12-20 Ma Horse Spring Formation. The Muddy Creek includes basalts dated at 5 to 6 Ma (Anderson, 1978; Damon and others, 1978), and 10.9 Ma (Blair, 1978);

it also includes tuffs about 8 Ma old (Blair, 1978; Bohannon, oral communication, 1982; and 1984). Deposition ceased with establishment of through-flowing drainage at about 5 to 6 Ma. The formation therefore is middle to latest Miocene in age.

Paleogeography

The Muddy Creek Formation was deposited in an asymmetrical basin formed by movement on the Grand Wash fault. The axis of the basin trended north-northeast, parallel to the fault, and was near the eastern margin of the basin. The floor of the basin sloped gently from the north as well as from the south toward a low point located approximately where Pierce Ferry and the north edge of Grapevine Mesa are now. The surface of Grapevine Mesa is near the original stratigraphic top of the basin fill in this low spot. Filling of the trough was dominantly from the west, as indicated by the predominance of igneous and metamorphic debris that includes clasts of the coarsely porphyritic rapakivi Gold Butte Granite of Longwell (1936). This granite crops out extensively in the south Virgin Mountains 4 to 12 miles (6 to 9 km) west of Wheeler Ridge (Volborth, 1962). Thirty-foot (nine-meter) boulders of the granite are present at Wheeler Ridge, and twenty foot (six meter) boulders at the foot of the lower Grand Wash Cliffs, a minimum transport distance of about 13 miles (20 km) from the nearest possible source area.

Two prominent Muddy Creek fan lobes are visible to the north from Grapevine Mesa: one, the Pierce lobe, is south of the Colorado River and west of Pierce Ferry; the other, Tassi lobe, is north of the Colorado. Both lobes are east of Wheeler Ridge. During development of the fans, the country west of Wheeler Ridge consisted of a pediment cut on bedrock and functioning as a zone of transport rather than as one of deposition. This ended late in Muddy Creek time when movement on the Wheeler fault isolated the fans in the Pierce Ferry area from their source areas and created a separate basin of deposition in what is now the Greggs Basin area. Influx of material into the Grand Wash trough from the Grand Wash Cliffs to the east was minimal; partly because streams on the cliff face drain small areas, and partly because the carbonate rocks that form most of the cliffs erode slowly under arid conditions. Substantial fan lobes are present only at the foot of the Grand Wash Cliffs at Pierce, Snap, and Pigeon Canyons (Fig. 6). The canyons that existed at these localities in Muddy Creek time were as deep and narrow as the present ones, but shorter and steeper.

Facies

All the fans are composed of poorly sorted breccia and conglomerate that contain chiefly angular to subangular clasts in pell-mell arrangement and with a high matrix-to-clast ratio. The tops of many depositional units show evidence of reworking by flowing water. These features, which suggest deposition by debris flows, can be studied conveniently in a prominent outcrop on the east side of the Pierce Ferry Road about 2.5 miles (4 km) north of the Sand Cove turnoff. The areas between fan lobes are underlain by a fine-grained facies composed of fresh-water limestone and dolomite, and gypsum. Silicic airfall tuffs are common, many with delicate glass shards and bubbles still preserved. Twenty-three individual tuff layers are exposed about 1.5 miles (2.5 km) southeast of Pierce Ferry. Transition from the fan material to the fine-grained facies occurs partly through a progressive decrease in grain size, partly through abrupt interfingering. Rocks of the fine-grained facies are well bedded and well sorted. Deposition in quiet water is indicated by even bedding and the presence of tuff, gypsum, and carbonate. Many of these features are exposed near Pierce Ferry.

The fine-grained facies were deposited in intermittent playas and lakes. Initially, these playas and lakes were small and restricted to the lowest parts of the basin because the influx of clastics was high. As the basin filled and relief waned, playas and lakes occupied progressively greater areas. Finally, a lake occupied much of the basin in the Pierce Ferry area. The Hualapai Limestone was deposited in the lake and eventually transgressed widely over other lithologies. These relations are well displayed on the north face of Grapevine Mesa (Fig. 8). The transgressive stacking of limestone, fine-grained facies, and fanglomerate can be observed in road cuts and natural exposures on the east side of the Pierce Ferry road where it starts dropping off the north end of Grapevine Mesa, just north of the turnoff to the viewpoint. The Hualapai Limestone therefore is not a sheet-like deposit that was laid down in a restricted interval at the end of Muddy Creek time, even though limestone deposition was most widespread at that time. Instead, it was deposited throughout the time represented by the 2000 feet (600 m) of Muddy Creek section exposed in the Pierce Ferry area as shown by the walls of Grapevine Canyon (cut into Grapevine Mesa), which are composed chiefly of Hualapai Limestone. At any time represented by the Pierce Ferry section, conglomerate, sandstone/siltstone, and limestone were being deposited simultaneously, but in different parts of the basin.

Inception of the Colorado River and Development of the Western Grand Canyon

Hypotheses

The Pierce Ferry area lies athwart the mouth of the Grand Canyon. Consequently, it provides important restrictions on interpretations of the history of the Colorado River and the development of the Grand Canyon. Longwell (1936, 1946) and Blackwelder (1934) long ago indicated that the presence of interior-basin deposits across the mouth of the Grand Canyon in the Pierce Ferry area effectively precludes the existence of the Colorado River in its present course in Muddy Creek time. Others, however, do not agree with this view. Contrary hypotheses fall into two main groups:

1. The Grand Canyon existed in Muddy Creek time. The Colorado River emptied into the Grand Wash trough and ultimately exited by a course different from the present one (Lovejoy, 1980). Or: the Grand Canyon was a dry valley carrying neither water nor sediment (D. Elston, oral communication, 1983).

2. The Colorado River existed in Muddy Creek time, but its course near the southwestern edge of the Colorado Plateau was different from the present one. Eventually, the river was ponded near the western margin of the Plateau, whence it drained by subterranean piping to form springs and a lake in the Grand Wash area. The Hualapai Limestone was deposited in this lake. The river eventually established its course in post-Muddy Creek time (Hunt, 1969).

<u>Information bearing on hypotheses of Group 1</u>.

There are no known deposits or structures in the Muddy Creek Formation that point to the existence of the Colorado River during Muddy Creek time. On the contrary, internal fabrics, facies distribution, as well as facies composition and relations all point to a closed basin of interior deposition. It is unlikely that Colorado River sediments were deposited and then dispersed by wave action or currents, given the abundant evidence for quiet-water deposition in the Muddy Creek Formation. Even the oldest preserved gravels of the Colorado River, some at altitudes of several hundred feet above present grade, are immediately recognizable because of their coarse size (pebble-and-cobble gravel), excellent rounding, and exotic, far-traveled lithologies.

The facies distribution of the Muddy Creek Formation shows no evidence for an inlet or outlet, as would be required had the Colorado River existed. Specifically, such facies do not occur either at the mouth of the Grand Canyon, or at the south end of Grapevine Mesa, which is Lovejoy's (1980) postulated outlet. The latter locality is at an altitude of about 4100 feet (1250 m), or 1150 feet (350 m) higher than the top of the basin fill near Pierce Ferry, and is underlain exclusively by locally-derived fanglomerate and bedrock.

There is little reason to suppose that a drainage system nearly as large as the present Colorado River would have carried no sediment when drainage systems such as Pierce, Snap, and Pigeon Canyons, which are far smaller and only a few miles from the Grand Canyon, carried sediment in abundance. Nor can the absence of river sediments be attributed to a reduced base flow. The western United States is characterized by drainage systems (washes) that are dry most of the time, yet transport sediment in great quantities during rare floods. The amount of material transported by a drainage system is not closely related to its base flow.

Finally, a remnant of the Muddy Creek fan issuing from Pierce Canyon is present directly south of the mouth of the Grand Canyon. This material could not have been deposited in that position had the Grand Canyon existed at the time.

<u>Information bearing on hypotheses of Group 2</u>.

The evidence provided by the Muddy Creek Formation for conditions of interior drainage rather than through-flowing drainage near the mouth of the Grand Canyon cannot be bypassed by postulating another course for the Colorado River because locally derived interior-basin deposits of Miocene age are ubiquitous in the lower Colorado River region. Older deposits that predate formation of the basin of interior drainage indicate regional northeasterly drainage onto the Colorado Plateau instead of a westerly or southwesterly Colorado River drainage (see, for example, the distribution of the Peach Springs Tuff and the Rim gravels).

There is no evidence for springs feeding Hualapai Lake in the Grand Wash trough: the Hualapai Limestone was deposited during much of Muddy Creek time in scattered topographically low spots, which were frequently subject to playa conditions. Only at the end of the Muddy Creek time was limestone deposition widespread, when it occurred not only in the Grand Wash trough, but also tens of miles away and perhaps in separate basins.

<u>Preferred hypothesis</u>

(Summarized from Lucchitta, 1966, 1972, 1979, and McKee and others, 1967)

The Muddy Creek Formation of the Grand Wash trough shows that no Colorado River existed at the mouth of the Grand Canyon when the Muddy Creek was being laid down in middle to latest Miocene time. The youngest radiometric dates obtained from rocks correlative with the Muddy Creek Formation at the Grand Wash trough range from 5 to 8 Ma. The oldest date on rocks that reflect the existence of the Colorado River is the 5.3 Ma obtained from the Bouse Formation (Damon and others, 1978), an estuarine deposit that crops out widely along the lower Colorado River. The conclusion is that the lower Colorado River came into being after the end of Muddy Creek deposition and after opening of the Gulf of California in latest Miocene time.

The probable date for establishment of the lower Colorado River is about 5.5 Ma. The lower Colorado worked its way onto the Colorado Plateau by headward erosion, and captured an older ancestral upper Colorado River, probably in the stretch between the Kaibab Plateau and the mouth of the Grand Canyon. In the process, the Canyon as we know it today was formed. The western Grand Canyon was cut in 4 Ma. at most, a remarkably short time.

Continue road log. **RESET ODOMETER TO ZERO** at intersection of Airport Point and Pierce Ferry roads.

0.2
Exposures on right show about 65 feet (20 m) of Hualapai Limestone overlying about 80 feet (25 m) of reddish poorly consolidated well bedded siltstone and sandstone, which in turn overlie crystalline-clast fanglomerate, abundantly exposed west of road.

1.5
Turnoff to South Cove boat ramp. Continue straight ahead on dirt road to Pierce Ferry.

3.5
Good exposures of crystalline-clast fanglomerate.

4.5
In this general area, good exposures of calichified, well indurated gravels disconformably overlying less permeable reddish sandstone and siltstone of the Muddy Creek Formation. These Pliocene to Quaternary gravels are related to through-flowing drainage. To north, across Pierce Wash, two prominent white bands are airfall tuff composed chiefly of glass shards but also containing unbroken glass bubbles and 5 percent or less biotite.

6.0
Pierce Ferry, site of old ferry across Colorado River. Rocks are siltstone-sandstone facies of the Muddy Creek Formation. White bands are tuffs mentioned above, here considerably lower topographically. Difference in altitude is probably due at least in part to greater compaction of the fine-grained sediments as compared to the fanglomerate.

Knob-like outcrops to east, across the arm of Lake Mead, are a string of cemented channel gravels laid down by Grapevine Wash at a former stand.

Pierce Ferry is a designated camp area equipped with pit toilets and garbage containers. There is no drinking water. We will camp here for the night.

<u>END OF OUTWARD-BOUND LEG OF FIELDTRIP</u>

<u>RETURN LEG OF FIELDTRIP</u>

RESET ODOMETER TO ZERO at Meadview intersection

0
Meadview intersection.

3-5
King Tut and Lone Jack placer gold mines on right, which worked westerly-derived Muddy Creek fanglomerate. Water was piped in from Grand Wash Cliffs.

7.0
Iron Mountain at 10:00.

9.4
Junction to Diamond Bar Ranch on left.

10.0
Pass at south end of Grapevine Mesa. Good view southward to Cerbat Mountains with sawtooth outcrops of Peach Springs Tuff, and to Table Mountain Plateau capped by basalts tilted gently eastward. The tilt is probably due to a fault between Table Mountain Plateau and the Cerbat Mountains.

16.2

Crossroads. To right, Hualapai Wash road; to left, road along Hualapai Valley to Antares on Highway 66. Go straight. The cross-roads is at a drainage divide separating the headwaters of Hualapai Wash from a wash on the left that drains southeastward into Red Lake. Consequently, the terrain on the left is still in 'interior basin time", whereas Hualapai Wash is in 'through-flowing drainage" time.

16.6
Turn left-onto graded dirt road (Stockton Hill Road) to Kingman.

19.6
Power line crossing.

23.5
Red Lake on left, underlain by large subsurface body of halite and sylvite. Hills on right consist of olivine basalt (presumably equivalent to that on top of Grand Wash Cliffs) overlying Precambrian basement. A veneer of gravel is present locally beneath the basalt.

30.4
Good view of jagged outcrops of Peach Springs Tuff filling a sag in the Cerbat Mountains at 3:00. This sag may correspond to the gravel and volcanic rockfilled sag on the Grand Wash Cliffs to east.

32.0
From here on, road follows east side of Cerbat Mountains and traverses a terrain composed chiefly of Precambrian igneous and metamorphic rocks overlain locally by patches of Miocene basalt flows and Peach Springs Tuff. Many of the patches are tilted gently east. The tilt presumably reflects rotation along faults of the Grand Wash system.

49
Good view of Hualapai Mountain to south. Miocene basalt in foreground.

50.7
Several mines on right, in the Stockton area. Turquoise is produced in some of these mines.

52
View of Kingman and Hualapai Mountains. To right, exposure of Peach Springs Tuff and Miocene basalts in the Kingman area. These rocks occupy a sag that may correspond to those at the west end of Truxton Valley, on the Grand Wash Cliffs to the east.

57.5
Interstate I-40.

RESET ODOMETER
Consult Figures 1 and 2 for Locations

0 MP52
Intersection with highway I-40. Enter eastbound (toward Flagstaff and Albuquerque). Peach Springs Tuff outcrop 0.5 mile (0.8 km) south of intersection.

View south toward Hualapai Mountains (2:00 to 3:00) shows Peach Springs Tuff lapping onto Precambrian rocks where tuff funneled through gap between Cerbats and Hualapai Mountains. Collapse and faulting in the Kingman area created a broad "sag" in the tuff outcrops.

11.3 MP64
Pass between Hualapai (right) and Peacock (left) ranges, both underlain chiefly by Precambrian rocks. Gradual curve in highway. At 10:00 two small buttes along flank of Peacock Range are capped by Peach Springs Tuff. Faulting is complex here: volcanic rocks dip toward the range as well as in various other directions.

18.9
Junction of I-40 with Arizona 93 to Wickenburg and Phoenix. Exit on 93 for optional 14-mile (22 km) side trip on unmaintained ranch roads to outcrops of faulted Peach Springs Tuff north of Austin Peak. Turn east (left) on Knight Creek Road 4.6 miles (7.5 km) from Interstate 40 and follow roads (bearing right at forks) to small wash in Section 15, T. 20 N., R. 12 W., Austin Peak 7-1/2 Quadrangle (road crosses wash about I mile or 1.6 km northwest of Austin Peak). Walk southward up drainage

that heads near the intrusive that forms Austin Peak. Wash approximately follows main branch of plateau-margin fault. Several small faults cut Peach Springs Tuff in downthrown block to west.

Examine fault zone, style of faulting, tuff outcrops, dike, related Miocene volcanic rocks, and Austin Peak. The Peach Springs Tuff of downthrown block in the wash is at an altitude of about 4100 feet and at 4900 to 5400 feet in the upthrown block near the Aquarius Mountains east of Austin Peak. Thus, most of the difference in altitude between the Plateau and the Basin and Range in this area can be accounted for by about 1200 feet (365 m) of post-Peach Springs Tuff faulting along this single branch of the fault zone. West of the fault is basin-range extended terrane characterized by high-angle normal faults that bound blocks rotated gently into the faults. As a consequence of this geometry, the Peach Spring Tuff is present in most of the blocks at a consistent attitude (3800 to 4200 feet).

Return to Interstate 40 via parallel access road (or short cut if possible) and return to divided highway at interchange 7.5 miles (12 km) east of the junction with Route 93.

19.8
Austin Peak at 1:00. Mesas to left are tuff. High mesa to right is basalt.

21.1 MP74
Odometer calibration point.

26.3
Interchange with Silver Springs Road (near Milepost 79). View southward of Austin Peak rhyodacite plug at 2:30 and downfaulted blocks just visited. Peach Springs Tuff also visible on prominent, flat-topped Penitentiary Butte on skyline east of Austin Peak. Section at Penitentiary Butte includes (from top): 47 feet (14 m) of Peach Springs Tuff with 4 feet (1.2 m) of basal ash; 403 feet (123 m) of tuffs breccias, and conglomerates of rhyodacite of Fort Rock Creek (Fuis, 1973); and 284 feet (86 m) of ash flow tuffs comprising eight flow units, each 11 to 90 feet (3.3 to 27 m) thick. Silicic rocks rest on agglomerates of Crater Pasture (Fuis, 1973). Equivalent basalts south of Austin Peak and beneath tuffs are 18.2 to 1.5 Ma. (Young and McKee, 1978).

27.8
Cross small wash as relief begins to increase sharply. Approximate location of major visible fault of the Plateau-margin system, which cuts across lower slope of small peak 2000 feet (600 M) south of highway and continues north of highway at 7:00 along base of Tin Mountain in notches upslope from small peaks that break the slope profile. Goff and others (1983) interpret the Tin Mountain block as a graben slightly lower structurally than the basin to the west. The main fault is presumed buried under alluvium near interchange to west.

East of the fault zone, begin 4.5 mile (7 km) section of road cuts in Precambrian rocks of the plateau block. Most rocks have steep foliation that trends north-northeast. Diabase and gabbroic intrusions are common. Outcrops include large masses of weakly to strongly foliated granite gneiss weathering into large rounded boulders.

30.0
Cross inferred eastern fault in Tin Mountain '.graben". Mesa-capping andesites (part of the Crater Pasture rocks of Fuis, 1973) and underlying basalts on left (north) at 9:00, 1400 feet (425 m) above highway. These rocks are correlated with late Oligocene volcanic rocks of Goff and others (1983) on the basis of a 24.3 Ma age on hornblende latite obtained 3 miles (5 km) north of highway. This age is consistent with those obtained by Young and McKee (1978) on similar rocks along the plateau edge 5 miles (8 km) south of Austin Peak. Basement rocks are chiefly Proterozoic granite gneiss and granite cut by dikes of diabase and gabbro.

32.8 MP86
Basalt flows and associated whitish ashflow and airfall nonwelded tuffs (Fort Rock Creek) on both sides of road. These rocks underlie Peach Springs Tuff elsewhere but may be similar in age.

33.8 MP87
Ahead and to the left, faulted basalt flows, flow breccias, cinders, bombs, ash, and lapilli. Well exposed and interesting primary structures. Part of Crater Pasture rocks of Fuis (1973), interbedded with tuff of Fort Rock Creek.

34.8 MP88
Peach Springs Tuff ledge on left about 200 feet (60 m) above road elevation.

35.8 MP89

Marked depositional angular unconformity in tuff of Fort Rock Creek.

36.0
Precambrian granitic terrane for 1.5 miles (2.5 km). Quaternary alluvium abundant on south side (right).

36.8 MP90
Cross Mountain straight ahead. Cross Mountain is made up of Cambrian through Mississippian (Tapeats through Redwall) rocks and rises to an elevation of 6200 feet (1900 m).

38.7 MP92
View southeast (2:00) from interchange area along open valley and powerline toward Fort Rock Dome 4 miles (6.5 km) from highway. The dome has 500 feet (150 m) of topographic relief, 900 feet (270 m) of structural relief, and steep monoclinal folds on flanks (average dip is 660). The dome was formed by intrusion of magma at depth accompanying eruptions that preceded deposition of rhyodacite and tuffs of Fort Rock Creek (Fuis, 1973). Tuffs originally buried most of the area of the dome, but slight post-intrusive collapse and faulting, and subsequent erosion, gave the feature its present appearance, which might lead to mistaken interpretations as an impact crater.

41.5
Volcanic complex of Mohon Mountain in distance at 3:00.

42.0
Precambrian granite south of highway, basalts to north.

42.6 MP96
Interchange. Tree covered rise on right is fault line scarp of Cross Mountain fault. Fault trends southeast through Tapeats Sandstone at base of Cross Mountain. Fault swings into more westerly trend north of highway and passes into flexure with northeast dips of 50°. A 22.4 Ma andesite dome occurs 1 mile (1.6 km) north of highway along the structure (Goff and others, 1983). This structure may represent a northwest-trending Laramide fold-flexure that was reactivated by faulting during the middle Tertiary and thus localized intrusive activity.

43.9
Tapeats Sandstone outcrops. Cross Mountain at 3:00.

44.7
More basalts of Peach Springs Tuff age. The easternmost known exposure of Peach Springs Tuff occurs I mile (1.6 km) due north of highway (not visible).

46.0
Crossing broad, low ridge of quartz-bearing olivine basalts mapped as younger than Peach Springs Tuff. Vent is 0.5 mile (0.8 km) north of highway. Begin crossing alluvial flat bounded on east by block-faulted olivine basalts approximately equivalent to Peach Springs Tuff (Western Juniper Mountains).

Higher peak with radio tower at 1:00 to 2:00 is Squaw Peak (elev. 6600 feet, 2000 m), which consists of flows similar to those just passed, resting on Permian and Pennsylvanian rocks.

46.8
Low hills to the north are underlain by Miocene(?) gravels, older Quaternary gravels (containing volcanic clasts) and, possibly, older prevolcanic gravels (rim gravels) as seen at mile 49.3 ahead.

48.6 MP102
Miocene quartz-bearing and olivine-bearing basalt flows and flow breccias cut by several high-angle faults and considered probably equivalent to Peach Springs Tuff by Goff and others (1983). However, these rocks may span a much greater age, as they are partly equivalent to the volcanic rocks of Squaw Peak and regionally interbedded with early Miocene flows, as mapped by Goff and others (1983).

50.1
Exit/Interchange (Jolly Road). Tertiary and Quaternary gravels underlie low hills and open plains. Tertiary gravels form reddish cut visible ahead.

53.5 MP107

Conspicuous primary sedimentary structures are exposed in cut straight ahead. Several gravel units are present. The oldest unit (rim gravels) has a reddish color and contains Precambrian clasts of general southerly derivation, including highly weathered igneous clasts. The younger unit is more locally derived and lighter colored; Paleozoic clasts are dominant.

54.5 MP108
Outcrops immediately east of large gravel cut at mile 51.7 (milepost 108) are lower Paleozoic limestone.

55.4 MP109
Tertiary basalt overlying volcanic sediments and gravels in cut.

56.4 MP110
View of San Francisco volcanic field; Mt. Humphreys at 12:00; Bill Williams Mountain at 12:30.

59.2
Interchange marks Audley Road, approximate crossing of Blue Mountain-Yampai-Purcell Canyon structural trend. Fault scarp south of highway continues north of highway (left) through gully and saddle in butte at 9:00.

60.0
Cuts in thin-bedded gray to purple Devonian Temple Buttle/Martin Limestone.

60.3 MP114
View into upper reaches of Chino Valley. Aubrey Cliffs at 9:30 to 10:00. Mount Floyd volcanic field at 11:00. Picacho Butte at 1:00.

64.0 MP118
Reddish outcrops in Supai(?).

67.2 MP121
Exit 121 to Seligman and Highway 66.

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